Fisheries Assessment Plenary

May 2020

Stock Assessment and Stock Status

Volume 2: Hoki to Redbait

Fisheries New Zealand
Tini a Tangaroa

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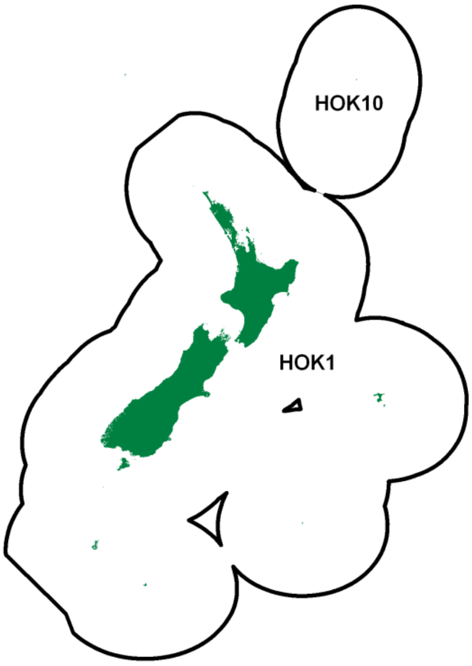
Volume 2: Hake to Pilchard

HOKI (HOK)

(*Macruronus novaezelandiae*)
Hoki



1. FISHERY SUMMARY

1.1 Commercial fisheries

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

Outside the spawning season, when hoki disperse to their feeding grounds, substantial fisheries have developed since the early 1990s on the Chatham Rise and in the Sub-Antarctic (Figure 1). These fisheries usually operate in depths of 300–800 m. The Chatham Rise fishery generally has similar catches over all months except in July-September, when catches are lower due to the fishery moving to the spawning grounds. In the Sub-Antarctic, catches have typically peaked in April-June. Out-of-season catches are also taken from Cook Strait and the east coast of the North Island, but these are small by comparison.

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

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

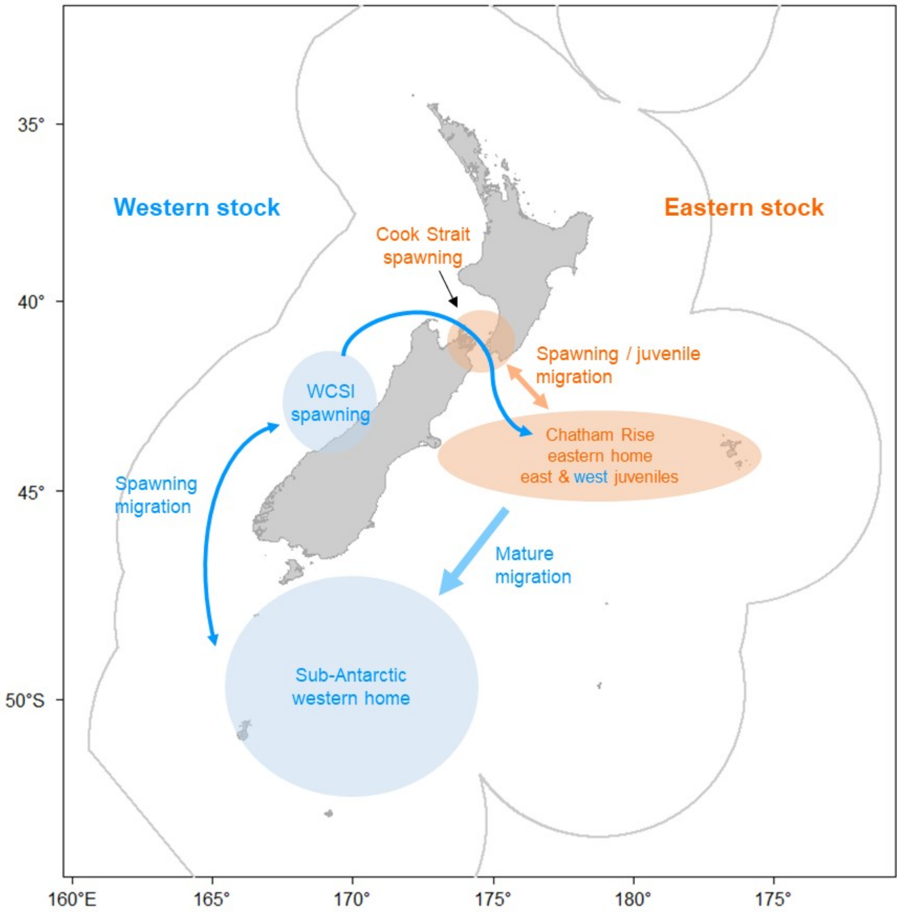


Figure 1: Hoki juvenile nurseries, spawning grounds, and migration routes for the eastern and western stocks.

Between 2012–13 and 2017, Precision Seafood Harvest (PSH) technology was tested in the hoki fishery. This included a prototype trawl system called a Modular Harvest System (MHS) that aimed to target specific species and fish size, as well as enabling fish to be landed in much better condition than traditional trawls. Approval to use MHS gear in the hoki, hake, and ling fisheries was granted in 2018. During the 2017–18 fishing year, seven vessels used the gear to target hoki and caught 9595 t (7% of the total hoki catch). In 2018–19, the MHS hoki catch increased to 17 100 t (14% of the total catch), taken by eight vessels.

Annual catches ranged between 175 000 t and 215 000 t from 1988–89 to 1995–96, increasing to 246 000 t in 1996–97, and peaking at 269 000 t in 1997–98, when the TACC was over-caught by 19 000 t. Catches declined, tracking the TACC as it was reduced to address poor stock status, reaching a low of 89 000 t in 2008–09, then increasing again up to 161 500 t in 2014–15 following increases in the TACC as stock status improved (Table 2). The TACC was reduced to 150 000 t in 2015–16, and catches in the past four years were below this level (Table 2). The annual catch in 2018–19 was 122 400 t.

The pattern of fishing has changed markedly since 1988–89 when over 90% of the total catch was taken in the WCSI spawning fishery. This has been due to a combination of TAC changes and redistribution of fishing effort. The WCSI fishery accounted for about 38% of the total hoki catch in 2018–19 and has been the largest hoki fishery in New Zealand since 2010–11 (Table 3). Cook Strait catches peaked at 67 000 t in 1995–96, but have been relatively stable in the range from 15 000 t to 20 000 t in the past 12 years. The Chatham Rise was the largest hoki fishery from 2006–07 to 2009–10 and has been the second largest since then, and contributed about 33% of the total catch in 2018–19. Catches from the Sub-Antarctic peaked at over 30 000 t from 1999–2000 to 2001–02, but have been variable since, ranging between 6000 t and 20 000 t over the past 12 years (Table 3). Catches from other areas remained at relatively low levels (Table 3).

Table 1: Reported trawl catches (t) from 1969 to 1987–88, 1969–83 by calendar year, 1983–84 to 1987–88 by fishing year (Oct-Sept). Source - FSU data.

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

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

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

Table 2: Reported catch (t) from QMS, estimated catch (t) data, and TACC (t) for HOK 1 from 1986–87 to 2018–19. Reported catches are from the QMR and MHR systems. Estimated catches include TCEPR and CELR data (from 1989–90), LCER data (from 2003–04), NCELR data (from 2006–07), TCER and LTCER data (from 2007–08), and ERS-trawl data (from 2017–18). Catches are rounded to the nearest 500 t.

Year	Reported catch	Estimated catch	TACC
1986–87	158 000	175 000	250 000
1987–88	216 000	255 000	250 000
1988–89	182 500	210 000	250 000
1989–90	210 000	210 000	251 884
1990–91	215 000	215 000	201 897
1991–92	215 000	215 000	201 897
1992–93	195 000	195 000	202 156
1993–94	191 000	190 000	202 156
1994–95	174 000	168 000	220 350
1995–96	210 000	194 000	240 000
1996–97	246 000	230 000	250 000
1997–98	269 000	261 000	250 000
1998–99	244 500	234 000	250 000
1999–00	242 500	237 000	250 000
2000–01	230 000	224 500	250 000
2001–02	195 500	195 500	200 000
2002–03	184 500	180 000	200 000
2003–04	136 000	133 000	180 000
2004–05	104 500	102 000	100 000
2005–06	104 500	100 500	100 000
2006–07	101 000	97 500	100 000
2007–08	89 500	87 500	90 000
2008–09	89 000	87 500	90 000
2009–10	107 000	105 000	110 000
2010–11	118 500	116 000	120 000
2011–12	130 000	126 000	130 000
2012–13	131 500	128 000	130 000
2013–14	146 500	144 000	150 000
2014–15	161 500	156 500	160 000
2015–16	136 500	136 000	150 000
2016–17	141 500	138 500	150 000
2017–18	135 000	131 500	150 000
2018–19	122 500	117 000	150 000

Note: Discrepancies between QMS data and actual catches from 1986 to 1990 arose from incorrect surimi conversion factors. The estimated catch in those years has been corrected from conversion factors measured each year by Scientific Observers on the WCSI fishery. Since 1990 the new conversion factor of 5.8 has been used, and the total catch reported to the QMS is considered to be more representative of the true level of catch.

In 2018–19 20 000 t of western ACE was voluntarily shelved by the fishing industry so the effective TACC was 130 000 t.

Table 3: Estimated total catch (t) (scaled to reported QMR or MHR) of hoki by area 1988–89 to 2018–19 and based on data reported on TCEPR, ERS-trawl, and CELR forms from 1988–89, but also including data reported on LCER (from 2003–04), NCELR (from 2006–07), TCER and LTCER (both from 2007–08) forms, and ERS-trawl (from 2017–18). Catches from 1988–89 to 1997–98 are rounded to the nearest 500 t and catches from 1998–99 to 2018–19 are rounded to the nearest 100 t. Catches less than 100 t are shown by a dash. Alternative estimated total catches based on logbook data only are given in Table 3a for 1988–89 to 1997–98. Unrep. is catch with no location information.

	Spawning fisheries				Non-spawning fisheries				Total
Fishing Year	WCSI	Puysegur	Cook Strait	ECSI	Sub-Antarctic	Chatham and ECSI	ECNI	Unrep.	Catch
1988–89	188 000	3 500	7 000	–	5 000	5 000	–	–	208 500
1989–90	165 000	8 000	14 000	–	10 000	13 000	–	–	210 000
1990–91	154 000	4 000	26 500	1 000	18 000	11 500	–	–	215 000
1991–92	105 000	5 000	25 000	500	34 000	45 500	–	–	215 000
1992–93	98 000	2 000	21 000	–	26 000	43 000	2 000	3 000	195 000
1993–94	113 000	2 000	37 000	–	12 000	24 000	2 000	1 000	191 000
1994–95	80 000	1 000	40 000	–	13 000	39 000	1 000	–	174 000
1995–96	73 000	3 000	67 000	1 000	12 000	49 000	3 000	2 000	210 000
1996–97	91 000	5 000	61 000	1 500	25 000	56 500	5 000	1 000	246 000
1997–98	107 000	2 000	53 000	1 000	24 000	75 000	4 000	3 000	269 000
1998–99	90 100	3 000	46 500	2 100	24 300	75 600	2 600	–	244 500
1999–00	101 100	2 900	43 200	2 400	34 200	56 500	1 400	500	242 400
2000–01	100 600	6 900	36 600	2 400	30 400	50 500	2 100	100	229 900
2001–02	91 200	5 400	24 200	2 900	30 500	39 600	1 200	-	195 500
2002–03	73 900	6 000	36 700	7 100	20 100	39 200	900	-	184 700
2003–04	45 200	1 200	40 900	2 100	11 700	33 600	900	-	135 800
2004–05	33 100	5 500	24 800	3 300	6 200	30 700	500	100	104 400
2005–06	38 900	1 500	21 800	700	6 700	34 100	700	-	104 400
2006–07	33 100	400	20 100	1 000	7 700	37 900	700	-	101 000
2007–08	21 000	300	18 400	2 300	8 700	38 000	600	-	89 300
2008–09	20 600	200	17 500	1 100	9 800	39 000	600	-	88 800
2009–10	36 300	300	17 900	700	12 300	39 100	600	-	107 200
2010–11	48 300	1 200	14 900	1 600	12 600	38 400	1 600	-	118 700
2011–12	54 000	1 300	15 900	2 500	15 700	39 000	900	-	130 100
2012–13	56 200	1 000	19 400	3 300	14 100	36 500	1 100	-	131 600
2013–14	69 400	800	18 400	2 800	19 900	33 800	1 300	-	146 300
2014–15	78 700	1 900	20 100	3 600	16 400	40 100	800	-	161 500
2015–16	68 900	1 100	18 400	4 100	6 600	36 700	900	-	136 700
2016–17	66 000	1 200	16 100	4 400	13 200	39 900	800	-	141 600
2017–18	55 500	1 100	21 500	3 600	15 400	37 200	1 100	-	135 400
2018–19	46 400	1 300	20 500	3 700	9 000	40 400	1 200	-	122 400

Table 3a: Alternative estimated total catch (t) (scaled to reported QMR) by area for 1989–90 to 1997–98 based on data reported on TCEPR and CELR forms. Catches from 1988–89 to 1997–98 are rounded to the nearest 100 t.

	Spawning fisheries				Non-spawning fisheries				
Fishing Year	WCSI	Puysegur	Strait	ECSI	Sub Antarctic	Chatham Rise and ECSI	ECNI	Un-reported	Total Catch
1989–90	160 400	7 400	14 700	300	11 800	13 200	900	200	210 000
1990–91	129 200	4 900	29 200	1 300	16 800	30 100	900	200	215 000
1991–92	101 500	4 900	24 900	900	30 700	48 200	1 100	100	215 000
1992–93	96 600	2 200	22 200	300	24 900	44 200	1 400	100	195 000
1993–94	115 900	2 400	37 300	500	11 600	22 700	1 800	200	191 000
1994–95	80 400	1 100	40 500	200	13 400	38 800	2 300	200	174 000
1995–96	72 900	2 400	67 600	1 000	13 100	49 000	2 800	900	210 000
1996–97	91 400	5 900	65 000	1 600	21 800	55 800	4 600	600	246 000
1997–98	106 300	2 200	51 900	1 600	25 100	77 200	4 700	400	269 000

From 1999–00 to 2001–02, there was a redistribution in catch from eastern stock areas (Chatham Rise, ECSI, ECNI, and Cook Strait) to western stock areas (WCSI, Puysegur, and Sub-Antarctic) (Table 4). This was initially due to industry initiatives to reduce the catch of small fish in the area of the Mernoo Bank, but from 1 October 2001 was part of an informal agreement with the Minister responsible for fisheries that 65% of the catch should be taken from the western fisheries to reduce pressure on the eastern stock. This arrangement ended following the 2003 hoki assessment in 2002–03, which indicated that the eastern hoki stock was less depleted than the western stock and effort was shifted back into eastern areas, particularly Cook Strait. From 2004–05 to 2006–07 there was an agreement with the Minister that only 40% of the catch should be taken from western fisheries and from 1 October 2007 the voluntary catch limit for the western fishing grounds was further reduced to 25 000 t within the overall TACC of 90 000 t. This voluntary catch limit was exceeded in both 2007–08 and 2008–09, with about 30 000 t taken from western areas (Table 3). In 2009–10, the voluntary catch limit from the western fishing grounds was increased to 50 000 t within the overall TACC of 110 000 t, and catches were at about these levels. Since then the voluntary catch limit for the eastern stock has remained at 60 000 t, and the voluntary western catch limit has further increased with changes in the overall TACC, up to a maximum of 100 000 t in 2014–15 (within the overall TACC 160 000 t). The voluntary western catch limit from 2015–16 to 2018–19 was 90 000 t, but 20 000 t of western ACE was shelved by the fishing industry in 2018–19. The split between eastern and western catches has been within 2000 t of the management targets since 2011–12, except in 2014–15 and 2018–19 when the eastern catch was 4600 t and 5700 t over the target respectively, and in 2015–16, 2016–17, 2017–18, and 2018–19 when the western catches were lower than the targets. Figure 2 shows the reported landings and TACC for HOK 1, and also the eastern and western catch components of this stock since 1988–89.

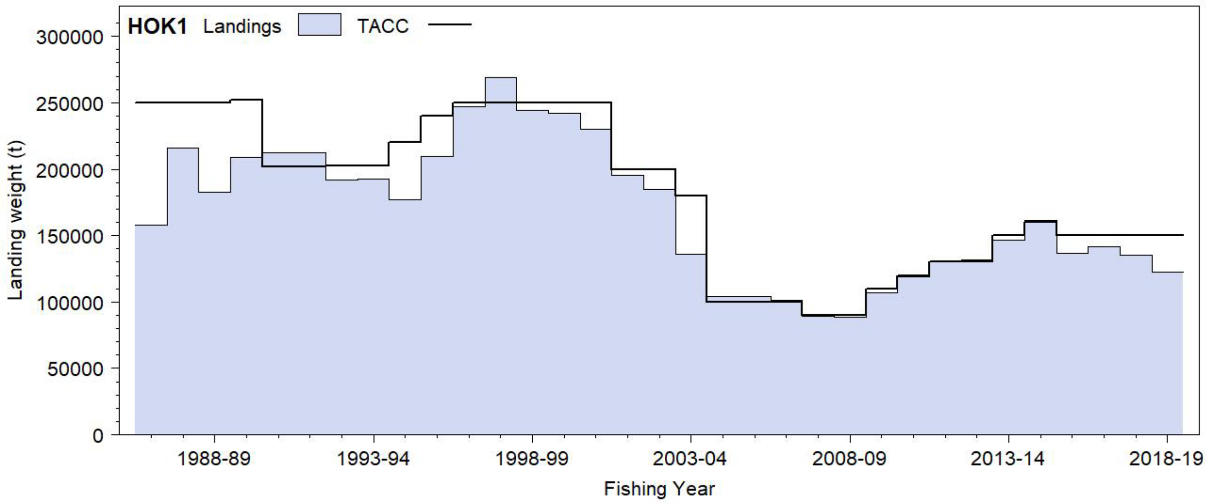


Figure 2a: Reported commercial landings and TACCs for HOK 1 since 1986–87. Note that this graph does not show data prior to entry into the QMS.

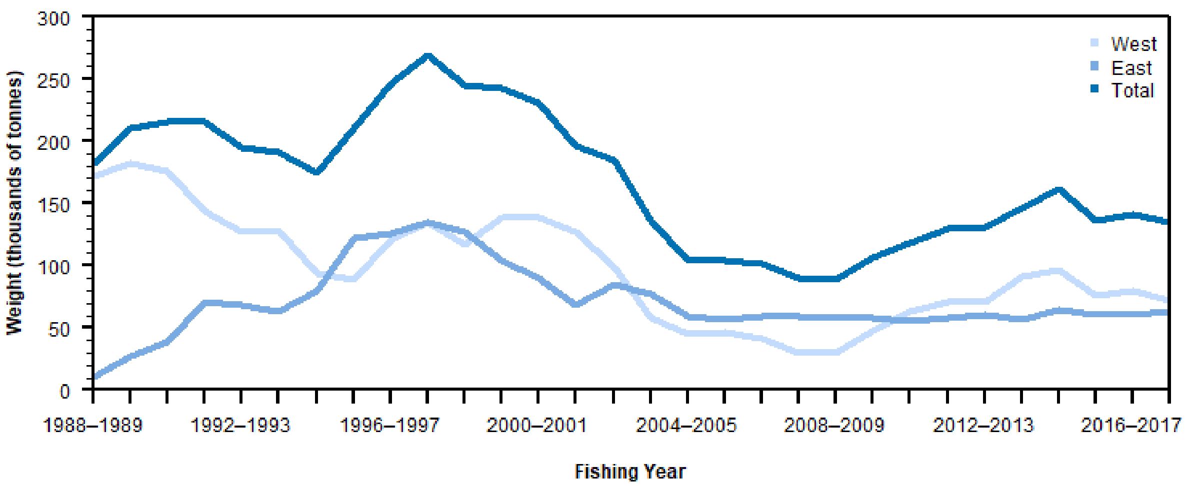


Figure 2b: The eastern and western components of the total HOK 1 landings since 1988–89. Note that these figures do not show data prior to entry into the QMS.

Table 4: Proportions of total catch for different fisheries.

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

Total Allowable Commercial Catch (TACC) and area restrictions

In the 2018–19 fishing year, the TACC for HOK 1 was 150 000 t. This TACC applied to all areas of the EEZ (except the Kermadec FMA which had a TACC of 10 t). With the allowance for other mortality at 1500 t and 20 t allowances for customary and recreational catch, the 2018–19 TAC was 151 540 t. However, 20 000 of western ACE was voluntarily shelved by the fishing industry (along with any HOK 1W ACE carried forward from 2017–18), so the effective TACC in 2018–19 was 130 000 t, with 70 000 t to be taken from western stock areas. From 1 October 2019 the TACC for HOK 1 was reduced to 115 000 t, with a non-regulatory catch split arrangement of 60 000 t from eastern stock areas and 55 000 t from western stock areas.

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

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

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

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

2018–19 hoki fishery

The overall catch of 122 405 t was about 13 000 t lower than the catch in 2017–18, and about 7600 t lower than the effective TACC of 130 000 t (Table 3). Relative to 2017–18, catches in 2018–19 decreased in western areas (WCSI and Sub-Antarctic) and increased on the Chatham Rise.

The WCSI catch decreased by 9100 t, to 46 400 t in 2019. Catches from inside the 25 n. mile line made up 32% of the total WCSI catch in 2019, an increase in proportion from 2018, but still lower than the peak of 41% of the catch taken from inside-the-line in 2004. The WCSI fishing season is now longer – with fishing beginning in May (although most pre-June catch is from inside the 25 n. mile line) and continuing into September. Most (69%) of the WCSI catch in 2019 was taken by midwater trawl. Twin trawls accounted for about half of the bottom trawl catch and 16% of the WCSI catch overall. Unstandardised catch rates decreased from 2018, with a median catch rate in all midwater tows targeting hoki of 3.0 t per hour in 2019. The WCSI catch in 2019 was dominated by fish from 60 to 110 cm from the 2008–15 year classes (ages 4–11). Only 3% of hoki caught on the WCSI were less than 65 cm. From 2000 to 2004, the sex ratio of the WCSI catch was highly skewed, with many more females caught than males. In 2005 to 2011, as the catch of younger fish increased, the sex ratio reversed with more males than females caught. The sex ratio of the WCSI catch was about even in 2019, with 55% females. The mean length-at-age for hoki off the WCSI increased from the start of the fishery to the mid-2000s, but has since decreased.

The Chatham Rise fishery caught 40 383 t in 2018–19, an increase of 3200 t from 2017–18. Over 64% of the 2018–19 Chatham Rise catch was taken in bottom trawls. There was an increase in catch from twin trawls, with this method accounting for 61% of the bottom trawl catch in 2018–19. The median unstandardised catch rate in bottom trawls targeting hoki was 1.2 t per hour. Most of the remaining Chatham Rise catch was taken using MHS (treated as a separate method to bottom trawls), with less than 1% of the catch taken by midwater trawl. Most of the catch was taken from October 2018 to August 2019, with an unusual peak in catches in late July to early August 2019, which coincided with the spawning fishery area closures. The length frequency distributions for both male and female hoki had modes at 50–80 cm, corresponding to fish from the 2012–15 year classes. In 2018–19 about 47% of the Chatham Rise catch by number was less than 65 cm.

The catch from Cook Strait in 2019 was 20 496 t, a decrease of 980 t from that in 2018. Peak catches were from mid-July to mid-September. Most catch (90%) is taken by midwater trawls. Unstandardised catch rates in Cook Strait continued to be high – although the median catch rate in midwater tows targeting hoki decreased from 21.7 t in 2018 to 9.5 t per hour in 2019. A broad size range of hoki was caught in 2019, with the main modes at ages 4–11 (2009 to 2015 year classes) for females, and ages 3–5 (2014–16 year classes) for males. About 23% of the Cook Strait catch was of fish less than 65 cm. As off the WCSI, the mean length at age in the Cook Strait fishery increased until the mid-2000s and has subsequently declined.

The catch from the Sub-Antarctic decreased by 6400 t from 2017–18 to 9044 t in 2018–19. Most catch (95%) was taken in bottom trawls, of which 44% was from twin trawls. MHS contributed only 4% of the catch. The median unstandardised catch rate in bottom trawls targeting hoki was similar to that on the Chatham Rise, at 1.2 t per hour in 2018–19. The observed catch had a mode at 60–65 cm, made up of fish from the 2015 year class, with a broad tail of larger fish of ages 4–12. About 50% of the Sub-Antarctic catch was of fish less than 65 cm.

Catches from ECSI, Puysegur, and ECNI in 2018–19 were similar to those in 2017–18, with catches of 3670 t, 1200 t, and 1180 t respectively.

1.2 Recreational fisheries
Recreational fishing for hoki is negligible.

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

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

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

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

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

2. BIOLOGY

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

The two main spawning grounds on the WCSI and in Cook Strait (Figure 1) are considered to comprise fish from separate stocks, based on the geographical separation of these spawning grounds and a number of other factors (see section 3 “Stocks and areas” below).
Hoki migrate to spawning grounds in Cook Strait, WCSI, Puysegur, and ECSI areas in the winter months. Throughout the rest of the year the adults are dispersed around the edge of the Stewart-Snares shelf, over large areas of the Sub-Antarctic and Chatham Rise, and to a lesser extent around the North Island. Juvenile fish (2–4 y) are found on the Chatham Rise throughout the year.

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

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

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

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

Estimates of biological parameters relevant to stock assessment are shown in Table 5 (but note that natural mortality was estimated in the model in the assessment).

Table 5: Estimates of fixed biological parameters.

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

3. STOCKS AND AREAS

Morphometric and ageing studies have found consistent differences between adult hoki taken from the two main dispersed areas (Chatham Rise and Sub-Antarctic), and from the two main spawning grounds in Cook Strait and WCSI (Livingston et al 1992, Livingston & Schofield 1996b, Horn & Sullivan 1996). These differences clearly demonstrate that there are two sub-populations of hoki. Whether or not they reflect genetic differences between the two sub-populations, or they are just the result of environmental differences between the Chatham Rise and Sub-Antarctic, is not known. No genetic differences have been detected with selectively neutral markers (Smith et al 1981, 1996) but a low exchange rate between stocks could reduce genetic differentiation.

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

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

4. CLIMATE AND RECRUITMENT

Annual variations in hoki recruitment have considerable impact on this fishery and a better understanding of the influence of climate on recruitment patterns would be very useful for the future projection of stock size. However, any link between climate, oceanographic conditions, and recruitment is still unknown. Analyses by Francis et al. (2006) do not support the conclusions of Bull & Livingston (2001) that model estimates of recruitment to the western stock are strongly correlated with the southern oscillation index (SOI). Francis et al. (2006) noted that there is a correlation of -0.70 between the autumn SOI and annual estimates of recruitment (1+ and 2+ fish) from the Chatham Rise trawl survey but found this hard to interpret because the survey is an index of the combined recruitment to both the eastern and western stocks. A more recent analysis supports some climate effect on hoki recruitment but remains equivocal about its strength or form (Dunn et al. 2009b). Bradford-Grieve & Livingston (2011) collated and reviewed information on the ocean environment off the WCSI in relation to hoki and other spawning fisheries. Hypotheses about which variables drive hoki recruitment were presented, but the authors noted that understanding of the underlying mechanisms and causal links between the WCSI marine environment and hoki year class survival remain elusive.

A baseline report summarising trends in climatic and oceanographic conditions in New Zealand that are of potential relevance for fisheries and marine ecosystem resource management in the New Zealand region has been completed (Hurst et al. 2012). There is also an updated chapter on oceanic trends in the Aquatic Environment & Biodiversity Annual Review 2018 (Fisheries New Zealand 2019). Any effects of recent warmer temperatures (e.g., such as the high surface temperatures on the WCSI during the 2016 and 2017 spawning seasons, marine heatwaves and general warming of the Tasman Sea (Sutton & Bowen 2019) on fish distribution, growth, or spawning success have yet to be determined.

A recent project has just reached completion that describes the state of knowledge of climate change-associated predictions for components of New Zealand’s marine environment that are most relevant to fisheries (Cumming et al in press). Past and future projected changes in coastal and ocean properties, including temperature, salinity, stratification and water masses, circulation, oxygen, ocean productivity, detrital flux, ocean acidification, coastal erosion and sediment loading, and wind and waves are reviewed. Responses to climate change for these coastal and ocean properties are discussed, as well as their likely impact on the fisheries sector, where known.

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

5. ENVIRONMENTAL AND ECOSYSTEM CONSIDERATIONS

This section was last fully reviewed by the Aquatic Environment Working Group for the May 2012 Fisheries Assessment Plenary. However, the tables have been updated annually with more recent data, where available, and minor corrections made to reflect the updates. This summary is from the perspective of the hoki fishery; a more comprehensive review from an issue-by-issue perspective is available in the 2019 Aquatic Environment and Biodiversity Annual Review (Fisheries New Zealand 2020).

5.1 Role in the ecosystem

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

5.1.1 Trophic interactions

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

5.1.2 Ecosystem Indicators

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

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

5.2 Bycatch (fish and invertebrates)

Hoki, hake, and ling made up 84%, 2%, and 3%, respectively, of the observed catch in target hoki trawls between 2013–14 and 2017–18 (Table 6).

Table 6: Percentage of total observed catch weight of species taken in hoki target trawls for the 2013–14 to 2017–18 fishing years. Only species with an observed annual catch of over 20 t for any of the five years are listed. Data were last updated in 2019 from the Centralised Observer Database (Anderson et al 2019). [Continued next page]

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

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

Table 7: Modelled annual bycatch estimates (t) for main bycatch species in the combined hoki, hake, ling, silver warehou, and white warehou trawl fishery from the 2012–13 to the 2016–17 fishing years, and percentage of total observed catch for the target trawl fishery from 1 Oct 2002 to 30 Sep 2017, in decreasing order (Anderson et al 2019).

	Model-based estimates of total catch					
Species	**2012–13**	**2013–14**	**2014–15**	**2015–16**	**2016–17**	**% of observed catch 2002–03 to 2016–17**
Combined target species (5 species)	148 525	160 402	178 661	149 150	156 636	90.14
Javelinfish	4 807	4 099	7 443	7 138	7 483	1.87
Rattails (excl. Javelinfish)	5 656	3 914	7 068	6 067	7 116	1.55
Spiny dogfish	1 957	3 841	3 596	2 114	3 764	1.41
Arrow squid	563	604	1 117	722	815	0.51
Barracuda	639	624	509	320	1 290	0.47
Morid cods	615	1 004	1 161	711	806	0.42
Pale ghostshark	747	1 084	1 151	1 298	923	0.32
Ribaldo	378	591	981	415	486	0.28
Sea perch	672	399	975	846	582	0.27
Dark ghostshark	418	477	581	842	560	0.24
Lookdown dory	551	555	833	681	664	0.23
Black oreo	673	1517	593	343	733	0.21
Southern blue whiting	28	232	175	135	143	0.17
Giant stargazer	283	314	619	371	327	0.16
Red cod	172	275	164	227	251	0.14
Shovelnose dogfish	274	338	211	346	217	0.13
Gemfish	164	236	173	281	689	0.12
Jack mackerel	21	14	62	45	29	0.08
Alfonsino	25	50	118	33	75	0.03
Orange roughy	8	8	9	11	6	0.02
Slickheads	6	13	14	11	13	0.01

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

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

5.3.1 Marine mammal interactions

New Zealand fur seal

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

Vessels targeting hoki incidentally catch fur seals (Baird 2005b, Smith & Baird 2009, Thompson & Abraham 2010a, Baird 2011, Abraham et al 2016, Abraham & Richard 2019). The lowest capture rates have occurred in the most recent years (Table 8). Observed captures have occurred mostly off the west coast South Island and in the Cook Strait. Estimated captures of New Zealand fur seals in the hoki fishery have accounted for 44% of all fur seals estimated to have been caught by trawling in the EEZ between 2002–03 and 2017–18 for those fisheries modelled. In 2018 the AEWG noted that the captures model described by Abraham et al (2016) was in many instances over-estimating the upper bound of the confidence interval of estimated captures, reflecting inappropriate partitioning of the estimates between strata with contrasting capture rates. The updated model described by Abraham et al. (2019) was judged by the AEWG to produce more plausible estimates, shown in Table 8.

Table 8: Number of tows by fishing year and observed and model-estimated total New Zealand fur seal captures in hoki trawl fisheries, 1998–99 to 2017–18. No. obs, number of observed tows; % obs, percentage of tows observed; Rate, number of captures per 100 observed tows, % inc, percentage of total effort included in the statistical model. * Estimates 1998–99 to 2001–02 from Smith & Baird (2009) who estimated captures by area and confidence intervals have not been estimated at this level of aggregation. Other estimates are based on methods described in Abraham et al (2019) and available via https://data.dragonfly.co.nz/psc. Estimates for 2002–03 to 2015–16 are based on data version 2018v1.

	Fishing effort			Observed		Estimated		
	Tows	No. obs	% obs	Captures	Rate	Mean	95% c.i.	% inc.
1998–99	32 293	3 561	11.0	84	2.4	919	*	95.6
1999–00	33 078	3 275	9.9	102	3.1	764	*	95.8
2000–01	32 019	3 548	11.1	66	1.9	804	*	97.6
2001–02	27 233	3 277	12.0	110	3.4	844	*	96.3
2002–03	27 785	2 593	9.3	45	1.7	650	392–866	100.0
2003–04	22 524	2 345	10.4	56	2.4	770	331–739	100.0
2004–05	14 544	2 134	14.7	120	5.6	782	659–1 273	100.0
2005–06	11 590	1 775	15.3	62	3.5	443	334–783	100.0
2006–07	10 610	1 755	16.5	29	1.7	271	216–503	100.0
2007–08	8 787	1 878	21.4	58	3.1	326	213–437	100.0
2008–09	8 176	1 661	20.3	37	2.2	204	132–295	100.0
2009–10	9 965	2 066	20.7	30	1.5	175	124–256	100.0
2010–11	10 404	1 724	16.6	24	1.4	180	144–399	100.0
2011–12	11 333	2 694	23.8	34	1.3	206	137–303	100.0
2012–13	11 689	4 512	38.6	60	1.3	255	230–568	100.0
2013–14	12 948	3 978	30.7	32	0.8	168	96–208	100.0
2014–15	13 588	3 613	26.6	42	1.2	320	164–375	100.0
2015–16	12 636	3 474	27.5	42	1.2	194	141–306	100.0
2016–17	12 952	2 908	22.5	37	1.3			
2017–18	13 792	4 769	34.6	41	0.9			

New Zealand sea lion

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

New Zealand sea lions are captured only rarely by vessels trawling for hoki; since 2002–03 there have been three observed captures during fishing season when 9–39% of the fishing effort was observed (Table 9). All observed captures have been close to the Auckland Islands.

Table 9: Number of tows by fishing year and observed New Zealand sea lion captures in hoki trawl fisheries, 2002–03 to 2017–18. Number observed, number of observed tows; % obs, percentage of tows observed; Rate, number of captures per 100 observed tows. Estimates are based on methods described in Abraham et al. (2016) and available via https://data.dragonfly.co.nz/psc. Estimates for 2002–03 to 2014–15 are based on data version 2018v1. [Continued on next page]

	Fishing effort			Observed captures		Estimated captures	
	Tows	No. obs	% obs	Captures	Rate	Mean	95%
2002–03	27 785	2 593	9.3	1	0	2	0–6
2003–04	22 524	2 345	10.4	0	0	1	0–5
2004–05	14 544	2 134	14.7	0	0	1	0–3
2005–06	11 590	1 775	15.3	0	0	0	0–2
2006–07	10 610	1 755	16.5	0	0	0	0–2
2007–08	8 787	1 878	21.4	1	0.1	1	1–2
2008–09	8 176	1 661	20.3	0	0	0	0–1
2009–10	9 965	2 066	20.7	0	0	0	0–2
2010–11	10 404	1 724	16.6	0	0	0	0–2
2011–12	11 333	2 694	23.8	0	0	0	0–2

Table 9 [Continued]:

	Fishing effort			Observed captures		Estimated captures	
	Tows	No. obs	% obs	Captures	Rate	Mean	95%
2012–13	11 689	4 512	38.6	1	0	1	1–3
2013–14	12 948	3 978	30.7	0	0	1	0–2
2014–15	13 588	3 613	26.6	0	0	1	0–3
2015–16	12 636	3 474	27.5	0	0		
2016–17	12 952	2 908	22.5	0	0		
2017–18	13 792	4 769	34.6				

5.3.2 Seabird interactions

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

Using the direct captures estimation approach, in the 2016–17 fishing year, there were 59 observed seabird captures in hoki trawl fisheries, and an estimated total of 280 (95% c.i. 213–374) captures (Table 10). In the 2017–18 fishing year, there were 143 observed seabird captures in hoki trawl fisheries, and an estimated total of 334 (95% c.i. 293–381) captures. Annual observed seabird capture rates have ranged between 1.3 and 4 per 100 tows in the hoki fishery over the time period 2002–03 to 2017–18, with little apparent trend. These figures represent summed totals across all seabird species and all methods of capture. To determine changes for particular species of interest or within particular subsets of the hoki fishery, more detailed analysis will be required.

Table 10: Number of tows by fishing year and observed and model-estimated total seabird captures in hoki trawl fisheries, 1998–99 to 2017–18. No. obs, number of observed tows; % obs, percentage of tows observed; Rate, number of captures per 100 observed tows, % inc, percentage of total effort included in the statistical model. Estimates are based on methods described in Abraham et al. (2016) and Abraham & Richard (2017, 2018) and available via https://data.dragonfly.co.nz/psc. Estimates for 2002–03 to 2017–18 are based on data version 2019v01.

		Observed				Estimated	
	Tows	No. obs	% obs	Captures	Rate	Mean	95% c.i.
2002–03	27 785	2 593	9.3	82	3.2	698	562–858
2003–04	22 523	2 345	10.4	32	1.4	442	345–548
2004–05	14 541	2 134	14.7	43	2.0	372	299–464
2005–06	11 589	1 775	15.3	53	3.0	317	247–401
2006–07	10 601	1 755	16.6	23	1.3	222	168–285
2007–08	8 787	1 877	21.4	28	1.5	186	144–237
2008–09	8 174	1 660	20.3	37	2.2	248	195–314
2009–10	9 965	2 066	20.7	53	2.6	266	214–328
2010–11	10 407	1 724	16.6	54	3.1	325	261–403
2011–12	11 331	2 694	23.8	58	2.2	265	219–320
2012–13	11 693	4 516	38.6	101	2.2	296	254–343
2013–14	12 947	3 975	30.7	157	3.9	405	353–465
2014–15	13 589	3 613	26.6	82	2.3	419	349–500
2015–16	12 641	3 474	27.5	48	1.4	249	205–299
2016–17	12 952	2 908	22.5	59	2.0	291	239–350
2017–18	13 794	4 768	34.6	143	3.0	334	293–381

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

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

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

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

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

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

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

5.3.3 Protected fish interactions

Basking shark

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

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

Table 12: Number of tows (data version 20200507), and number of captures (1994–95 to 2007–08 from Francis & Smith 2010; 2008–09 to 2017–18 from the Central Observer Database referred to the whole HOK/HAK/LIN/SWA/WWA trawl fishery) of basking shark in hoki trawls.

Year	Tows*	No. observed	% observed	No. Captures
1994–05	21 583	–	–	2
1995–06	24 610	–	–	0
1996–07	28 756	–	–	5
1997–08	30 354	–	–	14
1998–09	32 242	3 558	11.0	8
1999–00	33 061	3 273	9.9	2
2000–01	32 018	3 549	11.1	3
2001–02	27 224	3 274	12.0	0
2002–03	27 785	2 593	9.3	5
2003–04	22 535	2 346	10.4	2
2004–05	14 543	2 131	14.7	8
2005–06	11 590	1 775	15.3	0
2006–07	10 607	1 758	16.6	0
2007–08	8 786	1 877	21.3	1
2008–09	8 176	1 662	20.3	0
2009–10	9 966	2 066	20.7	0
2010–11	10 405	1 724	16.6	0
2011–12	11 332	2 579	22.8	1
2012–13	11 680	4 517	38.7	3
2013–14	12 947	3 975	30.7	7
2014–15	13 589	3 613	26.6	15
2015–16	12 641	3 474	27.5	16
2016–17	12 952	2 908	22.5	0
2017–18	13 794	4 768	34.6	0

5.4 Benthic interactions

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

Table 13: Summary of number of hoki target trawl tows (TCEPR only) in the hoki fishery from fishing years (FY) 1989–90 to 2017–18. (MW, mid-water trawl; BT, bottom trawl). [Continued next page]

Fishery	WCSI/Puysegur		Cook Strait/ECSI		Sub-Antarctic		Chatham Rise/ECSI				
Season	Spawning		Spawning		Non-spawn		Non-spawn		All areas combined		%
Method	MW	BT	MW	BT	MW	BT	MW	BT	MW	BT	BT
FY											
1989–90	7 849	1 187	1 084	25	36	2 109	28	2 027	8 997	5 348	37
1990–91	7 351	1 678	2 226	26	81	3 927	953	3 492	10 611	9 123	46
1991–92	5 624	1 579	1 772	14	117	5 442	443	5 555	7 956	12 590	61
1992–93	5 488	1 861	1 564	18	442	4 915	1 054	5 266	8 548	12 060	59
1993–94	8 014	1 639	1 852	154	562	2 039	1 331	3 448	11 759	7 280	38
1994–95	7 223	1 501	2 019	258	419	2 329	2 174	6 260	11 835	10 348	47
1995–96	5 698	2 017	3 187	1 439	418	2 506	2 305	7 913	11 608	13 875	54
1996–97	7 428	1 894	3 672	1 350	332	3 423	2 314	9 305	13 746	15 972	54
1997–98	6 979	1 548	2 371	701	165	4 376	3 780	11 456	13 295	18 081	58
1998–99	5 476	2 118	1 992	580	420	3 659	2 428	11 445	10 316	17 802	63
1999–00	5 470	2 275	1 943	370	516	5 943	2 706	9 494	10 635	18 082	63
2000–01	6 229	2 577	1 969	175	667	5 448	912	9 862	9 777	18 062	65
2001–02	4 988	3 095	1 136	173	132	6 449	858	7 820	7 114	17 537	71
2002–03	4 615	2 977	2 117	282	96	4 407	496	9 278	7 324	16 944	70
2003–04	4 274	1 887	1 812	72	78	3 023	385	7 225	6 549	12 207	65
2004–05	2 534	1 308	1 457	111	68	1 428	340	4 996	4 399	7 843	64
2005–06	1 783	1 508	1 020	49	74	719	140	4 822	3 017	7 098	70
2006–07	1 147	752	919	82	25	1 194	57	4 769	2 148	6 797	76
2007–08	813	492	393	386	36	925	75	4 203	1 317	6 006	82
2008–09	689	354	747	148	38	927	11	3 914	1 485	5 343	78
2009–10	1 182	612	799	77	56	1 251	116	4 361	2 153	6 301	75
2010–11	1 581	913	544	63	62	1 245	52	4 075	2 239	6 296	74
2011–12	1 660	1 188	836	81	70	1 202	74	4 397	2 640	6 868	72
2012–13	1 826	1 019	1 022	98	6	1 373	169	4 175	3 023	6 665	69
2013–14	2 318	1 111	1 011	65	12	1 872	131	3 981	3 472	7 029	67
2014–15	2 716	1 244	953	53	89	1 620	209	4 319	3 967	7 236	65
2015–16	2 694	1 529	823	93	10	834	101	4 066	3 628	6 522	64
2016–17	2 366	1 907	729	100	24	1 278	99	4 193	3 218	7 478	70
2017–18	2 102	2 042	833	18	81	1 724	63	3 647	3 079	7 431	71

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

During 1989–90 to 2015–16, about 390 000 bottom-contacting hoki trawls were reported on TCEPRs and TCERs (Baird & Wood 2018). The total footprint generated from these tows was estimated at about 167 100 km^2. This footprint represented coverage of 4.1% of the seafloor of the combined EEZ and the Territorial Sea areas; 11.8% of the 'fishable area', that is, the seafloor area open to trawling, in depths of less than 1600 m. In the 2016–17 fishing year, almost 10 000 hoki tows resulted in a trawl footprint of 26 932 km^2, equivalent to 0.7% of the EEZ and Territorial Sea and 1.9 % of the fishable area (Baird & Mules 2019). In 2017–18, the footprint contacted almost 30 000 km^2, based on about 10 800 tows, which represented 2.1% of the fishable area (Baird & Mules 2020).

The overall trawl footprint for hoki (1989–90 to 2015–16) covered 19% of the seafloor in 200–400 m, 25% of 400–600 m seafloor, and 24% of the 600–800 m seafloor (Baird & Wood 2018). The hoki footprint contacted 1%, 6%, and 2% of those depth ranges in 2016–17, respectively (Baird & Mules 2019) and 1%, 8%, and 4% in 2017–18. The Benthic-optimised Marine Environment Classification (BOMEC, Leathwick et al 2012) classes with the highest proportion of area covered by the hoki footprint were classes G (Cook Strait), H (Chatham Rise), I (Chatham Rise slope and shelf edge of the east coast South Island), and L (southern plateau waters). In 2016–17, the hoki footprint contacted 20% of the 52 224 km^2 of BOMEC class I and 4% of the 138 551 km^2 in class H (Baird & Mules 2019). In 2017–18, 3% of class G (6342 km^2), 4% of class H (138 551 km^2), 19.5% of class I, and 2.2% of class L were contacted by the hoki footprint (Baird & Mules 2020).

Bottom trawling for hoki, like trawling for other species, is likely to have effects on benthic community structure and function (e.g., Rice 2006) and there may be consequences for benthic productivity (e.g., Jennings et al 2001, Hermsen et al 2003, Hiddink et al 2006, Reiss et al 2009). These are not considered in detail here but are discussed in the Aquatic Environment and Biodiversity Annual Review 2019 (Fisheries New Zealand 2020).

5.5 Other factors

5.5.1 Spawning disruption

Fishing during spawning may disrupt spawning activity or success. Although there has been no research on the disruption of spawning hoki by fishing in New Zealand, the hoki quota owners voluntarily ceased fishing some defined spawning grounds for certain periods on the WCSI, Pegasus Canyon (ECSI), and Cook Strait as a precautionary measure from the 2004 to 2009 spawning seasons with the intention of assisting stock rebuilding. This closure was lifted in the 2010 spawning season because the biomass of the western stock was estimated to have rebuilt to within the management target range, but it was reintroduced for the 2019 spawning season.

5.5.2 Habitat of particular significance to fisheries management

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

6. STOCK ASSESSMENT

A stock assessment was carried out in 2019 using research time series of abundance indices (trawl and acoustic surveys), proportions at age data from the commercial fisheries and trawl surveys, and estimates of biological parameters. This included an update of the 2018 two stock base model (McKenzie 2019a), and alternative model runs focused on fitting the eastern or western biomass data better. New information included a trawl survey in the Sub-Antarctic in November-December 2018, an acoustic survey off the WCSI July-August 2018, and updated catch at age data from the Sub-Antarctic survey and the four main fisheries in 2017–2018. The general-purpose stock assessment programme, CASAL (Bull et al 2012), was used to perform the analyses.

The 2018 assessment updated the 2017 assessment, with similar assumptions and data weightings, but Working Group concerns over model fits to the survey biomass indices and the conflict between the biomass indices and age data led to Fisheries New Zealand commissioning a review of the assessment in mid-2018 (Dunn & Langley 2018). In 2019, the Working Group considered the recommendations of that review.

Recent trends (by fishing year) in survey abundance indices (Table 14) have been mostly downward. The Sub-Antarctic trawl survey estimate in November-December 2018 was down 18% from 2016, similar to that in 2014, and is now the lowest in the series since the four low points from 2003 to 2006. The acoustic survey biomass in Cook Strait in 2017 was half that in 2015 and the lowest since 2008. The 2018 WCSI acoustic survey was down 47% on 2013 and is the lowest in the time series, going back to 1988. The Chatham Rise 2018 trawl survey biomass was the only survey to show a slight increase, up by 6% from 2016. This increase was largely driven by the biomass estimates for 1+ and 2+ hoki. The relative biomass of recruited hoki (ages 3+ years and older) on the Chatham Rise in 2018 declined by 26% from that in 2016.

CPUE in the major fisheries have had mixed changes over the past few years: standardised indices have been relatively stable on the Chatham Rise for the last 10 years; increased by 29% over the last three years in Cook Strait; declined by 43% over the last three years off the WCSI; and declined by 27% since 2012 in the Sub-Antarctic. CPUE is not used in the stock assessment because it does not accurately index abundance over the long term.

In 2019, the Working Group focused on investigations of the commercial catch at age composition data and the data and model assumptions that influenced the stock status estimates for the western and eastern stocks. The results of the Working Group and plenary deliberations reflect the outcomes of these investigations.

Table 14: Abundance indices ('000 t) used in the stock assessment (* data new to this assessment). Years are fishing years (1990 = 1989–90). – no data.

Year	Acoustic survey WCSI winter WCacous	Trawl survey Sub-Antarctic December SAsumbio	Trawl survey Sub-Antarctic April SAautbio	Trawl survey Chatham Rise January CRsumbio	Acoustic survey Cook Strait winter CSacous
1988	266	–	–	–	–
1989	165	–	–	–	–
1990	169	–	–	–	–
1991	227	–	–	–	88
1992	229	80	68	120	–
1993	380	87	–	186	283
1994	–	100	–	146	278
1995	–	–	–	120	194
1996	–	–	89	153	92
1997	445	–	–	158	141
1998	–	–	68	87	80
1999	–	–	–	109	114
2000	263	–	–	72	–
2001	–	56	–	60	102
2002	–	38	–	74	145
2003	–	40	–	53	104
2004	–	14	–	53	–
2005	–	18	–	85	59
2006	–	21	–	99	60
2007	–	14	–	70	104
2008	–	46	–	77	82
2009	–	47	–	144	166
2010	–	65	–	98	–
2011	–	–	–	94	141
2012	283	46	–	88	–
2013	233	56	–	124	168
2014	–	–	–	102	–
2015	–	31	–	–	204
2016	–	–	–	115	–
2017	–	38	–	–	102
2018	123*	–	–	122	–
2019	–	31*	–	–	–

6.1 Methods

Model structure

The model partitioned the population into two sexes, 17 age groups (1 to 16 and a plus group, 17+), two stocks [eastern (E) and western (W)], and four areas [Chatham Rise (CR), West Coast South Island (WC), Sub-Antarctic (SA), and Cook Strait (CS)]. It is assumed that the adult fish of the two stocks do not mix: those from the western stock spawn off the West Coast South Island and spend the rest of the year in the Sub-Antarctic; the eastern fish move between their spawning ground, Cook Strait, and their home ground, the Chatham Rise. Juvenile fish from both stocks live on Chatham Rise, but natal fidelity is assumed for most model runs (i.e., all fish spawn in the area in which they were spawned). There is little direct evidence of natal fidelity for hoki, though its life history characteristics would indicate that 100% natal fidelity is unlikely (Horn 2011).

The model does not distinguish between mature and immature fish; rather than having a maturity ogive and a single proportion spawning (assumed to be the same for all ages), there is simply a spawning ogive. The reason for this is that there are no direct observations of maturity to use in the model but information about proportion spawning is available (there are three autumn observations in the Sub-Antarctic of proportions of females that will spawn that year).

The model's annual cycle divides the fishing year into five time steps and includes four types of migration (Table 15). The first type of migration involves only newly spawned fish, all of which are assumed to move from the spawning grounds (Cook Strait and the West Coast South Island) to arrive at the Chatham Rise at time step 2 and approximate age 1.6 y. The second affects only young western fish, some of which are assumed to migrate, at time step 3, from the Chatham Rise to the Sub-Antarctic. The last two types of migrations relate to spawning. Each year some fish migrate from their home ground (the Chatham Rise for eastern fish, the Sub-Antarctic for western fish) to their spawning ground (Cook Strait for eastern fish, the West Coast South Island for western fish) at time step 4. At time step 1 in the following year all spawners return to their home grounds. Both non-spawning fisheries (on the Chatham Rise and the Sub-Antarctic) are split into two halves to allow some of the catch to be taken before the Whome migration, and some after (and given the labels in the model of Ensp1, Ensp2, Wnsp1, Wnsp2).

The above describes the two stock model areas and structure. A simplified western stock only model was also constructed to assess the impact of the two stock model data and assumptions. In this model the eastern areas and data were dropped. Instead of young juvenile western fish being on the Chatham Rise, where some are caught and some die, they directly recruit to the Sub-Antarctic. Henceforth, as in the two stock model, they spawn off the West Coast South Island and return to the Sub-Antarctic. Although this model neglects catch on the Chatham Rise and processes between newly spawned fish and their arrival in the Sub-Antarctic, it removes conflicts between eastern data and western biomass indices when western biomass is estimated in the model.

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

			M	**Age**	**Observations**	
Step	**Approx. months**	**Processes**	**fraction**	**fraction**	**Label**	**Prop. Mort.**
1	Oct–Nov	migrations Wreturn: WC->SA, Ereturn: CS->CR	0.17	0.25	–	
2	Dec–Mar	recruitment at age 1+ to CR (for both stocks)	0.33	0.6	SAsumbio	0.5
		part1, non-spawning fisheries (Ensp1, Wnsp1)			CRsumbio	0.6
3	Apr–Jun	migration Whome: CR->SA	0.25	0.9	SAautbio	0.1
		part2, non-spawning fisheries (Ensp2, Wnsp2)			pspawn	
4	End Jun	migrations Wspmg: SA->WC, Espmg: CR->CS	0	0.9		
					CSacous	0.5
5	Jul–Sep	increment ages	0.25	0	WCacous	0.5
		spawning fisheries (Esp, Wsp)				

Data and error assumptions

Five series of abundance indices were used in the assessment (Table 14). New data were available from a trawl survey in the Sub-Antarctic in November–December 2019 (MacGibbon et al 2019) and a winter 2018 acoustic survey off the west coast South Island (O'Driscoll & Ballara 2019). The age data used in the assessment (Table 16) were similar to those used in 2018, but with an additional year's data.

The error distributions assumed were multinomial (Bull et al 2012) for the at-age data, and lognormal for all other data. The weight assigned to each data set was controlled by the effective sample size for each observation, calculated from the observation error, and a reweighting procedure for the data sets (McKenzie 2015a, Francis 2011). An arbitrary CV of 0.25 (as used by Cordue 2001) was assumed for the proportion spawning observations.

Table 16: Age data used in the assessment (* data new to this assessment). Data are from otoliths or from the length-frequency analysis program OLF (Hicks et al 2002). Years are fishing years (1990 = 1989–90).

Area	**Label**	**Data type**	**Years**	**Source of age data**
WC	Wspage	Catch at age	1988–2018*	Otoliths
SA	WnspOLF	Catch at age	1992–94, 96, 99–00	OLF
	Wnspage	Catch at age	2001–04, 06–14, 16, 18*	Otoliths
	SAsumage	Trawl survey	1992–94, 2001–10, 2012–13, 15, 17, 19*	Otoliths
	SAautage	Trawl survey	1992, 96, 98	Otoliths
	pspawn	Proportion spawning	1992, 93, 98	Otoliths
CS	Espage	Catch at age	1988–2010, 2014–18*	Otoliths
CR	EnspOLF	Catch at age	1992, 94, 96, 98	OLF
	Enspage	Catch at age	1999–2018*	Otoliths
	CRsumage	Trawl survey	1992–2014, 2016, 2018	Otoliths

Two alternative sets of CVs were used for the biomass indices. The "total" CVs represent an estimate of the total uncertainty associated with these data. For the trawl survey indices, these were calculated as the sum of an observation-error CV (which was calculated using the standard formulae for stratified random surveys, e.g., Livingston & Stevens (2002), and a process-error CV, which was either estimated or set at zero for the Chatham Rise and summer Sub-Antarctic surveys (note that CVs are added as squares: $CV_{total}^2 = CV_{process}^2 + CV_{observation}^2$). For the Sub-Antarctic autumn trawl survey the process error was set at 0.20 following Francis (2001). For final model MCMC runs the process-error CVs were set at their MPD values. The CVs of the biomass indices are shown in Table 17.

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

Table 17: Coefficients of variation (CVs) used with biomass indices in the assessment. Total CVs include both observation error CVs and process error CVs. Observation error CVs are shown for CRsumbio and SAsumbio and the process error CVs either estimated or set to zero for MPD runs. Total CVs shown here for CSacous and WCacous, and SAautbio. Years are fishing years (1990 = 1989–90).

CRsumbio	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003
Observation	0.08	0.10	0.10	0.08	0.10	0.08	0.11	0.12	0.12	0.10	0.11	0.09

CRsumbio	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2016	2018
Observation	0.12	0.11	0.08	0.11	0.11	0.15	0.14	0.10	0.15	0.10	0.14	0.16

SAsumbio	1992	1993	1994	2001	2002	2003	2004	2005	2006	2007	2008	2009
Observation	0.07	0.06	0.09	0.13	0.16	0.14	0.13	0.12	0.13	0.11	0.16	0.14

SAsumbio	2012	2013	2015	2017	2019
Observation	0.15	0.15	0.13	0.17	0.11

SAautbio	1992	1996	1998
Total	0.22	0.22	0.23
Observation	0.08	0.09	0.11

CSacous	1991	1993	1994	1995	1996	1997	1998	1999	2001	2002	2003	2005
Total	0.41	0.52	0.91	0.61	0.57	0.40	0.44	0.36	0.30	0.34	0.34	0.32
Observation	0.12	0.15	0.14	0.12	0.09	0.12	0.10	0.09	0.12	0.12	0.17	0.11

CSacous	2007	2008	2009	2011	2013	2015	2017
Total	0.46	0.30	0.39	0.35	0.30	0.33	0.36
Observation	0.26	0.06	0.11	0.14	0.15	0.18	0.17

WCacous	1988	1989	1990	1991	1992	1993	1997	2000	2012	2013	2018
Total	0.60	0.38	0.40	0.73	0.49	0.38	0.60	0.28	0.34	0.35	0.46
Observation	0.12	0.15	0.06	0.10	0.17	0.07	0.10	0.14	0.15	0.18	0.15

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

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

	Age range	
Data set	**Lower**	**Upper**
Espage, Wspage, SAsumage, SAautage	2	15+
Wnspage	2	13+
CRsumage, Enspage	1	13+
WnspOLF	2	6+
EnspOLF	1	6+
pspawn	3	9+

The catch for each year was divided among the six fisheries in the model according to area and month (Table 19). This division was done using TCEPR, TCER, CELR, NCELR, LTCER, LCER, TLCER data, and the resulting values were then scaled up to sum to the HOK 1 MHR total. The method of dividing the catches (Table 19) was the same as that used in the 2018 assessment, so the catches used in the model (Table 20) are unchanged, except for revisions to the assumed catch for 2018.

For the 2018–19 year, the TACC was 150 000 t with a catch limit arrangement for 60 000 t to be taken from the eastern fisheries and 90 000 t from the western fisheries, but with shelving of 20 000 t of catch from the western spawning stock and spawning closures. Industry representatives indicated that the total catch taken for 2018–19 would be likely to be 135 000 t with 64 000 t taken from the eastern fisheries and 71 500 t from the western fisheries. In the stock assessment model the non-spawning fisheries were split into two parts, separated by the migration of fish from the Chatham Rise to the Sub-Antarctic (Table 20).

Table 19: The division of annual catches by area and months into the six model fisheries (Esp, Wsp, Ensp1, Ensp2, Wnsp1, and Wnsp1). The small amount of catch reported in the areas west coast North Island and Challenger, typically about 100 t per year, has been distributed pro rata across all fisheries).

Fishery	Model fishery	Areas	Months
Western spawning fishery	Wsp	West Coast South Island & Puysegur	October–September
Western non-spawning fishery 1	Wnsp1	Sub-Antarctic	October–March
Western non-spawning fishery 2	Wnsp2	Sub-Antarctic	April–September
Eastern spawning fishery	Esp	Cook Strait & Pegasus Canyon	June–September
Eastern non-spawning fishery 1	Ensp1	Cook Strait & Pegasus Canyon Chatham Rise, East Coast South Island, East Coast North Island & null[1]	October–March
Eastern non-spawning fishery 2	Ensp2	Cook Strait & Pegasus Canyon	April–May
		Chatham Rise East Coast South Island East Coast North Island null[1]	April–September

[1] Catch reported with no area.

Further assumptions

Two key outputs from the assessment are B_0 – the average spawning stock biomass that would have occurred over the period of the fishery had there been no fishing – and the time series of year class strengths (YCSs). For example, the YCS for 1970, was for fish spawned in the winter of 1970, that first arrived in the model in area Chatham Rise, at age 1.6 y, in about December 1971, which was in model year 1972. Associated with B_0 was an estimated mean recruitment, R_0, which was used, together with a Beverton-Holt stock-recruit function and the YCSs, to calculate the recruitment in each year. The first five YCSs (for years 1970 to 1974) were set equal to 1 (because of the lack of at-age data for the early years), but all remaining YCSs (for 1975 to 2017) were estimated, with an equality constraint for the 2017 eastern and western YCSs (due to insufficient information to estimate the eastern and western YCSs separately). The model corrects for bias in estimated YCSs arising from ageing error. YCSs were constrained to average to 1 over the years 1975 to 2014, so that R_0 may be thought of as the average recruitment over that period. R_0 and a set of YCSs were estimated separately for each stock. The B_0 for each stock was calculated as the spawning biomass that would occur given no fishing and constant recruitment, R_0, and the initial biomass before fishing (B_{INIT}) was set equal to B_0. The steepness of the stock-recruitment relationship was assumed fixed at 0.75 (Francis 2009).

In model runs natural mortality was assumed to vary with age (following a double-exponential curve) and separately for each sex.

The model used six selectivity ogives (four for the eastern and western spawning and non-spawning fisheries and one each for the trawl surveys on the Chatham Rise and Sub-Antarctic) and three migration ogives (Whome, Espmg, and Wspmg).

Assumed maximum exploitation rates were as agreed by the Working Group in 2004: 0.5 and 0.67 for the non-spawning and spawning fisheries, respectively. Because the non-spawning fisheries were split into two approximately equal halves, a maximum exploitation rate of 0.3 was assumed for each half. This was approximately equivalent to 0.5 for the two halves combined. Penalty functions were used to discourage model fits which exceeded these maxima.

Prior distributions were assumed for all parameters (Table 21). In addition, bounds were imposed for parameters with non-uniform distributions. For the catchability parameters, these were calculated by O'Driscoll et al (2002, 2016) (who called them overall bounds); for other parameters, they were set at the 0.001 and 0.999 quantiles of their distributions. Prior distributions for all other parameters were assumed to be uniform, with bounds that were either natural (e.g., 0.1 for proportion migrating at age), wide enough so as not to affect point estimation, or, for some ogive parameters, deliberately set to constrain the ogive to a plausible shape.

Table 20: Catches (t) by fishery and fishing year (1972 means fishing year 1971–72), as used in this assessment. Years are fishing years (1990 = 1989–90). The 2019 catch is assumed, based on industry advice.

							Fishery
Year	Ensp1	Ensp2	Wnsp1	Wnsp2	Esp	Wsp	Total
1972	1 500	2 500	0	0	0	5 000	9 000
1973	1 500	2 500	0	0	0	5 000	9 000
1974	2 200	3 800	0	0	0	5 000	11 000
1975	13 100	22 900	0	0	0	10 000	46 000
1976	13 500	23 500	0	0	0	30 000	67 000
1977	13 900	24 100	0	0	0	60 000	98 000
1978	1 100	1 900	0	0	0	5 000	8 000
1979	2 200	3 800	0	0	0	18 000	24 000
1980	2 900	5 100	0	0	0	20 000	28 000
1981	2 900	5 100	0	0	0	25 000	33 000
1982	2 600	4 400	0	0	0	25 000	32 000
1983	1 500	8 500	3 200	3 500	0	23 300	40 000
1984	3 200	6 800	6 700	5 400	0	27 900	50 000
1985	6 200	3 800	3 000	6 100	0	24 900	44 000
1986	3 700	13 300	7 200	3 300	0	71 500	99 000
1987	8 800	8 200	5 900	5 400	0	146 700	175 000
1988	9 000	6 000	5 400	7 600	600	227 000	255 600
1989	2 300	2 700	700	4 900	7 000	185 900	203 500
1990	3 300	9 700	900	9 100	14 000	173 000	210 000
1991	17 400	14 900	4 400	12 700	29 700	135 900	215 000
1992	33 400	17 500	14 000	17 400	25 600	107 200	215 100
1993	27 400	19 700	14 700	10 900	22 200	100 100	195 000
1994	16 000	10 600	5 800	5 500	35 900	117 200	191 000
1995	29 600	16 500	5 900	7 500	34 400	80 100	174 000
1996	37 900	23 900	5 700	6 800	59 700	75 900	209 900
1997	42 400	28 200	6 900	15 100	56 500	96 900	246 000
1998	55 600	34 200	10 900	14 600	46 700	107 100	269 100
1999	59 200	23 600	8 800	14 900	40 500	97 500	244 500
2000	43 100	20 500	14 300	19 500	39 000	105 600	242 000
2001	36 200	19 700	13 200	16 900	34 800	109 000	229 800
2002	24 600	18 100	16 800	13 400	24 600	98 000	195 500
2003	24 200	18 700	12 400	7 800	41 700	79 800	184 600
2004	17 900	19 000	6 300	5 300	41 000	46 300	135 800
2005	19 000	13 800	4 200	2 100	27 000	38 100	104 200
2006	23 100	14 400	2 300	4 700	20 100	39 700	104 300
2007	22 400	18 400	4 200	3 500	18 800	33 700	101 000
2008	22 100	19 400	6 500	2 200	17 900	21 200	89 300
2009	29 300	13 100	6 000	3 800	15 900	20 800	88 900
2010	28 500	13 500	6 700	5 600	16 400	36 600	107 300
2011	30 500	12 800	7 500	5 200	13 300	49 500	118 800
2012	28 400	14 700	9 100	6 600	15 400	55 800	130 000
2013	29 900	11 800	6 500	7 600	18 600	57 200	131 600
2014	27 200	11 700	10 600	9 300	17 300	70 200	146 300
2015	32 300	12 500	9 100	7 300	19 800	80 600	161 600
2016	28 900	11 600	3 400	3 300	19 600	69 900	136 700
2017	31 500	12 600	5 300	7 900	17 100	67 200	141 600
2018	27 000	14 800	9 000	6 500	21 600	56 600	135 500
2019	31 700	17 300	5 200	3 800	15 000	62 500	135 000

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

Parameter	Description	Distribution	Values		Reference
log_B_0_total	$\log(B_{0,E} + B_{0,W})$	uniform	11.6	16.2	
pE (= B_0_prop_stock1)	proportion unfished stock in E	beta(0.1,0.6)[1]	0.344	0.072	Smith (2004)
recruitment[E].YCS	year-class strengths (E)	lognormal	1	0.95	Francis (2004a)
recruitment[W].YCS	year-class strengths (W)	lognormal	1	0.95	Francis (2004a)
q[CSacous].q	catchability, CSacous	lognormal	0.55	0.90	O'Driscoll et al (2016)
q[WCacous].q	catchability, WCacous	lognormal	0.39	0.77	O'Driscoll et al (2016)
q[CRsum].q	catchability, CRsumbio	lognormal	0.15	0.65	O'Driscoll et al (2002)
q[SAsum].q	catchability, SAsumbio	lognormal	0.17	0.61	O'Driscoll et al (2002)
q[SAaut].q	catchability, SAautbio	lognormal	0.17	0.61	O'Driscoll et al (2002)
selectivity[Wspsl].shift_a	allows annual shifting of Wspsl	normal	0	0.25	Francis (2006)
natural_mortality.all[2]	M	lognormal	0.298	0.153	Smith (2004)
natural_mortality[3]	M_{male} & M_{female}, ages 5–9 only	lognormal	0.182	0.509	Cordue (2006)

[1] This is a beta distribution, transformed to have its range from 0.1 to 0.6, rather than the usual 0 to 1.

[2] Used only in runs where M was independent of age and sex

Calculation of fishing intensity and B_{MSY}

The fishing intensity for a given stock and model run was calculated as an annual exploitation rate,

$$U_y = max_{as}(\sum_f C_{asfy}/N_{asy}$$

where the subscripts *a*, *s*, *f*, and *y* index age, sex, fishery, and year, respectively, *C* is the catch in numbers, and *N* is the number of fish in the population immediately before the first fishery of the year. This measure is deemed to be more useful than the spawning fisheries exploitation rates that have been presented in previous assessments, because it does not ignore the effect of the non-spawning fisheries, and thus represents the total fishing intensity for each stock.

For a given stock and run, the reference fishing intensities, $U_{35\%Bo}$ and $U_{50\%Bo}$, are defined as the levels of *U* that would cause the spawning biomass for that stock to tend to 35% B_0 or 50% B_0, respectively, assuming deterministic recruitment and individual fishery exploitation rates that are multiples of those in the current year. These reference fishing intensities were calculated by simulating fishing using a harvest strategy in which the exploitation rate for fishery *f* was $mU_{f,\text{current}}$, where $U_{f,\text{current}}$ is the estimated exploitation rate for that fishery in the current year, and *m* is some multiplier (the same for all fisheries). For each of a series of values of *m*, simulations were carried out with this harvest strategy and deterministic recruitment, with each simulation continuing until the population reached equilibrium. For a given stock, $U_{x\%Bo}$ was set equal to $m_{x\%}U_{\text{current}}$, where the multiplier, $m_{x\%}$ (calculated by interpolation) was that which caused the equilibrium biomass of that stock to be *x*% B_0

The assessment update was conducted in two steps. First, a set of initial model runs was carried out generating point estimates (so-called MPD runs, which estimate the Mode of the Posterior Distribution). Their purpose was to investigate model structure and assumptions to decide which runs to carry forward as final runs. The final runs were fully Bayesian, producing posterior distributions for all quantities of interest.

The final model runs, taken to MCMC, are summarised in Table 22. None of these runs is considered a base model, but rather show the range of possible biomass estimates when different weightings are given to fitting the eastern or western biomass indices.

Deterministic B_{MSY} estimates are no longer calculated, for the following reasons. First, it assumes a harvest strategy that is unrealistic in that it involves perfect knowledge (current biomass must be known exactly 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 (Francis 2009). Third, the closeness of B_{MSY} to the soft limit permits the limit to be breached too easily and too frequently, given, for example, a limited period of low recruitment. Fourth, it would be very difficult with such a low biomass target to avoid the biomass occasionally falling below 20% B_0, the default soft limit according to the Harvest Strategy Standard.

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

Table 22: Characteristics for final model runs.

Run	Short name	Main assumptions
1.17	two stock (update)	natal fidelity *M* is age-dependent single q for Sub-Antarctic trawl series process error of CRsumbio and SAsumbio was estimated
1.33	western only	Similar in assumptions to 1.17 but drop eastern areas and data process error zero for SAsumbio
1.34	two stock (west focus)	as 1.17 but process error zero for SAsumbio
1.37	two stock (east focus)	as 1.17 but process error zero for CRsumbio process error 0.70 for SAsumbio halve effective sample sizes for western at-age data

An update of the base case from the 2018 stock assessment (McKenzie 2019b) was carried out with the new data (run 1.17). However, diagnostics for the western stock in this model indicated that it failed to satisfactorily track the biomass trend from the Sub-Antarctic survey. This lack of fit, coupled with the model estimating stock status levels that did not match the current perception of the state of the fishery, resulted in the Working Group investigating alternative model runs. These model runs forced better fits to the biomass indices, focusing on either the western stock or the eastern stock (McKenzie 2019c, d, e, f, g).

The SAsumbio survey data shows large annual changes in numbers-at-age that cannot be explained entirely by changes in abundance, and which are suggestive of changes in survey catchability. Because of this, and to improve the fit to the SAsumbio series, model runs have previously been conducted where the catchability has changed over time (two q values were fitted to the survey time series). In the previous three assessments, one catchability was assumed for the whole time series but a higher process error was allowed to account for the annual variation in observations; this effectively down weights the Sub-Antarctic trawl survey data relative to other data sources in the model.

Process error was estimated for the updated two stock model. However, if it is believed that the Sub-Antarctic trawl survey does accurately track biomass, then a higher process error is inappropriate. To produce a better fit to the Sub-Antarctic trawl survey, a run was done for the two stock model in which the process error for the survey was set at zero (run 1.34).

For the simplified western stock only model, in which eastern areas and data were dropped, process error was also set to zero for the Sub-Antarctic survey (run 1.33). A simplified western stock only model was constructed because in the two stock model eastern at-age data were impacting on the estimation of western biomass.

Alternatively, when the focus was on fitting the eastern stock biomass indices, the process error was set to zero for the Chatham Rise trawl survey (run 1.37). In this model run the western data was given less influence by doubling the process error for the Sub-Antarctic trawl survey to 0.70 and halving the effective sample sizes for the western at-age data.

Bayesian posterior distributions were estimated for each of these runs using a Markov chain Monte Carlo (MCMC) approach. For each run, three chains of length four million were completed, with adaptive step size allowed during the first 100 000 samples. The initial 500 000 samples of each chain were discarded, and the remaining samples were concatenated and thinned to produce a posterior sample of size 2000.

6.2 Results

Model estimates are presented for the spawning stock biomass (Table 23), biomass trajectories, and year-class strengths (Figure 3). The current western biomass was estimated to be 56% B_0 (median value for the updated two stock model), 34% B_0 (western stock only model), and 29% B_0 (two stock with a west focus). Current eastern biomass estimates were 66% B_0 (two stock update) and 64% B_0 (two stock with east focus).

For run 1.17 process errors are estimated to be 0.15 (CRsumbio) and 0.35 (SAsumbio). For run 1.34 the estimated CRsumbio process error is 0.15. Otherwise the process errors for CRsumbio and SAsumbio were set to zero (Table 22).

Table 23: Estimates of spawning biomass (medians of marginal posterior, with 95% confidence intervals in parentheses). $B_{current}$ is the biomass in mid-season 2019. See Table 22 for the associated run numbers. For the two stock models, where the focus is on one of the stocks, biomass estimates are shown just for that stock.

	B_0('000 t)		$B_{current}$('000 t)		$B_{current}$(%B_0)	
Run	E	W	E	W	E	W
two stock (update)	550(438,717)	990(805,1355)	365(235,566)	550(309,999)	66(48,89)	56(37,78)
western only	–	948(806,1188)	–	325(210,629)	–	34(25,58)
two stock (west focus)	–	813(716,939)	–	239(163,353)	–	29(22,39)
two stock (east focus)	566(475,705)	–	358(243,531)	–	64(46,85)	–

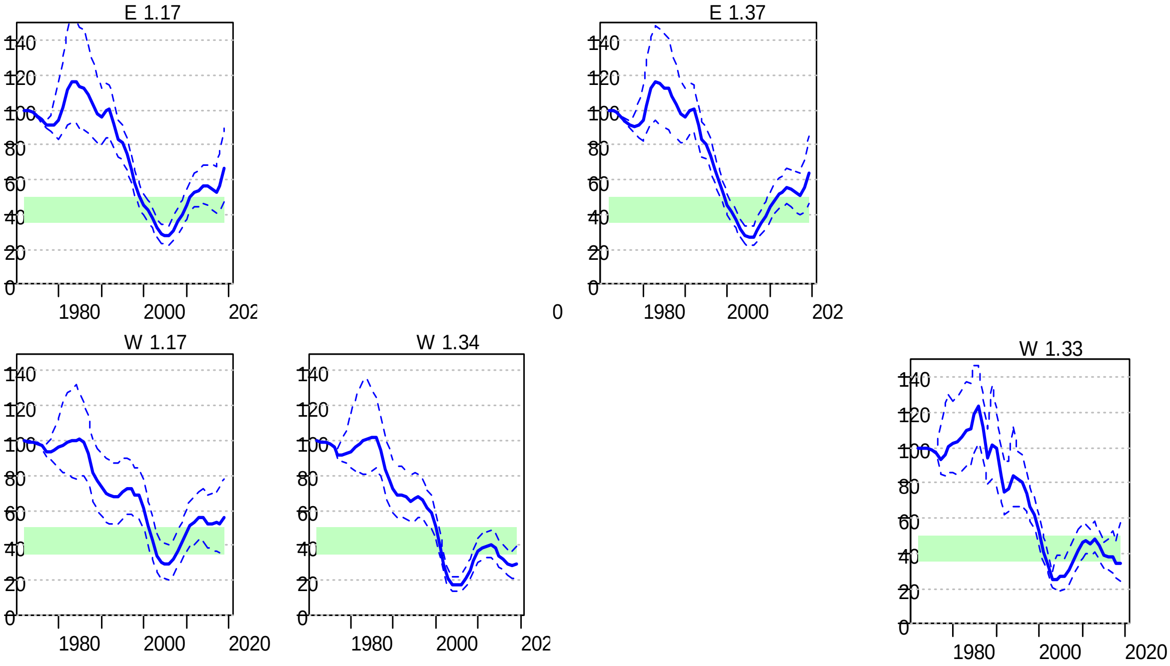


Figure 3 [Upper]: Estimated spawning-biomass trajectories from the MCMC runs, showing medians (solid lines) and 95% credible intervals (broken lines) by run for E (upper panels) and W (lower panels). The first three columns show the two stock models (update run 1.17), west focus (run 1.34), east focus (run 1.37)). The fourth column is the western only model. The shaded green region represents the target range of 35–50% B_0.

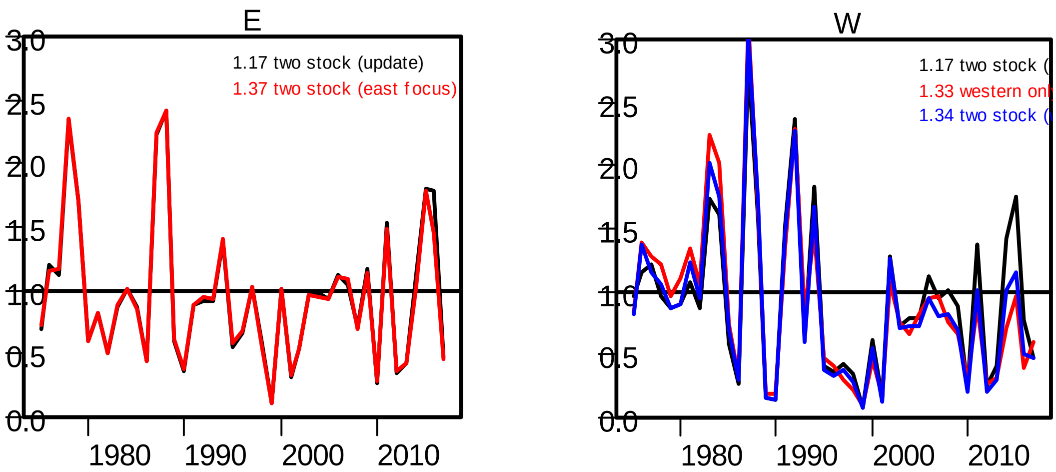


Figure 3 [Lower]: Year-class strengths (YCS) for the E (left panels) and W (middle panels). Plotted values are medians of marginal posterior distributions. Years are fishing years (1990 = 1989–90).

The runs show that the biomasses of both stocks were at their lowest points from about 2004 to 2006 (lowest values being at about 27% B_0 for the eastern stock run 1.37 and 26% B_0 for the western stock run 1.34) after the western stock experienced seven consecutive years of poor recruitment from 1995 to 2001 inclusive and the eastern stock had below average recruitment over the same period (Figure 3). The eastern stock has since increased to levels which exceed the target range, but the western stock remains below it for the two stock (west focus) or western only models. Recruitment to the western stock following the 1995–2001 period of poor recruitment was estimated to have been above average for run 1.17 in 2011, 2014, and 2015, but at or below average for most years for runs 1.33 and 1.34.

Fishing intensities for both stocks were estimated to be at or near all-time highs in about 2002 and are now substantially lower (Figure 4). Fishing intensities from run 1.33 (western only) are not presented for technical reasons.

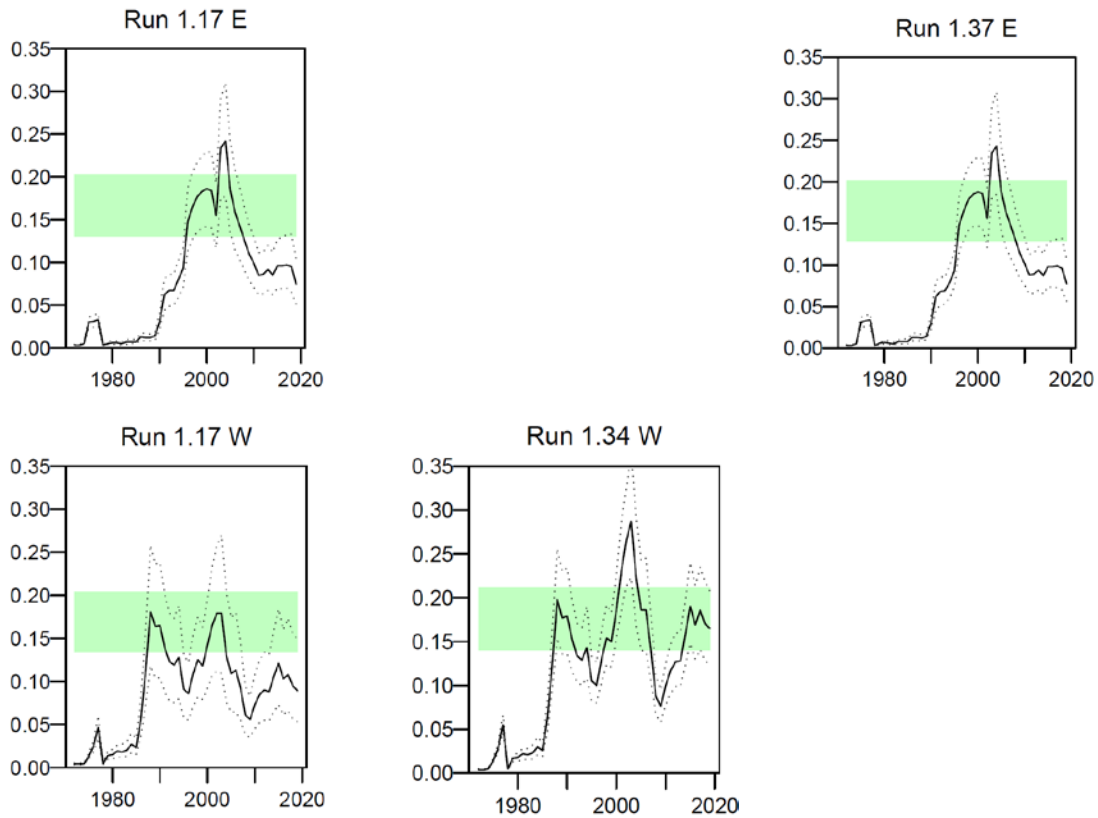


Figure 4: Fishing intensities, U (from MCMCs), for the two stock models (update (run 1.17), west focus (run 1.34), east focus (run 1.37)), plotted by stock. Shown are medians (solid black line) with 95% confidence intervals (dotted lines). Also shown shaded in green is the management range where the upper bound is the reference level $U_{35\%B_0}$ and the lower bound $U_{50\%B_0}$ which are the fishing intensities that would cause the spawning biomass to tend to 35% B_0 and 50% B_0, respectively.

6.3 Projections

Five-year projections were carried out for the four model runs by randomly selecting future recruitments based on two scenarios: (i) recruitments estimated for 2008–2017 (recent recruitment), and (ii) recruitments estimated for 1975–2017 (long-term recruitment). Total catch was assumed to equal that in 2019 of 135 500 t with 64 000 t catch for the eastern stock and 71 500 t for the western stock. The projections indicate that the eastern biomass will increase slightly over the next 5 years and remain above the target range (Figures 5a, b, Tables 24a, b). The western biomass will increase in either scenario under the 1.17 two stock (update) model and remain above the target range. For the other two model runs where the Sub-Antarctic trawl survey is fitted better (1.33, 1.34) the future western biomass is scenario dependent: (i) with recruitment from 2008–2017 the western biomass is flat and likely to remain below the target range, and (ii) with recruitment from 1975–2017 the western biomass will increase and likely be in the target range by the end of the projection period.

For the eastern stock, the estimated probability of being less than the soft or the hard limit at the end of the five year projection period is negligible (Tables 25a, b). For the western stock the estimated probability of being less than the hard limit at the end of the five projection period is negligible, but there is a greater than 10% chance of being below the soft limit in 5 years for the model runs where the Sub-Antarctic trawl survey is fitted better (1.33, 1.34).

An additional set of five-year projections was undertaken for two of the model runs (1.17 and 1.34) for the western stock based on the 2018–19 TACC and agreed catch split (90 000 t for the western stock), selecting future recruitments randomly from recent estimated recruitments (2008–2017) only. For both stocks, the split between non-spawning and spawning catch was assumed to be the same as in 2017–18. Analogous projections were not conducted for the eastern stock, because the eastern catch and TACC catch split were similar in 2017–18.

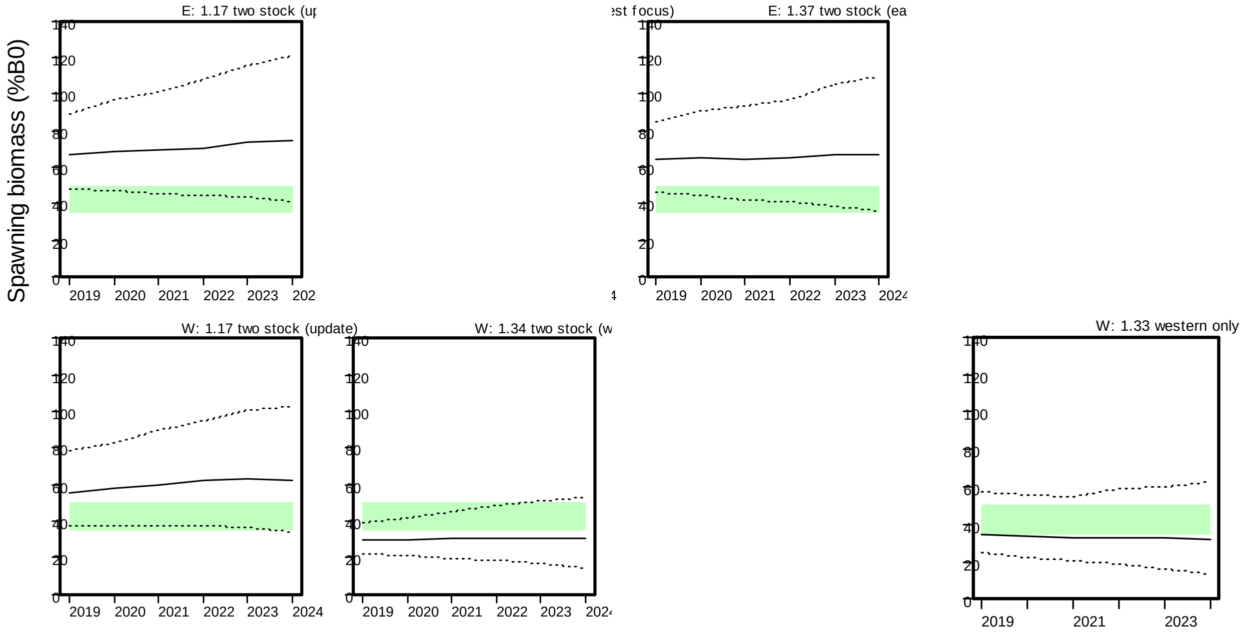


Figure 5a: Scenario with random recruitment from 2008–2017. Projected spawning biomass (as %B_0): median (solid lines) and 95% credible intervals (broken lines) for the four final model runs. The shaded green region represents the target management range of 35–50% B_0.

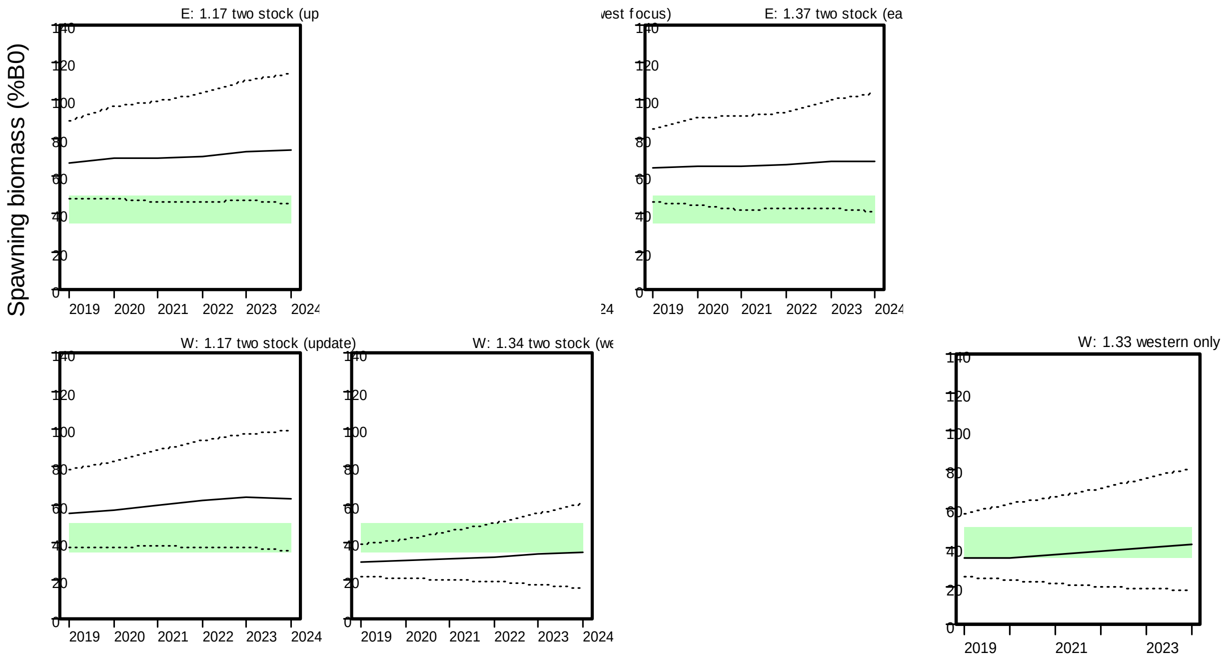


Figure 5b: Scenario with random recruitment from 1975–2017. Projected spawning biomass (as %B_0): median (solid lines) and 95% credible intervals (broken lines) for the four final model runs. The shaded green region represents the target management range of 35–50% B_0.

Table 24a: Projected median SSB (%B_0) for 2019 to 2024 when recruitment levels are randomly selected from 2008–2017 estimates (recent recruitment), assuming either the 2017–18 catch levels or the 2018–19 TACC and agreed E:W catch split.

	2019	**2020**	**2021**	**2022**	**2023**	**2024**
Based on 2017–18 catch levels						
EAST 1.17	67	69	70	71	73	74
EAST 1.37	64	65	64	65	67	67
WEST 1.17	56	57	60	62	63	62
WEST 1.34	29	30	30	31	31	30
WEST 1.33	34	34	33	33	33	32
Based on the 2018–19 TACC and agreed E:W catch split						
WEST 1.17	56	56	58	59	59	58
WEST 1.34	29	29	28	27	26	24

Table 24b: Projected median SSB (%B_0) for 2019 to 2024 when recruitment levels are randomly selected from 1975–2017 estimates (long-term recruitment), assuming the 2019 catch levels.

	2019	2020	2021	2022	2023	2024
EAST 1.17	67	69	69	70	73	74
EAST 1.37	64	65	65	66	68	68
WEST 1.17	56	57	60	63	64	63
WEST 1.34	29	30	31	32	34	35
WEST 1.33	34	35	36	38	40	42

Table 25a: Projected probabilities (to two decimal places) of SSB being below various levels of %B_0 for 2019 to 2024 when recruitment levels are **randomly selected from 2008–2017 estimates (recent recruitment).**

	2019	**2020**	**2021**	**2022**	**2023**	**2024**
Based on 2017–18 catch levels						
EAST 1.17						
P (SSB<10%B_0)	0	0	0	0	0	0
P (SSB<20%B_0)	0	0	0	0	0	0
P (SSB<35%B_0)	0	0	0	0	0	0.01
P (SSB<50%B_0)	0.05	0.04	0.06	0.07	0.07	0.09
EAST 1.37						
P (SSB<10%B_0)	0	0	0	0	0	0
P (SSB<20%B_0)	0	0	0	0	0	0
P (SSB<35%B_0)	0	0	0.01	0.01	0.01	0.02
P (SSB<50%B_0)	0.06	0.08	0.12	0.13	0.13	0.16
WEST 1.17						
P (SSB<10%B_0)	0	0	0	0	0	0
P (SSB<20%B_0)	0	0	0	0	0	0
P (SSB<35%B_0)	0.01	0.01	0.02	0.01	0.02	0.03
P (SSB<50%B_0)	0.28	0.25	0.21	0.18	0.18	0.22
WEST 1.34						
P (SSB<10%B_0)	0	0	0	0	0	0
P (SSB<20%B_0)	0.01	0.02	0.03	0.05	0.08	0.13
P (SSB<35%B_0)	0.88	0.82	0.76	0.70	0.67	0.67
P (SSB<50%B_0)	1	1	0.99	0.98	0.97	0.96
WEST 1.33						
P (SSB<10%B_0)	0	0	0	0	0	0
P (SSB<20%B_0)	0	0	0.02	0.04	0.07	0.11
P (SSB<35%B_0)	0.55	0.57	0.60	0.57	0.58	0.60
P (SSB<50%B_0)	0.95	0.96	0.95	0.93	0.92	0.91
Based on the 2018-19 TACC and agreed E:W catch split						
WEST 1.17						
P (SSB<10%B_0)	0	0	0	0	0	0
P (SSB<20%B_0)	0	0	0	0	0	0
P (SSB<35%B_0)	0.01	0.02	0.02	0.03	0.04	0.07
P (SSB<50%B_0)	0.28	0.28	0.26	0.26	0.27	0.32
WEST 1.34						
P (SSB<10%B_0)	0	0	0	0	0.02	0.05
P (SSB<20%B_0)	0.01	0.03	0.09	0.16	0.23	0.32
P (SSB<35%B_0)	0.88	0.87	0.86	0.83	0.81	0.82
P (SSB<50%B_0)	1	1	1	0.99	0.98	0.98

Table 25b: Projected probabilities (to two decimal places) of SSB being below various levels of %B_0 for 2019 to 2024 when recruitment levels are randomly selected from 1975–2017 estimates (long term recruitment).

	2019	2020	2021	2022	2023	2024
EAST 1.17						
P (SSB<10%B_0)	0	0	0	0	0	0
P (SSB<20%B_0)	0	0	0	0	0	0
P (SSB<35%B_0)	0	0	0	0	0	0
P (SSB<50%B_0)	0.05	0.04	0.06	0.06	0.05	0.06
EAST 1.37						
P (SSB<10%B_0)	0	0	0	0	0	0
P (SSB<20%B_0)	0	0	0	0	0	0
P (SSB<35%B_0)	0	0	0	0	0	0.01
P (SSB<50%B_0)	0.06	0.08	0.10	0.10	0.10	0.11
WEST 1.17						
P (SSB<10%B_0)	0	0	0	0	0	0
P (SSB<20%B_0)	0	0	0	0	0	0
P (SSB<35%B_0)	0.01	0.01	0.02	0.01	0.02	0.02
P (SSB<50%B_0)	0.28	0.24	0.20	0.15	0.16	0.19
WEST 1.34						
P (SSB<10%B_0)	0	0	0	0	0	0
P (SSB<20%B_0)	0.01	0.02	0.03	0.04	0.05	0.06
P (SSB<35%B_0)	0.88	0.81	0.72	0.62	0.54	0.51
P (SSB<50%B_0)	1	1	0.99	0.97	0.93	0.88
WEST 1.33						
P (SSB<10%B_0)	0	0	0	0	0	0
P (SSB<20%B_0)	0	0	0.01	0.03	0.03	0.04
P (SSB<35%B_0)	0.55	0.50	0.45	0.39	0.34	0.32
P (SSB<50%B_0)	0.95	0.91	0.86	0.81	0.75	0.70

7. FUTURE RESEARCH CONSIDERATIONS

- Further investigate the performance of alternative and/or simpler assessment models, with a focus on alternative stock structure and migration hypotheses.
- Examine the potential for confounding between natural mortality, selectivities, and migration parameters, with a view to better understanding model processes. Explore the utility of incorporating commercial catch, effort, and distribution data to better understand stock and fisheries dynamics.
- Further explore the influence of priors on the model.
- Examine the potential for density-dependent effects.
- Investigate the implications of trends in cryptic mortality to the model.
- Better understand the environmental drivers that may influence fish and fisheries distributions.
- Investigate the seasonality in fish and fisheries distributions to determine how to use or interpret catch at age data and whether to use alternative stratifications for compiling age frequencies, especially for the Sub-Antarctic (e.g., permanent strata vs post-stratification).
- Examine the pros and cons of increased sampling for biological and age data from observers and sheds.
- Review observer protocols to ensure that sampling is as representative as possible.
- Examine how data are recorded in the COD database to determine whether otoliths have been appropriately selected for ageing, especially for non-spawning fisheries.
- Future assessments should include a more complete set of diagnostics, such as MPD and MCMC fits to biomass indices and age frequencies; individual MCMC traces, not just cumulative distributions; expected numbers at age for the Chatham Rise trawl survey; and more emphasis on estimated parameters rather than derived variables. The diagnostics should include summarised Pearson residuals for all composition data by fishery.

8. STATUS OF THE STOCKS

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

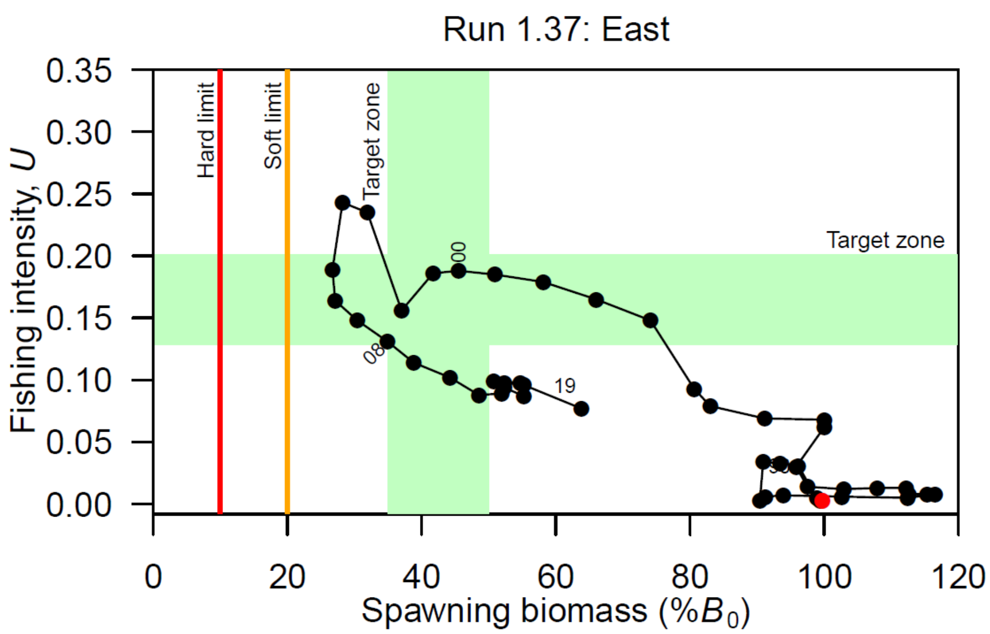
- Adults of the western stock occur on the west coast of the North and South Islands and the area south of New Zealand including Puysegur, Snares and the Sub-Antarctic;
- Adults of the eastern stock occur on the east coast of the South Island, Cook Strait and the ECNI up to North Cape;
- Juveniles of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

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

- **Eastern Hoki Stock**

Stock Status	
Year of Most Recent Assessment	2019
Assessment Runs Presented	Two stock (update), two stock (east focus):1.17, 1.37
Reference Points	Target: 35–50% B_0 Soft Limit: 20% B_0 Hard Limit: 10% B_0 Overfishing threshold: $F_{35\%B0}$
Status in relation to Target	B_{2019} was estimated to be 66% B_0 *(1.17)* or *64%* B_0 *(1.37)*; Virtually Certain (> 99%) to be at or above the lower end of the target range and Likely (> 60%) to be at or above the upper end of the target range
Status in relation to Limits	B_{2019} is Exceptionally Unlikely (< 1%) to be below either the Soft or Hard Limit
Status in relation to Overfishing	Overfishing is Exceptionally Unlikely (< 1%) to be occurring

Historical Stock Status Trajectory and Current Status



Trajectory over time of fishing intensity (*U*) and spawning biomass (%B_0), for the eastern hoki stock from the start of the assessment period in 1972 (represented by a red circle) to 2019 (19). The red vertical line at 10% B_0 represents the hard limit, the yellow line at 20% B_0 is the soft limit, and the shaded area represents the management target ranges in biomass and fishing intensity. Biomass and fishing intensity estimates are medians from MCMC results.

Fishery and Stock Trends	
Recent Trend in Biomass or Proxy	The two model runs suggest that biomass decreased to a minimum in 2005, then increased subsequently.
Recent Trend in Fishing Intensity or Proxy	- Stable for last five years
Other Abundance Indices	-
Trends in Other Relevant Indicators or Variables	Trawl surveys of the Chatham Rise in 2016 and 2018 suggested that the 2014 and 2015 year classes are above average. The actual split of recruitment between the eastern and western stocks for the three most recent year classes is uncertain.

Projections and Prognosis	
Stock Projections or Prognosis	If the year classes recruit to the eastern stock as estimated by the models, the biomass of the eastern hoki stock is expected to be flat over the next five years at assumed future catch levels using both recruitment from 10 years and all years recruitment.
Probability of Current Catch or TACC causing Biomass to remain below or to decline below Limits	Soft Limit: Exceptionally Unlikely (< 1%) Hard Limit: Exceptionally Unlikely (< 1%)
Probability of Current Catch or TACC causing Overfishing to continue or to commence	Exceptionally Unlikely (< 1%)

Assessment Methodology and Evaluation		
Assessment Type	Level 1 - Full Quantitative Stock Assessment	
Assessment Method	Age-structured CASAL model with Bayesian estimation of posterior distributions	
Assessment Dates	Latest assessment: 2019	Next assessment: 2020
Overall assessment quality rank	1 – High Quality	
Main data inputs (rank)	- Research time series of abundance indices (trawl and acoustic surveys) - Proportions at age data from the commercial fisheries and trawl surveys - Estimates of fixed biological parameters	1 – High Quality 1 – High Quality 1 – High Quality
Data not used (rank)	- Commercial CPUE	3 – Low Quality: does not track stock biomass
Changes to Model Structure and Assumptions	- Process error is no longer estimated for the eastern stock trawl survey abundance indices in the model that focused on the eastern stock.	
Major Sources of Uncertainty	- Stock structure and migration patterns - Split of the 2014, 2015, and 2016 year classes between eastern and western stocks with respect to projections - Data conflict between the biomass indices and composition data	

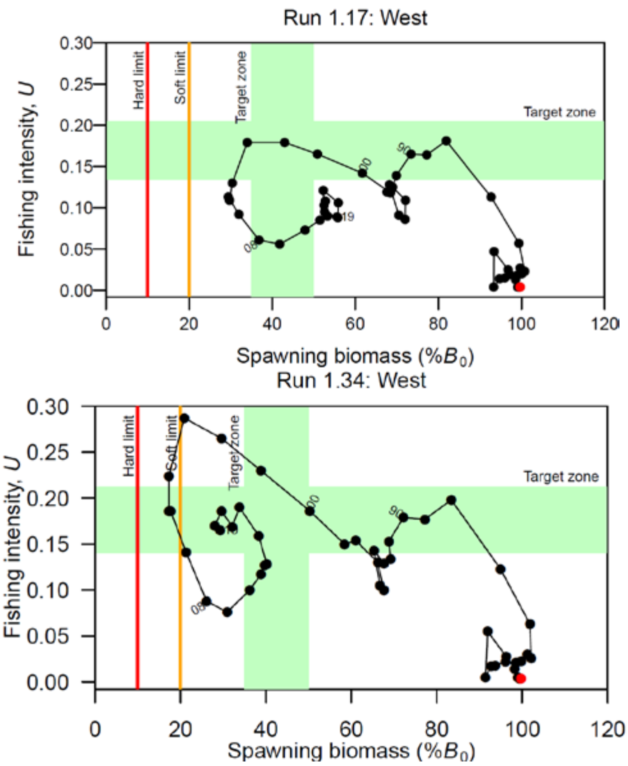
Qualifying Comments
The Cook Strait acoustic survey estimate was lower by 50% in 2017 from 2015, and the Chatham Rise trawl survey of 3++ fish was lower by 26% in 2018 from 2016. These biomass indices are not well fitted by the model due to observation and process error.

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

- **Western Hoki Stock**

Stock Status	
Year of Most Recent Assessment	2019
Assessment Runs Presented	Two stock (update), two stock (west focus): 1.17, 1.34. The two stock (update) is considered to overestimate current stock status, while the two stock (west focus) may underestimate stock status.
Reference Points	Target: 35–50% B_0 Soft Limit: 20% B_0 Hard Limit: 10% B_0 Overfishing threshold: $F_{35\%B0}$
Status in relation to Target	B_{2019} was estimated to be 56% B_0 *(1.17)* or *29%* B_0 *(1.34)*; About As Likely as Not (40–60%) to be at or above the lower end of the target range
Status in relation to Limits	B_{2019} is Very Unlikely (< 10%) to be below the Hard Limit and Unlikely (< 40%) to be below the Soft Limit
Status in relation to Overfishing	Unlikely

Historical Stock Status Trajectory



Trajectories over time of fishing intensity (*U*) and spawning biomass (%*B₀*), for two assessment models for the western hoki stock from the start of the assessment period in 1972 (represented by a red circle) to 2019 (19). The red vertical line at 10% B_0 represents the hard limit, the yellow line at 20% B_0 is the soft limit, and the shaded area represents the management target ranges in biomass and fishing intensity. Biomass and fishing intensity estimates are medians from MCMC results.

Fishery and Stock Trends	
Recent Trend in Biomass or Proxy	Run 1.17 suggests that biomass has been stable at an average of about 52% B_0 for the last 9 years, whereas run 1.34 suggests biomass has declined since about 2013 to currently be below 35% B_0.
Recent Trend in Fishing Intensity or Proxy	Stable for the last six years
Other Abundance Indices	-
Trends in Other Relevant Indicators or Variables	Trawl surveys of the Chatham Rise in 2016 and 2018 suggested that the 2014 and 2015 year classes are above average. The actual split of recruitment between the eastern and western stocks for the three most recent year classes is uncertain.

Projections and Prognosis	
Stock Projections or Prognosis	For run 1.17, if the year classes recruit to the western stock as estimated by the model, the biomass of the western hoki stock is expected to increase over the next five years at assumed future catch levels. For run 1.34, the biomass is expected to remain flat and below the bottom end of the target range (with recruitment as in 2008–2017), or increase and be in the target range of 35–50% B_0 at the end of five years (with recruitment as in 1975–2017).
Probability of Current Catch or TACC causing Biomass to remain below or to decline below Limits	*For current catch:* Soft Limit: Unlikely (< 40%) Hard Limit: Very Unlikely (< 10%) *For current TACC and agreed E:W catch split:* Soft Limit: Unlikely (< 40%) Hard Limit: Very Unlikely (< 10%)
Probability of Current Catch or TACC causing Overfishing to continue or to commence	*For current catch:* About as Likely as Not (40–60%) *For current TACC and agreed E:W catch split:* Likely (> 60%)

Assessment Methodology and Evaluation		
Assessment Type	Level 1 - Full Quantitative Stock Assessment	
Assessment Method	Age-structured CASAL model with Bayesian estimation of posterior distributions	
Assessment Dates	Latest assessment: 2019	Next assessment: 2020
Overall assessment quality rank	1 – High Quality	
Main data inputs (rank)	- Research time series of abundance indices (trawl and acoustic surveys)	1 – High Quality
	- Proportions at age data from the commercial fisheries and trawl surveys	1 – High Quality
	- Estimates of fixed biological parameters	1 – High Quality
Data not used (rank)	- Commercial CPUE	3 – Low Quality: does not track stock biomass
	- WCSI trawl survey biomass estimate	3 – Low Quality: not considered to index spawning biomass
	- Some years of age data, as described in Table 16	3 – Low quality: currently not used as it was not thought to be representative of the fishery

Changes to Model Structure and Assumptions	- Process error is no longer estimated for the western stock trawl survey abundance indices in the model that focused on the western stock.
Major Sources of Uncertainty	- Stock structure and migration patterns - Split of 2015, 2016, and 2017 year classes between eastern and western stocks with respect to projections - Data conflict between the biomass indices and composition data - Catchability changes in Sub-Antarctic trawl surveys

Qualifying Comments
In run 1.17 where process error is estimated for the two trawl surveys, there is increased uncertainty in the western stock assessment because of the lack of fit to the Sub-Antarctic trawl survey. If the Sub-Antarctic trawl survey is reflecting abundance trends, then the western stock status would be lower than estimated in run 1.17 and more like that in run 1.34.

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

8. FOR FURTHER INFORMATION

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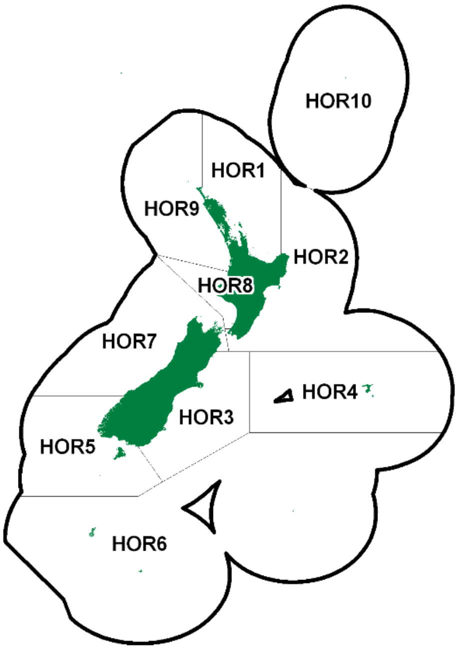
HORSE MUSSEL (HOR)

(*Atrina zelandica*)
Kukuroroa, Kupa, Hururoa



1. FISHERY SUMMARY

1.1 Commercial fisheries

Horse mussels (*Atrina zelandica*) were introduced into the Quota Management System on 1 April 2004, with a combined TAC of 103 t and TACC of 29 t. Customary non-commercial and recreational allowances are 9 t each, and 56 t was allowed for other sources of mortality. The fishing year is from 1 April to 31 March and commercial catches are measured in greenweight. TACCs have been allocated in HOR 1–HOR 9. Most reported landings have been from HOR 1, and, apart from 1994–95 and 2002–03 when catches of about 5 t and 7 t respectively were reported, reported landings have all been small (Table 1). About 90% of the catch is taken as a bycatch during bottom trawling and the remainder is taken as a bycatch of dredge and Danish seine. It is likely that there is a reasonably high level of unreported discarded horse mussel catch.

Table 1: TACCs and reported landings (t) of horse mussel by Fishstock from 1990–91 to 2018–19 from CELR and CLR data. There have never been any reported landings in HOR 4, 5, 6, or 8. These fishstocks each have a TACC of 1 t and are not reported in Table 1 below. [Continued on next page]

Fishing	HOR 1		HOR 2		HOR 3		HOR 7		HOR 9		Total	
year	Landings	TACC	Landings	TACC	Landings	TACC	Landings	TACC	Landings	TACC	Landings	TACC
1990–91	0.834	-	0	-	0	-	0	-	0	-	0.834	-
1991–92	0	-	0	-	0	-	0	-	0	-	0	-
1992–93	0	-	0	-	0	-	0	-	0	-	0	-
1993–94	0.003	-	0	-	0.016	-	0	-	0	-	0.019	-
1994–95	5.525	-	0	-	0	-	0	-	0	-	5.525	-
1995–96	0	-	0.019	-	0	-	0	-	0	-	0.019	-
1996–97	0.024	-	0	-	0	-	0	-	0	-	0.024	-
1997–98	0	-	0	-	0	-	0	-	0	-	0.128	-
1998–99	0	-	0	-	0	-	0	-	0	-	0	-
1999–00	0	-	0	-	0	-	0.81	-	0	-	0.1	-
2000–01	0	-	0	-	0	-	0.128	-	0	-	0.128	-
2001–02	0	-	0.002	-	0	-	0	-	0	-	0	-
2002–03	7.153	-	0	-	0	-	0	-	0	-	7.155	-
2003–04	0.026	4	0	2	0	2	0	16	0	1	0.026	29
2004–05	0.217	4	0	2	0	2	1.017	16	0.065	1	1.299	29
2005–06	0.026	4	0	2	0	2	0	16	0.942	1	0.968	29
2006–07	0	4	0	2	0	2	0.06	16	0.261	1	0.321	29
2007–08	0	4	0	2	0	2	0.451	16	0	1	0.451	29

Table 1 [Continued]

Fishing	HOR 1		HOR 2		HOR 3		HOR 7		HOR 9		Total	
year	Landings	TACC	Landings	TACC	Landings	TACC	Landings	TACC	Landings	TACC	Landings	TACC
2008–09	0.068	4	0	2	0	2	0	16	0	1	0.068	29
2009–10	0.289	4	0	2	0	2	0.112	16	0	1	0.401	29
2010–11	0	4	0	2	0	2	0.857	16	0	1	1	29
2011–12	0	4	0	2	0	2	0.605	16	0	1	0.605	29
2012–13	0	4	0	2	0	2	0	16	0	1	0	29
2013–14	0	4	0	2	0	2	0.214	16	0	1	0.214	29
2014–15	0	4	0	2	0	2	0.117	16	0	1	0.117	29
2015–16	0	4	0	2	0.005	2	0.380	16	0	1	0.385	29
2016–17	0	4	0	2	0.018	2	0.630	16	0	1	0.0648	29
2017–18	0	4	0	2	0.018	2	0.211	16	0	1	0.329	29
2018–19	0	4	0	2	0.015	2	0	16	0	1	0.015	29

1.2 Recreational fisheries

A. zelandica do not appear in records from recreational fishing surveys (Bradford 1998), but are nevertheless taken from time to time by recreational fishers. There are no estimates of recreational take for this species.

1.3 Customary non-commercial fisheries

A traditional food of Māori, this mussel is probably under-represented in midden shell counts because of the fragile and short-lived nature of the shell. Limited quantitative information on the level of customary take on HOR 1 is available from Fisheries New Zealand (Table 2). These numbers are likely to be an underestimate of customary harvest because only the catch in numbers and kilograms are reported in the table.

Table 2: Fisheries New Zealand records of customary harvest of horse mussel (reported as weight (kg) and numbers), 2005–06 to 2017–18. – no data.

		Weight (kg)		Numbers	
Stock	Fishing year	Approved	Harvested	Approved	Harvested
HOR 1	2005–06	–	–	2 000	150
	2006–07	220	220	150	150
	2007–08	200	150	–	–
	2008–09	150	70	90	90
	2009–10	–	–	–	–
	2010–11	–	–	100	0
	2011–12	–	–	50	0
	2012–13	–	–	–	–
	2013–14	–	–	–	–
	2014–15	–	–	–	–
	2015–16	–	–	–	–
	2016–17	100	50	80	0
	2017–18	40	40	–	–
	2018–19	–	–	–	–

1.4 Illegal catch

There is no known illegal catch of this mussel.

1.5 Other sources of mortality

There is no quantitative information on other sources of mortality, although widespread die-offs appear to be characteristic of this species. Storm scour, shell damage and subsequent predation, and exceeding carrying capacity have been suggested as possible reasons for this.

2. BIOLOGY

The horse (or fan) mussel, *Atrina zelandica*, is a widespread endemic bivalve that lives mainly on muddy-sand substrates in the lowest inter-tidal and sub-tidal shallows of mainly sheltered waters. Horse mussels are also found in deeper waters (to 50 m) off open coasts. The horse mussel is a flattened, emergent, filter-feeding mollusc, particularly conspicuous because of its size and abundance. Although more usually 260–300 mm long (110–120 mm wide) it can reach 400 mm in length and is New Zealand's largest bivalve. Horse mussels often live in groups, forming patches of up to 10 m^2 or more. The shell remains firmly embedded in the substrate by its pointed anterior end, the animal anchored to particles in the sediment by its byssus. The crenellated posterior edge projects a few centimetres above the substrate, keeping the water intake clear of surface deposits and providing attachment for an array of algae and invertebrates such as sponges and sea squirts.

Horse mussels are dioecious broadcast spawners. Although spawning may take place throughout much of the year it is probably mainly during summer. There is no information on the size or age at which breeding begins. A pelagic larva is free swimming for several days or weeks but nothing is known of its primary settlement locations, which may not necessarily be within the adult beds (some bivalves including soft sediment ones such as pipi settle in one area but later migrate to another where adult beds develop). Recruitment events can be sporadic and short-lived.

There is little published information on age, growth, and mortality for horse mussels. It appears that *Atrina* grows rapidly for at least the first 2–4 years: shells about 120 mm long in a northern bed increased about 40 mm per year until 166 mm, after which growth slowed dramatically (Hay C. pers. comm. in Hayward et al. 1999). Large shells are at least 5 y and possibly up to 15 y old. Widespread die-offs seem to be a feature of this species (Allan & Walshe 1984, Hayward et al. 1999). For example, in the Rangitoto Channel, densities of 200–300 per m^2 reduced to 1–35 per m^2 over 2–3 y, with storm scour, shell damage and subsequent predation, and exceeding carrying capacity being possible reasons (Hayward et al 1999).

Horse mussels have widespread effects on ecosystem structure and function (Lohrer et al. 2013). They provide shelter and refuge for invertebrates and fish (Townsend et al. 2015) and act as substrata for the settlement of epifauna such as sponges and soft corals. They also affect boundary layer dynamics and facilitate productivity and biodiversity by depositing pseudofaeces. The horse mussel community in most northern harbours is almost entirely subtidal, in medium to fine muddy, but fairly stable, sand with moderate current velocities and no wave action. Similar communities have been observed in the Hauraki Gulf and Marlborough Sounds. Scallops, dredge oysters, and green lipped mussels are the main commercial shellfish species with beds that sometimes broadly overlap with the horse mussel distribution.

3. STOCKS AND AREAS

For management purposes stock boundaries are based on FMAs; however, there is no biological information on stock structure, recruitment patterns, or other biological characteristics which might indicate stock boundaries.

4. STOCK ASSESSMENT

4.1 Estimates of fishery parameters and abundance

There are no estimates of fishery parameters or abundance for any horse mussel fishstock.

4.2 Biomass estimates

There are no biomass estimates for any horse mussel fishstock.

4.3 Yield estimates and projections

There are no estimates of *MCY* for any horse mussel fishstock.

There are no estimates of *CAY* for any horse mussel fishstock.

5. STATUS OF THE STOCKS

There are no estimates of reference or current biomass for any horse mussel fishstock. It is not known whether horse mussel stocks are at, above, or below a level that can produce *MSY*.

6. FOR FURTHER INFORMATION

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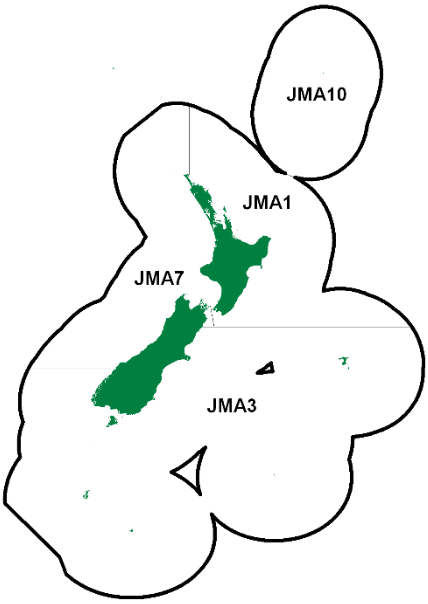
JACK MACKERELS (JMA)

(*Trachurus declivis*, *Trachurus novaezelandiae*, *Trachurus murphyi*)
Hauture



1. FISHERY SUMMARY

The jack mackerel fisheries catch three species: two endemic species, *Trachurus declivis* and *T. novaezelandiae*, and *T. murphyi* which appeared in New Zealand in the 1980s.

Jack mackerels have been included in the QMS since 1 October 1996, with four QMAs. Previously jack mackerels were considered part of the QMS, although ITQs were issued only in JMA 7. In JMA 1 and JMA 3, quota for the fishery was fully allocated as IQs by regulation with the exception of the 20% allocated to customary non-commercial catch. Before the 1995 jack mackerel regulations were issued, catch in JMA 1 taken in the Muriwhenua area north of 36° S to the limit of the Territorial Sea was not covered by the JMA 1 regulations. Allowances for customary non-commercial fishers, recreational fishers, and an allowance for other sources of mortality have only been set in JMA 3 (Table 1).

Table 1: TACs, TACCs, and allowances (t) for jack mackerels by fishstock.

Fishstock	TAC	TACC	Customary allowance	Recreational allowance	Other mortality
JMA 1	–	10 000	–	–	–
JMA 3	9 000	8 780	20	20	180
JMA 7	–	32 537	–	–	–
JMA 10	–	10	–	–	–

1.1 Commercial fisheries

In JMA 1, the jack mackerel catch is largely taken by the target purse seine fishery operating in the Bay of Plenty in Statistical Area 009 during March–November, with minor catches taken as a bycatch of kahawai and blue mackerel purse seine fisheries, and as a bycatch from trawl fisheries. In most years, relatively small catches were taken from off the east Northland coast (Statistical Areas 002 and 003), although this area accounted for a substantial proportion of the total catch in 1993–94 and 1994–95.

Since 1991–92, jack mackerel targeted landings in JMA 1 have represented more than 80% of total catch. The highest rates of bycatch are from kahawai and blue mackerel targeted operations which each account for about 7% of the total jack mackerel catch. The majority of JMA 1 catch over these years has been taken from Statistical Areas 008 and 009 (Bay of Plenty) between June and November;

considerably less has been taken in Statistical Areas 002 and 003, although high catches were recorded from these areas in 1993–94 and 1994–95.

In JMA 3 little targeting occurred before 1992–93. During the 1990s targeting increased and accounted for the majority of catch (about 50% between 1991–92 and 1996–97), but, after a peak of more than 80% in 1997–98 and 1998–99, the catch has decreased again to about 50–60% in recent years. The balance of the catch in this area comes from trawl bycatch (squid 15–30%, barracouta 15–20%) on the Chatham Rise and in the Southland/Sub-Antarctic region. A purse seine fishery has operated between the Clarence River mouth and the Kaikoura Peninsula, which peaked at 4400 t in 1992–93 and averaged more than 3000 t between 1989–90 and 1993–94. Purse seine catches have shown a steady decline since, dropping from 1000 t in 1994–95, to 100 t in 2001–02 and 2002–03; no catch was recorded for 2003–04, and purse seine catch has subsequently been rare.

Increased availability of jack mackerels caused by the influx of *T. murphyi* resulted in increased quotas in JMA 1 and JMA 3, to 8000 t and 9000 t respectively for the 1993–94 fishing year, and a further increase to 10 000 t and 18 000 t respectively for the 1994–95 year. The latter increases were made under the proviso that they be accounted for by increased catches of *T. murphyi* only; combined landings of *T. declivis* and *T. novaezelandiae* in JMA 1 and JMA 3 must not exceed the original quotas of 5970 t and 2700 t respectively. Industry agreed to these limits and voluntarily introduced monitoring programmes to provide the information necessary for them to be met.

For the 2016–17 fishing year, the TACC for JMA 3 was reduced to 8780 t, approximating the 1993–94 TACC level, on the basis that recent catches had been considerably lower than the TACC and that catches of *T. murphyi* were minimal, indicating low abundance of the species in New Zealand waters in recent years.

The three species occur in each of the Fishstocks but have not been individually identified in catch records. Historical estimated and recent reported jack mackerel landings and TACCs are shown in Tables 1 and 2, and Figure 1 shows the historical landings and TACC values for the main JMA stocks. Total annual landings have ranged between 21 059 t and 50 388 t since 1986–87 (Table 3).

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

Year	JMA 1	JMA 3	JMA 7	Year	JMA 1	JMA 3	JMA 7
1931–32	0	0	0	1957	0	0	6
1932–33	0	0	0	1958	0	0	9
1933–34	0	0	0	1959	2	0	0
1934–35	0	0	0	1960	2	0	5
1935–36	0	0	0	1961	1	0	5
1936–37	0	0	0	1962	5	0	5
1937–38	0	0	0	1963	7	2	13
1938–39	0	0	0	1964	5	4	10
1939–40	1	0	0	1965	14	0	8
1940–41	1	1	2	1966	47	0	54
1941–42	0	0	2	1967	213	0	250
1942–43	3	0	2	1968	172	505	4 558
1943–44	0	0	0	1969	128	388	7 065
1944	9	0	0	1970	75	1 029	7 274
1945	7	0	0	1971	473	776	12 684
1946	3	0	6	1972	350	5 450	15 581
1947	14	0	4	1973	395	1 238	14 648
1948	3	0	6	1974	1 236	2 016	16 943
1949	5	0	22	1975	204	3 615	10 043
1950	7	6	3	1976	838	5 690	14 228
1951	4	4	1	1977	1 317	5 228	13 729
1952	1	4	7	1978	1 250	1 547	4 657
1953	0	3	9	1979	2 158	516	4 475
1954	3	0	1	1980	2 504	104	3 533
1955	3	0	12	1981	2 815	110	8 665
1956	1	0	2	1982	1 607	119	8 364

Notes:
1. The 1931–1943 years are April–March but from 1944 onwards are calendar years.
2. Data up to 1985 are from fishing returns: data from 1986 to 1990 are from Quota Management Reports.
3. Data for the period 1931 to 1982 are based on reported landings by harbour and are likely to be underestimated as a result of under-reporting and discarding practices. Data includes both foreign and domestic landings.

Table 3: Reported landings (t) of jack mackerel by Fishstock from 1983–84 to 2018–19 and actual TACCs (t) for 1986–87 to 2018–19. QMS data from 1986–present.

	JMA 1		JMA 3		JMA 7		JMA 10		Total	
	Landings	TACC	Landings	TACC	Landings	TACC	Landings	TACC	Landings§	TACC
1983–84*	3 682	–	715	–	12 464	–	0	–	16 861	–
1984–85*	1 857	–	1 223	–	16 013	–	0	–	19 093	–
1985–86*	1 173	–	2 228	–	10 002	–	0	–	13 403	–
1986–87	4 056	5 970	1 638	2 700	19 815	20 000	0	10	25 509	28 680
1987–88	3 108	5 970	1 883	2 700	17 879	22 697	0	10	22 870	31 377
1988–89	2 986	5 970	1 919	2 700	17 403	26 008	0	10	22 308	34 688
1989–90	4 226	5 970	4 013	2 700	21 776	32 027	0	10	30 015	40 707
1990–91	6 472	5 970	6 403	2 700	17 786	32 069	0	10	30 661	40 749
1991–92	7 017	5 970	5 779	2 700	25 880	32 069	0	10	38 676	40 749
1992–93	7 529	5 970	15 399	2 700	24 659	32 537	0	10	47 587	41 216
1993–94‡	14 256	8 000	9 115	9 000	22 377	32 537	0	10	45 748	49 546
1994–95‡	7 832	10 000	11 519	18 000	18 912	32 537	0	10	38 263	60 547
1995–96	6 874	10 000	19 803	18 000	12 270	32 537	0	10	38 947	60 547
1996–97	6 912	10 000	15 687	18 000	12 056	32 537	0	10	34 655	60 547
1997–98	7 695	10 000	15 452	18 000	14 293	32 537	0	10	37 440	60 547
1998–99	5 641	10 000	15 111	18 000	13 629	32 537	0	10	34 381	60 547
1999–00	2 864	10 000	10 306	18 000	7 889	32 537	0	10	21 059	60 547
2000–01	8 360	10 000	2 744	18 000	15 703	32 537	0	10	26 807	60 547
2001–02	5 247	10 000	5 000	18 000	22 338	32 537	0	10	32 585	60 547
2002–03	6 172	10 000	2 225	18 000	26 084	32 537	0	10	34 481	60 547
2003–04	7 396	10 000	705	18 000	28 888	32 537	0	10	36 989	60 547
2004–05	9 418	10 000	716	18 000	36 507	32 537	0	10	46 641	60 547
2005–06is	9 924	10 000	5 000	18 000	27 782	32 537	0	10	42 706	60 547
2006–07	5 293	10 000	1 857	18 000	32 039	32 537	0	10	39 189	60 547
2007–08	11 167	10 000	2 629	18 000	34 059	32 537	0	10	47 855	60 547
2008–09	9 791	10 000	1 964	18 000	28 828	32 537	0	10	40 583	60 547
2009–10	9 086	10 000	2 706	18 000	31 152	32 537	0	10	42 944	60 547
2010–11	8 262	10 000	3 592	18 000	28 177	32 537	0	10	40 031	60 547
2011–12	8 911	10 000	3 085	18 000	28 266	32 537	0	10	40 261	60 547
2012–13	8 054	10 000	3 830	18 000	31 776	32 537	0	10	43 659	60 547
2013–14	10 520	10 000	4 693	18 000	35 175	32 537	0	10	50 388	60 547
2014–15	10 177	10 000	4 115	18 000	33 970	32 537	0	10	48 262	60 547
2015–16	6 989	10 000	2 756	18 000	30 875	32 537	0	10	40 621	60 547
2016–17	8 890	10 000	4 665	8 780	33 802	32 537	0	10	47 357	51 327
2017–18	5 553	10 000	5 559	8 780	34 190	32 537	0	10	45 302	51 327
2018–19	4 332	10 000	4 651	8 780	21 752	32 537	0	10	40 734	51 327

* FSU data.
§ Includes landings from unknown areas before 1986–87.
‡ JMA 1 & 3 landings are totals from CLR and CELR data.

Landings in JMA 1 before 1989–90 were generally well below the quota of 5970 t (Table 3), with the maximum in 1986–87 only slightly above 4000 t. Landings increased to 7529 t in 1992–93, followed by a substantial increase to the highest recorded value of 14 256 t in 1993–94, which was more than twice the original quota and exceeded the quota of 8000 t set for that year. In 1994–95 reported landings (7832 t) were half those of 1993–94. Landings from 1994–95 to 1997–98 were around 7000 t. Over the period 1997–98 to 2004–05, annual catches from JMA 1 increased to near the level of the TACC (10 000 t) and, until 2014–15, annual catches fluctuated about 8000–10 000 t, with the exception of a considerably lower catch in 2006–07 and a peak catch of 11 200 t in 2007–08. JMA 1 landings since 2015–16 have been consistently less than the TACC of 10 000 t. The 2017–18 JMA 1 landings were the lowest since 2006–07, at 5553 t.

Estimates of the species composition of the JMA 1 purse seine catches are available from 1989–90 to 2017–18 (Figure 2, Table 4). During 1989–90 and 1990–91, annual catches were dominated by *T. novaezelandiae*, but included a small component of *T. declivis*. The proportion of *T. murphyi* in the catch increased considerably over the following years, accounting for 65% of the total catch in 1993–94 and continued to account for a considerable proportion of the JMA 1 catch during 1994–95 to 1998–99. Since 1999–00, annual catches of *T. murphyi* have been small. From 1999–00 to 2016–17, annual catches from JMA 1 were generally dominated by *T. novaezelandiae*. The annual catch of this species increased from about 2000 t to 5000 t during the 1990s to an average of 8150 t in 2007–08 to 2016–17. Correspondingly, cumulative catches of *T. declivis* and *T. murphyi* were low during this period (7% and 2%, respectively). *T. novaezelandiae* annual catches dominated the JMA 1 purse seine fishery from 2014–15 to 2016–17, ranging from 6488 t to 8858 t, but dropped to 2432 t and 52% of the catch in 2017–18. The 2017–18 catch of *T. declivis* increased to 2156 t.

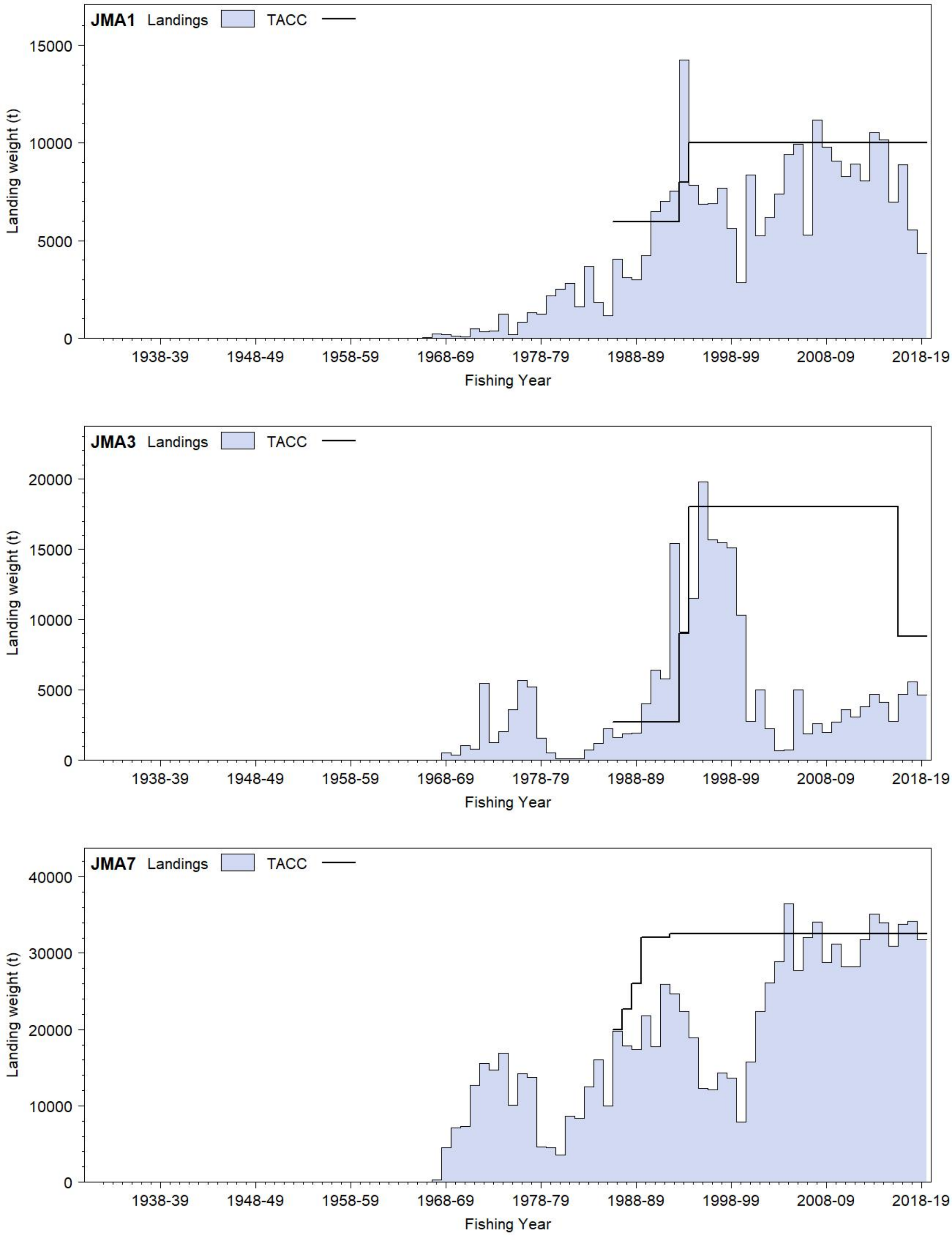


Figure 1: Reported commercial landings and TACC for the three main JMA stocks. From top: JMA 1 (Auckland East, Central East), JMA 3 (South East coast, South East Chatham Rise, Sub-Antarctic, Southland), and JMA 7 (Challenger, Central Egmont, Auckland West).

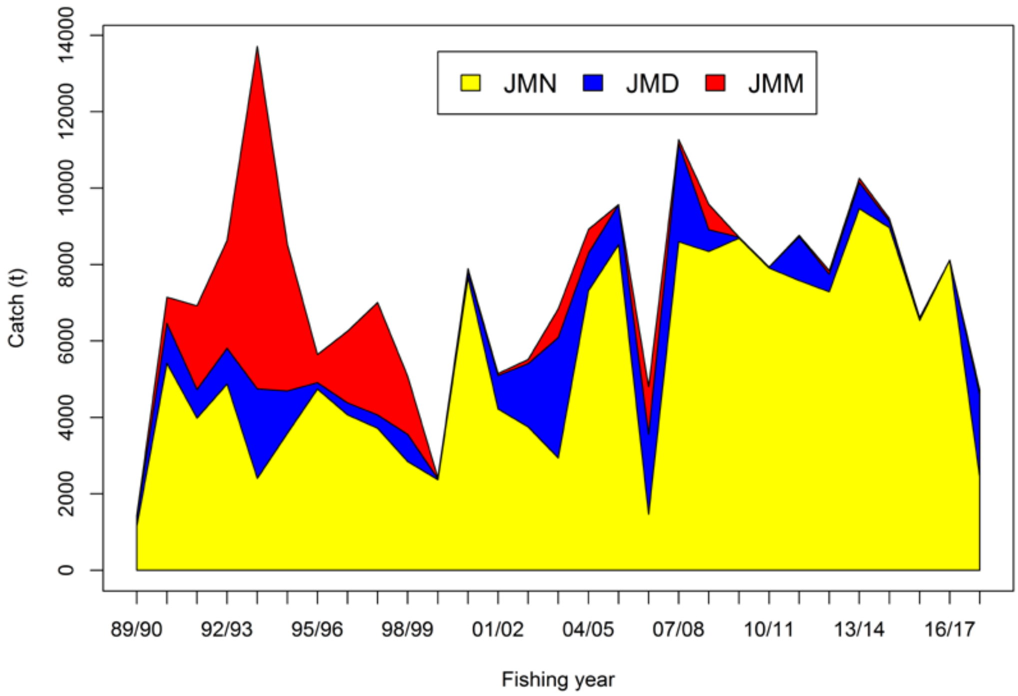


Figure 2: The time series of annual species catch estimates from the JMA 1 purse seine fishery (JMN, *T. novaezelandiae*; JMD, *T. declivis*; JMM, *T. murphyi*).

Table 4: Total JMA 1 purse seine catches and the time series of annual estimates of the species composition of the catch (JMN, *T. novaezelandiae*; JMD, *T. declivis*; JMM, *T. murphyi*) (compiled from various sources, see appendix 5 (Langley et al 2016) and Langley & Middleton 2019).

Fishing year	Catch (t)	Species proportion		
		JMD	JMM	JMN
1989–90	1 433	0.15	0.04	0.81
1990–91	7 147	0.15	0.10	0.76
1991–92	6 921	0.11	0.32	0.58
1992–93	8 629	0.11	0.33	0.56
1993–94	13 710	0.17	0.65	0.18
1994–95	8 530	0.13	0.45	0.42
1995–96	5 643	0.03	0.13	0.84
1996–97	6 256	0.05	0.30	0.65
1997–98	7 009	0.05	0.42	0.53
1998–99	5 077	0.14	0.30	0.56
1999–00	2 416	0.01	0.01	0.98
2000–01	7 896	0.02	0.01	0.97
2001–02	5 146	0.17	0.01	0.82
2002–03	5 518	0.30	0.02	0.68
2003–04	6 838	0.46	0.11	0.43
2004–05	8 919	0.11	0.07	0.82
2005–06	9 568	0.11	0.00	0.89
2006–07	4 803	0.44	0.26	0.31
2007–08	11 270	0.23	0.01	0.76
2008–09	9 579	0.06	0.07	0.87
2009–10	8 714	0.00	0.00	1.00
2010–11	7 936	0.00	0.00	1.00
2011–12	8 765	0.13	0.00	0.86
2012–13	7 841	0.06	0.01	0.93
2013–14	10 260	0.07	0.01	0.92
2014–15	9 094	0.02	0.01	0.97
2015–16	6 555	0.01	0.00	0.99
2016–17	8 115	0.00	0.00	1.00
2017–18	4 710	0.46	0.03	0.52

Total landings in JMA 3 over the period 1984–85 to 1988–89 were relatively constant, at a level below the quota of 2700 t. Landings increased over subsequent years to peak in 1992–93 at almost three times that of the preceding year and more than five times the quota. Under the first of two consecutive annual increases to the JMA 3 TACC in 1993–94, landings were slightly above the limit set, but dropped well below the higher TACC level in 1994–95. The lower 1994–95 catch relative to that in 1992–93 has been attributed to the delayed implementation of the quota, less targeting of jack mackerel, and low bycatch in the squid trawl fishery. The reduced effort is thought to be a result of marketing difficulties for the relatively lower valued *T. murphyi*. Landings in JMA 3 increased markedly in 1995–96 (19 803 t) to a value exceeding the quota, with catches remaining stable around 15 500 t over three subsequent years. More recently, landings have decreased to levels well below the TACC, fluctuating between 700 t and 5 000 t since 2000–01. Declines in landings are attributed to declining abundance of *T. murphyi*, which historically comprised the bulk of JMA 3 landings. JMA 3 landings in 2018–19 were 4651 t.

Landings in JMA 7 represent the greatest proportion of total landings and were mainly taken by bottom trawlers in the early 1990s, but are now mainly taken by midwater trawlers. Landings fluctuated between 17 403 t and 25 880 t from 1986–87 to 1994–95. From 1995–96 to 1998–99, landings were in the range of 12 056–14 293 t. Subsequently, landings increased steadily from 15 703 t in 2000–01, to 28 888 t in 2003–04, and to 36 507 t in 2004–05. The 2004–05 landings were 3971 t in excess of the TACC. This increase in JMA 7 landings has been attributed to market demand and a lack of availability of preferred species quota as a result of cuts in quotas for other species and taking the lower-cost option of targeting jack mackerel instead of hoki. The 2007–08 landings were 34 059 t, about 1500 t larger than the TACC. In 2008–09 catches decreased below the TACC by nearly 4000 t, but increased again in 2009–10 to 31 152 t, which is within 1500 t of the quota. JMA 7 landings in 2018–19 were 31 752 t.

A number of factors have been identified that can influence landing volumes in the jack mackerel fisheries. In the purse seine fishery during the 1990s, jack mackerel was often mixed with kahawai. Fishing companies tend to avoid these mixed schools to conserve kahawai quota, particularly at the beginning of the fishing year. When mixing of the two species is prevalent, a low kahawai TACC can result in the targeting of jack mackerel being inhibited. Both skipjack tuna and blue mackerel have been fished in preference to jack mackerel in the purse seine fishery, with the jack mackerel season being influenced by the availability of these species. However, global increases in the market price for jack mackerel have increased its importance in the purse seine fishery to a level similar to blue mackerel, and as a result, the seasonal catch for jack mackerel has broadened considerably in recent years. This has provided fishers with a cost-effective alternative to traditional purse seine targets, particularly skipjack tuna, which incurs higher costs related to onboard storage and handling.

In recent years, there has been a change in the operation of the JMA 1 purse-seine fleet. In response to market requirements, fish are no longer stored in brine on board the vessel. This has resulted in shorter trip durations and consequently a concentration of fishing effort in the Bay of Plenty (where *T. novaezelandiae* dominate) in close proximity to the processing facilities in Tauranga. Market requirements for fish size also affect the jack mackerel species targeted, and consequently the areas fished.

1.2 Recreational fisheries

Jack mackerels do not rate highly as a recreational target species although they are popular as bait.

Recreational catch in the northern region (JMA 1) was estimated at 333 000 fish (CV 0.13) by a diary survey in 1993–94 (Bradford 1996), 79 000 fish (CV 0.16) in a national recreational survey in 1996 (Bradford 1998), 349 000 fish (CV 39%) in the 2000 survey (Boyd & Reilly 2002) and 295 000 fish (CV 0.2%) in the 2001 survey (Boyd et al 2004). The surveys suggest a harvest of 80–110 t per year for JMA 1, insignificant in the context of the commercial catch. Estimates from other areas are very low (between 500 and 47 000 fish) and are insignificant in the context of the commercial catch

The harvest estimates provided by telephone/diary surveys between 1993 and 2001 are no longer considered reliable for various reasons. A Recreational Technical Working Group concluded that these harvest estimates should be used only with the following qualifications: a) they may be very inaccurate; b) the 1996 and earlier surveys contain a methodological error; and c) the 2000 and 2001 estimates are implausibly high for many important fisheries. In response to these problems and the cost and scale challenges associated with onsite methods, a National Panel Survey was conducted for the first time throughout the 2011–12 fishing year (Wynne-Jones et al 2014). The panel survey used face-to-face interviews of a random sample of 30 390 New Zealand households to recruit a panel of fishers and non-fishers for a full year. The panel members were contacted regularly about their fishing activities and harvest information collected in standardised phone interviews. The national panel survey was repeated during the 2017–18 fishing year using very similar methods to produce directly comparable results (Wynne-Jones et al 2019). Recreational catch estimates from the two national panel surveys are given in Table 5. Note that national panel survey estimates do not include recreational harvest taken under s111 general approvals.

Table 5: Recreational harvest estimates for jack mackerel stocks (Wynne-Jones et al 2014, 2019). Mean fish weights were obtained from boat ramp surveys (Hartill & Davey 2015, Davey et al 2019).

Stock	Year	Method	Number of fish	Total weight (t)	CV
JMA 1	2011–12	Panel survey	101 076	32.2	0.20
	2017–18	Panel survey	62 710	18.6	0.24
JMA 3	2011–12	Panel survey	50	<1	1.01
	2017–18	Panel survey	0	0	–
JMA 7	2011–12	Panel survey	11 194	10.2	0.57
	2017–18	Panel survey	20 026	6.2	0.51

1.3 Customary non-commercial fisheries
Quantitative information on the current level of Māori customary non-commercial catch is not available.

1.4 Illegal catch
There is no information on illegal activity or catch but it is considered to be insignificant.

1.5 Other sources of mortality
There is no information on other sources of mortality.

2. BIOLOGY

The three species of jack mackerel in New Zealand have different geographical distributions, but their ranges partially overlap. *T. novaezelandiae* predominates in waters shallower than 150 m and warmer than 13 °C; it is uncommon south of latitude 42° S. *T. declivis* generally occurs in deeper (but less than 300 m) waters cooler than 16 °C, north of latitude 45° S (Robertson 1978). *T. murphyi* occurs to depths of least 500 m and has a wide latitudinal range (0° S at the Galapagos Islands and coastal Ecuador, to south of 40° S off the Chilean coast) (Kawahara et al 1988).

T. murphyi was first described from New Zealand waters in 1987 (Kawahara et al 1988). Its presence was recorded off the south and east coasts of the South Island. It expanded onto the west coast of the South Island and the North and South Taranaki bights by the late 1980s, reaching the Bay of Plenty in appreciable quantities by 1992 and becoming common on the east coast of Northland by June 1994. However, this extensive distribution has decreased in more recent years and, since the late 1990s, its presence north of Cook Strait has been sporadic with occasional landings in the JMA 1 purse seine fishery north of East Cape and from the JMA 1 inshore trawl fishery south of East Cape. The total range of *T. murphyi* extends along the west coast of South America, across the South Pacific, to the New Zealand EEZ, and into waters off south-eastern Australia.

All species can be caught by bottom trawl, midwater trawl, or by purse seine nets targeting surface schools.

The vertical and horizontal movement patterns are poorly understood. Jack mackerels are presumed to be generally off the bottom at night, and surface schools can be quite common during the day.

Jack mackerels have a protracted spring-summer spawning season. *T. novaezelandiae* probably matures at about 26–30 cm fork length (FL) at an age of 3–4 years, and *T. declivis* matures when about 26–

30 cm FL at an age of 2–4 years. Spawning occurs in the North and South Taranaki bights, and probably in other areas as well.

The reproductive biology of *T. murphyi* in New Zealand waters is not well understood. Pre- and post-spawning fish have been recorded from the Chatham Rise, Stewart-Snares shelf, Northland east coast, and off Kaikoura in summer, but it is unknown whether there has been any resulting recruitment in New Zealand waters. A study by Taylor (2002a) showed that older size/age groups become increasingly dominant in catches westward from the South American coast, suggesting that an eastward migration of oceanic spawned larvae and juveniles occurs in the South Pacific Ocean.

Initial ageing of *T. murphyi* taken in New Zealand waters has been completed, but the estimates are yet to be validated. Initial growth is rapid, slowing at 6–7 years, and *T. murphyi* is a moderately long-lived species with a maximum observed age of 32 years. *T. novaezelandiae* and *T. declivis* have moderate initial growth rates that slow after about 6 years. Both species reach a maximum age of 25+ years.

The best available estimate of M for *T. novaezelandiae* and *T. declivis* is 0.18 based on the age-frequency distributions of lightly exploited populations in the Bay of Plenty. Assuming $M = 0.18$, estimates of Z made in 1989 suggest that F is less than 0.05 for both endemic species off the central west coast (the main jack mackerel fishing ground). Biological parameters relevant to the stock assessment are shown in Table 6.

Table 6: Estimates of biological parameters.

Fishstock			**Estimate**	**Source**
1. Natural mortality (M)				
All			0.18	
			Considered best estimate for both endemic species from all areas.	Horn (1991a)
2. Weight = a(length)^b (Weight in g, length in cm fork length)				
			All	
		a	b	
T. declivis		0.023	2.84	Horn (1991a)
T. novaezelandiae		0.028	2.84	Horn (1991a)
3. von Bertalanffy growth parameters				
			All	
	L_∞	k	t_0	
T. declivis	46 cm	0.28	-0.40	Horn (1991a)
T. novaezelandiae	36 cm	0.30	-0.65	Horn (1991a)
T. s. murphyi	51.2 cm	0.155	-1.4	Taylor et al (2002b)

3. STOCKS AND AREAS

There is no new information that would alter the stock boundaries given in previous assessment documents. For assessment purposes the three jack mackerel species are treated separately where possible.

There are two possible hypotheses on the stock structure of *T. murphyi* in New Zealand waters: it is either a separate stock established by fish migrating from South America, or part of a single, extensive trans-Pacific stock. Although successful recruitment in New Zealand waters would indicate the establishment of a separate stock, current evidence favours the latter hypothesis with an extensive stock between latitudes 35–50° S, linking the coasts of Chile and New Zealand across what has been described as ‘the jack mackerel belt’. Few detailed data are available to document the process of range expansion by *T. murphyi* or indicate the relative abundance of the three species in particular areas. As a requirement of the increased TACCs introduced in 1994–95, improvements to jack mackerel catch monitoring were made to provide adequate data for quantifying species composition and relative abundance in JMA 1 and JMA 3.

4. ENVIRONMENTAL AND ECOSYSTEM CONSIDERATIONS

This section was updated for the 2020 Fisheries Assessment Plenary based on Fisheries New Zealand data updates for jack mackerel fisheries interaction tables in this section. Fishery interactions are described more fully issue-by-issue in the 2019 Aquatic Environment and Biodiversity Annual Review (Fisheries New Zealand 2020).

4.1 Role in the ecosystem

A study of fish assemblages using research trawls suggested that *Trachurus novaezelandiae* is part of an inshore assemblage that prefers shallow northern waters (centred on about 60 m depth and latitude about 38.7° S). All three species overlap spatially, but *T. declivis* is part of a deeper assemblage around central New Zealand (centred on about 130 m and about 40.1° S), and *T. murphyi* occurs deeper still and further south (centred on about 220 m and about 44.7° S) (Francis et al 2002). *T. novaezelandiae* and *T. declivis* range through the water column from surface to the sea floor. The behaviour of *T. murphyi* in New Zealand is less well known but studies off Chile suggest that this species tends to aggregate at night and that this could reflect nocturnal foraging (Bertrand et al 2004, 2006). The effect on the ecosystem of extracting, for example, about 10 000 t of jack mackerels from JMA 1 and 30 000 t from JMA 3 per year over the past decade is unknown.

4.1.1 Trophic interactions

Stevens et al (2011) reported the diet of *T. novaezelandiae* and *T. declivis* from the Bay of Plenty, Northland, and the west coast South Island to be predominantly euphausiids with fewer amphipods and fish (see also Hurst 1980). Crustaceans (several groups) were the dominant prey of *T. novaezelandiae* in the Hauraki Gulf, with fewer fish and polychaetes (Godfriaux 1968, 1970). The diet of *T. murphyi* from research trawls on shelf areas around New Zealand, mainly down to 500 m depth, included: crustaceans (55%, mainly euphausiids 38%, amphipods 12%, and *Munida* 6%); salps (36%); and teleosts (11% frequency of occurrence in non-empty stomachs, Stevens et al 2011).

Predators of jack mackerels are likely to include many fishes, seabirds, and marine mammals given the relatively high abundance of jack mackerels. The diet of gemfish from research trawls in Southland included *Trachurus* spp. (6% of total, Stevens et al 2011). *T. declivis* and *T. murphyi* were identified from the stomachs of leafscale gulper shark and Plunket's shark and *T. declivis* from the stomachs of school shark (Dunn et al 2010). The diet of spiny dogfish included scavenged jack mackerel (Dunn et al 2013).

4.2 Bycatch (fish and invertebrates)

Between 2009 and 2011, *T. novaezelandiae* dominated 97% of purse seine landings in JMA 1 (Walsh et al 2012). The estimated proportions by year were 1–17% for *T. declivis*, 0–3% for *T. murphyi*, and 81–99% for *T. novaezelandiae*. There was spatial and temporal heterogeneity in size and abundance; *T. novaezelandiae* dominated landings from the Bay of Plenty throughout the year and large *T. declivis* and *T. murphyi* were common in east Northland during winter (Walsh et al 2016).

Anderson et al (2017) used data from scientific observers and commercial catch-effort returns to estimate the rates and annual levels of fish and invertebrate bycatch and discards in the jack mackerel trawl fisheries, from 2002–03 to 2013–14. Jack mackerel species (*Trachurus* spp.) accounted for 75% of the total estimated catch from trawls targeting jack mackerels between 1 October 2002 and 30 September 2014. The remaining 25% comprised mostly other commercial species, including barracouta (*Thyrsites atun*, 13%), blue mackerel (*Scomber australasicus*, 3.4%), and frostfish (*Lepidopus caudatus*, 3.4%) (Table 7). Over 90% of reported catch was of QMS species, although altogether 320 taxa were identified by observers. Species with notable levels of discards included spiny dogfish (66%), porcupine fish (77%), thresher shark (99%), and sunfish (100%).

Table 7: Bycatch and discards from all observer records for the target trawl fishery for jack mackerel from 1 October 2002 to 30 September 2014 for species or species groups with a total catch of 100 t or more, ordered by decreasing percentage of catch (Anderson et al 2017).

Species code	Common name	Scientific name	Estimated catch (t)	% of catch	% discarded
JMA	Jack mackerel	*Trachurus declivis, T. murphyi, T. novaezelandiae*	88 169	44.03	0
JMD	Greenback jack	*Trachurus declivis*	41 105	20.53	0
BAR	Barracouta	*Thyrsites atun*	25 857	12.91	0
JMN	Yellowtail jack	*Trachurus novaezelandiae*	17 150	8.56	0
EMA	Blue mackerel	*Scomber australasicus*	6 879	3.44	0
FRO	Frostfish	*Lepidopus caudatus*	6 745	3.37	0
RBT	Redbait	*Emmelichthys nitidus*	4 917	2.46	1
JMM	Slender jack	*Trachurus murphyi*	4 061	2.03	0
RBM	Rays bream	*Brama brama*	612	0.31	0
SWA	Silver warehou	*Seriolella punctata*	568	0.28	0
STU	Slender tuna	*Allothunnus fallai*	535	0.27	7
SPD	Spiny dogfish	*Squalus acanthias*	499	0.25	66
SQU	Arrow squid	*Nototodarus sloanii* & *N. gouldi*	496	0.25	0
SNA	Snapper	*Pagrus auratus*	297	0.15	0
KIN	Kingfish	*Seriola lalandi*	273	0.14	31
SDO	Silver dory	*Cyttus novaezealandiae*	239	0.12	1
PIL	Pilchard	*Sardinops sagax*	228	0.11	0
WAR	Blue warehou	*Seriolella brama*	225	0.11	0
JDO	John dory	*Zeus faber*	147	0.07	0
POP	Porcupine fish	*Allomycterus jaculiferus*	137	0.07	77

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

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

4.3.1 Marine mammal interactions

Jack mackerel trawlers occasionally catch marine mammals, primarily common dolphin, long-finned pilot whale, and New Zealand fur seal (which are all classified as "Not Threatened" under the New Zealand Threat Classification System in 2019 (Baker et al 2019)).

Between 2002–03 and 2017–18, there were 198 observed captures of whales and dolphins in jack mackerel trawl fisheries: common dolphin (183), long-finned pilot whale (13), dusky dolphin (1), and long-beaked common dolphin (1). In the 2016–17 and 2017–18 fishing years there were 0 and 1 observed captures (of long-beaked common dolphin) in jack mackerel trawl fisheries, respectively (Table 8). Estimated captures for 2002–03 to 2017–18 are shown in Table 8. Common dolphins were observed captured off the Taranaki coast or off the west coast of the North Island (Abraham et al 2016). Modifications to the captures estimation model are currently being evaluated by the Aquatic Environment Working Group, reflecting structural changes in fisheries operations in recent years. For this reason, capture estimates are not currently available for the 2015–16 fishing year onwards. The fifteen year average of the rate of capture for common dolphins is 2.1 captures per 100 tows (range 0 to 11.2) in the jack mackerel fishery.

Table 8: Number of tows by fishing year and observed and model-estimated total common dolphin captures in jack mackerel trawl fisheries, 2002–03 to 2017–18. No. obs, number of observed tows; % obs, percentage of tows observed; Rate, number of captures per 100 observed tows. Estimates are based on methods described in Abraham et al (2016) and available via https://data.dragonfly.co.nz/psc. Estimates for 2002–03 to 2014–15 are based on data version 2018v1. [Continued on next page]

		Observed				Estimated	
Fishing year	Tows	No.obs	%obs	Capture	Rate	Captures	95%c.i.
2002–03	3 067	346	11.3	21	6.07	128	54-243
2003–04	2 383	152	6.4	17	11.18	105	46-196
2004–05	2 509	558	22.2	21	3.76	82	43-135
2005–06	2 809	709	25.2	2	0.28	10	2-29
2006–07	2 711	802	29.6	11	1.37	50	20-94
2007–08	2 650	818	30.9	20	2.44	41	23-68
2008–09	2 169	813	37.5	11	1.35	26	13-49

Table 8 [Continued]:

				Observed		Estimated	
Fishing year	**Tows**	**No.obs**	**%obs**	**Capture**	**Rate**	**Captures**	**95%c.i.**
2009–10	2 406	786	32.7	4	0.51	23	6-55
2010–11	1 880	593	31.5	7	1.18	63	24-120
2011–12	2 032	1 548	76.2	5	0.32	7	5-14
2012–13	2 215	1 941	87.6	15	0.77	16	15-20
2013–14	2 454	2 194	89.4	28	1.28	30	28-36
2014–15	1 746	1 511	86.5	19	1.25	21	19-28
2015–16	1 546	1 384	89.5	2	0.14		
2016–17	1 405	1 022	72.7	0	0.00		
2017–18	1 689	1 475	87.3	1	0.07		

4.3.2 Seabird interactions

Annual observed seabird capture rates ranged from 0 to 1.4 per 100 tows in jack mackerel fisheries between 2002–03 and 2017–18 (Abraham & Thompson 2009, Abraham et al 2009, Abraham & Thompson 2011, Thompson et al 2013, Abraham et al 2016). Capture rates have fluctuated without obvious trend at this low level (Table 9). In the 2015–16 fishing year there were 6 observed captures of seabirds in the jack mackerel trawl fishery, and 4 in the 2016–17 fishing year, at a rate of 0.4 birds per 100 observed tows. Total estimated seabird captures in the jack mackerel trawl fishery varied from 7 to 25 between 2002–03 and 2017–18 (Table 9).

Table 9: Number of tows by fishing year and observed seabird captures in jack mackerel trawl fisheries, 2002–03 to 2017–18. No. obs, number of observed tows; % obs, percentage of tows observed; Rate, number of captures per 100 observed tows. Estimates are based on methods described in Abraham et al (2016) and Abraham & Richard (2017, 2018) and are available via https://data.dragonfly.co.nz/psc. Estimates for 2002–03 to 2017–18 are based on data version 2019v1.

	Fishing effort			Observed captures		Estimated captures	
Fishing year	**Tows**	**No. Obs**	**% obs**	**Captures**	**Rate**	**Mean**	**95% c.i.**
2002–03	3 067	346	11.3	4	1.2	23	13–36
2003–04	2 383	152	6.4	0	0.0	7	2–14
2004–05	2 509	558	22.2	8	1.4	16	11–23
2005–06	2 809	709	25.2	0	0.0	20	9–35
2006–07	2 711	802	29.6	1	0.1	9	3–16
2007–08	2 650	818	30.9	1	0.1	9	3–16
2008–09	2 169	813	37.5	6	0.7	14	8–21
2009–10	2 406	786	32.7	9	1.1	15	10–22
2010–11	1 880	593	31.5	7	1.2	15	9–22
2011–12	2 032	1 548	76.2	5	0.3	9	5–14
2012–13	2 215	1 941	87.6	24	1.2	25	24–27
2013–14	2 454	2 194	89.4	6	0.3	7	6–11
2014–15	1 746	1 511	86.5	11	0.7	13	11–17
2015–16	1 546	1 384	89.5	6	0.4	7	6–10
2016–17	1 405	1 022	72.7	4	0.4	6	4–10
2017–18	1 689	1 475	87.3	16	1.1	11	10–14

Observed seabird captures since 2002–03 have been mostly prions, shearwaters, and petrels (77 of the 103 observed seabird captures), with 26 observed albatross captures (Table 10). Seabird captures in the jack mackerel fishery have been observed mostly on the Stewart-Snares shelf, off Taranaki, and off the east coast South Island. These numbers should be regarded as only a general guide on the distribution of captures because the numbers are small, and the observer coverage is not uniform across areas and may not be representative.

The jack mackerel target trawl fishery contributes to the total risk posed by New Zealand commercial fishing to seabirds (Table 11). The species to which the fishery poses the most risk is Southern Buller's albatross; this target fishery posing 0.002 of PST (Table 11). Southern Buller's albatross was assessed at high risk (Richard et al 2017).

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

Table 10: Number of observed seabird captures in jack mackerel trawl fisheries, 2002–03 to 2017–18, by species and area.

Species	Risk category	Taranaki	West coast North Island	Chatham Rise	Stewart-Snares shelf	East coast South Island	West coast South Island	Total
Salvin's albatross	High	0	0	0	0	3	0	3
Southern Buller's albatross	High	0	0	1	3	2	0	6
New Zealand white-capped albatross	Medium	4	0	0	9	4	0	17
Total albatrosses	–	4	0	1	12	9	0	26
Westland petrel	High	0	0	0	0	0	1	1
White-chinned petrel	Negligible	0	0	0	31	5	0	36
Sooty shearwater	Negligible	1	0	0	10	2	0	13
Common diving petrel	Negligible	0	0	0	1	0	1	3
White-faced storm petrels	Negligible	0	3	1	0	0	0	4
Australasian gannet	Negligible	1	0	0	0	0	0	1
Fairy prion	Negligible	5	0	0	1	1	0	6
Cape petrels	–	1	0	0	0	0	1	2
Fulmar prion	–	9	0	0	0	0	0	10
Grey-backed storm petrel	–	0	0	1	0	0	0	1
Large seabird	–	1	0	0	0	0	0	1
Total other birds	–	17	3	2	43	8	3	77

Table 11: Risk ratio of seabirds predicted by the level two risk assessment for the jack mackerel and all fisheries included in the level two risk assessment, 2006–07 to 2016–17, showing seabird species with a risk ratio of at least 0.001 of PST. The risk ratio is an estimate of aggregate potential fatalities across trawl and longline fisheries relative to the Population Sustainability Threshold, PST (from Richard et al 2017, where full details of the risk assessment approach can be found). The DOC threat classifications are shown (Robertson et al 2017 at http://www.doc.govt.nz/documents/science-and-technical/nztcs19entire.pdf).

Species name	PST (mean)	Risk ratio: MAC risk ratio	Risk ratio: Total	Risk category	DOC Threat Classification
Southern Buller's albatross	1 368.4	0.002	0.392	High	At Risk: Naturally Uncommon
New Zealand white-capped albatross	10 900.3	0.001	0.353	High	At Risk: Declining

4.3.3 Protected fish interactions

Mobulid rays (spinetail devilrays, *Mobula mobular*, and manta rays, *Mobula birostris,* both protected since 2010 under the Wildlife Act 1953) occur mainly in north-eastern North Island waters during summer and could potentially be caught in purse seine nets along the north-east coast of North Island. However, observers monitoring mackerel purse seine fisheries (coverage 0–17.8% per year, 2002–18) have not reported any captures of mobulid rays to date.

4.4 Benthic interactions

Jack mackerel are taken using trawls that are sometimes fished on or near the seabed. The spatial extent of seabed contact by trawl fishing gear in New Zealand's EEZ and Territorial Sea has been estimated and mapped in numerous studies for trawl fisheries targeting deepwater species (Baird et al 2011, Black et al 2013, Black & Tilney 2015, Black & Tilney 2017, Baird & Wood 2018, and Baird & Mules 2019, 2020b) and species in waters shallower than 250 m (Baird et al. 2015, Baird & Mules 2020a).

Target jack mackerel tows accounted for about 3.5% of all tows reported on TCEPR forms that fished on or close to the bottom between 1989–90 and 2004–05 (Baird et al 2011). These tows were located in Benthic-optimised Marine Environment Classification (BOMEC, Leathwick et al 2012) classes C, E (shelf), H (upper slope), and J (mid-slope) (Baird & Wood 2012), and 91% were in water shallower than 200 m (Baird et al 2011).

During 1989–90 to 2015–16, about 50 100 bottom-contacting jack mackerel trawls were reported on TCEPRs (Baird & Wood 2018); this represents about 1200–3300 tows in most years up to 2013–14 and about 850 tows each for 2014–15 and 2015–16. The total footprint generated from these tows was estimated at about 44 430 km^2. This footprint represented coverage of 1.1% of the seafloor of the combined EEZ and the Territorial Sea areas; 3.2% of the 'fishable area', that is, the seafloor area open to trawling, in depths of less than 1600 m. For the 2016–17 fishing year, 784 jack mackerel bottom-contacting tows had an estimated footprint of 3796 km^2 which represented coverage of 0.1% of the EEZ and Territorial Sea and 0.3% of the fishable area (Baird & Mules 2019). In 2017–18, the estimated footprint of 2890 km^2 (from 923 bottom-contacting tows) covered 0.2% of the fishable area (Baird & Mules 2020b).

The overall trawl footprint for jack mackerel (1989–90 to 2015–16) covered 14% of the seafloor in < 200 m, 6% of 200–400 m seafloor, and < 0.05% of the 400–600 m seafloor (Baird & Wood 2018). The jack mackerel footprint contacted 1%, 0.1%, and < 0.01% of those depth ranges, respectively, in 2016–17 and 2017–18 (Baird & Mules 2019, 2020). The BOMEC class C (off the west coast of the North Island) had the highest proportion of area covered by the jack mackerel footprint in 2016–17 (4%), with the remainder of the footprint covering about 0.3% of the 61 000 km^2 of class E (Stewart-Snares shelf) and 138 550 km^2 of class H (Chatham Rise) (Baird & Mules 2019). In 2017–18, the footprint covered 2.5% of class C, 0.6% of class H, and 0.2% of class H (Baird & Mules 2020b).

Trawling for jack mackerel with some or all of the gear contacting the bottom, like trawling for other species, is likely to have effects on benthic community structure and function (e.g., Rice 2006) and there may be consequences for benthic productivity (e.g., Jennings et al 2001, Hermsen et al 2003, Hiddink et al 2006, Reiss et al 2009). These consequences are not considered in detail here but are discussed in the 2019 Aquatic Environment and Biodiversity Annual Review (Fisheries New Zealand 2020).

4.5 Other considerations

4.5.1 Spawning disruption

Fishing may disrupt spawning activity or success. Canadian research carried out on Atlantic cod (*Gadus morhua*) concluded that "Cod exposed to a chronic stressor are able to spawn successfully, but there appears to be a negative impact of this stress on their reproductive output, particularly through the production of abnormal larvae" (Morgan et al 1999). Morgan et al (1997) also reported disruption of a spawning shoal of Atlantic cod: "Following passage of the trawl, a 300-m-wide "hole" in the aggregation spanned the trawl track. Disturbance was detected for 77 min after passage of the trawl." There have been no specific studies for jack mackerel in New Zealand waters, but information on the timing and location of spawning and fishing exists. *T. declivis* and *T. novaezelandiae* are serial spawners with a protracted spring-summer spawning season (Hurst et al 2000). *T. murphyi* appears to spawn from late winter through to summer (Horn 1991b, Hurst et al 2000). The JMA 7 trawl fishery has peaks of catch and effort in spring-summer (October–March) and in winter (April–September) (McKenzie 2008), the former overlapping with spawning. Most of the purse seine catch from the Bay of Plenty is taken in September–October, but an increasing proportion has been caught in November–December since 2005–06 (Walsh et al 2012), also overlapping the spring–summer spawning.

4.5.2 Habitat of particular significance to fisheries management

Habitat of particular significance for fisheries management (HPSFM) does not have a policy definition (Ministry for Primary Industries 2016), although work is underway to generate one. Studies of potential relevance have identified areas of importance for spawning and juveniles (Hurst et al 2000). *T. declivis* spawning was found to be common on the southwest and northwest North Island outer shelf, and moderate to high abundance of juveniles was recorded from northwest North Island, Hauraki Gulf, and Bay of Plenty outer shelf. *T. novaezelandiae* spawning was found to be common on the southwest and northwest inner and outer shelf of the North Island, and moderate to high abundance of juveniles was recorded from Hauraki Gulf and Bay of Plenty inner and outer shelf, East Cape inner shelf, and Tasman Bay/Golden Bay. *T. murphyi* spawning was found to be common on the southwest outer shelf and only low abundance of juveniles was recorded from the outer Southland shelf and at 300–600 m on the Chatham Rise.

4.5.3 Genetic effects
Fishing and environmental changes, including those caused by climate change or pollution, could alter the genetic composition or diversity of a species. There are no known studies of the genetic diversity of jack mackerels in New Zealand.

4.5.4 Marine heatwave
The effects of the marine heatwave on jack mackerel fisheries that was experienced in New Zealand waters in the summer months of 2017–18 are unknown.

5. STOCK ASSESSMENT

Stock assessments for jack mackerel are complicated by the reporting and management of three species under a single code.

Preliminary stock assessments for *T. declivis* and *T. novaezealandiae* in JMA 7 were undertaken in 2007 based on outputs from a Bayesian analysis for splitting the recorded commercial catch into *T. declivis, T. novaezealandiae,* and *T. murphyi* components. This analysis was based on species proportions sampled by fishery observers and was used to derive CPUE indices and a catch history for the *T. declivis* fishery in JMA 7, which were incorporated along with a proportions-at-age series into stock assessments. However, work in 2020 concluded that the observer data (stored in the Centralised Observer Database *cod*) were inadequate for deriving species splits in JMA 7 (Webber & Starr in prep.) rendering the previous analyses unusable.

5.1 Challenger, Central West, and Auckland West (JMA 7)

Species proportion estimates
Previously a species proportion model fitted to observer data was used to estimate the proportion of *T. declivis* in the reported (TCEPR) catch for the JMA 7 fishery from 1989–90 through to 2004–05 (Rohan et al. 2006). In the model the species proportions are estimated for six strata each year (1989–90 to 2004–05). However, work in 2020 concluded that the *cod* data were inadequate for deriving species splits in JMA 7 (Webber & Starr, in prep.) rendering this analysis unusable. Currently, there do not appear to be any alternative data for estimating species proportions in JMA 7. The main issue with the observer data is the representativeness of samples. Samples will often be unrepresentative of the entire catch in a tow because observers will usually take a single sample (i.e., a few bins of fish) at the beginning of unloading the tow. Because JMA, both within and between species, are not homogeneously mixed within a tow, such a sample is likely to be unrepresentative of the entire tow.

CPUE
Although the species proportion model could not be used, a set of CPUE standardisations of all three species combined was done for positive catches of JMA only (i.e., the CPUE series could be assumed to track the abundance of all three species). This was done because 98% of observed targeted JMA tows caught JMA. Three different series were produced: a bottom trawl (BT) series from 1990–2002 based on the *cod* database (Figure 3, Table 12). The earlier BT series seems to fluctuate more from year to year when compared with the two MW trawl series. The two MW trawl series, based on different data sets, align reasonably well, lending some credibility to these series. All three series suggest a generally increasing trend in CPUE over the past 30 years.

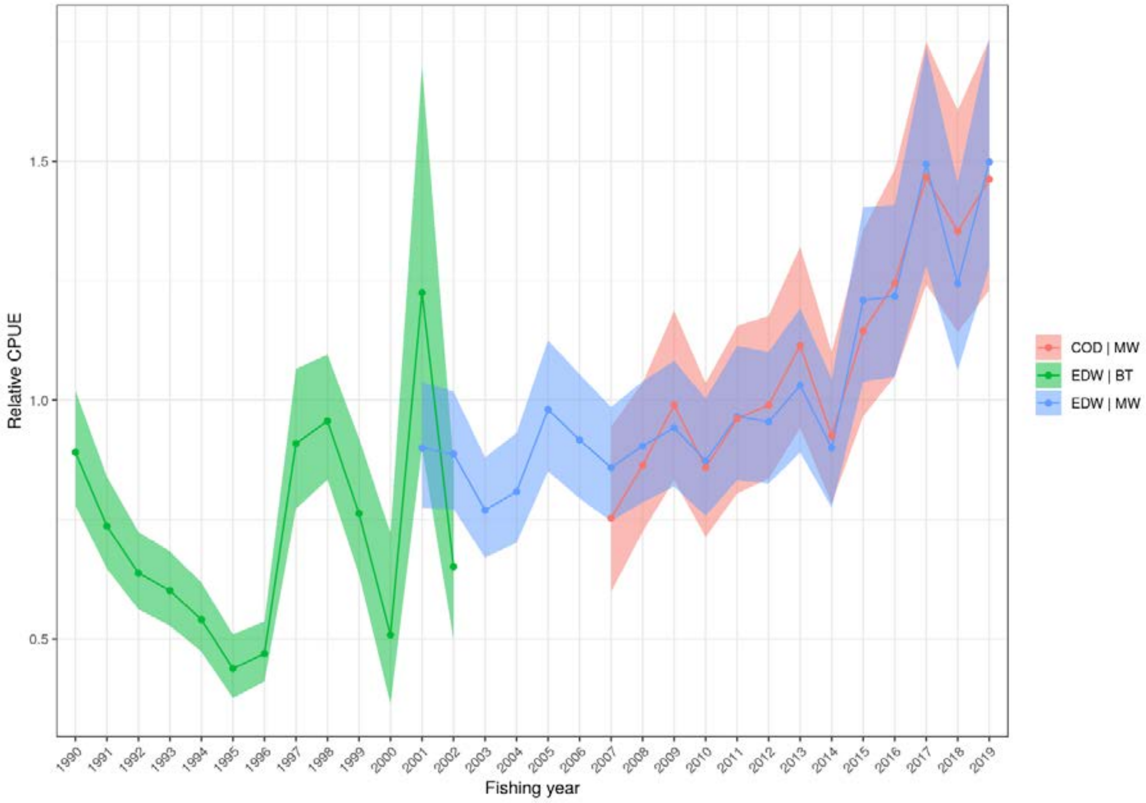


Figure 3: Standardised catch per unit effort (CPUE) indices of all three JMA species combined (i.e. JMD, JMM, and JMN) in JMA 7 from 1990-2019. Three series are presented: a bottom trawl (BT) series from 1990–2002 based on data held in the Electronic Data Warehouse (EDW); a midwater (MW) series from 2001–19 also based on EDW data; and a MW series from 2007–19 based on data held in the Centralised Observer Database *cod*). Points represent the median, and shaded region represents the 95% credible interval. The MW EDW series is scaled to have a geometric mean of 1, and the MW COD and BT EDW series are scaled to have the same geometric mean as the MW EDW series for the overlapping years.

Table 12: Standardised CPUE indices (i.e., relative year effects, each series is rescaled to have a geometric mean of 1) from 1990–91 to 2019–20.The mean and CV for each series are provided. [Continued on next page]

	EDW BT		EDW MW		COD MW	
Fishing year	**CPUE**	**CV**	**CPUE**	**CV**	**CPUE**	**CV**
1990–91	1.2925	0.069	–	–	–	–
1991–92	1.0691	0.067	–	–	–	–
1992–93	0.9256	0.065	–	–	–	–
1993–94	0.8735	0.066	–	–	–	–
1994–95	0.7855	0.067	–	–	–	–
1995–96	0.6372	0.078	–	–	–	–
1996–97	0.6818	0.068	–	–	–	–
1997–98	1.3209	0.082	–	–	–	–
1998–99	1.3870	0.070	–	–	–	–
1999–00	1.1105	0.095	–	–	–	–
2000–01	0.7498	0.176	–	–	–	–
2001–02	1.8005	0.166	0.899	0.073	–	–
2002–03	0.9550	0.141	0.886	0.072	–	–
2003–04	–	–	0.770	0.070	–	–
2004–05	–	–	0.809	0.072	–	–
2005–06	–	–	0.980	0.072	–	–
2006–07	–	–	0.917	0.072	–	–
2007–08	–	–	0.859	0.071	0.708	0.115
2008–09	–	–	0.904	0.071	0.812	0.092
2009–10	–	–	0.942	0.072	0.931	0.089
2010–11	–	–	0.874	0.072	0.807	0.094
2011–12	–	–	0.966	0.074	0.905	0.093
2012–13	–	–	0.955	0.074	0.929	0.087
2013–14	–	–	1.031	0.074	1.046	0.086
2014–15	–	–	0.900	0.075	0.870	0.085

Table 12 [Continued]:

	EDW BT		EDW MW		COD MW	
Fishing year	**CPUE**	**CV**	**CPUE**	**CV**	**CPUE**	**CV**
2015–16	–	–	1.209	0.076	1.075	0.086
2016–17	–	–	1.218	0.076	1.169	0.087
2017–18	–	–	1.495	0.078	1.379	0.088
2018–19	–	–	1.244	0.080	1.272	0.087
2019–20	–	–	1.498	0.082	1.374	0.090

Catch History
Catch records for jack mackerel extend back to 1946, although landings are small until the mid-1960s. Recreational catch, illegal catch, and customary non-commercial catch are not well known, though are small relative to the commercial catch, so no components are included for these in the catch history.

Catch at Age
Catch-at-age data were used from the commercial fishery in the years 1989–90, 1990–91, 1995–96, 2004–05, and 2005–06 to 2016–17, but proportions have been scaled on the discredited species proportions in 2020.

5.2 Biomass estimates
Estimates of current biomass are not available.

5.3 Other yield estimates and stock assessment results
For *T. declivis* and *T. novaezelandiae* catch-at-age proportions are available for the years 2006–07 to 2008–09 in JMA 7. These were used to estimate instantaneous total mortality *Z* values by the Chapman-Robson maximum likelihood method (Chapman & Robson 1960). As a sensitivity analysis, the assumed age of recruitment was varied between three and six years (Smith 2011).

For *T. declivis* estimates of *Z* varied between 0.17 y^{-1} and 0.23 y^{-1}. For *T. novaezelandiae*, *Z* varied between 0.23 $y^{-1}$and 0.43 y^{-1}. Estimates were lowest in the 2008–09 year for both species. The accepted value of natural mortality for both species is 0.18 y^{-1}, indicating that estimates of average instantaneous fishing mortality (*F*) were well below *M* for *T. declivis* and about equal to *M* for *T. novaezelandiae*.

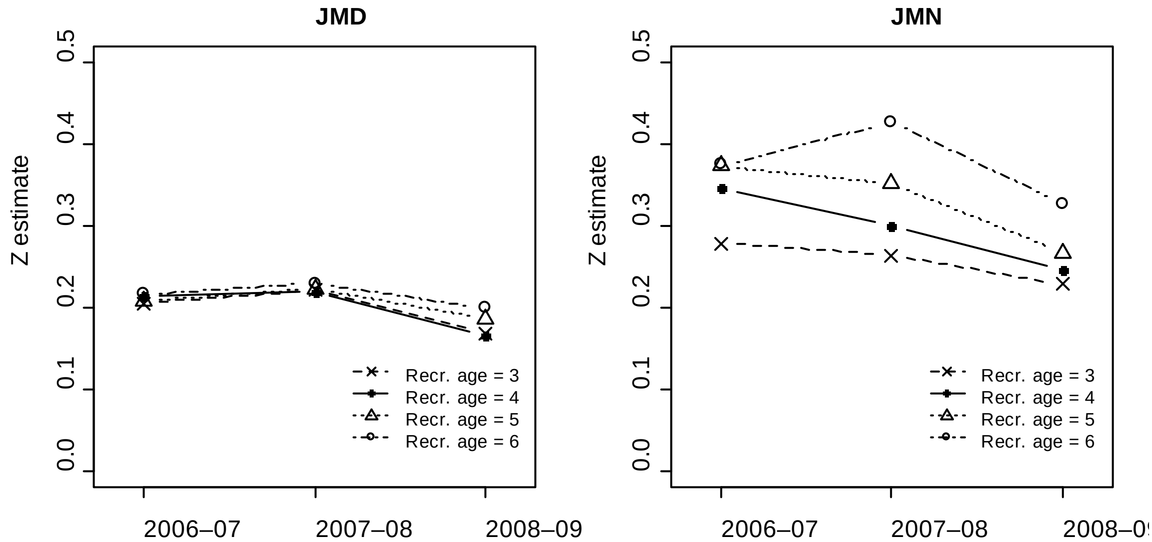


Figure 4: Estimates of instantaneous total mortality (*Z*) by year for *T. declivis* and *T. novaezelandiae* in JMA 7.

5.4 Other factors
T. murphyi has been known at times to comprise a substantial proportion of the purse seine catches in the area between Cook Strait and Kaikoura, in the Bay of Plenty, and off the east Northland coast, although the proportion of this component has declined considerably since the late 1990s. *T. murphyi* has also been an important component of the west coast North Island jack mackerel trawl fishery but has declined in recent years. Thus, there has been a contraction in the range of this species in New

Zealand waters, although it is unknown yet whether this represents a decrease in its overall abundance here. The effect of *T. murphyi* on the range and abundance of the other two species is unknown.

Aerial sightings data were used to produce a time series of relative abundance indices for jack mackerel. The time series covered the period from the beginning of the purse seine fishery in 1976 to 1993. It indicated an increase in abundance in JMA 1 from the early 1990s, and, although the result is not as clear, a similar trend in JMA 3 and JMA 7. These increases were attributed to the invasion of *T. murphyi*.

The validity of this early aerial sightings abundance index is uncertain. Further analysis of these data have been the focus of considerable effort in recent years and the Northern Inshore Working Group had not yet accepted revised abundance indices due to data and model concerns.

The stipulation that catches in JMA 1 and JMA 3 above the original TACs (5970 t and 2700 t, respectively) be accounted for by increases in *T. murphyi* only, is a method of managing this species independently of the other two. This approach was introduced as a means of maintaining stocks of the endemic species while allowing exploitation of increased stocks of *T. murphyi* resulting from its invasion.

The increase in *T. novaezelandiae* catch has predominantly occurred within the Bay of Plenty fishery area. There has been a small decrease in the length of fish caught from the fishery since 2006–07 to 2008–09, although it is unknown whether the decline in fish size is attributable to an increase in fishing mortality rates, changes in fishing operation, or variation in annual recruitment. Age composition data are available for the *T. novaezelandiae* catch from 2006–07 to 2008–09, but age-based sampling was discontinued due to the relatively high inter-annual variability in the age compositions, with the fishery targeting size classes based on market demand.

Future Research Considerations

- Develop and implement new sampling and data recording protocols to enable the Fisheries New Zealand observer programme to adequately sample and record the species composition of the JMA complex from commercial catches in the main JMA fisheries. The current practice of taking a sample of JMA from the beginning of a bag is not adequate because species are not homogeneously mixed within a tow. Instead, samples need to be collected throughout a bag all the way to the cod-end.
- The utility of shed sampling for some of the JMA fisheries should be explored. Although shed sampling would not help split the catch on a tow-by-tow basis, it could help determine the proportion of each species on a trip-by-trip basis and could be applicable to observed and unobserved trips. If done after observed trips then observer sampling could be confirmed.
- Develop a custom stock assessment model to overcome the lack of historic species split information. This should model all three species combined and be fitted to combined data for those years without known species-splits, and to standard data for the remaining years. A simulation model to ensure that the ‘custom model’ is capable of producing outputs useful to management may also be required.
- A simpler, alternative approach to the ‘custom’ assessment described above, would be to use a standard assessment model and test a wide variety of assumed historical catch histories for the three species. The historical species split may be informed by Australian catch information for JMM (assuming that this will also reflect the same timing of influxes into New Zealand waters) and/or from historical New Zealand sales data where price or market differences by species may have existed.

6. STATUS OF THE STOCKS

Assessment of the status of JMA is complicated by the reporting and management of three species under a single code. This is further complicated by the uncertain ‘status’ of *T. murphyi*. The effect of the *T. murphyi* invasion on stocks of the New Zealand jack mackerels is unknown.

Stock Structure Assumptions
The three species have different levels of mobility and different spatial distributions within New Zealand. *T. murphyi* has been extremely mobile, with a widespread distribution throughout New Zealand during the 1990s, but is now rarely seen in areas where once it was common. The degree to which its biomass has actually declined is difficult to determine and there are no recent reliable estimates of its current spatial distribution. There are reports from hoki surveys in Cook Strait of aggregations of *T. murphyi* lying in deeper water.

T. declivis is also believed to be highly mobile within New Zealand. Because of this, a single biological stock is assumed, but this has not yet been reliably determined The mobility of *T. novaezelandiae* is assumed to be lower, given that it is a smaller animal with a more northerly and inshore distribution than *T. declivis*. Consequently, there is a higher probability of multiple independent breeding populations for *T. novaezelandiae*.

- **JMA 1**

Stock Status	
Year of Most Recent Assessment	-
Reference Points	Target(s): Not established but B_{MSY} assumed Soft Limit: 20% B_0 Hard Limit: 10% B_0 Overfishing threshold: Not established
Status in relation to Target	Unknown
Status in relation to Limits	Unknown
Status in relation to Overfishing	-
Historical Stock Status Trajectory and Current Status **-**	
Fishery and Stock Trends	
Recent Trend in Biomass or Proxy	An index for JMA 1 is not available at this time. Recent work and discussions concerning the use of aerial sightings data for annual relative abundance indices concluded that the inter-annual variation was too great for these data to provide a reliable index.
Recent Trend in Fishing Mortality or Proxy	-
Trends in other Relevant Indicators or Variables	-

Projections and Prognosis	
Stock Projections or Prognosis	It is not known whether catches at the level of the current TACCs or recent catch levels are sustainable in the long-term.
Probability of Current Catch or TACC causing Biomass to remain below or to decline below Limits	Soft Limit: Unknown Hard Limit: Unknown
Probability of Current Catch or TACC causing Overfishing to continue or to commence	-

Assessment Methodology and Evaluation		
Assessment Type	Level 3 — Qualitative Evaluation: Fishery characterisation with evaluation of fishery trends (e.g., catch, effort and nominal CPUE, length-frequency information) - there is no agreed index of abundance	
Assessment Method	-	
Assessment Dates	Latest assessment: 1993	Next assessment: Unknown

Overall assessment quality rank	-	
Main data inputs (rank)	Species proportions estimates	
Data not used (rank)		
Changes to Model Structure and Assumptions	-	
Major Sources of Uncertainty	-	

Qualifying Comments
-
Fishery Interactions
JMA 1 catches are primarily taken by targeted purse seine. Because jack mackerel often occur in mixed schools with kahawai, particularly towards the end of the fishing year, this can inhibit jack mackerel targeting in this fishery at this time. Interactions with other species are currently being characterised.

- **JMA 3**

Stock Status	
Year of Most Recent Assessment	-
Reference Points	Management Target: 40% B_0 Soft Limit: 20% B_0 Hard Limit: 10% B_0 Overfishing threshold: Not established
Status in relation to Target	Unknown
Status in relation to Limits	Unknown
Status in relation to Overfishing	-

Historical Stock Status Trajectory and Current Status
-

Fishery and Stock Trends	
Recent Trend in Biomass or Proxy	-
Recent Trend in Fishing Intensity or Proxy	-
Other Abundance Indices	-
Trends in Other Relevant Indicators or Variables	-

Projections and Prognosis	
Stock Projections or Prognosis	It is not known whether catches at the level of the current TACCs or recent catch levels are sustainable in the long-term.
Probability of Current Catch or TACC causing Biomass to remain below or to decline below Limits	Soft Limit: Unknown Hard Limit: Unknown
Probability of Current Catch or TACC causing Overfishing to continue or to commence	-

Assessment Methodology and Evaluation	
Assessment Type	Level 4: Low information evaluation — there are only data on catch and TACC, with no other fishery indicators. Catch is qualified with species proportions estimates from MPI observer data. Some length-frequency information is available.
Assessment Method	-

Assessment Dates	Latest assessment: -	Next assessment: -
Overall assessment quality rank		
Main data inputs (rank)	-	
Data not used (rank)	-	
Changes to Model Structure and Assumptions	-	
Major Sources of Uncertainty	-	

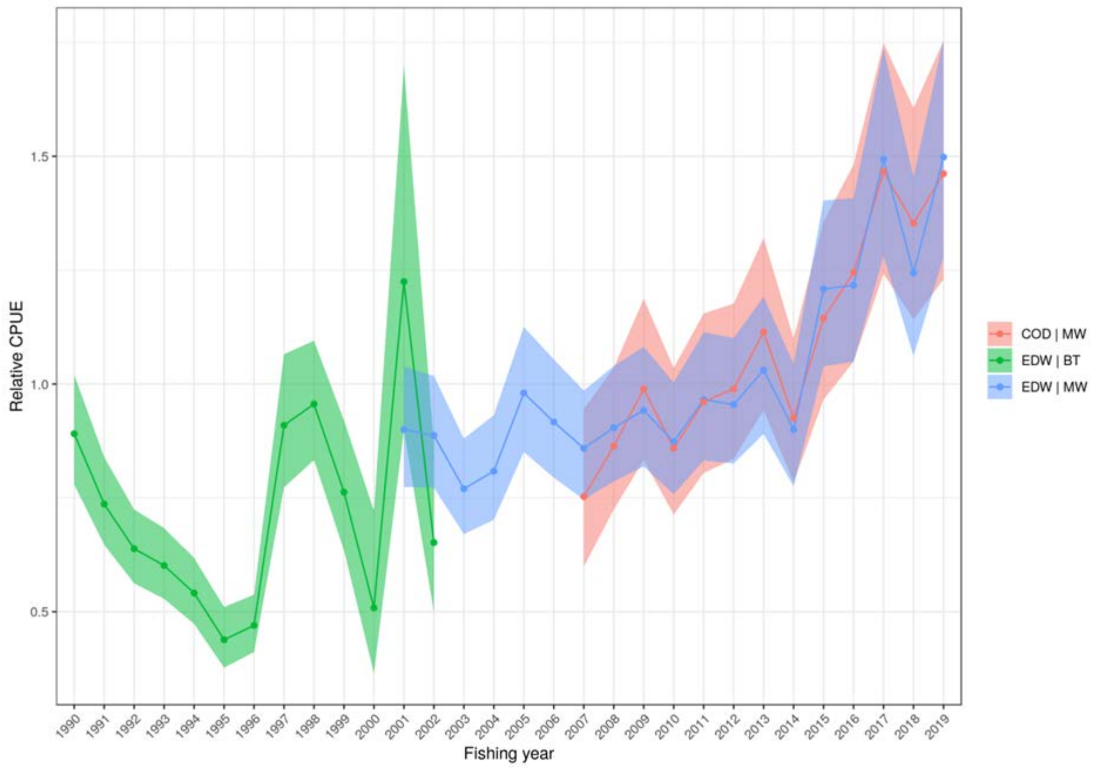
Qualifying Comments
-

Fishery Interactions
JMA 3 catches are primarily taken by midwater trawl. Non-target species captured in this fishery include barracouta, blue mackerel and frostfish. Incidental captures of protected species have been recorded for New Zealand fur seals and cetaceans. Trawls on or near the seabed interact with benthic habitats.

- **JMA 7**

Stock Status	
Year of Most Recent Assessment	2020
Reference Points	Management Target: 40% B_0 Soft Limit: 20% B_0 Hard Limit: 10% B_0 Overfishing threshold: $F_{40\%\ B0}$
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



Fishery and Stock Trends	
Recent Trend in Biomass or Proxy	CPUE for all 3 species combined has shown a long term increase.
Recent Trend in Fishing Intensity or Proxy	Unknown
Other Abundance Indices	-
Trends in Other Relevant Indicators or Variables	-

Projections and Prognosis	
Stock Projections or Prognosis	Unknown
Probability of Current Catch or TACC causing Biomass to remain below or to decline below Limits	Soft Limit: Unknown Hard Limit: Unknown
Probability of Current Catch or TACC causing Overfishing to continue or to commence	Unknown

Assessment Methodology and Evaluation		
Assessment Type	Level 2 - Partial quantitative stock assessment	
Assessment Method	CPUE analysis	
Assessment Dates	Latest assessment: 2020	Next assessment: 2022
Overall assessment quality rank	2 – Medium or mixed quality: combined index for 3 species	
Main data inputs (rank)	- combined CPUE - age frequency - length frequency	1 – High Quality 1 – High Quality 1 – High Quality
Data not used (rank)	- species split data	3 – Low Quality: representativeness of data are questionable
Changes to Model Structure and Assumptions	- Catch curve analysis replaced with CPUE analyses	
Major Sources of Uncertainty	- The catch split between the 3 species cannot be reliably estimated.	

Qualifying Comments
- Although abundance indices are available for the 3 species combined, it is not possible to undertake a full stock assessment with the current sources of data.

Fishery Interactions
JMA 7 catches are primarily taken by midwater trawl. A number of bycatch issues exist with blue mackerel, an important component of this fishery, and the non-availability of ACE for kingfish, blue mackerel, and snapper potentially influences targeting in some sub-areas. Incidental captures of protected species have been recorded for New Zealand fur seals and cetaceans. Trawls on or near the seabed interact with benthic habitats.

Yield estimates, TACCs and reported landings for the recent fishing year are summarised in Table 13.

Table 13: Summary of TACCs (t) and reported landings (t) for all three species in the most recent fishing year.

Fishstock		**FMAs**	**2018–19 Actual TAC**	**2018–19 Reported landings**
JMA 1	Auckland (East)/ Central (East)	1, 2	10 000	4 332
JMA 3	South-East/Southland/Sub-Antarctic	3, 4, 5, 6	8 780	4 651
JMA 7	Challenger/Central (West)/Auckland (West)	7, 8, 9	32 537	31 752
JMA 10	Kermadec	10	10	0
Total			51 327	40 735

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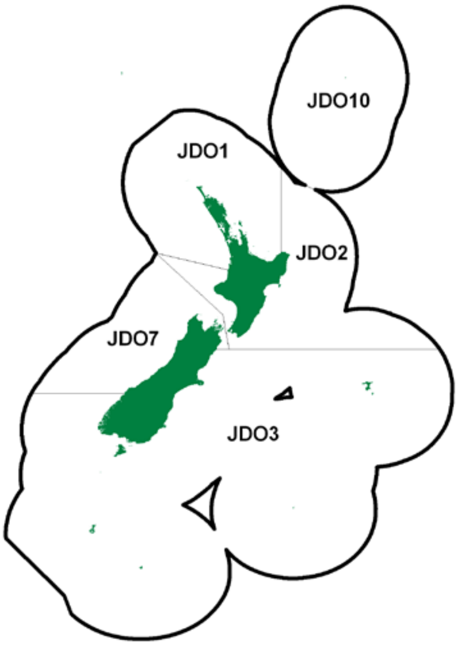
JOHN DORY (JDO)

(*Zeus faber*)
Kuparu



1. FISHERY SUMMARY

John dory was introduced into the QMS on 1 October 1986; current allowances, TACCs, and TACs are summarised in Table 1. The TACCs for JDO 1, JDO 2, and JDO 3 were increased gradually during the late 1980s and early 1990s, but have remained unchanged since 1994–95. The TACC for JDO 7 was increased from 131 to 150 t in October 2012, and to 190 t on 1 October 2016. The TACC for JDO 10 has remained unchanged since 1986.

Table 1: TACs, TACCs, and allowances (t) for John dory for fishing year 2019-20.

Fishstock	Recreational allowance	Customary non–commercial allowance	Other mortality	TACC	TAC
JDO 1	–	–	–	704	704
JDO 2	–	–	–	269.5	269.5
JDO 3	–	–	–	31.9	31.9
JDO 7	4	2	11	230	247
JDO 10	–	–	–	10	10

1.1 Commercial fisheries

John dory are taken mainly as a bycatch of the trawl and Danish seine fisheries. In recent years, around 50–65% of the total reported catch has been taken in JDO 1, and around 20% taken in JDO 2. Reported landings for the main QMAs from 1931 to 1982 are given in Table 2. Recent reported landings by Fishstock are given in Table 3, and the historical landings and TACC values for the three main JDO stocks are depicted in Figure 1.

The increase in JDO 1 landings after 1986–87 is largely attributed to increased targeting of John dory by trawl and Danish seine. Annual catches reached a peak during 1994–95 to 1996–97, at about the level of the TACC of 704 t. There was a general decline in annual landings over the subsequent years. In recent years (2009–10 to 2017–18), landings were maintained at about 350 t per annum, but in 2018–19 landings dropped below 300 t for the first time since 1975. Most of the decline in John dory catch occurred in the Hauraki Gulf-East Northland fishery. Annual catches from the west coast (FMA 9) have been maintained at about 80–140 t over the last 25 years (from 1990–91), predominantly as a bycatch of the snapper, red gurnard, and trevally trawl fisheries. Annual catches from the Bay of Plenty fishery (trawl and Danish seine) were about 80–120 t during the same period.
Annual landings in JDO 2 have never exceeded the TACC and, in the mid-90s, were around 50% of the TACC in each year (Figure 1). From 1999–00 to 2002–03 landings were above 200 t, but in recent

years landings have decreased, being below 150 t since 2006–07. Landings from JDO 2 are considered to be approximately equally split between FMAs 2 and 8. Substantial proportions of John dory landings are taken as bycatch in target trawl fisheries for jack mackerels in FMA 8, and as tarakihi and red gurnard bycatch in FMA 2.

Landings from JDO 7 increased markedly after 1999–2000, as a result of increasing abundance. JDO 7 is taken largely as a bycatch of FMA 7 trawl fisheries. The JDO 7 TACC has been increased four times since 2003–04 and is currently 190 t (Table 3). Nevertheless, landings in 2017–18 and 2018–19 exceeded the TACC, by 13 t and 7 t respectively.

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

Year	JDO 1	JDO 2	JDO 3	JDO 7	Year	JDO 1	JDO 2	JDO 3	JDO 7
1931–32	70	0	0	0	1957	110	37	0	20
1932–33	60	0	0	0	1958	132	54	0	40
1933–34	57	0	0	0	1959	157	64	0	50
1934–35	42	0	0	0	1960	158	81	0	53
1935–36	92	0	0	0	1961	156	76	0	52
1936–37	105	4	0	1	1962	150	87	0	38
1937–38	80	3	0	0	1963	114	96	0	44
1938–39	78	3	1	0	1964	112	85	1	30
1939–40	40	5	0	0	1965	111	101	0	32
1940–41	0	2	1	1	1966	148	110	0	37
1941–42	0	7	1	3	1967	162	102	0	41
1942–43	3	4	3	3	1968	203	83	0	36
1943–44	12	4	3	3	1969	189	96	0	19
1944	11	7	2	5	1970	259	137	0	24
1945	12	6	0	1	1971	234	141	1	38
1946	27	7	0	3	1972	213	122	0	34
1947	23	12	2	12	1973	259	99	0	30
1948	21	20	1	1	1974	340	101	0	28
1949	22	79	0	4	1975	261	92	0	22
1950	17	65	0	6	1976	362	135	0	55
1951	5	38	0	2	1977	315	141	0	73
1952	34	50	0	5	1978	392	119	0	24
1953	163	62	0	7	1979	503	121	0	29
1954	181	52	0	25	1980	563	173	0	26
1955	162	50	0	24	1981	646	186	0	38
1956	175	46	0	24	1982	577	162	0	28

Notes:

1. The 1931–1943 years are April–March but from 1944 onwards are calendar years.
2. Data up to 1985 are from fishing returns: data from 1986 to 1990 are from Quota Management Reports.
3. Data for the period 1931 to 1982 are based on reported landings by harbour and are likely to be underestimated as a result of under-reporting and discarding practices. Data includes both foreign and domestic landings. Data were aggregated to FMA using methods and assumptions described by Francis & Paul (2013).

Table 3: Reported landings (t) of John dory by Fishstock from 1983–84 to 2018–19 and actual TACCs (t) for 1986–87 to 2018–19. QMS data from 1986–present.

Fishstock	JDO 1		JDO 2		JDO 3		JDO 7	
FMA (s)	1 & 9		2 & 8		3, 4, 5 & 6		7	
	Landings	TACC	Landings	TAC	Landings	TACC	Landings	TACC
1983–84*	659	–	131	–	1	–	35	–
1984–85*	620	–	110	–	0	–	36	–
1985–86*	531	–	158	–	1	–	45	–
1986–87	409	510	168	240	3	30	57	70
1987–88	476	633	192	246	1	30	89	75
1988–89	480	662	151	253	6	30	47	82
1989–90	494	704	152	262	1	30	54	88
1990–91	505	704	171	269	1	31	53	88
1991–92	562	704	214	269	1	31	60	88
1992–93	578	704	217	269	8	31	50	91
1993–94	640	704	186	269	2	32	37	91
1994–95	721	704	140	270	3	32	30	91
1995–96	696	704	139	270	< 1	32	42	91

Table 3 [Continued]

Fishstock	JDO 1		JDO 2		JDO 3		JDO 7	
FMA (s)	1 & 9		2 & 8		3, 4, 5 & 6		7	
	Landings	TACC	Landings	TACC	Landings	TACC	Landings	TACC
1996–97	689	704	140	270	< 1	32	35	91
1997–98	651	704	134	270	< 1	32	26	91
1998–99	672	704	182	270	< 1	32	34	91
1999–00	519	704	235	270	< 1	32	71	91
2000–01	497	704	217	270	1	32	104	91
2001–02	453	704	240	270	4	32	124	91
2002–03	440	704	239	270	2	32	114	91
2003–04	492	704	184	270	< 1	32	155	91
2004–05	561	704	182	270	1	32	133	114
2005–06	549	704	159	270	1	32	124	114
2006–07	544	704	143	270	1	32	127	114
2007–08	482	704	133	270	< 1	32	110	114
2008–09	411	704	136	270	< 1	32	116	114
2009–10	359	704	152	270	< 1	32	109	125
2010–11	386	704	138	270	< 1	32	112	125
2011–12	351	704	131	270	< 1	32	126	125
2012–13	365	704	138	270	< 1	32	128	150
2013–14	349	704	142	270	< 1	32	151	150
2014–15	354	704	147	270	< 1	32	150	150
2015–16	342	704	129	270	< 1	32	151	190
2016–17	361	704	139	270	1	32	177	190
2017–18	322	704	135	270	1	32	203	190
2018–19	279	704	135	270	1	32	197	209

Fishstock	JDO 10			
FMA (s)	10		Total	
	Landings	TACC	Landings	TACC
1983–84*	0	–	826	–
1984–85*	0	–	766	–
1985–86*	0	–	735	–
1986–87	< 1	10	638	860
1987–88	0	10	758	994
1988–89	0	10	684	1 037
1989–90	0	10	701	1 094
1990–91	0	10	730	1 102
1991–92	0	10	837	1 102
1992–93	0	10	853	1 105
1993–94	0	10	865	1 106
1994–95	0	10	894	1 107
1995–96	0	10	877	1 107
1996–97	0	10	864	1 107
1997–98	0	10	811	1 107
1998–99	0	10	889	1 107
1999–00	0	10	826	1 107
2000–01	0	10	819	1 107
2001–02	0	10	819	1 107
2002–03	0	10	795	1 107
2003–04	0	10	832	1 107
2004–05	0	10	877	1 129
2005–06	0	10	833	1 129
2006–07	0	10	815	1 129
2007–08	0	10	725	1 129
2008–09	0	10	663	1 129
2009–10	0	10	620	1 140
2010–11	0	10	637	1 140
2011–12	0	10	609	1 140
2012–13	0	10	633	1 165
2013–14	0	10	642	1 165
2014–15	0	10	652	1 165
2015–16	0	10	622	1 205
2016–17	0	10	678	1 205
2017–18	0	10	661	1 205
2018–19	0	10	612	1 224

* FSU data.

Overall the majority of John dory catch is reported from the snapper bottom trawl fishery (16%), followed by the John dory bottom trawl (14%), and the tarakihi bottom trawl fisheries (14%). Danish seine accounts for the second largest John dory catch across fishing methods (Figure 2).

Catches of John dory in JDO 1 are predominantly taken by bottom trawl in the snapper (23%), John dory (19%), and trevally (10%) target fisheries. Danish seine, bottom pair trawl, and bottom longline comprise the remaining John dory catch by fishing method (Figure 3). John dory in JDO 2 are taken predominantly by bottom trawl targeting tarakihi (30%) and gurnard (25%), with midwater and set net fishing methods comprising the remainder of the catch (Figure 4). John dory in JDO 7 is predominantly caught by bottom trawl targeting flatfish (25%), barracouta (23%), and tarakihi (18%) (Figure 5). Throughout the North Island, the trawl and Danish seine fisheries targeting John dory take the majority of their catch targeting snapper (33%) followed by the John dory target fishery (23%) (Figure 6). No data were available for JDO set net fisheries in the South Island.

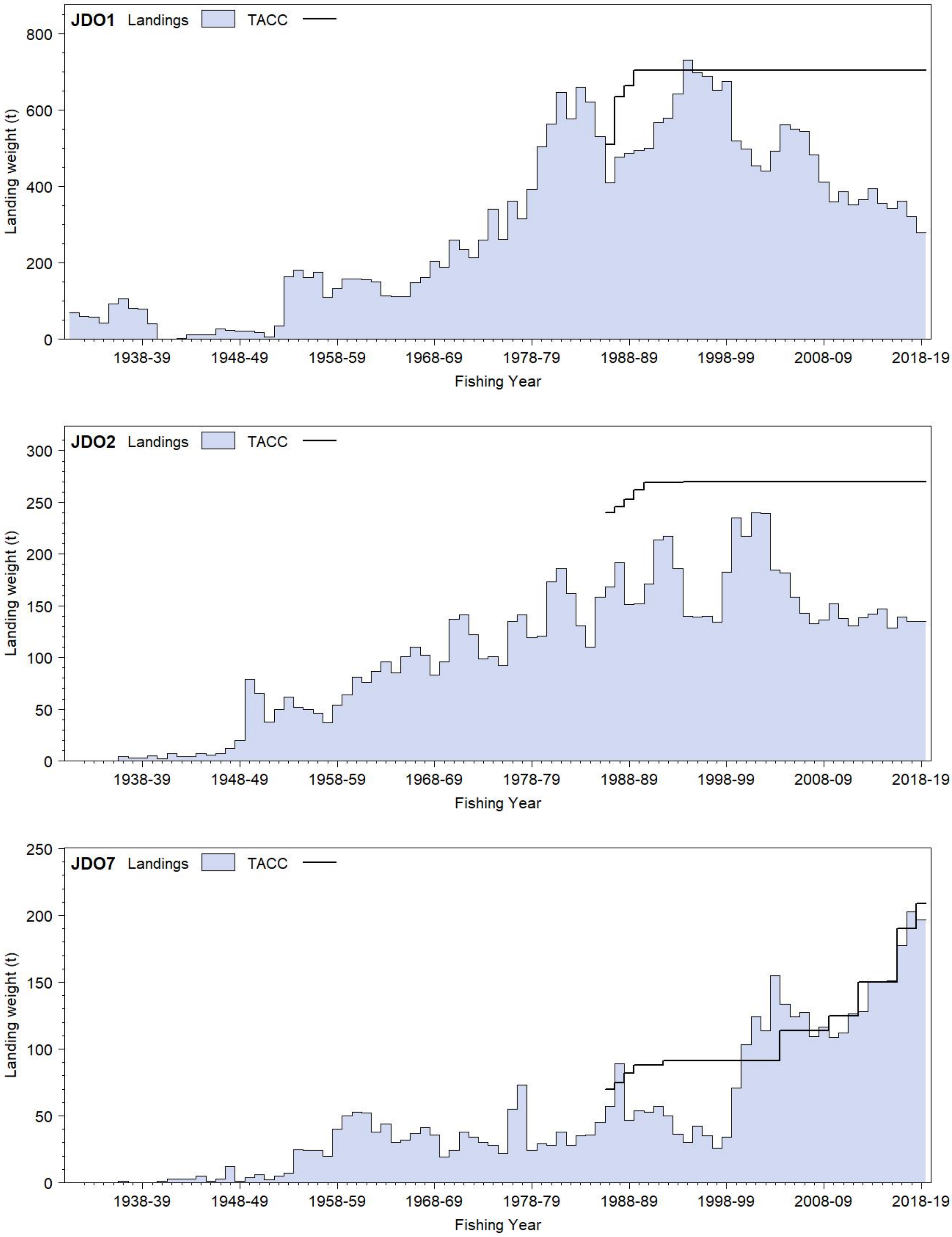


Figure 1: Reported commercial landings and TACC for the three main JDO stocks. JDO 1 (Auckland East), JDO 2 (Central East), and JDO 7 (Challenger).

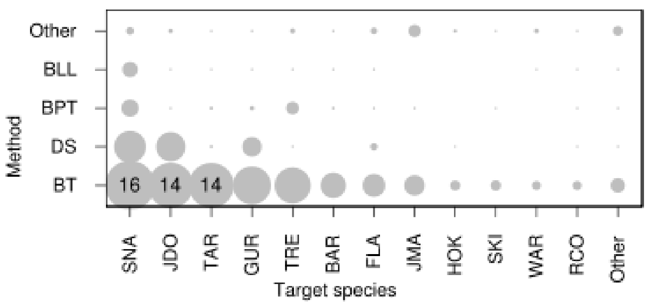


Figure 2: A summary of the proportion of landings of John dory (all QMAs) taken by each target fishery and fishing method. The area of each circle is proportional to the percentage of landings taken using each combination of fishing method and target species. The number in the bubble is the percentage. BT = bottom trawl, DS = Danish seine, BPT = bottom pair trawl, BLL = bottom longline (Bentley et al 2012).

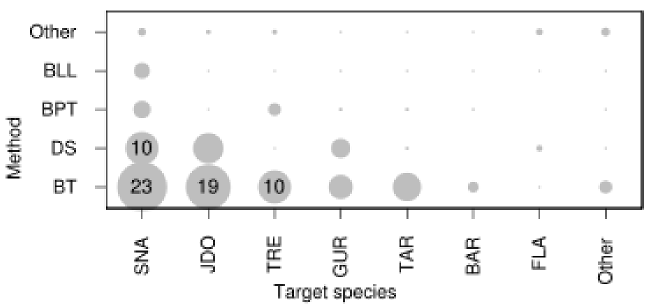


Figure 3: A summary of the proportion of landings of JDO 1 taken by each target fishery and fishing method. The area of each circle is proportional to the percentage of landings taken using each combination of fishing method and target species. The number in the bubble is the percentage. BT = bottom trawl, DS = Danish seine, BPT = bottom pair trawl, BLL = bottom longline (Bentley et al 2012).

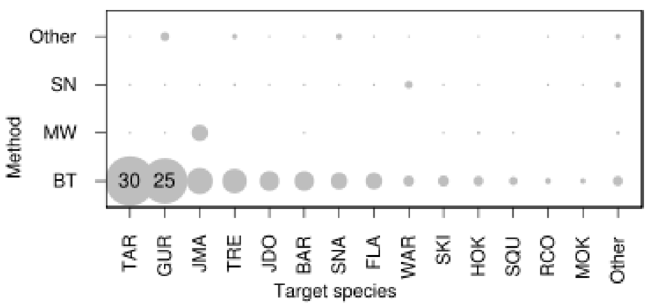


Figure 4: A summary of the proportion of landings of JDO 2 taken by each target fishery and fishing method. The area of each circle is proportional to the percentage of landings taken using each combination of fishing method and target species. The number in the bubble is the percentage. BT = bottom trawl, MW = mid-water, SN = setnet (Bentley et al 2012).

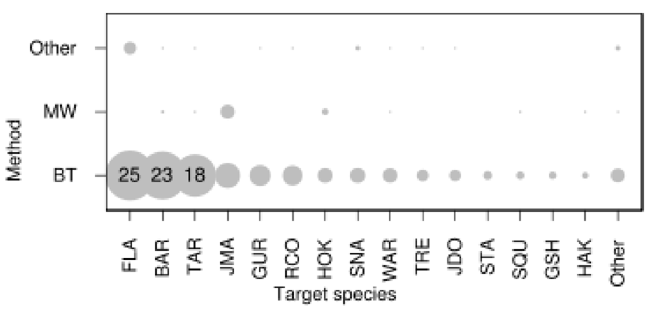


Figure 5: A summary of the proportion of landings of JDO 7 taken by each target fishery and fishing method. The area of each circle is proportional to the percentage of landings taken using each combination of fishing method and target species. The number in the bubble is the percentage. BT = bottom trawl, MW = mid-water (Bentley et al 2012).

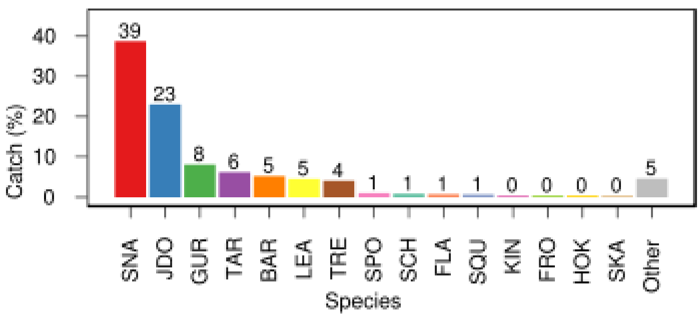


Figure 6: A summary of species composition of the reported trawl and Danish seine catch in trips targeting John dory off the North Island. Catch is expressed as the percentage by weight of each species calculated for all trawl and Danish seine trips (Bentley et al 2012).

1.2 Recreational fisheries

John dory is an important recreational species in the north of New Zealand. They are caught using line fishing methods, predominantly on rod and reel with some longline catch.

1.2.1 Management controls

The main method used to manage recreational harvests of John dory is daily bag limits. Fishers can take up to 20 John dory as part of their combined daily bag limit in the Auckland and Kermadec, Central, and Challenger Fishery Management Areas.

1.2.2 Estimates of recreational harvest

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 John dory were calculated using an offsite approach, the offsite regional telephone and diary survey approach. Estimates for 1996 came from a national telephone and diary survey (Bradford 1998). Another national telephone and diary survey was carried out in 2000 (Boyd & Reilly 2002). The harvest estimates provided by these telephone diary surveys (Table 4) are no longer considered reliable.

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 development and implementation of a national panel survey for the 2011–12 fishing year (Wynne-Jones et al 2014). The panel survey used face-to-face interviews of a random sample of 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 catch information collected in standardised phone interviews. The national panel survey was repeated during the 2017–18 fishing year using very similar methods to produce directly comparable results (Wynne-Jones et al 2019). Recreational catch estimates from the two national panel surveys are given in Table 4. Note that national panel survey estimates do not include recreational harvest taken under s111 general approvals.

1.3 Customary non-commercial fisheries

No quantitative information is available on the current level of Māori customary non-commercial catch.

1.4 Illegal catch

No quantitative information is available.

Table 4: Recreational harvest estimates for John dory stocks. The telephone/diary surveys ran from December to November but are denoted by the January calendar year. National panel surveys ran through the October to September fishing year but are denoted by the January calendar year. Mean fish weights were obtained from boat ramp surveys (see Hartill & Davey 2015, Davey et al 2019, for panel survey mean weights).

Stock	Year	Method	Number of fish	Total weight (t)	CV
JDO 1	1996	Telephone/diary	49 000	87	0.09
	2000	Telephone/diary	129 000	227	0.23
	2012	Panel survey	28 863	36	0.13
	2018	Panel survey	22 595	26	0.20
JDO 2	2000	Telephone/diary	9 000	16	0.43
	2012	Panel survey	2 000	3	0.33
	2018	Panel survey	2 587	3	0.34
JDO 3	2012	Panel survey	88	< 1	1.00
	2018	Panel survey	183	< 1	1.00
JDO 7	2012	Panel survey	1 351	2	0.52
	2018	Panel survey	699	1	0.47

1.5 Other sources of mortality

No quantitative information is available.

2. BIOLOGY

John dory are widespread, being found in the eastern Atlantic Ocean, the Mediterranean Sea, and around New Zealand, Australia, and Japan. They are common in the inshore coastal waters of northern New Zealand, and to a lesser extent in Tasman Bay, to depths of 50 m. In the Hauraki Gulf, adults move to deeper waters during summer, and occasional feeding aggregations occur during winter.

John dory are serial spawners (spawning more than once in a season). There appears to be substantial variation in the time of spawning in New Zealand, with spawning occurring between December and April on the northeast coast. The eggs are large and pelagic, taking 12–14 days to hatch. Initially John dory grow rapidly with both males and females reaching 12 to 18 cm standard length (SL) after the first year. From the second year onwards females grow faster than males and reach a greater maximum length. Females mature at a size of 29 to 35 cm SL and in general, larger females mature earlier in the season and are more fecund. Males mature at 23 to 29 cm SL.

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 unexploited stock. Using a maximum observed age of 12 years, M was estimated to equal 0.38. Biological parameters relevant to the stock assessment are shown in Table 5.

Table 5: Estimates of biological parameters of John dory.

Fishstock						Estimate	Source
1.Weight = a (length)^b (Weight in g, length in cm total length)							
Combined sexes					a	b	
JDO 1					0.048	2.7	from *Ikatere* 2003
2. von Bertalanffy growth parameters							
	Females			Males			
	K	t_0	L_∞	K	t_0	L_∞	
JDO 1	0.425	-0.223	41.13	0.48	-0.251	36.4	Hore (1982)

3. STOCKS AND AREAS

In 2012 the stock structure of John dory was reviewed (Dunn & Jones 2013). The approach evaluated patterns in the distribution of catch and CPUE, research survey biomass trends, location of spawning and nursery grounds, size and age compositions, and anecdotal information from the fishery.

John dory have been caught around most of the North Island and the northern South Island, indicating that the QMA boundaries are not biologically appropriate. The analysis suggested five stocks around New Zealand: (1) Hauraki Gulf and east Northland; (2) Bay of Plenty; (3) west coast North Island; (4) southeast North Island; and (5) northern South Island.

Spawning fish and nursery grounds are found in all five stocks. In addition, on the east coast North Island, CPUE analyses support the separation of the Hauraki Gulf, Bay of Plenty, and Hawkes Bay fisheries, and research trawl survey biomass estimates had different trends in Hauraki Gulf and the Bay of Plenty. Very few John dory are found south of Hawkes Bay on the southeast North Island, providing a gap between the east and west coast components of JDO 2. There is relatively strong evidence to separate the northeast and northwest coasts of JDO 1, including fishery CPUE analyses, length and age compositions, and research trawl survey biomass trends. The distribution of John dory off the west coast North Island is continuous between JDO 1 and the northern part of the west coast JDO 2, and the combination of these areas is also supported by CPUE analyses. There is evidence to separate the northern South Island from stocks to the north including the occurrence of unusually large fish on the northern South Island, and CPUE analyses. John dory appear to reach the southern limit of their range off the north and northwest coasts of the South Island.

4. STOCK ASSESSMENT

4.1 Estimates of fishery parameters and abundance

An investigation into the stock structure of New Zealand John dory (Dunn & Jones 2013) supported five biological stocks: (1) Hauraki Gulf and east Northland, (2) Bay of Plenty, (3) West coast North Island, (4) Southeast North Island, and (5) Northern South Island. The first three stocks are found within JDO 1, the fourth consists of the east coast portion of JDO 2, and the fifth of JDO 7 and the portion of JDO 2 located on the south and east coast of the North Island.

JDO 1

Relative abundance indices have been obtained from trawl surveys of the Bay of Plenty, west coast North Island, and Hauraki Gulf within the JDO 1 Fishstock (Table 6). However, there was a change in the configuration of the trawl gear following the 1988 trawl survey. Modifications to the trawl gear may have resulted in a change in the catchability of John dory part way through the time series. Therefore, surveys conducted between 1982 and 1988 and from 1989 onwards should be considered separately for comparisons of biomass indices to be valid.

In 2018, the CPUE indices for the three sub-areas within JDO 1 (Hauraki Gulf and east Northland, Bay of Plenty, and west coast North Island) were updated to 2016–17. The catch and effort data set included individual bottom trawl records from trawl targeting a range of inshore finfish species (BAR, TAR, TRE, GUR, SNA, and JDO). The landed catch of John dory from a trip was allocated to the individual trawl records in proportion to the estimated catch. The analyses used a delta-lognormal CPUE model incorporating positive catch (lognormal) and presence/absence (binomial) components. For a number of analyses, different trends were apparent between the lognormal and binomial CPUE models. Further investigation indicated that the differences may have been attributable to changes in the recording of smaller John dory catches over the time period. Potential biases introduced by changes in catch reporting are likely to be adequately accounted for by applying the delta-lognormal approach.

Table 6: Estimates of John dory biomass (t) from *Kaharoa* trawl surveys.

Year	Trip Code	Biomass	CV (%)
Bay of Plenty			
1983	KAH8303	113	24
1985	KAH8506	128	12
1987	KAH8711	155	38
1990	KAH9004	157	16
1992	KAH9202	236	12
1996	KAH9601	193	44
1999	KAH9902	176	14
North Island east coast			
1993	KAH9304	265	17
1994	KAH9402	268	31
1995	KAH9502	170	18
1996	KAH9605	172	48
North Island west coast (FMA 8)			
1989	KAH8918	68	25
1991	KAH9111	142	62
1994	KAH9410	33	47
1996	KAH9615	19	38
North Island west coast (FMA 9)			
1986	KAH8612	155	35
1987	KAH8715	160	16
1989	KAH8918	148	16
1991	KAH9111	216	37
1994	KAH9410	102	47
1996	KAH9615	147	15
1999	KAH9915 (FMAs 8 & 9)	374	9
Hauraki Gulf			
1984	KAH8421	292	22
1985	KAH8517	245	20
1986	KAH8613	211	25
1987	KAH8716	181	12
1988	KAH8810	477	32
1989	KAH8917	250	22
1990	KAH9016	322	13
1992	KAH9212	227	35
1993	KAH9311	374	24
1994	KAH9411	288	17
1997	KAH9720	387	18
2000	KAH0012	260	26
West coast South Island			
1992	KAH9204	102	29
1994	KAH9404	59	26
1995	KAH9504	27	36
1997	KAH9701	17	31
2000	KAH0004	141	16
2003	KAH0304	288	19
2005	KAH0503	222	14
2007	KAH0704	174	26
2009	KAH0904	269	23
2011	KAH1104	378	18
2013	KAH1305	231	21
2015	KAH1503	486	16
2017	KAH1703	431	12
2019	KAH1902	274	31

Hauraki Gulf and east Northland (part of JDO 1)
In Hauraki Gulf and east Northland, the standardised CPUE indices fluctuated during the 1990s and 2000s and then steadily declined from 2004–05 to 2012–13 and then increased relatively slowly during 2013–14 to 2016–17 (Figure 7).

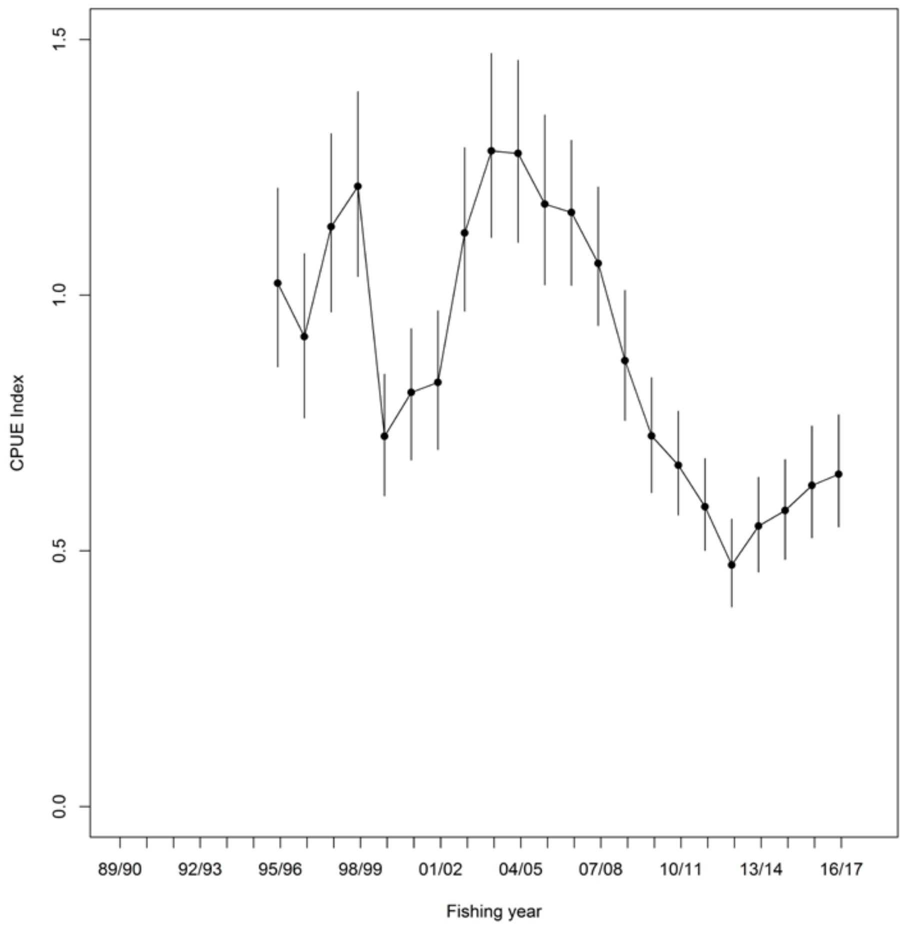


Figure 7: CPUE indices of abundance for Hauraki Gulf and east Northland (part of JDO 1) (combined model of catch rates in mixed species bottom trawl tows). Vertical lines show the 95% confidence intervals.

Bay of Plenty (part of JDO 1)
The standardised CPUE series declined during the late 1990s, remained relatively stable during the 2000s, dropped in 2012–13 to 2013–14 and then increased from 2015–16 to 2016–17 to just below the series mean (Figure 8).

West coast North Island (western JDO 1 and western JDO 2)
The standardised CPUE series suggests that biomass has fluctuated over the study period. CPUE indices were at a high level in 2010–11 to 2012–13 and declined over the subsequent four years (to 2016–17) to below the series mean (Figure 9).

Establishing B_{MSY} compatible reference points for JDO 1
In 2012, the Working Group accepted mean standardised bottom trawl CPUE for the period 1994–95 to 2010–11 as B_{MSY}-compatible proxies for each of the three JDO 1 sub-stocks. All three series were based on combined positive catch and probability of capture models derived from event scale fishing events (i.e., tow). JDO abundance tends to fluctuate in cycles, according to recruitment, and the period chosen included two periods of high abundance and high catch. The Working Group accepted the default Harvest Strategy Standard definitions that the Soft and Hard Limits would be one half and one quarter the target for each sub-stock, respectively.

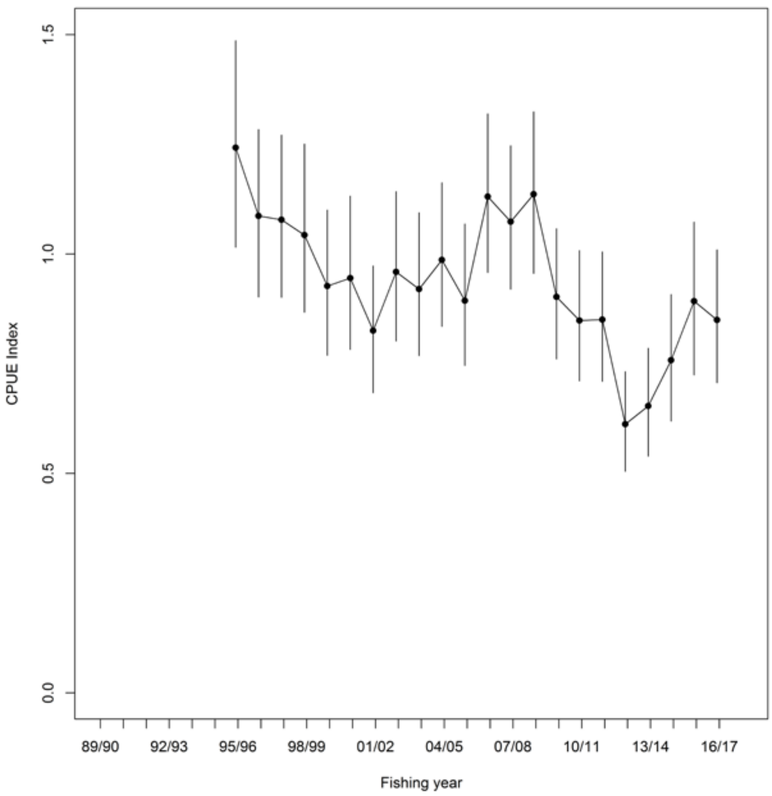


Figure 8: CPUE indices of abundance for the Bay of Plenty (part of JDO 1) (combined model of catch rates in mixed species bottom trawl tows). Vertical lines show the 95% confidence intervals.

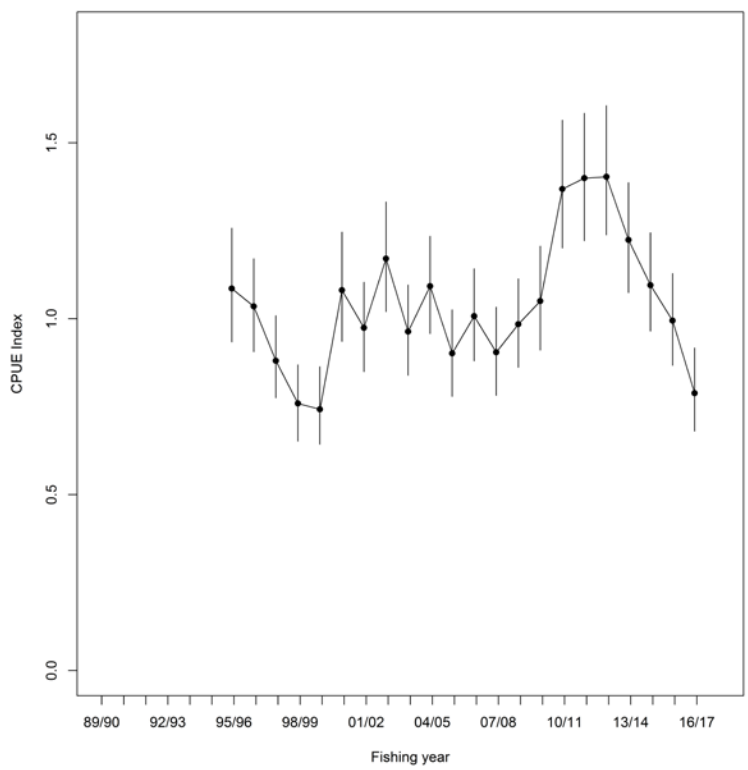


Figure 9: CPUE indices of abundance for the West coast North Island (western JDO 1 and western JDO 2) (combined model of catch rates in mixed species bottom trawl tows). Vertical lines show 95% confidence intervals.

Southeast North Island (part of JDO 2)
The standardised CPUE series suggests an increase in abundance from a low in the mid-1990s to a peak in 2000–01, followed by a steady decline to a series low in 2010–11 (Figure 10).

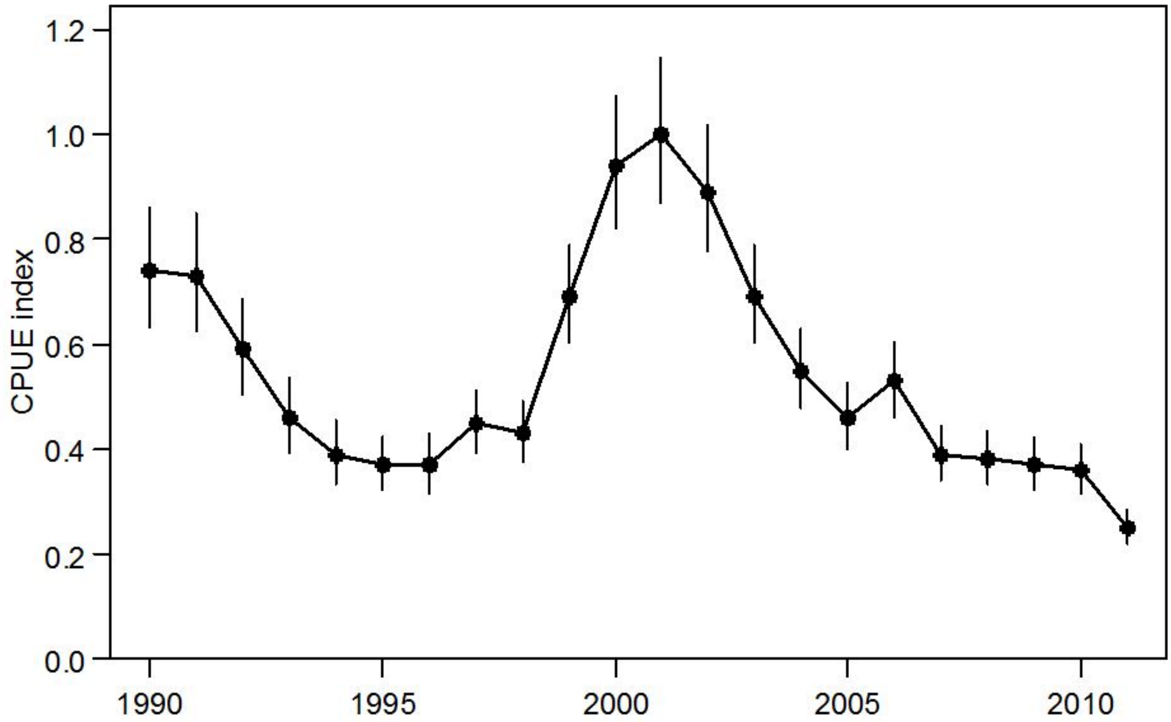


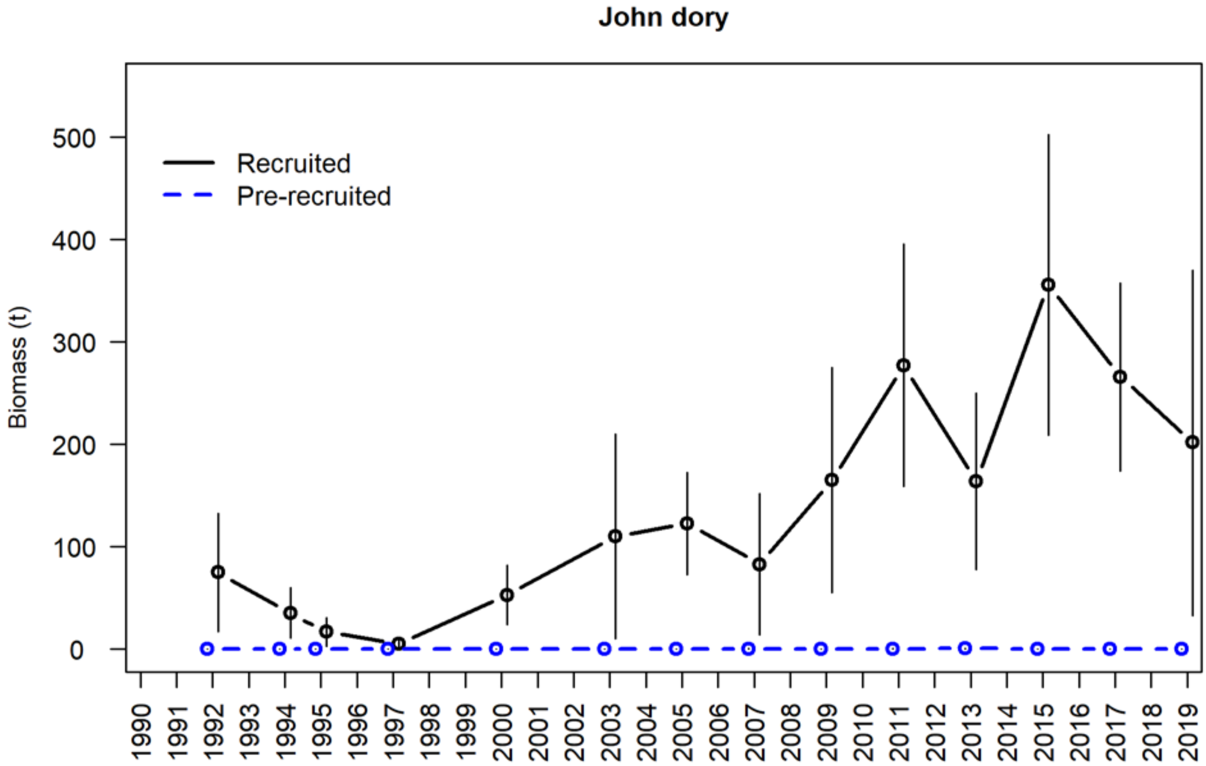
Figure 10: CPUE indices of abundance for the Southeast North Island (part of JDO 2), combined model of catch rates in mixed species bottom trawl tows (Dunn & Jones 2013). Vertical lines show the 95% credible intervals. Years labeled as year-ending (i.e., 1990 is 1989–90).

Northern South Island (JDO 7, and part of JDO 2)
In 2014, the CPUE indices for the Northern South Island zone (JDO 7, and part of JDO 2) were revised and updated to include data to 2012–13 (Langley 2014). The CPUE index was based on JDO bycatch from the following bottom trawl targets: BAR, FLA, GUR, JDO, JMA, RCO, and TAR, in Statistical Areas 033–039.

The Southern Inshore Working Group agreed that the west coast South Island (WCSI) trawl survey series appears to monitor trends in abundance of John dory, particularly recruited biomass (defined as fish of at least 25 cm TL) (Figure 11). Length frequency trends for the John dory survey catch from the west coast South Island and Tasman Bay/Golden Bay are presented in Figure 12. Smaller (20–35 cm) fish tend to be caught in the latter survey region. The 2017 1+ cohort (21–32 cm) is the strongest in the time series. Biomass levels were low before 2003, with recruited biomass increasing two to three fold since then.

Trawl surveys from 2011–2017 estimated the recruited biomass of John dory in the WCSI area to be at the highest level of the entire time series (Figure 11). However, the strong 1+ cohort visible in length frequencies from the 2017 survey doesn’t appear to have translated into 3+ fish in 2019. The 2019 biomass has decreased from 2017 and is more similar to the long term mean.

The standardised CPUE series shows a similar trend to the trawl survey biomass index, with a large increase in biomass between the late 1990s and early 2000s, which has persisted to 2013 (Figure 13).



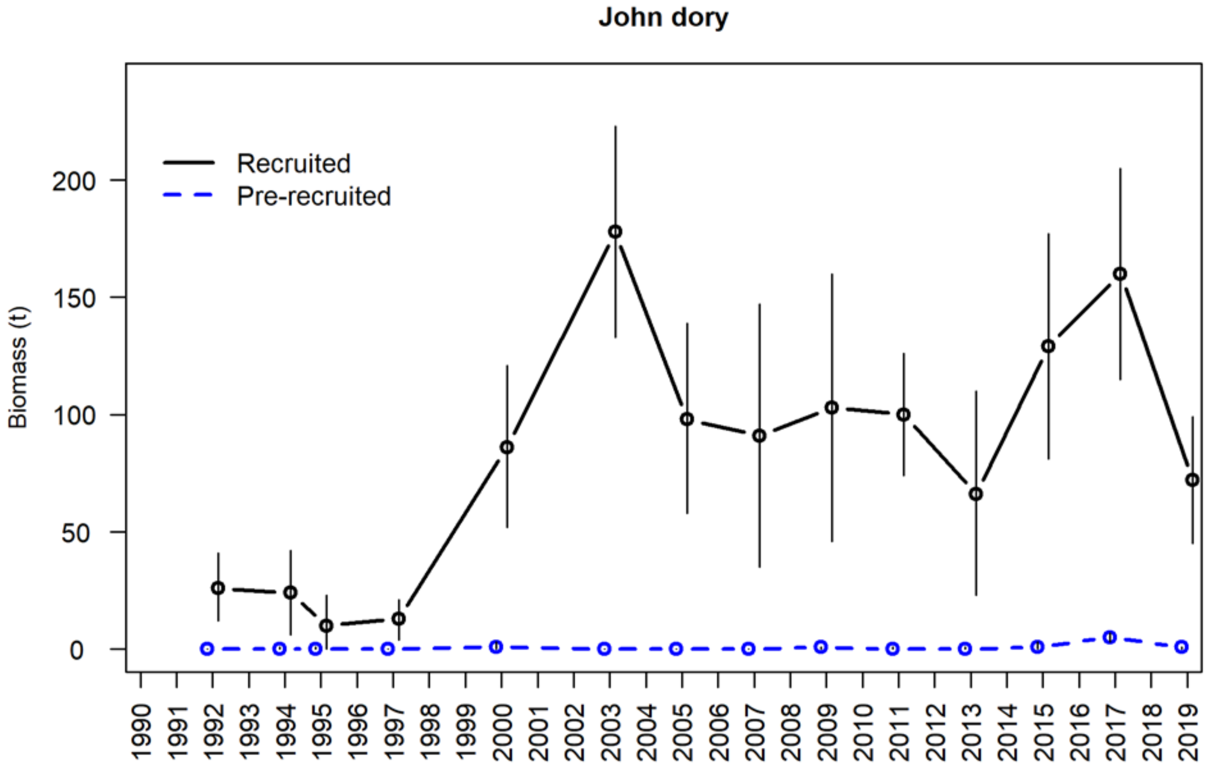


Figure 11: WCSI trawl survey biomass estimates of recruited and pre-recruit John dory for the west coast South Island strata (top plot) and Tasman Bay/Golden Bay (bottom plot). Error bars are ± two standard deviations. John dory are assumed to recruit to the commercial fishery at 25 cm TL.

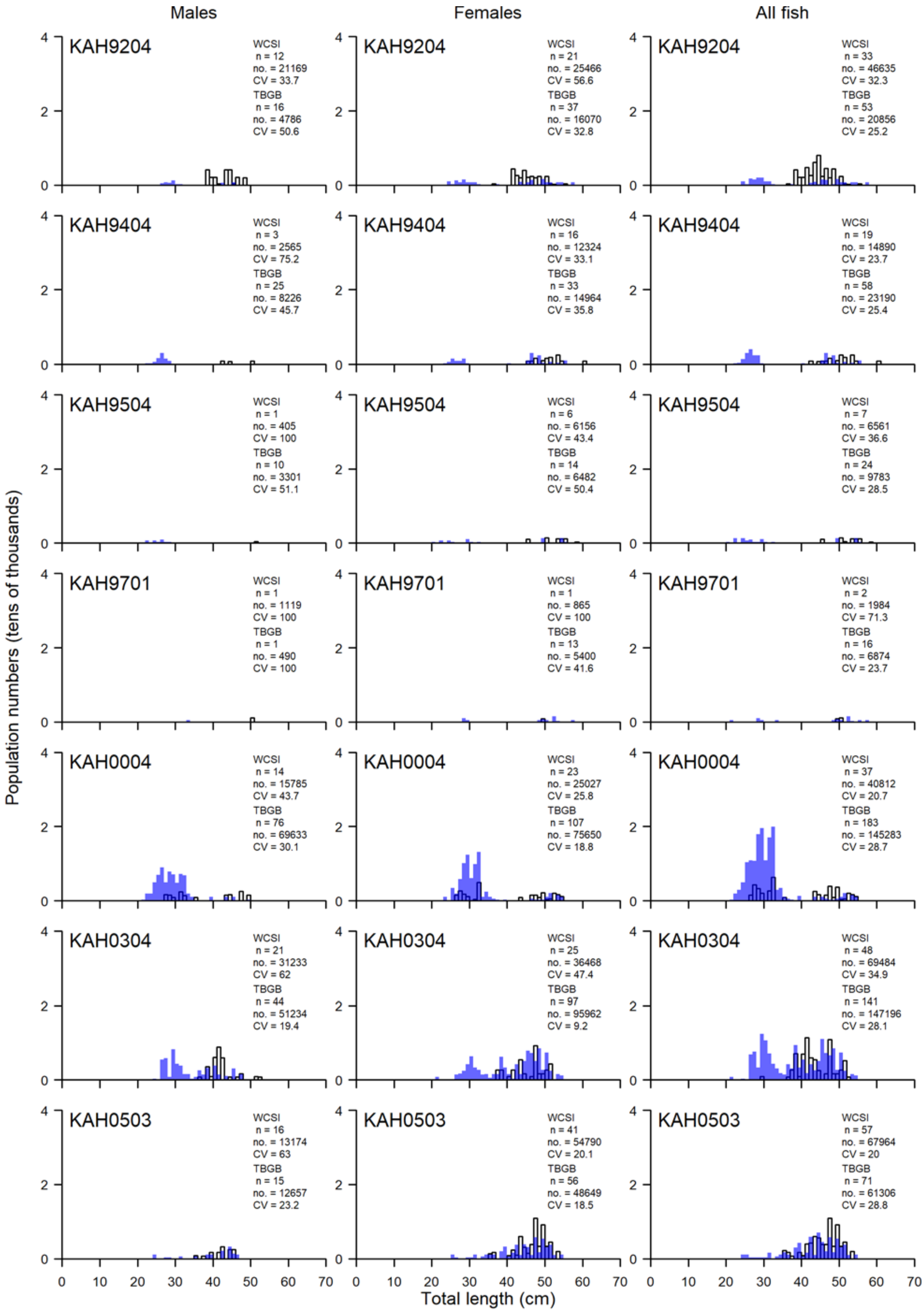


Figure 12: Scaled population length frequency distributions for John dory in 30–400 m for west coast (white bars) and Tasman Bay/Golden Bay (blue bars), from WCSI surveys. n = number of fish measured, no. = scaled population number, CV = coefficient of variation (%). [Continued on next page]

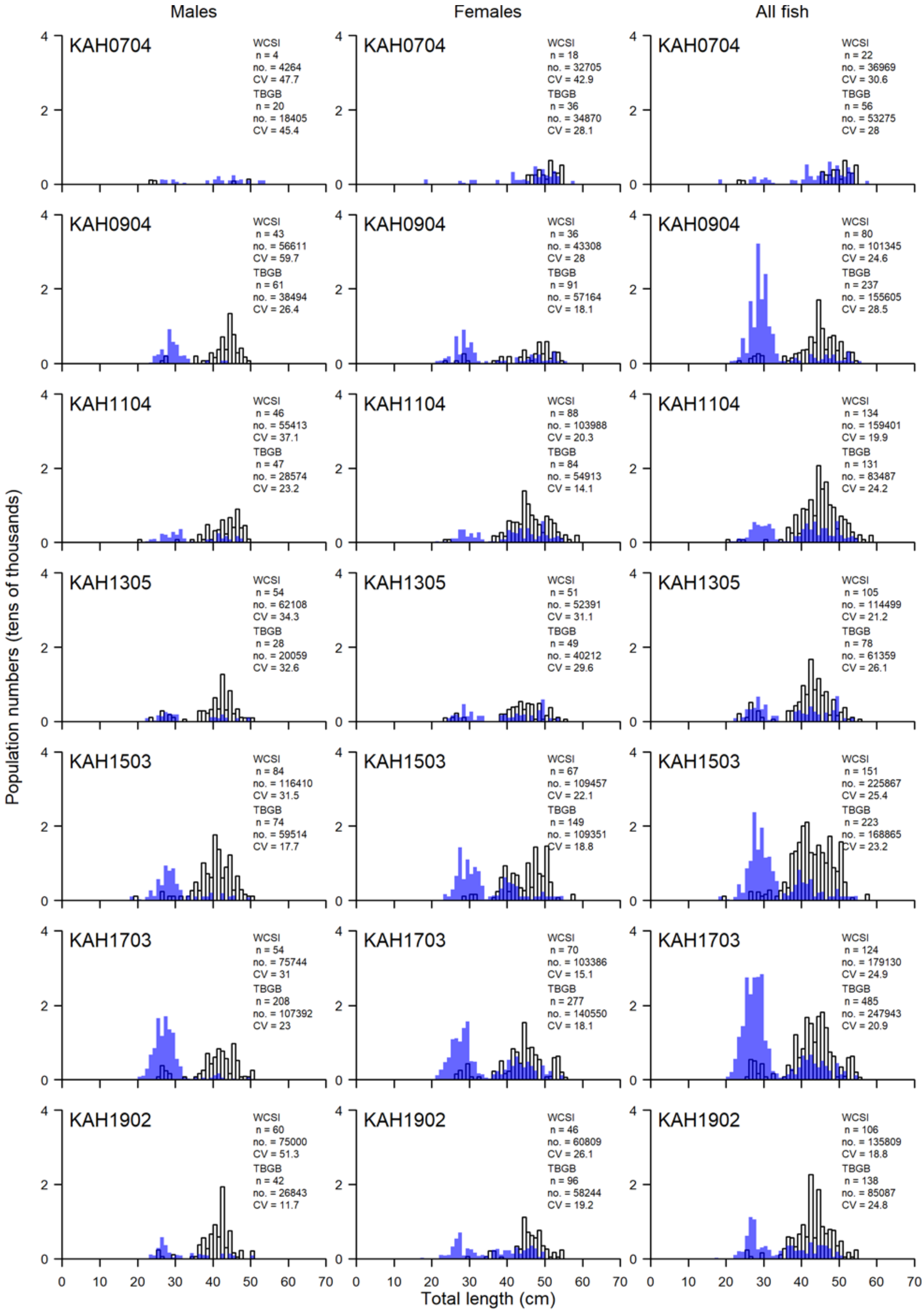


Figure 12 [Continued]

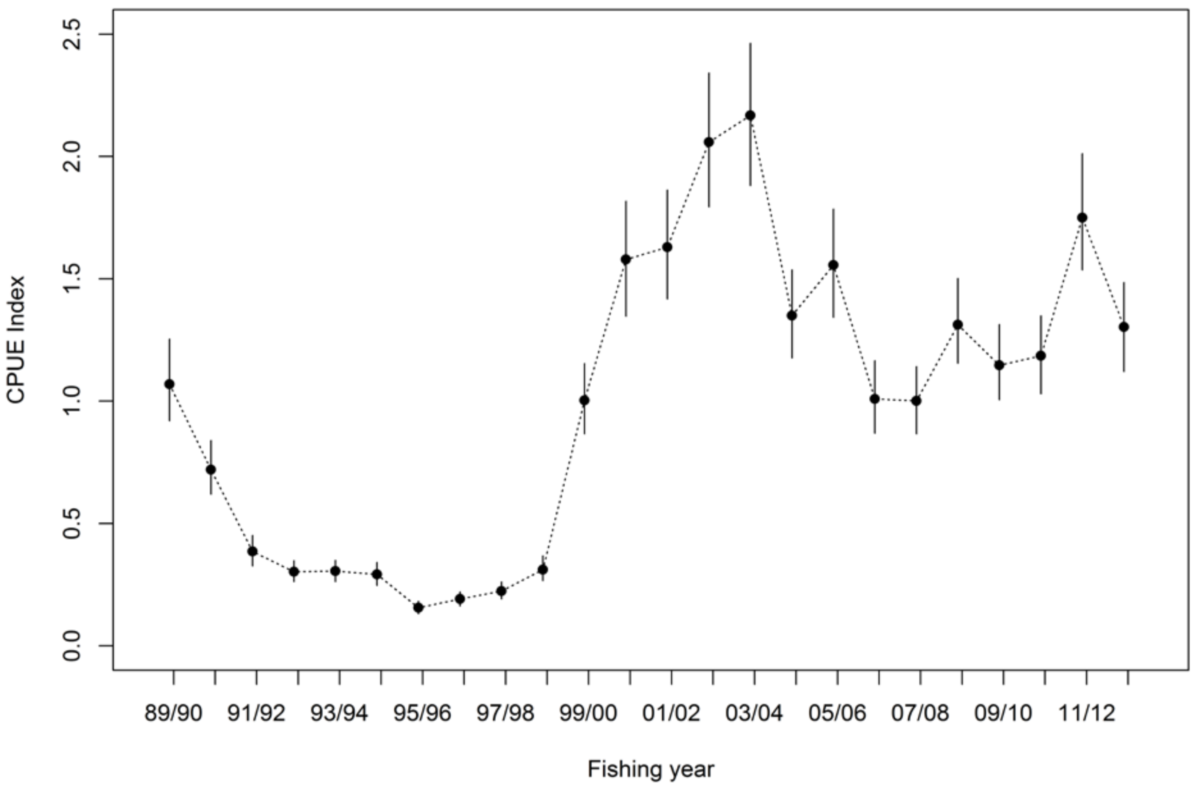


Figure 13: CPUE indices of abundance for the northern South Island (JDO 7 and part of JDO 2), combined model of catch rates in mixed species bottom trawl tows (Langley 2014). Vertical lines show the 95% credible intervals.

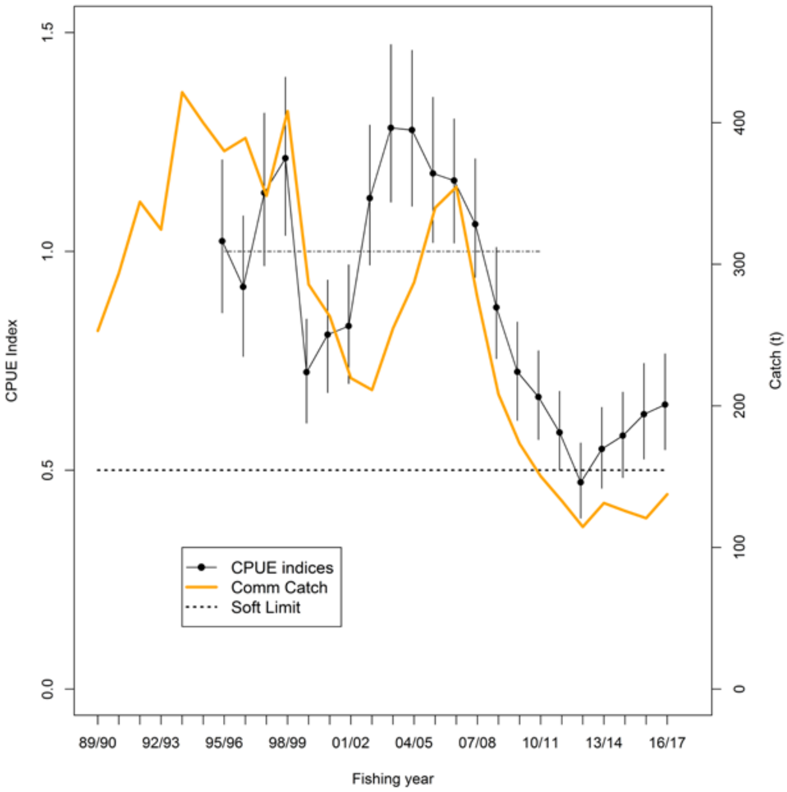
4.2 Biomass estimates
Estimates of absolute reference and current biomass are not available.

5. STATUS OF THE STOCKS

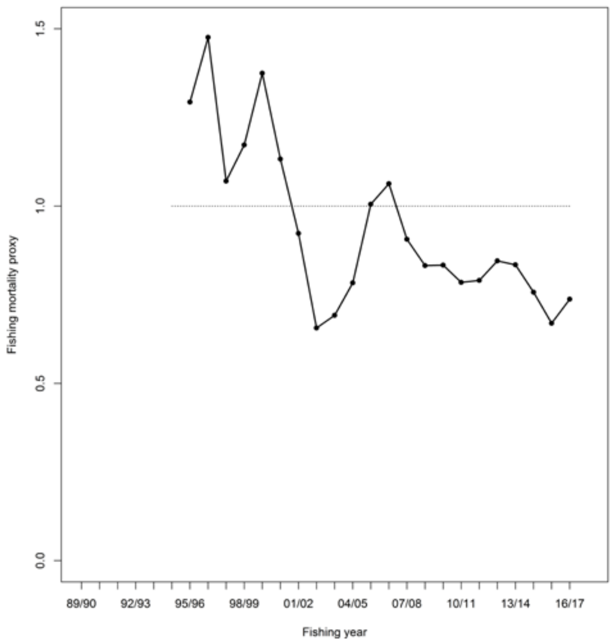
- **JDO 1 (Hauraki Gulf and east Northland)**

Stock Status	
Year of Most Recent Assessment	2018
Assessment Runs Presented	Standardised CPUE
Reference Points	Interim Target: Mean of the CPUE indices for John dory in Hauraki Gulf and east Northland from combined binomial and lognormal models from 1995–96 to 2010–11 Soft Limit: 50% of target Hard Limit: 25% of target Overfishing threshold: F_{MSY}
Status in relation to Target	Very Unlikely (< 10%) to be at or above the target
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	Unlikely (< 40%) that overfishing is occurring

Historical Stock Status Trajectory and Current Status



Standardised CPUE indices for John dory in Hauraki Gulf and east Northland from combined binomial and lognormal models of catch rate in bottom trawl tows in a mixed target fishery. Broken horizontal lines indicate the target and soft limit. The commercial catch from the area is also presented. Vertical lines show the 95% confidence intervals.

Fishery and Stock Trends	
Recent Trend in Biomass or Proxy	The CPUE indices steadily declined from the mid-2000s to approximate the soft limit in 2012–13. The CPUE indices have increased over the last four years and the 2016–17 index is 65% of the target CPUE level.
Recent Trend in Fishing Intensity or Proxy	 **Relative fishing mortality proxy derived from total area catch divided by CPUE indices from the recent CPUE analysis (black points). The horizontal line represents the average fishing mortality in the period used to define the reference points.**

	The fishing mortality proxy indicates that fishing mortality has been lower in the recent period as total catch from the fishery has declined more than the decline in CPUE and catches have remained low during the last four years, while CPUE increased. The absolute level of fishing mortality that corresponds to the target biomass level is unknown.
Other Abundance Indices	The trend in Danish seine CPUE indices from the Hauraki Gulf fishery is comparable to the BT CPUE index (to 2013–14).
Trends in Other Relevant Indicators or Variables	-

Projections and Prognosis	
Stock Projections or Prognosis	Annual catches and fishing mortality have been relatively low over the last five years. There has been a modest increase in the CPUE indices over the last 4 years indicating the stock is rebuilding slowly. It is likely that recruitment had been low during the preceding period. The continued rebuilding of the stock to the target biomass level will depend on future levels of recruitment.
Probability of Current Catch or TAC causing Biomass to remain below or to decline below Limits	Soft Limit: Unlikely (< 40%) at the current catch levels (which are the lowest of the time-series) Hard Limit: Very Unlikely (< 10%) over the next five years at current catch levels
Probability of Current Catch or TAC causing Overfishing to continue or to commence	Current catch is Unlikely (< 40%) to cause overfishing

Assessment Methodology and Evaluation		
Assessment Type	Level 2 - Partial Quantitative Stock Assessment	
Assessment Method	Standardised CPUE	
Assessment Dates	Latest assessment: 2018	Next assessment: 2021
Overall assessment quality rank	1 – High Quality	
Main data inputs (rank)	- Catch and effort data	1 – High Quality
Data not used (rank)	N/A	
Changes to Model Structure and Assumptions	-	
Major Sources of Uncertainty	- Lack of information on incoming recruitment	

Qualifying Comments
As CPUE is at a relatively low level the stock status should be routinely monitored. It is intended to update the CPUE analysis in 2021.

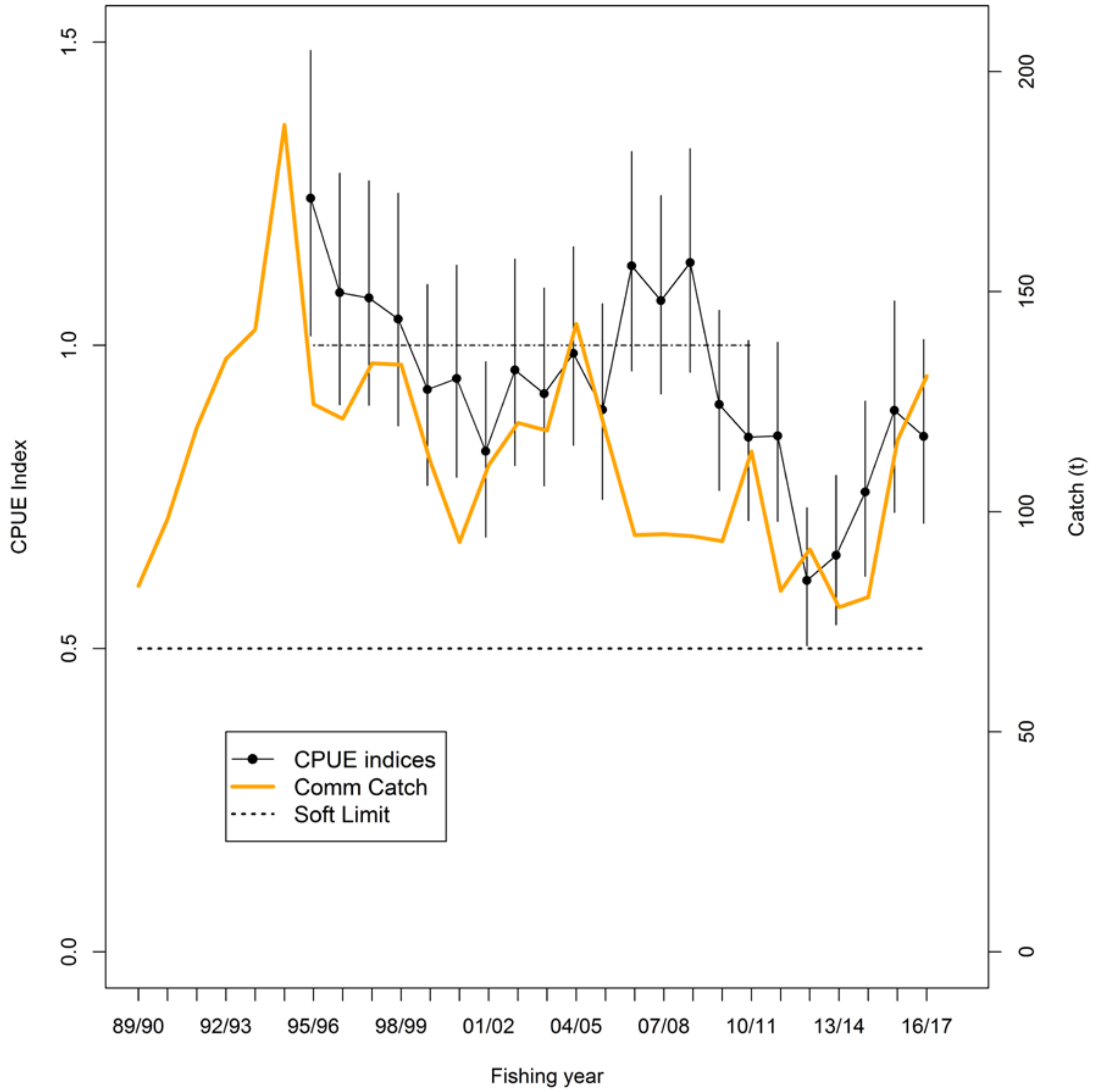
Fishery Interactions
John dory is taken on the east coast by bottom trawl and Danish seine targeted at John dory and snapper. Interactions with other species are currently being characterised.

- **JDO 1 (Bay of Plenty)**

Stock Status	
Year of Most Recent Assessment	2018
Assessment Runs Presented	Standardised CPUE
Reference Points	Interim Target: Mean of the CPUE indices for John dory in Bay of Plenty from combined binomial and lognormal models from 1994–95 to 2010–11 Soft Limit: 50% of target Hard Limit: 25% of target

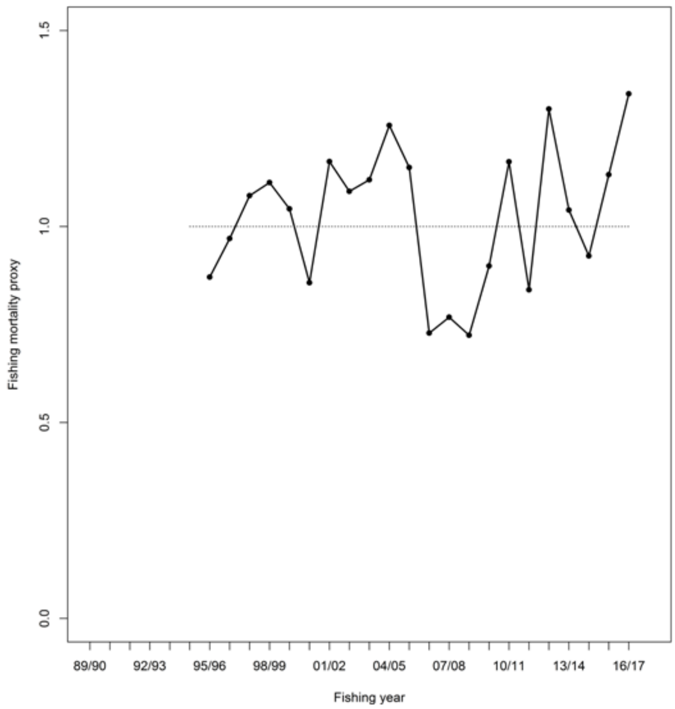
	Overfishing threshold F_{MSY}
Status in relation to Target	Unlikely (< 40%) to be at or above the target
Status in relation to Limits	Soft Limit: Very Unlikely (< 10%) to be below Hard Limit: Very Unlikely (< 10%) to be below
Status in relation to Overfishing	Likely (> 60%) that overfishing is occurring

Historical Stock Status Trajectory and Current Status



Standardised CPUE indices for John dory in Bay of Plenty from combined binomial and lognormal models of catch rate in bottom trawl tows in a mixed target fishery. Broken horizontal lines indicate the target and soft limit. The total catch from the area is also presented. Vertical lines show the 95% confidence intervals.

Fishery and Stock Trends	
Recent Trend in Biomass or Proxy	The CPUE indices fluctuated over the time-series and reached the lowest level in 2012–13. The CPUE indices increased in subsequent years and the 2016–17 index was at 85% of the target biomass level.

Recent Trend in Fishing Mortality or Proxy	 **Relative fishing mortality proxy derived from total area catch divided by CPUE indices from the recent CPUE analysis (black points). The horizontal line represents the average fishing mortality in the period used to define the reference points.** The fishing mortality proxy has increased since 2008–09 and in 2016–17 was 34% higher than the reference (F_{MSY} proxy) level.
Other Abundance Indices	The general trend in Danish seine CPUE indices from the Bay of Plenty fishery is comparable to the BT CPUE index (to 2013–14).
Trends in Other Relevant Indicators or Variables	-

Projections and Prognosis	
Stock Projections or Prognosis	Annual catches have increased considerably over the last three years following the increase in abundance (as indexed by CPUE). There has been an increasing trend in fishing mortality over the last 8 years and fishing mortality in 2016–17 was the highest in the series and considerably higher than the reference level. The current (higher) level of the fishing mortality may cause the stock to begin to decline.
Probability of Current Catch or TAC causing Biomass to remain below or to decline below Limits	Soft Limit: Unlikely (< 40%) at current catch levels Hard Limit: Very Unlikely (< 10%) at current catch levels
Probability of Current Catch or TACC causing Overfishing to continue or to commence	Likely (> 60%) at the current level of catch

Assessment Methodology and Evaluation		
Assessment Type	Level 2 - Partial Quantitative Stock Assessment	
Assessment Method	Fishery characterisation and standardised CPUE	
Assessment Dates	Latest assessment: 2018	Next assessment: 2021
Overall assessment quality rank	1 – High Quality	
Main data inputs (rank)	- 2018 CPUE analysis	1 – High Quality
Data not used (rank)	N/A	
Changes to Model Structure and Assumptions	-	
Major Sources of Uncertainty	-	

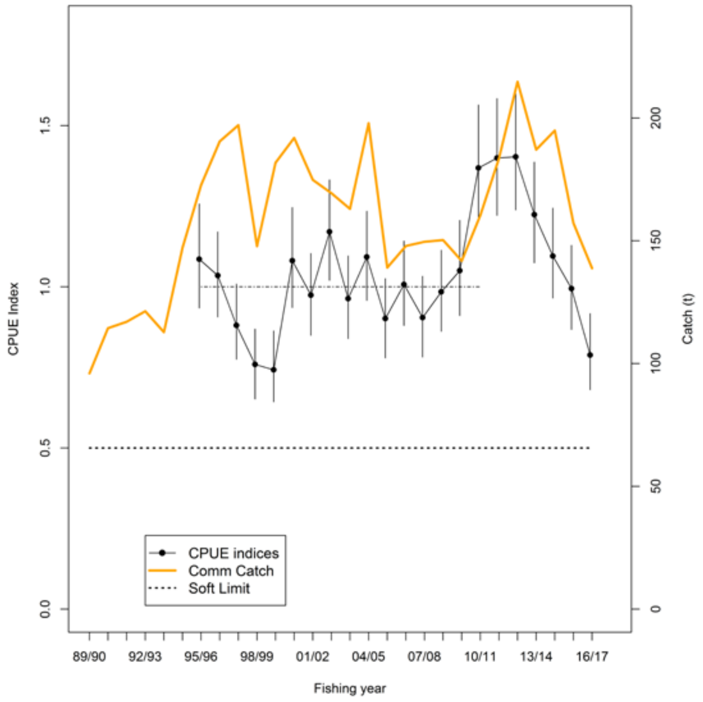
Qualifying Comments
Stock biomass is variable, probably in response to recruitment variation, and the stock abundance had increased in recent years This makes it difficult to predict future trends without recruitment information. Total fishing effort by the Danish seine fleet increased in 2015–16 to 2016–17, while effective effort in the trawl fishery also increased in the same period.

Fishery Interactions
John dory is taken in the Bay of Plenty by bottom trawl targeted at John dory, snapper, trevally, tarakihi and gurnard; and by Danish seine targeted at snapper and gurnard. Interactions with other species are currently being characterised.

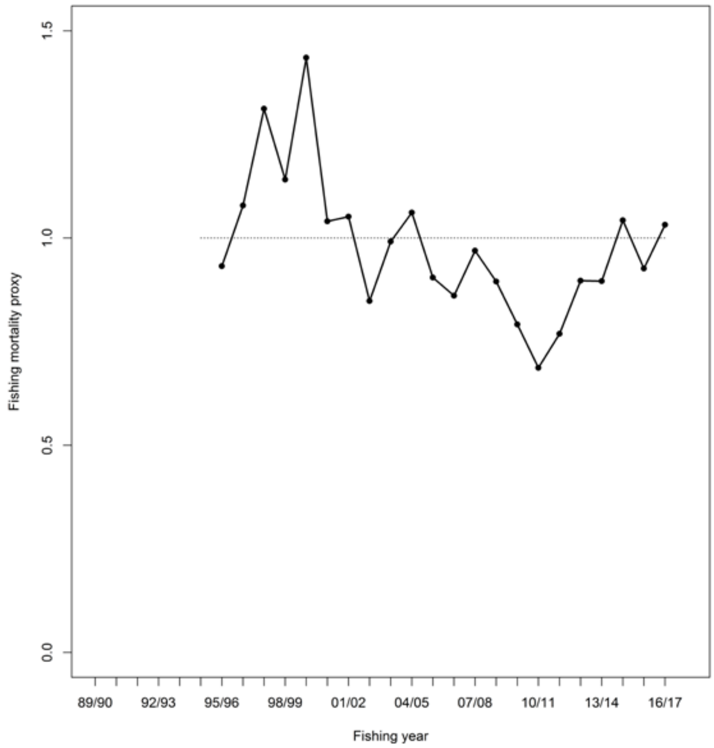
- **JDO 1 (West Coast North Island)**

Stock Status	
Year of Most Recent Assessment	2018
Assessment Runs Presented	Standardised CPUE
Reference Points	Interim Target: Mean of the CPUE indices for John dory on West Coast North Island from combined binomial and lognormal models from 1994–95 to 2010–11 Soft Limit: 50% of target Hard Limit: 25% of target Overfishing threshold: F_{MSY}
Status in relation to Target	Unlikely (< 40%) to be at or above the target
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	About as Likely as Not (40–60%) to be occurring

Historical Stock Status Trajectory and Current Status



Standardised CPUE indices for John dory in West Coast North Island from combined binomial and lognormal models of catch rate in bottom trawl tows in a mixed target fishery. Broken horizontal lines indicate the target and soft limit. Vertical lines show the 95% confidence intervals. Commercial catch represents the catch from this area.

<table>
<tr><td colspan="2">Fishery and Stock Trends</td></tr>
<tr><td>Recent Trend in Biomass or Proxy</td><td>CPUE indices have fluctuated over the time series. CPUE indices were at the highest level in 2010–11 to 2012–13 and declined over the next four years. The 2016–17 CPUE index is at 79% of the target biomass level.</td></tr>
<tr><td>Recent Trend in Fishing Intensity or Proxy</td><td>Relative fishing mortality proxy derived from total area catch divided by CPUE indices from the recent CPUE analysis (black points). The horizontal line represents the average fishing mortality in the period used to define the reference points.

Fishing mortality was at a relatively low level in 2010–11 to 2012–13 (corresponding to the high CPUE indices). Fishing mortality has been maintained at about the reference level during 2014–15 to 2016–17.</td></tr>
<tr><td>Other Abundance Indices</td><td>-</td></tr>
<tr><td>Trends in Other Relevant Indicators or Variables</td><td>-</td></tr>
</table>

Projections and Prognosis	
Stock Projections or Prognosis	Likely to fluctuate above the soft limit.
Probability of Current Catch or TACC causing Biomass to remain below or to decline below Limits	Soft Limit: Unlikely (< 40%) at current catch levels Hard Limit: Very Unlikely (< 10%) at current catch levels
Probability of Current Catch or TACC causing Overfishing to continue or to commence	About as Likely as Not (40 – 60%%) at current catch levels

Assessment Methodology and Evaluation		
Assessment Type	Level 2 - Partial Quantitative Stock Assessment	
Assessment Method	Fishery characterisation and standardised CPUE	
Assessment Dates	Latest assessment: 2018	Next assessment: 2021
Overall assessment quality rank	1 – High Quality	
Main data inputs (rank)	2018 CPUE analysis	1 – High Quality
Data not used (rank)	N/A	

Changes to Model Structure and Assumptions	-
Major Sources of Uncertainty	- The stock relationship between JDO 1 and JDO 2

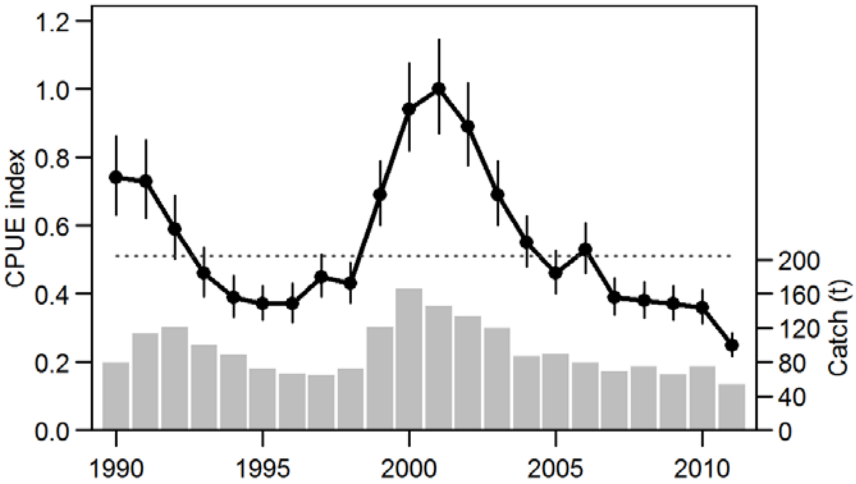
Qualifying Comments
-

Fishery Interactions
John dory is taken on the west coast by bottom trawl targeted at snapper trevally, gurnard and tarakihi. Interactions with other species are currently being characterised.

- **JDO 2 (Southeast North Island)**

Stock Status	
Year of Most Recent Assessment	2013
Assessment Runs Presented	Standardised CPUE
Reference Points	Interim Target: Mean of the CPUE indices for John dory in South East coast of the North Island from combined binomial and lognormal models from 1989–90 to 2010–11 Soft Limit: 50% of target Hard Limit: 25%of target Overfishing threshold F_{MSY}
Status in relation to Target	Unlikely (< 40%) to be at or above the target
Status in relation to Limits	Soft Limit: About as Likely as Not (40–60%) to be below Hard Limit: Unlikely (< 10%) to be below
Status in relation to Overfishing	Unknown

Historical Stock Status Trajectory and Current Status



Standardised CPUE indices for John dory in Southeast North Island from combined binomial and lognormal models of catch rate in bottom trawl trips in a mixed target fishery (Dunn & Jones 2013). Broken horizontal line indicates the mean from 1989–90 to 2010–11; Bars represent catch from this area.

Fishery and Stock Trends	
Recent Trend in Biomass or Proxy	The CPUE series has fluctuated with a cyclical trend. The data points since 2006–07 have been below the long-term mean. 2010–11 is the lowest in the series.
Recent Trend in Fishing Intensity or Proxy	Unknown
Other Abundance Indices	-

Trends in Other Relevant Indicators or Variables	-

Projections and Prognosis	
Stock Projections or Prognosis	Without information on recruitment, it is not possible to predict how the stock will respond in the next few years.
Probability of Current Catch or TACC causing Biomass to remain below or to decline below Limits	Soft Limit: Likely (> 60%) Hard Limit: About as Likely as Not (40–60%)
Probability of Current Catch or TACC causing Overfishing to continue or to commence	Unknown

Assessment Methodology and Evaluation		
Assessment Type	Level 2 - Partial Quantitative Stock Assessment	
Assessment Method	Fishery characterisation and standardised CPUE	
Assessment Dates	Latest assessment: 2013	Next assessment: Unknown
Overall assessment quality rank	1 – High Quality	
Main data inputs (rank)	- Catch and effort data	1 – High Quality
Data not used (rank)	N/A	
Changes to Model Structure and Assumptions	-	
Major Sources of Uncertainty	- The stock relationship between JDO 1 and JDO 2 - Lack of information on incoming recruitment	

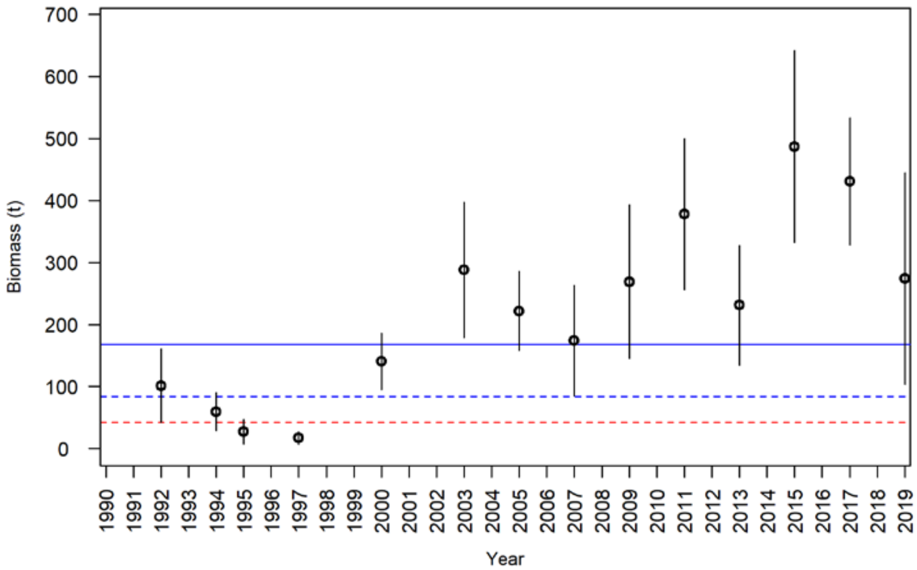
Qualifying Comments
As the John dory fishery in FMAs 1 and 9 has a long history, it is not possible to infer stock status from abundance trends from only the last 22 years. This sub-stock appears to be cyclical, probably in response to recruitment variation. This makes it difficult to predict future trends without recruitment information.

Fishery Interactions
John dory is taken on the east coast by bottom trawl targeted primarily at tarakihi and red gurnard. Interactions with other species are currently being characterised.

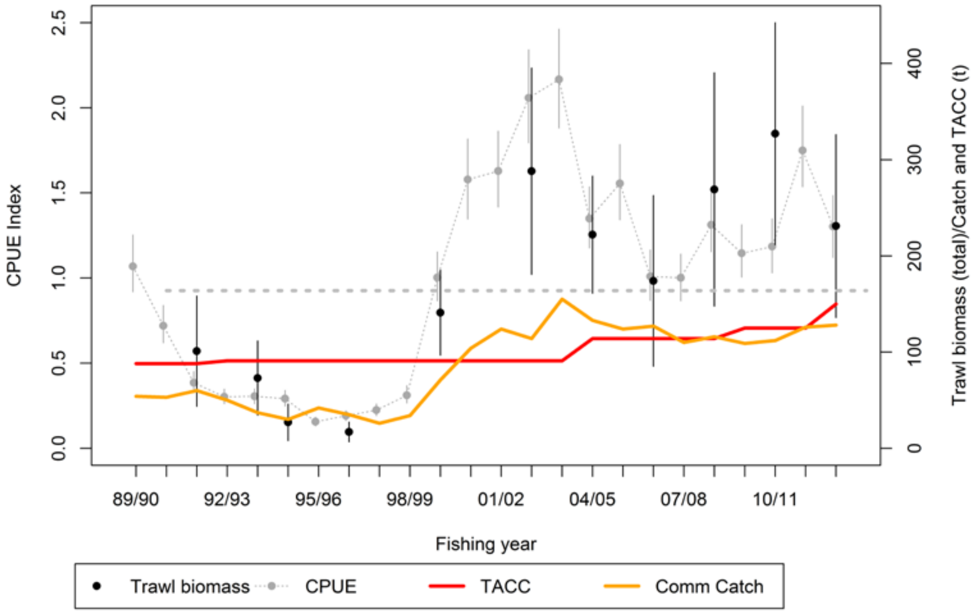
- **JDO 7 (Northern South Island)**

Stock Status	
Year of Most Recent Assessment	2018
Assessment Runs Presented	Trawl survey biomass index (2017) and standardised CPUE (2014)
Reference Points	Interim Target: Mean total biomass from the West Coast South Island trawl survey (WCSI and TBGB) from 1992 to 2011 Soft Limit: 50% of target Hard Limit: 25% of target Overfishing threshold F_{MSY}
Status in relation to Target	Very Likely (> 90%) 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	Overfishing is Very Unlikely (< 10%) to be occurring

Historical Stock Status Trajectory and Current Status



Biomass trends from the west coast South Island inshore trawl survey time series. Error bars are ± two standard deviations. The solid blue line represents the interim target and dashed blue and red lines the soft and hard limits, respectively.



A comparison of trends in trawl survey biomass estimates (total biomass, WCSI), CPUE indices and the commercial catch relative to the TACC. The dashed line represents the interim target biomass level relative to the trawl survey biomass indices.

Fishery and Stock Trends	
Recent Trend in Biomass or Proxy	The trawl survey series declined through the 1990s then increased between 1997–98 and 2003–04. The 2019 estimate is down from the 2017 estimate and is more similar to the trend since 2003. The series has been above the long term mean since 2000–01. Trends in CPUE are comparable to trawl survey biomass trends.
Recent Trend in Fishing Intensity or Proxy	The commercial catch trends generally followed those of the trawl survey biomass estimates up to 2006–07. Since then, the annual catch has been maintained at about the annual TACC level, while trawl survey biomass has increased.

Other Abundance Indices	-
Trends in Other Relevant Indicators or Variables	Length frequency analysis from the West Coast South Island trawl survey showed very good recruitment in 2000, 2003 and 2009 and these are probably supporting the high biomass at this time. Recruitment from the 2011 and 2013 surveys was more modest but was again high in 2015 and 2017. Recruitment appears to be modest again in 2019.

Projections and Prognosis	
Stock Projections or Prognosis	The stock is currently at a relatively high level, above the interim target biomass level, and previous high catches appear to have been sustained by intermittent high recruitment. The strong 1+ year class seen in 2017 is likely to sustain biomass levels, at least in the short term.
Probability of Current Catch or TACC causing Biomass to remain below or to decline below Limits	Soft Limit: Unlikely (< 40%) Hard Limit: Very Unlikely (< 10%)
Probability of Current Catch or TACC causing Overfishing to continue or to commence	Very Unlikely (< 10%), for TACC and current catch. Non target species so that even if abundance declines considerably the exploitation rates are unlikely to substantially increase.

Assessment Methodology and Evaluation		
Assessment Type	Level 2 - Partial Quantitative Stock Assessment	
Assessment Method	Evaluation of survey biomass and length frequencies. Standardised CPUE	
Assessment Dates	Latest assessment: 2018 (Survey) 2014 (CPUE)	Next assessment: 2021 (survey)
Overall assessment quality rank	1 – High Quality	
Main data inputs (rank)	- West Coast South Island trawl survey - Survey length frequency - CPUE	1 – High Quality 1 – High Quality 1 – High Quality
Data not used (rank)	N/A	
Changes to Model Structure and Assumptions	- More complete data set obtained for CPUE analysis	
Major Sources of Uncertainty	- The stock relationship between JDO 7 and JDO 2	

Qualifying Comments
-

Fishery Interactions
John dory are primarily taken in conjunction with the following QMS species: barracouta, red cod, stargazer, red gurnard and tarakihi in the Northern South Island bottom trawl fishery. Interactions with other species are currently being characterised.

6. FOR FURTHER INFORMATION

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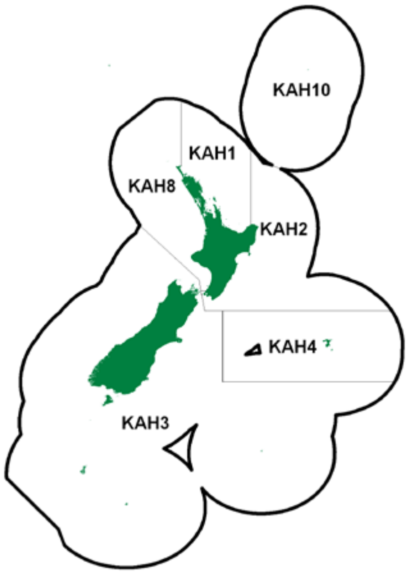
KAHAWAI (KAH)

(Arripis trutta and Arripis xylabion)
Kahawai



1. FISHERY SUMMARY

Kahawai (*Arripis trutta*) and Kermadec kahawai (*Arripis xylabion*) were introduced into the QMS on 1 October 2004 under a single species code, KAH. Within the QMS, kahawai management is based on six QMAs (KAH 1, KAH 2, KAH 3, KAH 4, KAH 8, and KAH 10).

These QMAs differ from the management areas used before kahawai were introduced into the QMS. The definitions of KAH 1, KAH 2, and KAH 10 remain unchanged, but KAH 4 was formerly part of KAH 3, as was the part of KAH 8 south of Tirua Point. The area of KAH 8 north of Tirua point was formerly called KAH 9.

TACs totalling 7612 t were set on introduction into the QMS. These TACs were based on a 15% reduction from both the level of commercial catch and assumed recreational use prior to introducing kahawai into the QMS. The Minister reviewed the TACs for kahawai for the 2005–06 fishing year. Subsequently, he decided to reduce TACs, TACCs, and allowances by a further 10% as shown in Table 1.

Table 1: KAH allowances, TACCs, and TACs, from 1 October 2010 to present.

Fishstock	Recreational Allowance	Customary Non-Commercial Allowance	Other mortality	TACC	TAC
KAH 1	900	200	45	1 075	2 200
KAH 2	610	185	30	705	1 530
KAH 3	390	115	20	410	935
KAH 4	4	1	0	9	14
KAH 8	385	115	20	520	1 040
KAH 10	4	1	0	9	14

1.1 Commercial fisheries

Commercial fishers take kahawai by a variety of methods. Purse seine vessels take most of the catch; however, substantial quantities are also taken seasonally in set net fisheries and as a bycatch in surface longline and trawl fisheries.

The kahawai purse seine fishery cannot be understood without taking into account the other species that the vessels target. The fleet, which is based in Tauranga, preferentially targets skipjack tuna (*Katsuwonus pelamis*) between December and May, with very little bycatch. When skipjack are not available, usually from June to November, the fleet fishes for a mix of species including kahawai, jack mackerels (*Trachurus* spp.), trevally (*Pseudocaranx dentex*), and blue mackerel (*Scomber australasicus*). These are caught ‘on demand’ as export orders are received (to reduce product storage costs). However, since the mackerels and kahawai school together there is often a bycatch of kahawai resulting from targeting of mackerels. Historical estimated kahawai landings are shown in Table 2, from 1931 to 1982. Reported landings, predominantly of *A. trutta*, are shown for 1962 up to and including 1982 in Table 3 by calendar year for all areas combined, and from 1983–84 onwards by fishing year and by historic management areas in Table 4 and by QMAs in Table 5. The historical landings and TACC for the main KAH stocks are depicted in Figure 1.

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

Year	KAH 1	KAH 2	KAH 3	KAH 4	Year	KAH 1	KAH 2	KAH 3	KAH 4
1931–32	1	0	0	0	1957	25	6	0	0
1932–33	1	0	0	0	1958	33	13	0	0
1933–34	0	0	1	0	1959	31	2	0	0
1934–35	0	0	0	0	1960	40	1	0	0
1935–36	0	0	0	0	1961	40	0	0	0
1936–37	0	0	0	0	1962	54	7	0	0
1937–38	2	1	1	0	1963	60	11	0	0
1938–39	2	2	1	0	1964	75	4	1	0
1939–40	1	1	1	0	1965	85	13	0	0
1940–41	1	4	2	0	1966	143	106	0	0
1941–42	2	1	1	0	1967	147	303	0	0
1942–43	21	1	2	0	1968	107	159	29	0
1943–44	58	3	4	0	1969	163	29	12	0
1944	90	7	4	0	1970	141	59	22	0
1945	102	2	3	0	1971	185	258	10	0
1946	94	0	4	0	1972	168	151	22	0
1947	54	0	4	0	1973	295	132	13	0
1948	58	2	1	0	1974	357	206	17	0
1949	23	3	0	0	1975	140	28	18	0
1950	34	2	1	0	1976	401	108	30	0
1951	22	1	0	0	1977	631	385	218	0
1952	27	2	0	0	1978	1237	487	279	0
1953	14	1	0	0	1979	1642	552	608	0
1954	18	2	0	0	1980	1213	885	810	0
1955	19	6	0	0	1981	659	625	1301	0
1956	16	3	0	0	1982	1133	639	980	0

Year	KAH 8	Year	KAH 8
1931–32	0	1957	13
1932–33	0	1958	12
1933–34	0	1959	14
1934–35	3	1960	10
1935–36	0	1961	12
1936–37	0	1962	16
1937–38	0	1963	11
1938–39	0	1964	7
1939–40	0	1965	4
1940–41	1	1966	5
1941–42	0	1967	5
1942–43	0	1968	7
1943–44	3	1969	33
1944	6	1970	74
1945	1	1971	119
1946	9	1972	53
1947	1	1973	147
1948	1	1974	226
1949	1	1975	154
1950	1	1976	186
1951	2	1977	224
1952	3	1978	217
1953	4	1979	267
1954	2	1980	350
1955	7	1981	498
1956	7	1982	484

Notes:
The 1931–1943 years are April–March but from 1944 onwards are calendar years.
Data up to 1985 are from fishing returns: data from 1986 to 1990 are from Quota Management Reports.Data for the period 1931 to 1982 are based on reported landings by harbour and are likely to be underestimated as a result of under-reporting.

Table 3: Reported total landings (t) of kahawai from 1970 to 1982. Note that these data include estimates of kahawai from data where kahawai were reported within a general category of 'mixed fish' rather than separately as kahawai.

Year	Landings	Year	Landings	Year	Landings
1962	76	1969	234	1976	729
1963	81	1970	294	1977	1 461
1964	86	1971	572	1978	2 228
1965	102	1972	394	1979	3 782
1966	254	1973	586	1980	5 101
1967	457	1974	812	1981	3 794
1968	305	1975	345	1982	5 398

Source: 1962 to 1969, Watkinson & Smith (1972); 1970 to 1982, Sylvester (1989).

Before 1988 there were no restrictions in place for the purse seine fishery.

Table 4: Reported landings (t) of kahawai by management areas as defined prior to 2004, from 1983–84 to 2003–04. Estimates of fish landed as bait or as 'mixed fish' are not included. Data for the distribution of catches among management areas and total catch are from the FSU database up to 1987–88 and from the CELR database after that date. Total LFRR or MHR values are the landings reported by Licensed Fish Receivers (to 2000–01) or on Monthly Harvest returns (to 2003–04).

Fishstock	KAH 1	KAH 2	KAH 3	KAH 9	KAH 10	Unknown Area	Total Catch	Total LFRR/MHR
FMA(s)	1	2	3–8	9	10			
1983–84	1 941	919	813	547	0	46	4 266	–
1984–85	1 517	697	1 669	299	0	441	4 623	–
1985–86	1 597	280	1 589	329	0	621	4 416	–
1986–87	1 890	212	3 969	253	0	1 301	7 525	6 481
1987–88	4 292	1 655	2 947	135	0	581	9 610	9 218
1988–89	2 170	779	4 301	179	0	–	7431	7 377
1989–90	2 049	534	5 711	156	0	16	8 466	8 696
1990–91	1 617	872	2 950	242	0	4	5 687	5 780
1991–92	2 190	807	1 900	199	< 1	7	5 104	5 071
1992–93	2 738	1 132	1 930	832	2	0	6 639	6 966
1993–94	2 054	1 136	1 861	98	15	0	5 164	4 964
1994–95	1 918	1 079	1 290	168	0	24	4479	4 532
1995–96	1 904	760	1 548	237	7	46	4 502	4 648
1996–97	2 214	808	938	194	1	3	4 158	3 763
1997–98	1 601	291	525	264	0	19	2 700	2 823
1998–99	1 833	922	1 209	468	0	3	4 435	4 298
1999–00	1 616	1 138	718	440	0	< 1	3 912	3 941
2000–01	1 746	886	925	272	0	1	3 829	3 668
2001–02	1 354	816	377	271	0	< 1	2 819	2 796
2002–03	933	915	933	221	0	< 1	3 001	2 964
2003–04	1 624	807	109	205	0	0	2 745	2 754

A total commercial catch limit for kahawai was set at 6500 t for the 1990–91 fishing year, with 4856 t set aside for those harvesting kahawai by purse seine (Table 6). Before the 2002–03 fishing year a high proportion of the purse seine catch was targeted, but in recent years approximately half of the landed catch has been reported as bycatch while targeting other species with purse seine gear.

In KAH 1, a voluntary moratorium was placed on targeting kahawai by purse seine in the Bay of Plenty from 1 December 1990 to 31 March 1991; this was extended from 1 December to the Tuesday after Easter in subsequent years. Although total landings decreased in 1991–92, landings in KAH 1 increased, and in 1993–94 the competitive catch limit for purse seining in KAH 1 was reduced from 1666 t to 1200 t. Purse seine catches reported for KAH 9 were also included in this reduced catch limit, although seining for kahawai off the west coast of the North Island ceased after the reduction in the KAH 1 purse seine limit. Purse seine catch limits were reached in KAH 1 between 1998–99 and 2000–01 and in 2003–04.

Prior to the introduction to the QMS, no change was made to the purse seine limit of 851 t for KAH 2. The KAH 2 purse seine fishery was closed early due to the catch limit being reached before the end of the season in each year between 1991–92 and 1995–96 and in 2000–01 and 2001–02.

Table 5: Prorated landings (t) of kahawai by the Fishstocks (and FMA) defined in 2004 for the fishing years from 1998–99 to the present. Distribution of data were derived by linking through the trip code, catch landing data (CLD), statistical areas, and landing points and prorating to CLD totals. Landings since 2004–05 are from QMS MHR data. The TACC is provided for those years since the introduction to the QMS.

	KAH 1		KAH 2		KAH 3		KAH 4		KAH 8		KAH 10			
Fishing		1		2		3, 5, 7		4		8, 9		10		Total
year	Catch	TACC	Catch	TACC	Catch	TACC	Catch	TACC	Catch	TACC	Catch	TACC	Catch	TACC
1998–99	1 652	–	975	–	697	–	0	–	1 120	–	0	–	4 444	–
1999–00	1 677	–	973	–	499	–	0	–	768	–	0	–	3 917	–
2000–01	1 678	–	922	–	425	–	0	–	581	–	0	–	3 606	–
2001–02	1 326	–	857	–	156	–	0	–	489	–	0	–	2 831	–
2002–03	869	–	855	–	650	–	0	–	542	–	0	–	2 916	–
2003–04	1 641	–	806	–	33	–	0	–	342	–	0	–	2 822	–
2004–05	1 147	1 195	708	785	129	455	< 1	10	544	580	0	10	2 529	3 025
2005–06	903	1 075	530	705	233	410	0	9	346	520	0	9	2 013	2 728
2006–07	1 046	1 075	672	705	382	410	< 1	9	407	520	0	9	2 507	2 728
2007–08	1 002	1 075	564	705	152	410	0	9	570	520	0	9	2 288	2 728
2008–09	945	1 075	823	705	157	410	0	9	381	520	0	9	2 306	2 728
2009–10	988	1 075	518	705	38	410	< 1	9	451	520	0	9	1 995	2 728
2010–11	1 002	1 075	719	705	46	410	0	9	454	520	0	9	2 221	2 728
2011–12	1 004	1 075	498	705	310	410	0	9	514	520	0	9	2 326	2 728
2012–13	1 095	1 075	502	705	195	410	0	9	468	520	0	9	2 260	2 728
2013–14	1 062	1 075	196	705	372	410	<1	9	472	520	0	9	2 102	2 728
2014–15	992	1 075	523	705	59	410	0	9	607	520	0	9	2 181	2 728
2015–16	1 086	1 075	611	705	44	410	<1	9	481	520	0	9	2 222	2 728
2016–17	1 021	1 075	399	705	58	410	0	9	316	520	0	9	1 794	2 728
2017–18	983	1 075	752	705	59	410	0	9	346	520	0	9	2 139	2 728
2018–19	1 046	1 075	635	705	41	410	0	9	321	520	0	9	2 042	2 728

Within KAH 3, the kahawai purse seine fleet has voluntarily agreed, since 1991–92, not to fish in a number of near-shore areas around Tasman Bay and Golden Bay, the Marlborough Sounds, Cloudy Bay, and Kaikoura. The main purpose of this agreement is to minimise local depletion of schools of kahawai found in areas where recreational fisheries occur, and to minimise catches of juveniles. The purse seine catch limit for KAH 3 was reduced from 2339 to 1500 tonnes from 1995–96. Purse seine catch limits have never been reached in KAH 3.

Table 6: Reported catches (t) by purse seine method and competitive purse seine catch limit (t) from 1990–91 to 2003–04. All data are from weekly reports furnished by permit holders to the Ministry of Fisheries except those for 1993–94 which are from the CELR database. Fishstocks are as defined prior to 2004.

	KAH 1		KAH 2		KAH 3		KAH 9		KAH 10		Total	
Year	Catch	Catch limit	Catch	Catch limit	Catch	Catch limit	Catch	Catch limit	Catch	Catch limit	Catch	Catch limit
1990–91	1 422	1 666	493	851	n/a#	2 839*	0	none	0	none	n/a	5 356
1991–92	1 613	1 666	735*	851	1 714	2 339	0	none	0	none	4 080	4 856
1992–93	1 547	1 666	795*	851	1 808	2 339	140	none	0	none	4 290	4 856
1993–94	1 262	1 200	1 101*	851	1 714	2 339	15	§	0	none	4 092	4 390
1994–95	1 225	1 200	821*	851	1 644	2 339	0	§	0	none	3 690	4 390
1995–96	1 077	1 200	805*	851	1 146	1 500	0	§	0	none	3 028	3 551
1996–97	1 017	1 200	620	851	578	1 500	0	§	0	none	2 784	3 551
1997–98	969	1 200	175	851	153	1 500	0	§	0	none	1 297	3 551
1998–99	1 416*	1 200	134	851	463	1 500	2	§	0	none	2 015	3 551
1999–00	1 371*	1 200	553	851	520	1 500	0	§	0	none	2 444	3 551
2000–01	1 322*	1 200	954*	851	430	1 500	0	§	0	none	2 706	3 551
2001–02	838	1 200	747*	851	221	1 500	0	§	0	none	1 806	3 551
2002–03	514	1 200	819	851	816	1 500	0	§	0	none	2 149	3 551
2003–04	1 203*	1 200	714	851	1	1 500	0	§	0	none	1 918	3 551

By March 1991 when the catch limit was imposed, the purse seine catch had already exceeded 2339 t and the fishery was immediately closed. Because this occurred before the Minister's decision was announced, an extra 500 t was allocated to cover kahawai bycatch only.
* Purse seine fishery for kahawai closed.
§ Combined landings from KAH 9 and KAH 1 were limited to 1200 t.

Since kahawai entered the Quota Management System on 1 October 2004, the purse seine catch limits no longer apply, and landings (regardless of fishing method) are now restricted by quota availability and fishing company policies. KAH 1 landings have ranged between 903 t and 1095 t since the introduction of the current TACC of 1075 t in 2005 (Figure 1). Landings in KAH 2 have been more variable, falling to just 399 t in 2016–17, but exceeding the TACC of 705 t in 2008–09, 2010–11, and 2017–18. KAH 3 landings have been well below the TACC 2014–15, with just 41 t landed in 2018–19. KAH 8 landings exceeded the TACC of 520 t in 2007–08 and 2014–15, but have recently declined, ranging between 316 t and 346 t in 2016–17 to 2018–19.

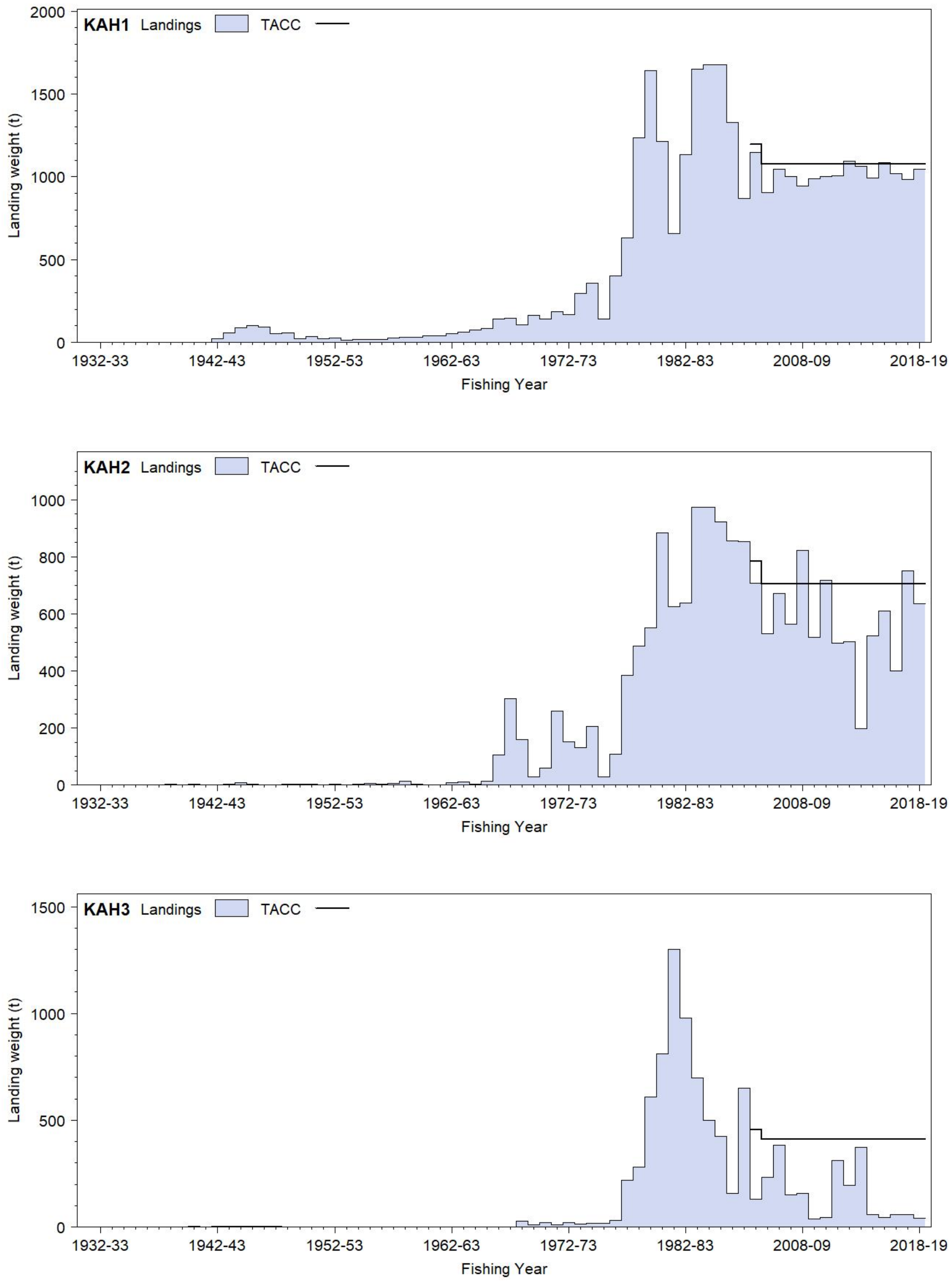


Figure 1: Total commercial landings and TACC for the four main KAH stocks. From top left to bottom right: KAH 1 (Auckland East), KAH 2 (Central East), KAH 3 (South East Coast, South East Chatham Rise, Sub-Antarctic, Southland, Challenger). [Continued on next page]

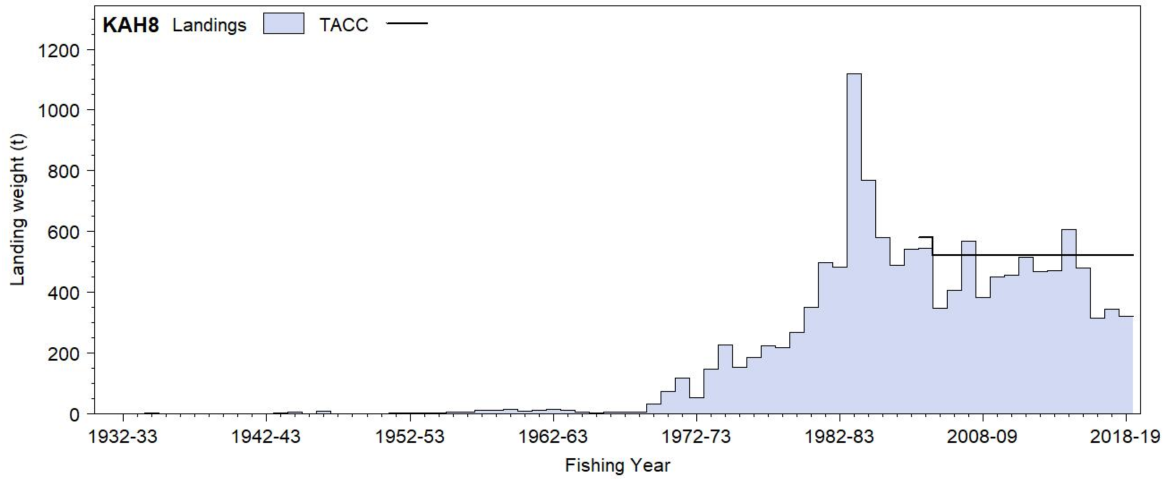


Figure 1: [Continued] Total commercial landings and TACC for the four main KAH stocks: KAH 8 (Central Egmont, Auckland West).

1.2 Recreational fisheries

Kahawai is the second most important recreational species in FMA 1 (after snapper). Kahawai are highly prized by many recreational fishers, who employ a range of shore and boat-based fishing methods to target and/or catch the species. Kahawai is one of the fish species more frequently caught by recreational fishers, and recreational groups continue to express concern about the state of kahawai stocks in some areas. Historical kahawai recreational catches are poorly known. The current allowances within the TAC for each fishstock are shown in Table 1.

Information from the 2011–12 national panel survey (Wynne-Jones et al 2014) show that kahawai were mainly caught by rod or line (93.7%), with just over half of the landed catch taken from trailer boats (54.4%), and a third were taken off land, with very similar percentages seen in 2017–18 (Wynne-Jones et al 2019).

1.2.1 Management controls

The main method used to manage recreational harvests of kahawai is the daily bag limit. The current limits for kahawai are: up to 20 kahawai within a multi-species bag limit of 20 fish in the Auckland, Kermadec, Central, and Challenger management areas; up to 15 kahawai within a multi-species bag limit of 30 fish in the South-East, Southland, and Fiordland management areas; and up to 10 kahawai within a multi-species bag limit of 30 fish in the Kaikoura management area. A minimum net mesh size applies in all areas (the mesh sizes do vary by management area and net type).

1.2.2 Harvest estimates

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 their fishing location, or at an access point when they return to land after their fishing trip; and offsite methods, where some form of post-event interview and/or diary is used to collect data from fishers.

The first estimates of recreational harvest for kahawai were generated using an offsite regional telephone and diary survey approach in: MAF Fisheries South (1991–92), Central (1992–93), and North (1993–94) regions (Teirney et al 1997). Estimates for 1996 came from a national telephone and diary survey (Bradford 1998). Another national telephone and diary survey was carried out in 2000 (Boyd & Reilly 2002) and a rolling replacement of diarists in 2001 (Boyd et al 2004) provided estimates for a further year (mean weights were not re-estimated in 2001). Other than for the 1991–92 MAF Fisheries South survey, the diary method used mean weights of kahawai obtained from fish measured at boat ramps.

The harvest estimates provided by telephone-diary surveys between 1993 and 2001 are no longer considered reliable for various reasons. A Recreational Technical Working Group concluded that these harvest estimates should be used only with the following qualifications: a) they may be very inaccurate; b) the 1996 and earlier surveys contain a methodological error; and c) the 2000 and 2001 estimates are implausibly high for many important fisheries. This led to the development of an alternative maximum count aerial-access onsite method that provides a more direct means of estimating recreational harvests for boat-based 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 relative 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 (Hartill et al 2007b).

This aerial-access method was first use to estimate the recreational snapper harvest in the Hauraki Gulf in 2003–04 (Hartill et al 2007b), which was subsequently extended to survey the wider SNA 1 fishery in 2004–05 (Hartill et al 2007c). One benefit of this method is that it also provides harvest estimates for other key species, in particular kahawai (Table 7). The Marine Amateur Fisheries Working Group has concluded that this approach generally provides broadly reliable estimates of recreational harvest for KAH 1. It is not, however, possible to reliably quantify shore-based fishing from the air and it is necessary to derive scalars from recent offsite surveys to account for the shore-based kahawai catch. Aerial-access surveys, focusing on snapper, provided kahawai harvest estimates for the Hauraki Gulf in 2003–04 and for all of FMA 1 in 2004–05, 2011–12, and 2017–18. Aerial-access surveys in FMA 1 in 2011–12 and 2017–18 (Hartill et al 2013, 2019) provided independent harvest estimates for comparison with those generated from national panel surveys in those years.

In response to problems with previous telephone-diary surveys and the cost and scale challenges associated with onsite methods, a National Panel Survey was conducted for the first time throughout the 2011–12 fishing year. The panel survey used face-to-face interviews of a random sample of 30 390 New Zealand households to recruit a panel of fishers and non-fishers for a full year. The panel members were contacted regularly about their fishing activities and harvest information collected in standardised phone interviews. The two 2011–12 surveys appear to provide plausible results that corroborate each other for KAH 1 and are therefore considered to be broadly reliable (Hartill et al 2013). The panel survey and corroborating aerial-access survey were repeated over the 2017–18 fishing year.

Recreational harvest estimates from offsite surveys up to and including 2017–18 are given in Table 8 (from Wynne-Jones et al 2014, 2019, and Hartill & Davey 2015 and Hartill et al 2019), noting that the QMAs do not all match up with the strata used for the older harvest estimates (in particular for KAH 3 and 8).

Table 7: Summary of kahawai harvest estimates (t) derived from an aerial overflight survey of the Hauraki Gulf in 2003–04 (1 December 2003 to 30 November 2004, Hartill et al 2007b) and a similar KAH 1 wide survey conducted in 2004–05 (1 December 2004 to 30 November 2005, Hartill et al 2007c) and in 2011–12 and 2017–18 (1 October to 30 October, Hartill et al 2013, 2019). Values in brackets denote CVs associated with each estimate.

Year	East Northland	Hauraki Gulf	Bay of Plenty	KAH 1
2003–04	–	56 (0.15)	–	–
2004–05	129 (0.14)	98 (0.18)	303 (0.14)	530 (0.09)
2011–12	191 (0.16)	483 (0.13)	268 (0.12)	942 (0.08)
2017–18	312 (0.13)	517 (0.09)	390 (0.11)	1 219 (0.06)

1.2.3 Monitoring harvest

In addition to estimating absolute harvests, a system to provide relative estimates of harvest over time for key fishstocks has been designed and implemented for some key recreational fisheries. The system uses web cameras to continuously monitor trends in trailer boat traffic at key boat ramps complemented by creel surveys that provide estimates of the proportion of observed boats that were used for fishing and the average harvest of snapper and kahawai per boat trip. These data are combined to provide relative harvest estimates for KAH 1, that have been scaled by concurrent region wide aerial-access harvest estimates, to estimate annual harvest tonnages landed by recreational fishers by substock (Table 9).

Table 8: Recreational catch estimates for kahawai stocks. The surveys ran from October or December to September or November but are denoted by the January calendar year. Mean fish weights were obtained from boat ramp surveys (for the telephone/diary and panel survey catch estimates). Totals are given in bold.

Stock	Year	Method	Number of fish (thousands)	Mean weight (g) (summer/winter)	Total weight (t)	CV
KAH 1	1994	Telephone/diary	727	1	978	–
	1996	Telephone/diary	666		960	0.06
	2000	Telephone/diary	1 860		2 195	0.13
	2001	Telephone/diary	1 905	2	2 248	0.13
Hauraki Gulf only	2004	Aerial-access			56	0.15
East Northland	2005	Aerial-access			129	0.14
Hauraki Gulf	2005	Aerial-access			98	0.18
Bay of Plenty	2005	Aerial-access			303	0.14
Total	2005	Aerial-access			**530**	**0.09**
East Northland	2012	Aerial-access		1 473/1 220[3]	191	0.16
Hauraki Gulf	2012	Aerial-access		1 565/1 475[3]	483	0.13
Bay of Plenty	2012	Aerial-access		1 477/1 628[3,4]	268	0.12
Total	2012	Aerial-access		3,4,5	**942**	**0.08**
East Northland	2012	Panel survey	139	1 473/1 220[3]	198	0.14
Hauraki Gulf	2012	Panel survey	245	1 565/1 475[3]	377	0.09
Bay of Plenty	2012	Panel survey	238	1 477/1 628[3,4]	238	0.11
Total	2012	Panel survey	638	3,4,5	**958**	**0.07**
East Northland	2018	Aerial-access			312	0.13
Hauraki Gulf	2018	Aerial-access			517	0.09
Bay of Plenty	2018	Aerial-access			390	0.11
Total	2018	Aerial-access			**1 219**	**0.06**
East Northland	2018	Panel survey	130	1 717	224	
Hauraki Gulf	2018	Panel survey	219	1 702/1 794	378	
Bay of Plenty	2018	Panel survey	215	1 693	364	
Total	2018	Panel survey	565		**966**	**0.07**
KAH 2	1993	Telephone/diary	195		298	-
	1996	Telephone/diary	142		217	0.09
	2000	Telephone/diary	1 808		2 937	0.74
	2001	Telephone/diary	492	2	799	0.20
	2012	Panel survey	146	1 583/1 449[3]	228	0.12
	2018	Panel survey	132	1 698	224	0.14
KAH 3	1992	Telephone/diary	231		210	-
	1994	Telephone/diary	6	6	8.4	-
	1996	Telephone/diary	226		137	0.07
	2000	Telephone/diary	413		667	0.16
	2001	Telephone/diary	353	2	570	0.18
	2012	Panel survey	105	1 279/2 340[3]	147	0.18
	2018	Panel survey	68	1 056	72	0.15
KAH 8	1994	Telephone/diary	254	1	340	-
	1996	Telephone/diary	199		204	0.09
	2000	Telephone/diary	337		441	0.20
	2001	Telephone/diary	466	2	609	0.24
	2012	Panel survey	282	1 664/1 318[3]	452	0.11
	2018	Panel survey	245	1 872/1 505	439	0.11

[1] Mean weight obtained from 1992–93 boat ramp sampling.
[2] The 2000 mean weights were used in the 2001 estimates.
[3] Separate mean weight estimates were used for summer (1 October 2011 to 30 April 2012) and for winter (1 May to 30 September 2012).
[4] Separate mean weight estimates were used for the eastern and western Bay of Plenty.
[5] Temporally and spatially separate mean weight estimates used as per notes 3 and 4.
[6] No harvest estimate available in the survey report, estimate presented is calculated as average fish weight for all years and areas by the number of fish estimated caught.

Trends inferred from this monitoring programme were initially very similar to that inferred from aerial-access harvest estimates in the Hauraki Gulf in 2004–05, 2006–07, and 2011–12, but the camera/creel kahawai harvest estimate for the Hauraki Gulf in 2017–18 is substantially lower than concurrent aerial-access and national panel surveys estimates for the same year (Table 9 c.f. Table 8). This difference appears to be due to a recent substantial increase in recreational fishing effort and catch around expanding mussel farms in the Firth of Thames, coinciding with a lesser increase in effort in the northwestern gulf. Additional creel survey monitoring has been initiated to monitor changes in the recreational fishery in these areas, which had not been adequately monitored from boat ramps in the Auckland metropolitan area up until 2019–20. There is, however, a good correspondence between trends inferred from camera/creel survey based indices and aerial-access survey and/or national panel survey harvest estimates, for recreational harvesting of kahawai for East Northland and the Bay of Plenty. In East Northland, the kahawai catch landed at the two monitored ramps has gone through similar fluctuations, with no apparent long-term trend evident. In the Bay of Plenty the recreational kahawai halved immediately after 2011–12 and remained at this level before spiking up to the highest estimated harvest tonnage in 2017–18, before declining back to the level seen in the years immediately after 2011–12. These estimates show the variability of recreational harvests between years and, in particular, that harvest levels can be driven not only by stock abundance but also by changes in localised availability.

Table 9: Recreational catch estimates (t) for kahawai in different parts of the KAH 1 stock area calculated from web camera and creel monitoring at key ramps combined with aerial-access estimates for each area in 2004–05 and 2006–07 (Hauraki Gulf only) and 2011–12 and 2017–18 (all areas within KAH 1). Recent estimates, especially for the Hauraki Gulf, are lower than expected but the reasons for this are still being investigated.

Year	East Northland	CV	Hauraki Gulf	CV	Bay of Plenty	CV	Total KAH 1	CV
2004–05	149	0.20	88	0.26	229	0.15	465	0.11
2006–07	–	–	69	0.30	–	–	–	–
2011–12	217	0.18	541	0.19	259	0.21	1017	0.12
2012–13	207	0.22	212	0.20	139	0.21	558	0.12
2013–14	175	0.19	229	0.18	167	0.24	571	0.12
2014–15	86	0.20	191	0.19	107	0.26	384	0.13
2015–16	241	0.17	298	0.18	184	0.17	723	0.10
2016–17	158	0.22	181	0.19	170	0.24	509	0.13
2017–18	275	0.15	260	0.16	404	0.15	938	0.09
2018–19	227	0.16	245	0.17	174	0.16	646	0.10

Web camera and creel monitoring has commenced in other kahawai QMAs but the results have not yet been used to infer trends in those fisheries, although levels of recreational harvesting from these stocks are relatively low.

1.3 Customary non-commercial fisheries

Kahawai is an important traditional and customary food fish for Maori. The level of customary catch has not been quantified and an estimate of the current customary non-commercial catch is not available. Some Maori have expressed concern over the state of their traditional fisheries for kahawai, especially around the river mouths in the eastern Bay of Plenty.

1.4 Illegal catch

Estimates of illegal catch are not available, but are probably insignificant.

1.5 Other sources of mortality

There is no information on other sources of mortality. Juvenile kahawai may suffer from habitat degradation due to run-off, situation and loss of shelter in estuarine areas.

2. BIOLOGY

Kahawai (*Arripis trutta*) are a schooling pelagic species belonging to the family Arripididae. Kahawai are found around the North Island, the South Island, the Kermadec Islands and Chatham Islands. They occur mainly in coastal seas, harbours, and estuaries and will enter the brackish water sections of rivers. A second species, *A. xylabion*, has been described (Paulin 1993). It is known to occur in the northern EEZ, at the Kermadec Islands and seasonally around Northland.

Kahawai feed mainly on fishes but also on pelagic crustaceans, especially krill (*Nyctiphanes australis*). Kahawai smaller than 100 mm mainly eat copepods. Although kahawai are principally pelagic feeders, they will take food from the seabed.

The spawning habitat of kahawai is unknown but is thought to be associated with the seabed offshore. Schools of females with running ripe ovaries have been caught by bottom trawl in 60–100 m in Hawke Bay (Jones et al 1992). Other females with running ripe ovaries have been observed in east coast purse seine landings sampled in March and April 1992, and between January and April in 1993 (McKenzie, NIWA, unpublished data). Length-maturation data collected from thousands of samples in the early 1990s suggest that the onset of sexual maturity in males occurs at around 39 cm (fork length) and in females at 40 cm (McKenzie, NIWA, unpublished data). This closely matches an estimate of 39 cm used for Australian *A. trutta* (Morton et al 2005). This length roughly corresponds to fish of four years of age in both countries. Eggs have been found in February in the outer Hauraki Gulf. Juvenile fish (0+ year class) can be found in shallow water over eelgrass meadows (*Zostera* spp.) and in estuaries.

Kahawai are usually aged using otoliths, following an ageing technique that has been validated (Stevens & Kalish 1998). Kahawai grow rapidly, attaining a length of around 15 cm at the end of their first year, and mature after 3–5 years at about 35–40 cm, after which their growth rate slows. The longest recorded *A. trutta* had a fork length of 79 cm and was caught by a recreational fisher in the Waitangi Estuary in Hawke Bay in August 1997 (Duffy & Petherick 1999). Northern kahawai, *Arripis xylabion*, grow considerably bigger than kahawai and attain a maximum length of at least 94 cm, but beyond this, little is known about the biology of *A. xylabion*. Male and female von Bertalanffy growth curves appear to be broadly similar, with females attaining a slightly higher value for L_∞, although statistical comparison of sex specific curves using a likelihood ratio test (Kimura 1980) suggests that they are statistically different (Hartill & Walsh 2005). Combined-sex growth curves are probably adequate for modelling purposes and are provided for some areas in Table 10. Sex specific growth parameters given for KAH 1 in previous plenary documents have higher estimates for L_∞ (56.93 for males and 55.61 for females).

The maximum recorded age of kahawai is 26 years and this age has been previously used to estimate the instantaneous rate of natural mortality (*M*) using the equation $M = \log_e 100/\text{maximum age}$ (Jones et al 1992). The resulting estimate of *M* of 0.18 assumes that this maximum observed age equates to that at which 1% of the population would survive in an unexploited stock, but a higher value for *M* is now considered more likely. This is because a re-analysis of purse seine catch-at-age data collected by Eggleston from KAH 2 & 3 between 1973 and 1975 suggested that 1% of the unexploited population would have lived for 20 years, which equates to an *M* of 0.23. A Chapman-Robson estimate of *M* of 0.22 was also derived from these catch-at-age data. Estimates of *M* ranging from 0.18 to 0.23 were therefore considered in the 2015 stock assessment and the assumed value used in the base case model was 0.20.

Table 10: Estimates of biological parameters.

Fishstock			**Estimate**	**Source**
1. Natural mortality (*M*)				
All			0.20	Hartill & Bian (2016)
2. Weight = a(length)^b (weight in g, length in cm fork length)				
		a	b	
	KAH 1 (resting)	0.0306	2.82	Hartill & Walsh (2005)
	KAH 1 (mature)	0.0103	3.14	Hartill & Walsh (2005)
	KAH 1 & 3 (all)	0.0236	2.89	Hartill & Walsh (2005)
3. von Bertalanffy growth parameters				
	K	t_0	$L\infty$	
KAH 1	0.35	0.13	54.6	Hartill & Bian (2016)
KAH 2	0.34	0.60	53.5	Drummond (1995)
KAH 3	0.30	0.25	54.2	Drummond & Wilson (1993)
KAH 9	0.23	-0.26	55.9	McKenzie, NIWA, unpubl. data

3. STOCKS AND AREAS

Kahawai are presently defined as separate units for the purpose of fisheries management: KAH 1 (FMA 1); KAH 2 (FMA 2); KAH 3 (FMAs 3, 5, 6, & 7); KAH 4 (FMA 4); KAH 8 (FMAs 8 & 9), and KAH 10 (FMA 10).

Returns from tagging programmes do not provide definitive information on the level of potential mixing between KAH QMAs, but tagging returns suggest that most kahawai (*A. trutta*) remain in the same area for several years, but some move throughout the kahawai habitat. The pattern of kahawai movement around New Zealand is poorly understood and there are regional differences in age structure and abundance that are consistent with limited mixing between regions.

Smith et al (2008) compared otolith micro-chemistry (multi-element chemistry and stable isotopes) and meristics (e.g., fin counts) from 0-group kahawai from two regions (Okahu Bay, Waitematā Harbour and Hakahaka Bay, Port Underwood). Two distant sites were chosen to provide the best chance of successful discrimination. Neither meristics nor stable isotopes provided any discrimination, and magnesium and barium concentrations provided only weak discriminatory power.

On balance it seems possible that there are least two stocks of kahawai (*A. trutta*) within New Zealand waters with centres of concentration around the Bay of Plenty and the northern tip of the South Island. These two areas could be assumed to be separate for management purposes. Tagging data show that there is some limited mixing between these areas. Due to the shared QMA boundaries in the lower North Island and South Island, there is likely to be more mixing between the southern KAH QMAs than with the northern QMA (KAH 1).

There is no information about stock structure of *A. xylabion*.

4. STOCK ASSESSMENT

An age-structured assessment of the KAH 1 stock was first undertaken in 2007 (Hartill 2009) and was updated and revised in 2015 (Hartill & Bian 2016). Both assessments were undertaken using CASAL (Bull et al 2004). This assessment is reported below.

There are no accepted assessments for kahawai stocks outside KAH 1, although there are some catch curve estimates of *Z* from these areas from the early 1990s, which are reported here.

4.1 KAH 1

4.1.1 Estimates of catch, selectivity, and abundance indices

(i) Commercial catch
The commercial catch history used in the assessment is provided in Table 11. Annual catch by method landings statistics up until 1981–82 were provided by Francis & Paul (2013), and Fisheries Statistics Unit data were used to generate landings statistics for 1982–83 to 1988–89. It is noted that catches during these early years are less certain due to reporting issues (e.g., see Table 4 legend).

(ii) Recreational catch
The recreational catch history in KAH 1 is poorly known. Aerial overflight estimates are available for the Hauraki Gulf in 2003–04 (Hartill et al 2007b) and for all three regions of KAH 1 in 2004–05 (Hartill et al 2007c) and in 2011–12 (Hartill et al 2013). Recreational harvest estimates for all three regions of KAH 1 are also available from a National Panel Survey undertaken in 2011–12 (Wynne-Jones et al 2014), which were of a similar magnitude to those provided by the aerial-access survey.

Levels of recreational harvesting vary from year to year, however, and the aerial-overflight estimates were therefore used to scale up regional catch per trip (landed catch weight per hour fished) indices derived from creel surveys conducted since 1990, to gauge likely levels of harvesting taking place across a wider range of years (Figure 2). The coefficient used to scale up the catch rate index in each region was the geometric mean of the aerial overflight estimates divided by the geometric mean of catch index during the aerial overflight survey years. The 2011–12 aerial overflight estimate was not used to inform the Bay of Plenty recreational catch history because the closure of waters of around Motiti Island following the grounding of the M.V. *Rena* in early October 2011 would have reduced levels of recreational catch and effort in an atypical fashion. The constant catch history estimates given in Figure 2 were used to inform regional constant catch histories for 1974–75 to 2012–13.

Table 11: Commercial catch (t) time series used in the 2015 stock assessment of KAH 1.

Fishing	Bottom		Purse		
year	trawl	set net	seine	Other	KAH 1
1930–31	0.1	0.3	–	0.1	1
1931–32	0.3	0.8	–	0.3	1
1932–33	–	–	–	–	–
1933–34	–	–	–	–	–
1934–35	–	–	–	–	–
1935–36	–	–	–	–	–
1936–37	0.4	1.3	–	0.4	2
1937–38	0.3	0.9	–	0.3	2
1938–39	0.3	0.9	–	0.3	1
1939–40	0.3	0.8	–	0.3	1
1940–41	0.4	1.1	–	0.4	2
1941–42	4.2	12.6	–	4.2	21
1942–43	11.6	34.9	–	11.6	58
1943–44	18.0	53.9	–	18.0	90
1944–45	20.4	61.3	–	20.4	102
1945–46	18.7	56.2	–	18.7	94
1946–47	10.7	32.2	–	10.7	54
1947–48	11.6	34.7	–	11.6	58
1948–49	4.6	13.8	–	4.6	23
1949–50	6.7	20.1	–	6.7	34
1950–51	4.4	13.2	–	4.4	22
1951–52	5.4	16.2	–	5.4	27
1952–53	2.7	8.2	–	2.7	14
1953–54	3.6	10.9	–	3.6	18
1954–55	3.9	11.6	–	3.9	19
1955–56	3.3	9.8	–	3.3	16
1956–57	5.0	15.0	–	5.0	25
1957–58	6.5	19.6	–	6.5	33
1958–59	6.2	18.6	–	6.2	31
1959–60	8.1	24.2	–	8.1	40
1960–61	7.9	23.7	–	7.9	40
1961–62	10.9	32.6	–	10.9	54
1962–63	12.0	35.9	–	12.0	60
1963–64	15.0	45.1	–	15.0	75
1964–65	17.0	50.9	–	17.0	85
1965–66	28.5	85.5	–	28.5	143
1966–67	29.4	88.2	–	29.4	147
1967–68	21.4	64.2	–	21.4	107
1968–69	32.5	97.6	–	32.5	163
1969–70	28.1	84.4	–	28.1	141
1970–71	36.9	110.8	–	36.9	185
1971–72	33.6	100.9	–	33.6	168
1972–73	58.9	176.7	–	58.9	295
1973–74	71.4	214.3	–	71.4	357
1974–75	19.0	63.8	37.7	19.8	140
1975–76	65.0	148.4	139.5	47.7	401
1976–77	122.7	163.0	270.6	74.5	631
1977–78	200.4	460.6	431.8	144.2	1 237
1978–79	379.5	228.2	875.4	159.4	1 642
1979–80	249.6	270.4	561.3	132.1	1 213
1980–81	131.7	158.6	292.3	76.7	659
1981–82	201.9	357.0	439.5	134.9	1 133
1982–83	105.6	526.4	169.1	180.9	982
1983–84	64.4	320.9	1 445.4	110.3	1 941
1984–85	82.5	410.9	882.4	141.2	1 517
1985–86	52.8	263.1	1 190.8	90.4	1 597
1986–87	44.9	223.8	1 544.4	76.9	1 890
1987–88	42.6	212.4	3 964.0	73.0	4 292
1988–89	68.2	339.8	1 644.0	116.8	2 169
1989–90	42.0	293.6	1 699.4	58.6	2 094
1990–91	66.6	321.2	1 562.9	62.1	2 013
1991–92	38.8	319.8	1 725.4	68.8	2 153
1992–93	70.5	532.5	3 066.3	111.5	3 781
1993–94	31.2	538.2	1 322.8	105.8	1 998
1994–95	35.0	389.0	1 290.8	135.9	1 851
1995–96	74.8	294.6	1 270.0	131.9	1 771
1996–97	69.6	253.8	1 291.4	100.3	1 715
1997–98	42.0	318.3	1 056.4	62.9	1 480
1998–99	94.3	167.9	1 573.8	75.3	1 911
1999–00	105.8	196.7	1 352.7	36.8	1 692
2000–01	74.6	199.5	1 393.3	52.7	1 720
2001–02	58.8	244.8	938.9	61.4	1 304
2002–03	44.1	199.0	765.6	33.2	1 042
2003–04	45.8	178.0	1 263.0	21.4	1 508
2004–05	48.5	161.5	833.5	35.6	1 079
2005–06	68.1	199.6	570.8	51.7	890
2006–07	39.2	255.3	686.8	52.9	1 034
2007–08	57.6	253.1	767.9	32.7	1 111
2008–09	30.2	266.2	658.7	33.3	988
2009–10	61.9	307.0	554.9	40.7	964
2010–11	61.5	292.0	700.1	56.3	1 110
2011–12	67.5	178.9	862.9	80.1	1 189
2012–13	114.7	211.1	706.4	50.8	1 083

Constant harvest tonnages were used because there was concern that if a catch history with an assumed trend was used, this trend could influence the model results, despite being essentially unknown. Estimates of recreational harvest were required back to 1930–31, however, and the harvest at that time was assumed to be 10% of that in 1974–75, which was then ramped up to that value over the intervening years. These regional catch histories were then combined into a single catch history for KAH 1, which is assumed to include harvests taken by customary fishers (Figure 3).

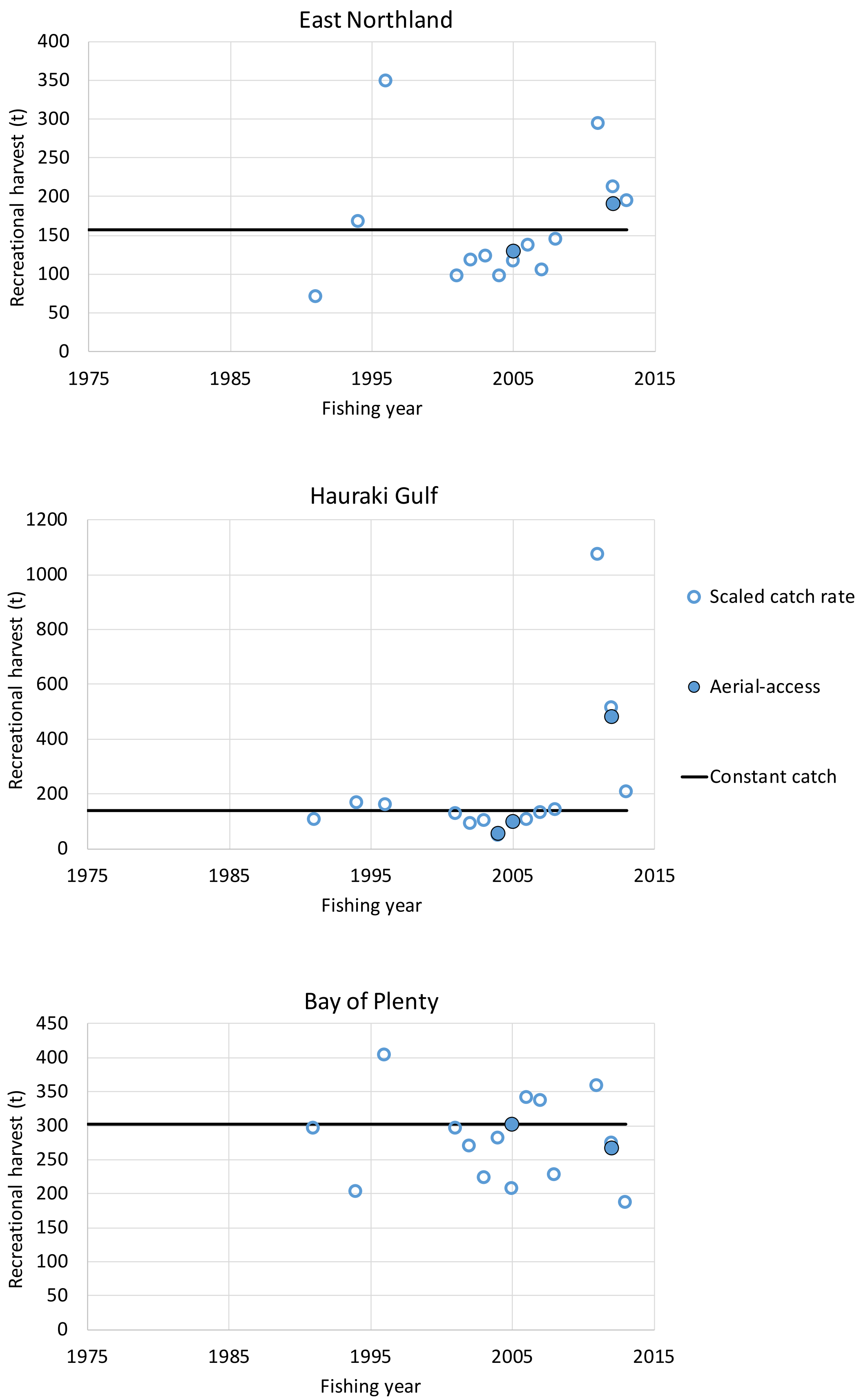


Figure 2: Regional recreational catch histories based on estimates provided by recent aerial-access surveys in 2004–05 and 2011–12. The 2011–12 estimate for the Bay of Plenty was not used because harvests in this year may have been adversely affected by the grounding of the M.V. *Rena*.

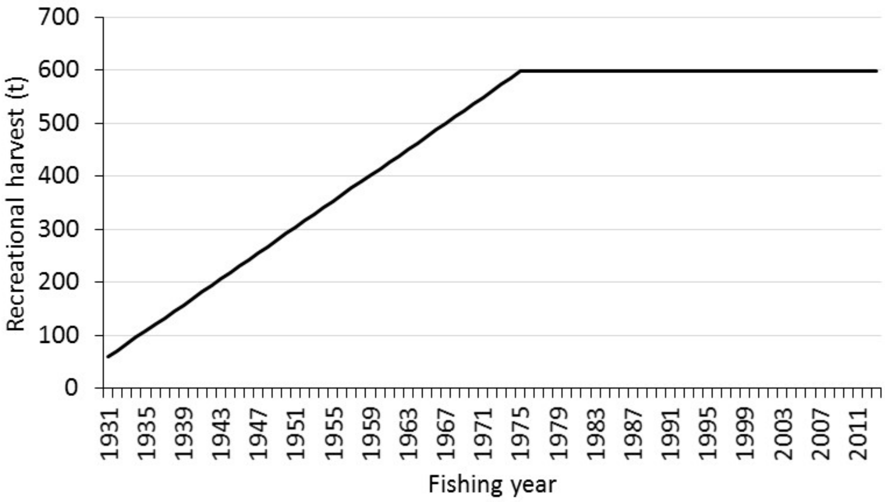


Figure 3: Recreational catch history for KAH 1 from 1931 to current that was assumed in the 2015 assessment.

(iii) Catch composition data and selectivity estimates

The earliest catch-at-age data that are available were collected from single trawl and purse seine landings sampled in 1991, 1992, and 1993. Purse seine landings were also sampled in 2005, 2011, and 2012. Catch-at-age data were available from set net landings from the Hauraki Gulf in 2011 and 2012, which were sampled so that the selectivity for this method could be estimated.

Recreational landings sampled during 10 years between 2001 and 2012 provided the most consistently sampled source of catch-at-age data used in the assessment (Hartill et al 2007a, 2007d, 2008, Armiger et al 2006, 2009, 2014). Boat ramp surveys were conducted in East Northland, the Hauraki Gulf, and the Bay of Plenty between January and April in each year. Annual catch-at-age distributions for each of the three regions were weighted together given the assumed catch history for each region, to provide a single time series for KAH 1 for this fishery.

All composition data were iteratively reweighted following the Francis method, which resulted in effective sample sizes being down weighted by about 98% for the recreational and purse seine catch-at-age data and by 85% for the single trawl data. This process maintained CVs for the abundance indices at the level originally estimated outside of the model.

Logistic selectivity ogives were estimated for the purse seine, single trawl, and recreational fisheries, and the single trawl ogive was also used when accounting for the relatively small tonnage landed by other methods such as Danish seine and beach seine. A double normal selectivity was estimated from the set net catch-at-age data and subsequently fixed at MPD parameter values.

(iv) Indices of abundance

Three indices of abundance were available for the assessment, but only two of these were ultimately offered to the model. Both a recreational CPUE and an aerial Sightings per Unit Effort (SPUE) were considered informative, but the set net CPUE index used in the 2007 assessment was no longer considered reliable because ring net fishing is often reported as set net fishing.

Recreational CPUE index

The recreational CPUE index used in the model was based on creel survey data collected at boat ramps during surveys conducted intermittently since 1991. Creel survey data were only used from East Northland and the Bay of Plenty, because catch rates in the Hauraki Gulf in about 2008 increased as a result of an influx of large kahawai, reflecting localised availability rather than abundance.

Separate CPUE (kg/hr) indices were initially calculated for East Northland and the Bay of Plenty, which were then weighted together based on the relative harvest taken from these regions, to provide a single abundance index for the KAH 1 stock. These indices were calculated from data collected between January and April only, because few surveys were conducted at other times of the year. Rod and line catch rate data were used from a core set of ramps only, which were surveyed in all past surveys.

Attempts were made to generate a standardised index but very few variables were available to inform any standardisation, especially as neither fisher nor vessel identifiers are recorded during creel surveys. The first term selected by any of the standardisations attempted was always fishing year, and remaining terms such as fishing location and month were often not selected or had little effect on the indices produced. The recreational CPUE index used in this assessment was therefore unstandardised (Figure 4).

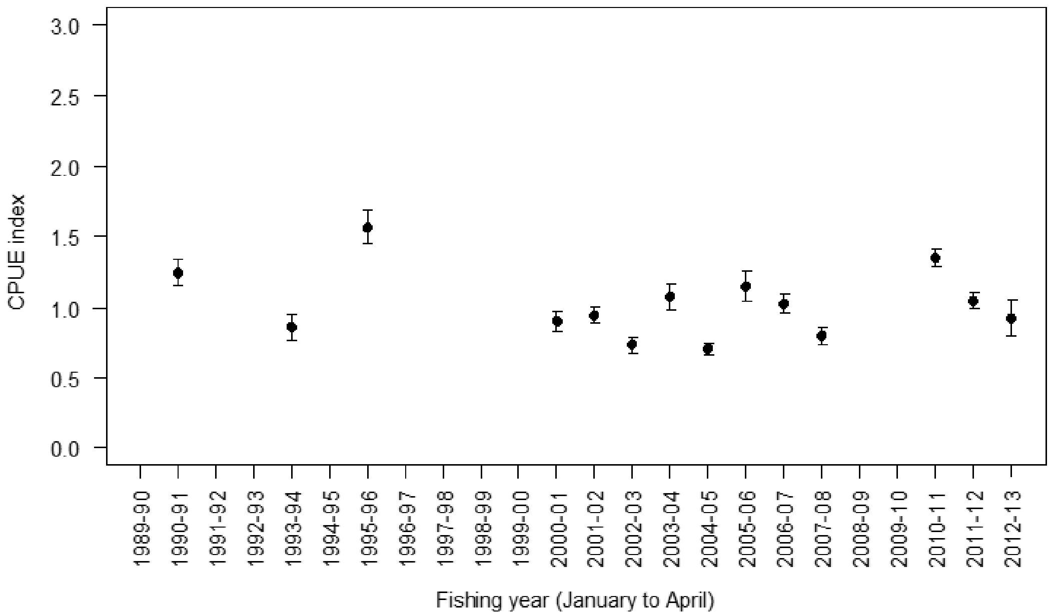


Figure 4: Unstandardised recreational CPUE (kg/hr). Vertical lines are bootstrap 95% confidence intervals.

Aerial sightings index

In 2012, an index of abundance [sightings per unit effort (SPUE)] based on commercial aerial sightings data was accepted by the Northern Inshore Working Group. This index was calculated using data from the *aer_sight* database and applying a generalised additive model (GAM) to produce standardised annual relative abundance indices (Taylor 2014).

Flights were restricted to those that were exclusive to the Bay of Plenty (BoP) (i.e., those having flight paths that remained within an area defined as the BoP), only flown by pilot #2 and were the first flight of the day (apart from some defined exceptions, e.g., short refuelling flights at the start of the day).

Estimates of relative year effects were obtained using a forward stepwise GAM, where the data were fitted using two models: 1) the probability of a flight having a positive sighting modelled using a binomial regression; and 2) the tonnage sighted on positive flights modelled using a lognormal regression. These two models were combined into a single index. The data used for the SPUE analyses consisted of aerial sightings of kahawai, trevally, jack mackerel, blue mackerel, and skipjack tuna collected over the period 1986–87 to 2010–11, with missing years in 1988–89, from 1994–95 to 1996–97, and in 2006–07. Most of these missing years were the result of there being no available data. By contrast, 2006–07 was dropped because the working group identified a bias in the annual index for that year because of the low number of available flights. The first year of the original series (1985–86) was dropped by the working group for the same reason.

The species with the maximum daily purse seine catch from the vessels that the pilot was working with in the BoP was used as a proxy for target species. Catch data before 1989 were from the *fsu-new* database and data from 1989 to 2013 were from the *warehou* database.

The working group accepted the combined model of SPUE for kahawai as an index of abundance in the BoP. The BoP combined SPUE index for kahawai shows substantial inter-annual variation with an overall gradual declining trend from 1986–87 to 2002–03; thereafter increasing sharply to a peak in 2007–08, and then declining to points above the long-term mean (Table 12, Figure 5).

Table 12: Standardised sightings per unit effort (SPUE) indices for the Bay of Plenty KAH 1 stock, derived as a combination of year effect estimates from a lognormal and a binomial regression for 1986–87 to 2012–13.

Fishing year	Combined	CV
1986–87	1.14	0.31
1987–88	0.86	0.27
1988–89	No data	No data
1989–90	0.58	0.27
1990–91	0.78	0.27
1991–92	0.66	0.28
1992–93	1.19	0.27
1993–94	1.17	0.30
1994–95	No data	No data
1995–96	No data	No data
1996–97	No data	No data
1997–98	0.81	0.28
1998–99	0.45	0.28
1999–00	0.47	0.54
2000–01	0.70	0.29
2001–02	0.66	0.29
2002–03	0.36	0.29
2003–04	1.30	0.35
2004–05	1.67	0.30
2005–06	1.93	0.29
2006–07	Insufficient data	Insufficient data
2007–08	2.45	0.27
2008–09	1.25	0.28
2009–10	1.49	0.28
2010–11	1.72	0.27
2011–12	1.78	0.32
2012–13	1.43	0.28

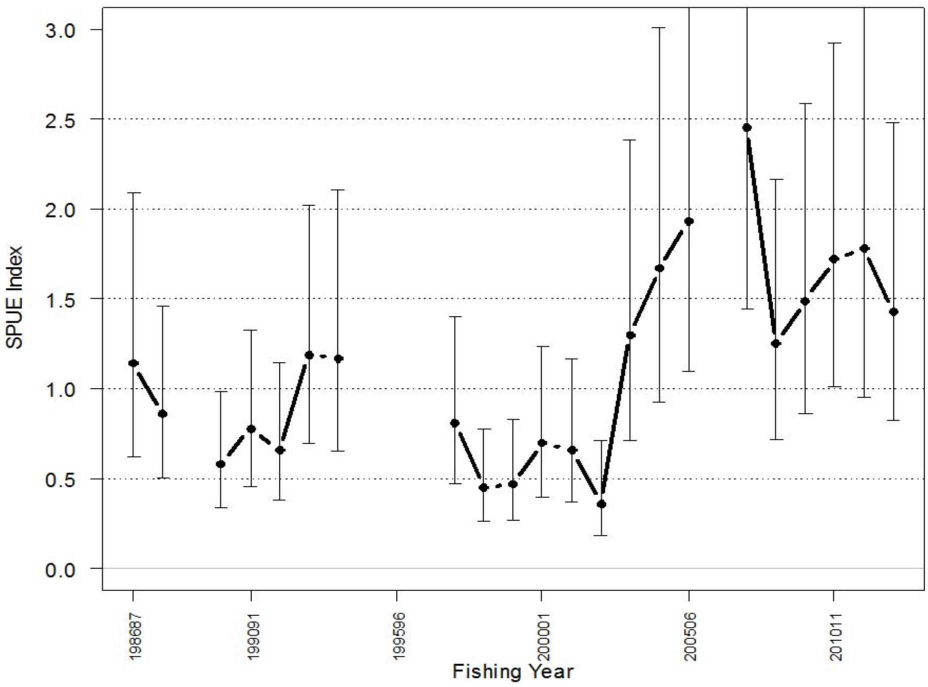


Figure 5: Standardised sightings per unit effort (SPUE) indices for the Bay of Plenty KAH 1 stock, derived as a combination of year effect estimates from a lognormal and a binomial regression. Vertical lines are 95% confidence intervals.

4.1.2 Model structure

The stock assessment was restricted to KAH 1, because this is the QMA where most of the observational data have been collected. Future assessments may consider a broader stock definition, but improved understanding of the movement dynamics of this species and further development of this model are required before this can be attempted. Even within KAH 1 there is little information on connectivity between the three main areas of the fishery: East Northland, Hauraki Gulf, and the Bay of Plenty. There are few tag data available that can be used to estimate these migration processes, because almost all of the kahawai that have been tagged have been released in the Bay of Plenty. This provides little information about emigration from the Hauraki Gulf and from East Northland. Recreational catch-at-age data collected since the 2007 assessment now suggest that size based migration between areas may vary more considerably and unpredictably than previously thought. For these reasons, the data used in the assessment were no longer regionally partitioned, but were combined into a single stock model which includes most of the currently available data.

In the stock assessment model it is assumed that KAH 1 is a single biological stock, exploited by several fisheries. Deviations from the spawner recruitment curve were estimated for those years when there were three or more years of observational catch-at-age data and were constrained to a mean of 1.0 across all fishing years from 1974–75 to 2012–13.

A single annual time step was used, in which ageing was followed by recruitment, maturation, growth, and then mortality (natural and fishing). The relationships between length and age, and length and weight, were both assumed to be constant through time and were based on updated parameter values given in Table 10. Annual abundances of the age classes 1 to 20 were estimated in the model, with 20 year olds representing all fish older than 19 years. The model was not sex specific. Maturation was knife-edged at four years of age. There is no information on the relationship between stock size and recruitment, and the rate of natural mortality is uncertain. Sensitivity to these parameters is discussed in the next section.

It was assumed that the population was at an unfished equilibrium state (B_0) in 1930, as reported commercial landings between 1930 and 1940 were only in the order of 1 to 2 tonnes per year. Key model outputs are probably robust to this assumption because commercial landings were only of the order of a few hundred tonnes and recreational landings were assumed to be low relative to stock size prior to this time. Total fishing mortality was apportioned between fisheries according to observed catches and estimated selectivities. Method specific annual landings from five fishing methods were considered: recreational, purse seine, single trawl, set net, and other minor commercial fisheries.

4.1.3 Evaluation of uncertainty

Evaluations of preliminary models identified three sources of uncertainty which were subsequently investigated in more detail: the assumed value for natural mortality (*M*); choice of abundance index; and the assumed steepness (*h*) of the Beverton-Holt stock recruitment relationship.

Alternative values of steepness of 0.75 and 0.90 appeared to have little influence on either current biomass or stock status, because sensitivity model runs suggested the spawning stock biomass has never fallen to low enough levels for this to have an effect. A base case value of 0.75 was assumed for all subsequent model runs.

An *M* of 0.20 was assumed for the base case model, in which both the SPUE and Recreational CPUE were considered. Three sensitivity models were also considered: two with alternative *M* estimates (0.18 and 0.23), and another where *M* was assumed to be 0.20, but only the recreational CPUE index was offered to the model (i.e., the SPUE index was omitted).

MCMCs were run for all four of these models. However, the M = 0.23 sensitivity model performed poorly despite an extended burn-in period of 2 million iterations. MCMC traces for some parameters fluctuated markedly and the run terminated as it approached its 4 millionth iteration. This model was rejected due to the lack of convergence and results are not reported here.

The three remaining models were projected for a five year period (2014 to 2019), with future catches for each fishing year being set to those in 2012–13. Year class strengths were drawn from the 10-year period, 2000–2009.

4.1.4 Results

All models suggested that the stock was gradually fished down until the late 1970s, followed by a steeper decline that coincided with the development of the purse seine fishery during the 1980s. There have since been marked fluctuations in stock size but there is general evidence of a rebuild since the early 2000s.

The assumed value for *M* had the greatest influence on the model results, with the base case of *M* = 0.2 producing higher stock biomass and stock status (Figure 6). The lower value of 0.18 resulted in lower biomass estimates and lower current stock status when both abundance indices were offered to the model. Dropping the SPUE index suggested there had been less of a rebuild since the early 1990s, but there was still evidence of an increase in spawning stock biomass in recent years.

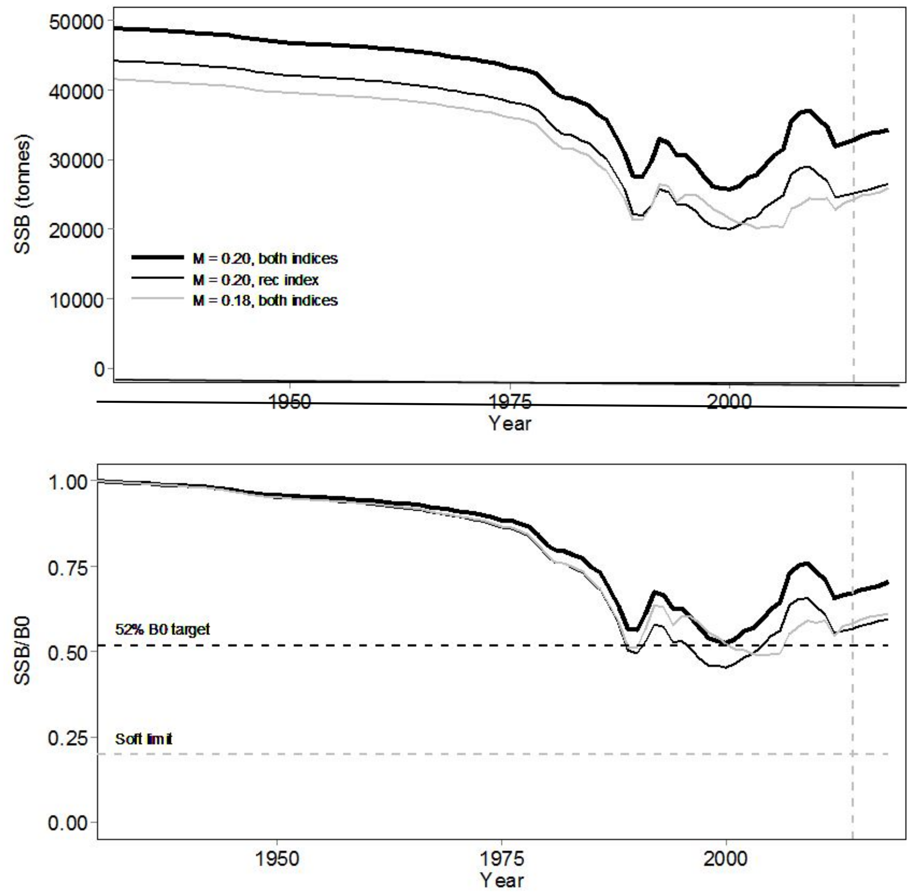


Figure 6: Comparison of spawning stock biomass (upper panel) and stock status trajectories (lower panel) for the base case (where *M* was assumed to be 0.20 and both the recreational CPUE and SPUE indices were offered to the model) and for two other sensitivities. The vertical dashed line denotes first year of the projection period (2014).

All three model runs suggest that the KAH 1 stock has never fallen below about 40% B_0 (Figure 6). Median %B_0 in 2013 was estimated to be 66% for the base case, 56% for the case with lower *M* and 58% when the SPUE was excluded (Table 13). In 2010 the Minister of Fisheries set a target reference point of 52% B_0 for this shared fishery, and although two of the sensitivity runs suggest that the KAH 1 stock biomass has fallen below this level at times, there is a high probability that the current biomass predicted by each model is well above this level (Tables 13 & 14).

Table 13: Biomass (t) and stock status estimates derived from MCMC runs for the base model (M20_both; three chains combined) and two sensitivity models (medians with 95% credible intervals in parentheses).

Model	SSB_0	SSB_{2013}	$SSB_{52\%}$	SSB_{2013}/SSB_0	$SSB_{2013}/SSB_{52\%}$
M20_both	48 888	31 889	25 225	0.663	1.275
(Base case)	(38 973–92 822)	(20 334–79 232)	(20 266–48 267)	(0.521–0.854)	(1.000–1.641)
M18_both	44 340	24 952	17 736	0.563	1.407
	(38 536–56 991)	(17 250–39 700)	(15414–22 796)	(0.448–0.697)	(1.119–1.7415)
M20_rec	41 569	23 933	16 628	0.576	1.439

(38 305–46 362)	(20 054–29 511)	(15 322–18 545)	(0.524–0.637)	(1.309–1.591)

Table 14: Probability of the KAH 1 stock in 2013 falling below soft and hard limits and being at or above the target reference point. The target reference point of 52% B_0 was set by the Minister of Fisheries for this stock in 2010. Probabilities are calculated from the distribution of MCMC estimates calculated from each model.

Model	**Pr(SSB_{2013} < 10% SSB_0)**	**Pr(SSB_{2013} < 20% SSB_0)**	**Pr(SSB_{2013} > 52% SSB_0)**
M20_both	0.000	0.000	0.975
M18_both	0.000	0.000	0.738
M20_rec	0.000	0.000	0.755

4.1.5 Projections and yield estimates

The base and sensitivity models were projected forward five years, with empirical resampling from the 10-year period, 2000–2009, using the reported 2013 catch. These projections suggest that current stock status is likely to improve further under all three scenarios, with a faster level of increase seen in the less optimistic lower *M* scenario (Table 15, Figure 7). The probability of the stock being at or above 52% B_0 in 2018 is 0.945 for the base case.

Table 15: Probability of the KAH 1 stock in 2018 falling below soft and hard limits and being at or above the target reference point. The target reference point of 52% B_0 was set by the Minister of Fisheries for this stock in 2010. Probabilities are calculated from the distribution of MCMC estimates calculated from each model (three chains combined for the base model).

Model	**SSB_{2018}/SSB_0**	**Pr(SSB_{2018} < 10% SSB_0)**	**Pr(SSB_{2018} < 20% SSB_0)**	**Pr(SSB_{2018} > 52% SSB_0)**
M20_both	0.693 (0.629–0.742)	0.000	0.000	0.940
M18_both	0.596 (0.563–0.648)	0.000	0.000	0.756
M20_rec	0.620 (0.557–0.673)	0.000	0.000	0.755

The deterministic yield corresponding to 52% B_0 from the base case model is 2414 t.

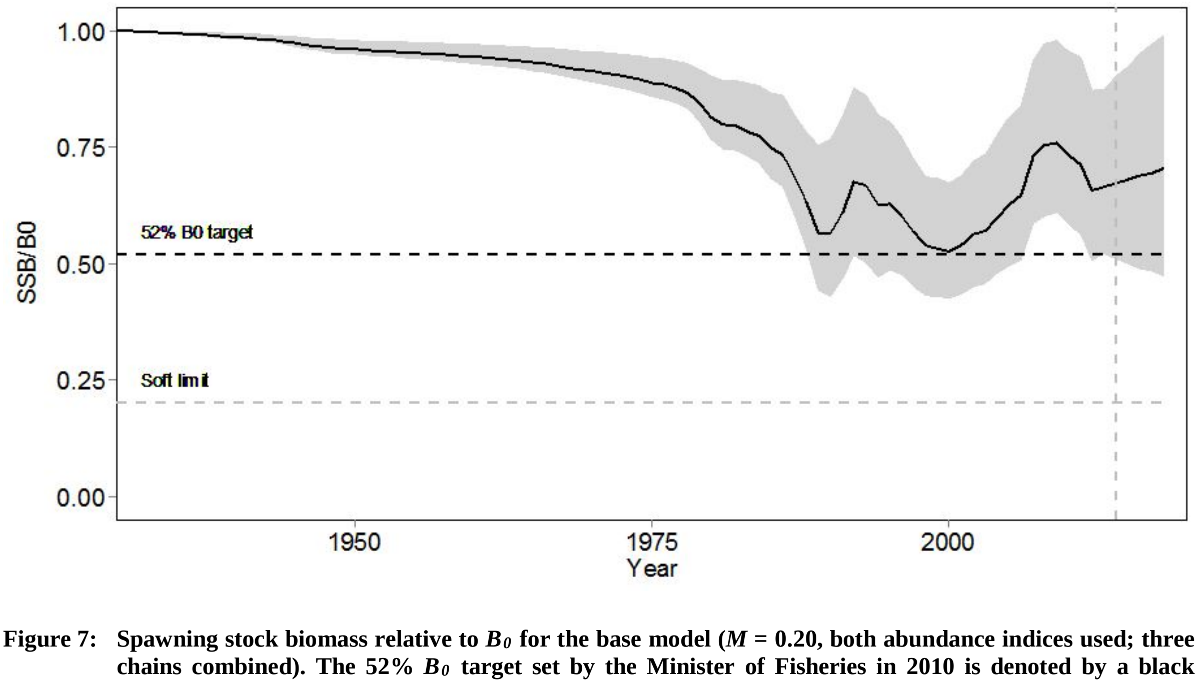


Figure 7: Spawning stock biomass relative to B_0 for the base model (M = 0.20, both abundance indices used; three chains combined). The 52% B_0 target set by the Minister of Fisheries in 2010 is denoted by a black dashed line and the 20% B_0 soft limit is denoted by the grey dashed line. The grey shaded area denotes 95% credible intervals derived from the MCMC model run and the black line denotes the median estimate for each year. The vertical dashed line denotes the first year of the projection period (2014).

4.1.6 Catch-curve analysis

Annual estimates of total mortality (*Z*) have also been derived from recreational catch data sampled in East Northland and the Bay of Plenty (Figure 8). They were calculated using a Chapman-Robson estimator independently from the stock assessment model (Table 16). These estimates were calculated using a range of assumed ages for full recruitment to demonstrate the sensitivity of the results to this assumption.

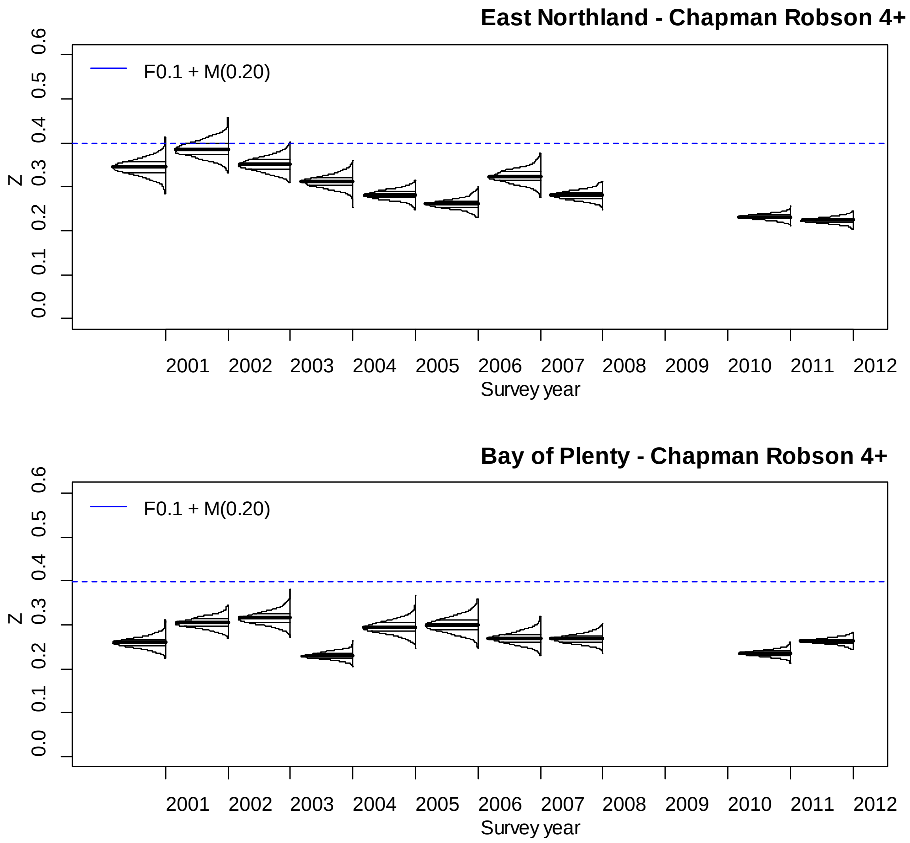


Figure 8: The distribution of bootstrap Chapman-Robson estimates of total mortality (*Z*) by survey year for East Northland (top panel) and the Bay of Plenty (lower panel). A theoretical optimal level of *Z* derived from a YPR curved generated from the 2015 assessment is denoted as a horizontal line for reference purposes (adapted from Armiger et al 2014).

Table 16: Estimates of *Z* derived from recreational catch sampling in KAH 1, by survey year by assumed age-at-recruitment (from Armiger et al 2014).

									Year	**East Northland**	
Area	**2001**	**2002**	**2003**	**2004**	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**	**2011**	**2012**
3	0.33	0.33	0.32	0.28	0.24	0.23	0.28	0.24	–	–	0.20	0.21
4	0.34	0.38	0.35	0.31	0.28	0.26	0.32	0.28	–	–	0.23	0.22
5	0.30	0.37	0.39	0.33	0.33	0.32	0.35	0.33	–	–	0.27	0.25
6	0.30	0.40	0.41	0.38	0.36	0.36	0.41	0.34	–	–	0.32	0.28

										Year	**Bay of Plenty**	
Area	**2001**	**2002**	**2003**	**2004**	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**	**2011**	**2012**
3	0.23	0.25	0.28	0.20	0.27	0.25	0.24	0.24	–	–	0.20	0.23
4	0.26	0.30	0.32	0.23	0.29	0.30	0.27	0.27	–	–	0.23	0.26
5	0.28	0.33	0.34	0.26	0.30	0.30	0.24	0.29	–	–	0.26	0.29
6	0.30	0.36	0.38	0.32	0.30	0.32	0.26	0.29	–	–	0.31	0.31

4.1.7 Future research needs

- Otoliths from the Hauraki Gulf should be collected in future recreational catch-at-age creel surveys so that they are available for reading if required, as this was not done in 2011 and 2012.
- A spatial model should be considered for the next assessment if there are data to inform it on movements of different age/size classes between sub-areas. This may reduce the patterns in residuals for model fits to recreational catch at age.

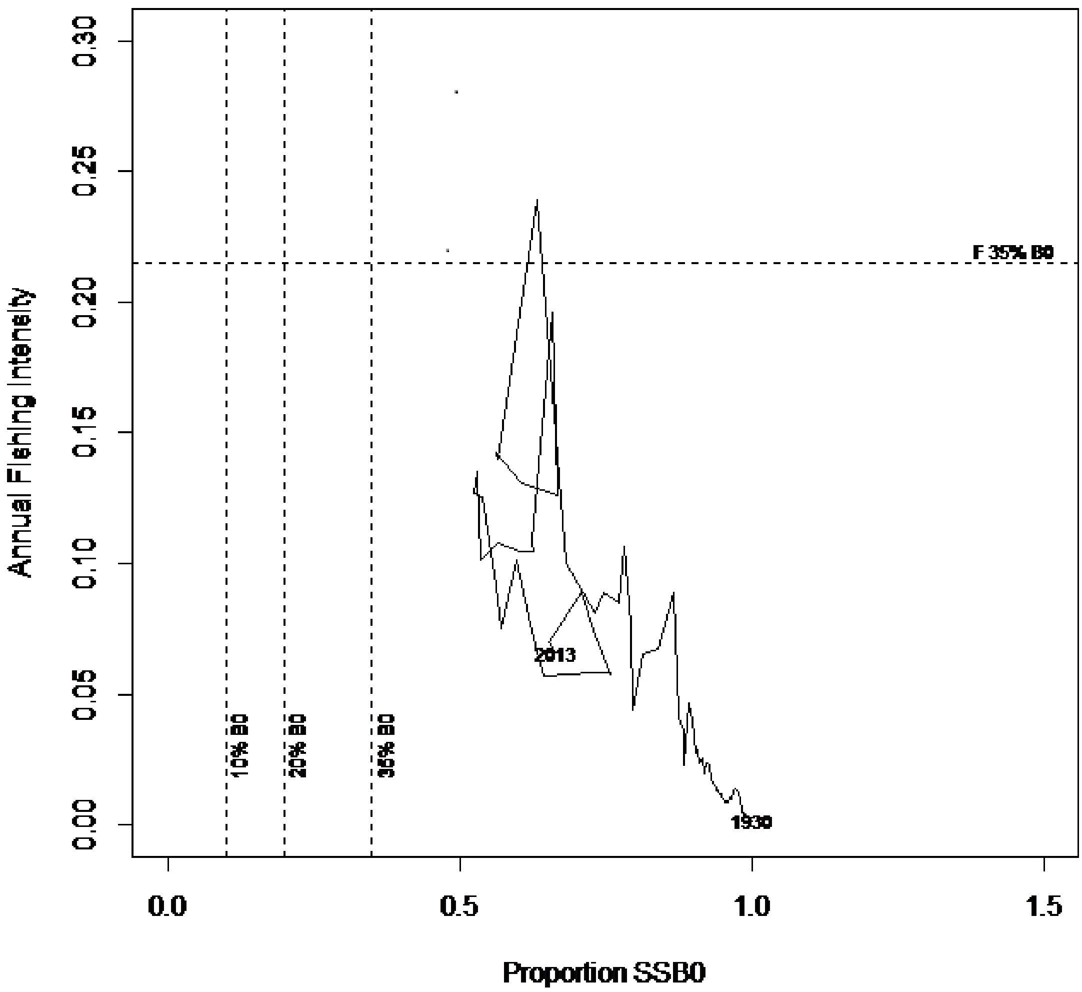
5. STATUS OF THE STOCKS

KAH 1

Stock Structure Assumptions
Two stocks of kahawai (*A. trutta*) are assumed to exist within New Zealand waters with centres of concentration around the Bay of Plenty and the northern tip of the South Island. Tagging data show that there is limited mixing between these areas.

Stock Status	
Year of Most Recent Assessment	2015: Age based stock assessment
Assessment Runs Presented	Base case model with *M*=0.2 and two abundance indices (recreational CPUE and aerial sightings)
Reference Points	Target: 52% B_0 (set by Minister of Fisheries in 2010) Soft Limit: 20% B_0 Hard Limit: 10% B_0 Overfishing threshold: $F_{35\%B0}$
Status in relation to Target	Very Likely (> 90%) to be at or above
Status in relation to Limits	Soft Limit: Very Unlikely (< 10%) to be below. Hard Limit: Exceptionally Unlikely (< 1%) to be below
Status in relation to Overfishing	Overfishing is Very Unlikely (<10%) to be occurring

Historical Stock Status Trajectory and Current Status



Trajectory of spawning stock biomass relative to B_0 for the base model (M = 0.20, both abundance indices used) and annual fishing intensity. The 52% B_0 target set by the Minister of Fisheries in 2010 is denoted by a black dashed line and the 20% B_0 soft limit and 10% B_0 hard limit are denoted by the grey dashed lines.

Fishery and Stock Trends	
Recent Trend in Biomass or Proxy	Stock biomass has increased in recent years.
Recent Trend in Fishing Mortality or Proxy	Fishing mortality has declined since the early 1990s and is now well below the overfishing threshold.
Other Abundance Indices	None available other than regional set net CPUE indices which are not considered to be reliable because of confusion between set net and ring net effort reporting.
Trends in Other Relevant Indicators or Variables	- A time series of total mortality estimates for East Northland and the Bay of Plenty from 2001 to 2012, based on recreational catch-at-age data, suggests that there has been little change in fishing mortality over this period. Estimates of total mortality were at or below that associated with $F_{0.1}$ suggesting that fishing mortality was at or below F_{MSY}.

Projections and Prognosis	
Stock Projections or Prognosis	The KAH 1 stock is likely to increase over the next five years at 2013 catch levels.
Probability of Current Catch or TAC causing biomass to remain below or to decline below Limits	Soft Limit: Very Unlikely (< 10%) Hard Limit: Exceptionally Unlikely (< 1%)
Probability of current catch or TAC causing overfishing to continue or to commence	Exceptionally Unlikely (< 1%)

Assessment Methodology and Evaluation		
Assessment Type	Level 1 – Full Quantitative Stock Assessment	
Assessment Method	Statistical catch at age model implemented under CASAL	
Assessment Dates	Latest assessment: 2015	Next assessment: 2020
Overall assessment quality rank	1 – High Quality	
Main data inputs (rank)	- Proportions-at-age from purse seine, single trawl, set net and recreational fisheries - Unstandardised recreational CPUE index - Estimates of biological parameters (e.g. growth, age-at-maturity, length/weight) - Estimates of recreational harvest - Commercial catch statistics - Aerial SPUE index	1 – High Quality: but set net data were only used to estimate MPD selectivity 1 – High Quality 1 – High Quality 1 – High Quality 1 – High Quality 2 – Medium or Mixed Quality: only covers western Bay of Plenty
Data not used (rank)	- Set net CPUE indices	3 – Low Quality: confusion between set net and ring net fishing reporting
Changes to Model Structure and Assumptions	-Change from grid to age structured base case with MCMC -Change from quasi regional to single stock structure -Dropped set net CPUE -Included age composition for set net catch -Included SPUE -Started model in 1930 at equilibrium instead of 1975 -Changed default M from 0.18 to 0.20	

Major Sources of Uncertainty	- Under-reported commercial catch prior to 1980 - Recreational catch history, especially prior to 1990 - Assumption of constant selectivity and catchability in the abundance indices may compromise their ability to index biomass - Spatial complexity in the movement of different sizes/ages of kahawai - Age composition and selectivity of purse seine unlikely to be consistent from year to year due to kahawai schooling by age/size

Qualifying Comments
-

Fishery Interactions
Commercial catches of KAH 1 are primarily taken by purse-seine in association with jack mackerel, blue mackerel and trevally. Interactions with other species are currently being characterised.

All other KAH regions

No accepted assessment is available that covers these regions. It is not known if the current catches, allowances or TACCs are sustainable. The status of KAH 2, 3 and 8 relative to B_{MSY} is unknown.

6. FOR FURTHER INFORMATION

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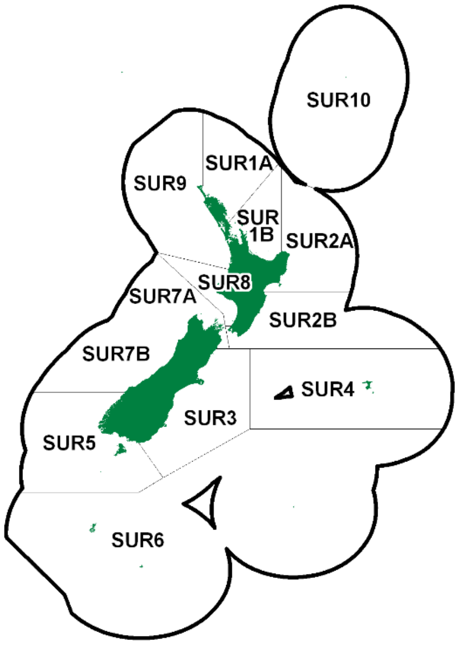
KINA (SUR)

(*Evechinus chloroticus*)
Kina



1. FISHERY SUMMARY

South Island kina was introduced into the Quota Management System in October 2002. North Island kina was introduced into the Quota Management System from October 2003. Five Quota Management Areas based on the FMAs 3, 4, 5, 7A (Marlborough Sounds) and 7B (west coast) were created in the South Island and seven Quota Management Areas based on the FMAs 1A (Auckland-North), 1B (Auckland-South), 2A (Central (East-North)), 2B (Central (East-South)), 8, 9 and 10 were created in the North Island. Current allowances, TACCs and TACs are summarised in Table 1. The historical landings and TACC values for the main SUR stocks are depicted in Figure 1.

Table 1: Current Total allowable catches (TAC, t) allowances for customary fishing, recreational fishing, and other sources of mortality (t) and Total Allowable Commercial Catches (TACC, t) for kina.

	TAC	Customary	Recreational	Other Mortality	TACC
SUR 1A	172	65	65	2	40
SUR 1B	324	90	90	4	140
SUR 2A	204	60	60	4	80
SUR 2B	102	35	35	2	30
SUR 3	42	10	10	1	21
SUR 4	255	20	7	3	225
SUR 5	480	10	10	5	455
SUR 7A	238	80	20	3	135
SUR 7B	26	10	5	1	10
SUR 8	26	12	12	1	1
SUR 9	33	11	11	1	10
SUR 10	0	0	0	0	0

1.1 Commercial fisheries

Most kina are found in waters less than 10 m deep and are harvested by breath-hold diving, although about 10% of the total catch in 1998–99 was by taken by dredge in SUR 7. Some target dredging also occurs in SUR 7. There is no minimum legal size for kina. Almost all of the roe harvested in this fishery is consumed on the domestic market. In 1988–89, competitive TACCs were established in the more important FMAs but not in east Northland (SUR 1) or at the Chatham Islands (SUR 4), both of which developed into productive fisheries in the 1990s (Table 2). On 1 October 1992 the Ministry of Fisheries placed a moratorium on the issue of permits to commercially harvest kina. The kina fishery has evolved considerably since the imposition of the moratorium. Where present, the competitive TACCs were either not caught or were exceeded, both by wide margins. Much of the increase in catch observed in SUR 5 in the early 1990s can be attributed to an experimental fishery developed in SUR 5, between Puysegur Point and Breaksea Island. The short-lived Kina Development Programme harvested kina from Dusky Sound in 1993 under special permit. In recent years landings have fluctuated around the TACCs for SUR 1A, 1B, 5 and 7A. Landings in SUR 2A, 2B, 3 and 4 and 7B have remained well below the TACCs with the exception of the fishing year 2016-17 in SUR 4 when landings exceeded 200 t.

Table 2: Total reported landings (t greenweight) of kina (SUR) by FMA and fishing year by all methods and target species.

Year	SUR 1	SUR 1A	SUR 1B	SUR 2	SUR 2A	SUR 2B	SUR 3	SUR 4	SUR 5	SUR 6, 8, & 9	SUR 7	SUR 7A	SUR 7B	Total
1983	66.2	-	-	33.0	-	-	4.8	11.3	0.5	3.6	26.3	-	-	157
1984	81.4	-	-	180.3	-	-	14.4	4.0	0.9	0.3	55.1	-	-	342
1985	64.5	-	-	83.8	-	-	4.0	7.4	4.6	0.9	99.6	-	-	275
1986	72.0	-	-	139.1	-	-	6.2	52.7	0.2	2	86.6	-	-	360
1987	52.1	-	-	142.6	-	-	2.4	28.4	4.3	0.1	52.6	-	-	283
1988	22.1	-	-	154.1	-	-	1.7	76.5	2.3	-	175.6	-	-	432
1989	35.5	-	-	92.8	-	-	0.8	216.6	19	1.5	6.2	-	-	372
1990	10.0	-	-	282.4	-	-	4.1	190.0	13.4	6.5	41.5	-	-	548
1991	71.5	-	-	87.2	-	-	21.3	35.3	166.9	4.4	56.3	-	-	443
1992	78.7	-	-	37.3	-	-	15.8	192.9	272.2	5	114.4	-	-	717
1993	89.7	-	-	170.4	-	-	9.9	21.8	*530.3	-	210.2	-	-	1 032
1994	150.7	-	-	176.7	-	-	8.8	55.3	327.2	2.3	98.2	-	-	820
1995	155.9	-	-	129.7	-	-	7.1	100.7	342.9	89.5	149	-	-	975
1996	174.5	-	-	41.2	-	-	6.0	99.5	446.4	0.1	142.2	-	-	910
1997	161.6	-	-	49.9	-	-	5.4	225.7	171.6	0.2	121.7	-	-	736
1998	134.8	-	-	36.5	-	-	3.8	303.1	91.2	1.4	144.7	-	-	716
1999	201.4	-	-	20.2	-	-	38.4	168.2	120.6	0.5	113.9	-	-	663
2000	297.4	-	-	14.5	-	-	50.4	396.5	106.3	0.1	87.9	-	-	956
2001	184.5	-	-	11.4	-	-	11.2	472.6	69.8	3.1	80.1	-	-	832
2001–02	237.0	-	-	3.0	-	-	5.2	368.0	184.9	-	31.7	-	-	829.7
2002–03	211.2	-	-	30.4	-	-	0.3	167.3	132.5	0.9	1.3	63.2	0	607.4
2003–04	1.7	26.9	111.0	0	14.5	4.6	0.3	114.8	199.1	3.8	0	85.4	0	562.3
2004–05	-	20.9	131.1	-	6.5	1.4	0.5	91.7	350.4	0.9	-	101.3	-	704.7
2005–06	-	41.0	138.6	-	22.1	0.2	< 0.1	70.2	473	4.0	-	72.1	5.3	826.5
2006–07	-	37.1	147.3	-	13.8	< 0.1	3.2	108.3	423	8.6	-	117.3	9.2	868
2007–08	-	31.7	140.4	-	18.0	0.2	2.1	147.4	276.2	5.8	-	134.6	6.5	762.9
2008–09	-	30.5	130.6	-	19.8	< 0.1	4.2	135.6	294.9	3.4	-	128.7	6.1	753.8
2009–10	-	40.8	129.9	-	0.1	0.3	5.1	89.7	320.4	2.3	-	119.7	3.5	711.9
2010–11	-	31.7	122.1	-	4.1	< 0.1	5.2	134.9	339.2	2.5	-	97.4	7.2	741.9
2011–12	-	37.9	134.2	-	5.9	1.1	4.3	137.7	402	8.2	-	131.6	6	862.1
2012–13	-	38.7	145.4	-	10.6	0	4.8	76.2	474.8	4.0	-	115.5	5	875
2013–14	-	43.4	139.3	-	10.1	3.8	0.4	101.2	462.8	9.1	-	126.3	0	896
2014–15	-	39.7	147.5	-	18.8	2.3	0.2	75.2	458.4	7.9	-	142.8	0	885
2015–16	-	40.9	131.6	-	17.8	2.5	4.1	116.3	453.1	2.5	-	134.0	2.5	901
2016–17	-	39.6	142.7	-	9.3	13.4	8.6	220.0	460.1	10.3	-	138.6	0	952
2017–18	-	38.7	136.2	-	21.8	7.9	<0.1	189.4	421.6	0.5	-	121.3	0	947
2018–19	-	36.5	133.3	-	9.0	13.2	2.3	94.8	466.7	4.8	-	140.0	0	891.5

Data from 1989 and 1990 are combined from the FSU and CELR databases. – indicates no recorded catch. Data for the period 1983 to 1999 are from Andrew (2001), and have been groomed. Catch estimates for 2000 and 2001 are taken directly from MFish. * includes 133 t caught in Dusky Sound experimental fishery. Catches from SUR 6, 8, and 9 have been pooled because too few permit holders recorded catches in these FMAs to report them singly.

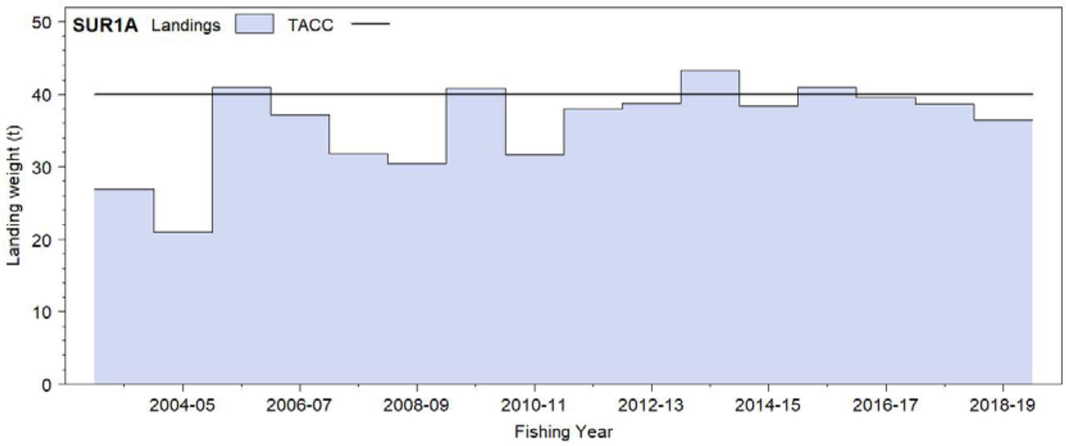
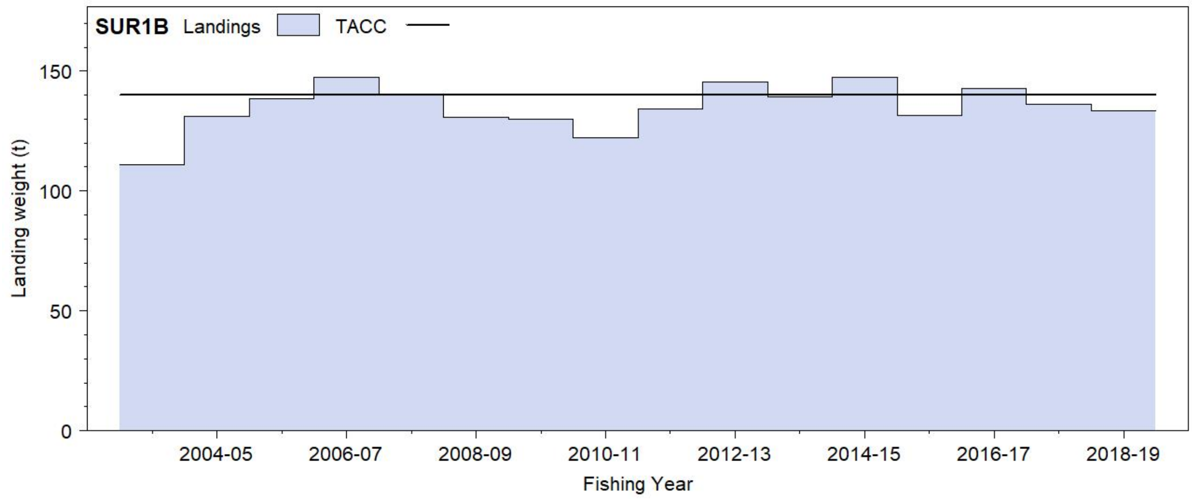
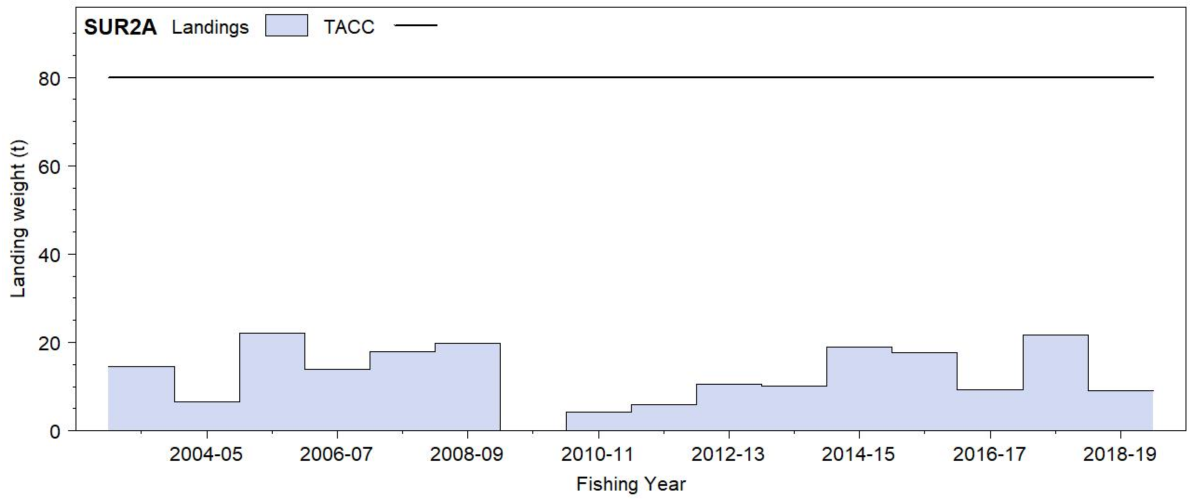


Figure 1: Reported commercial landings and TACC for the nine main SUR stocks. From top: SUR 1A (Northland). [Continued on next page]





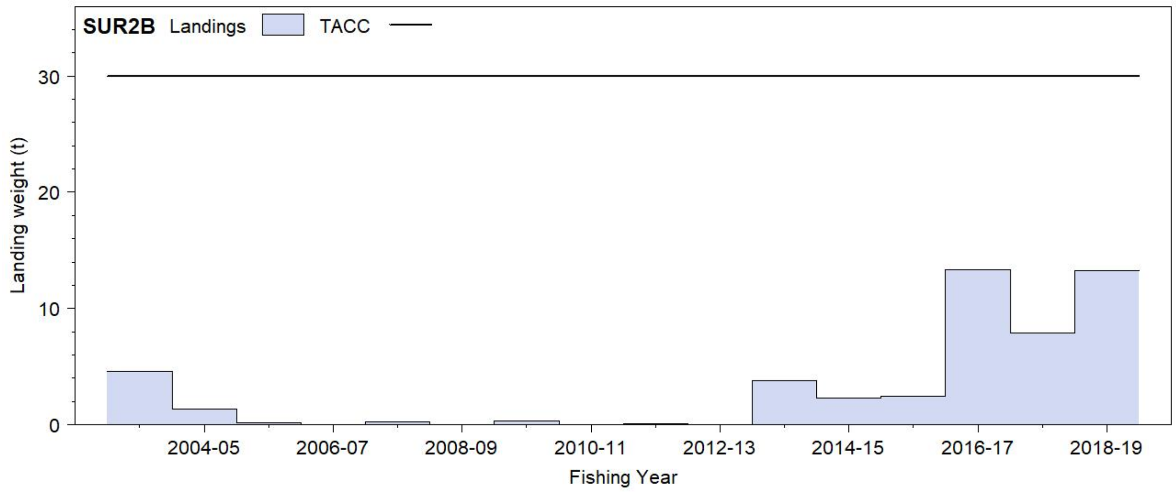
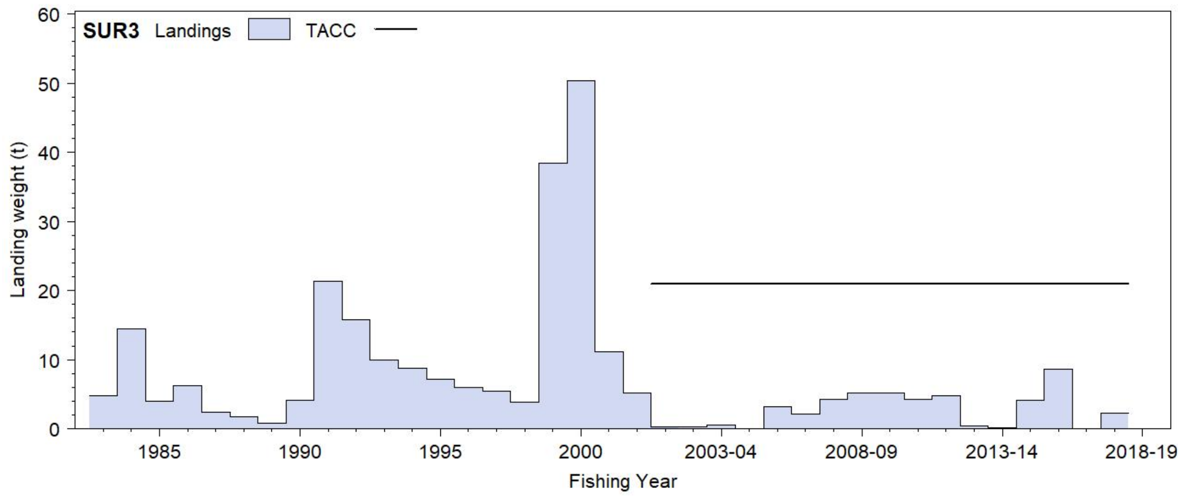
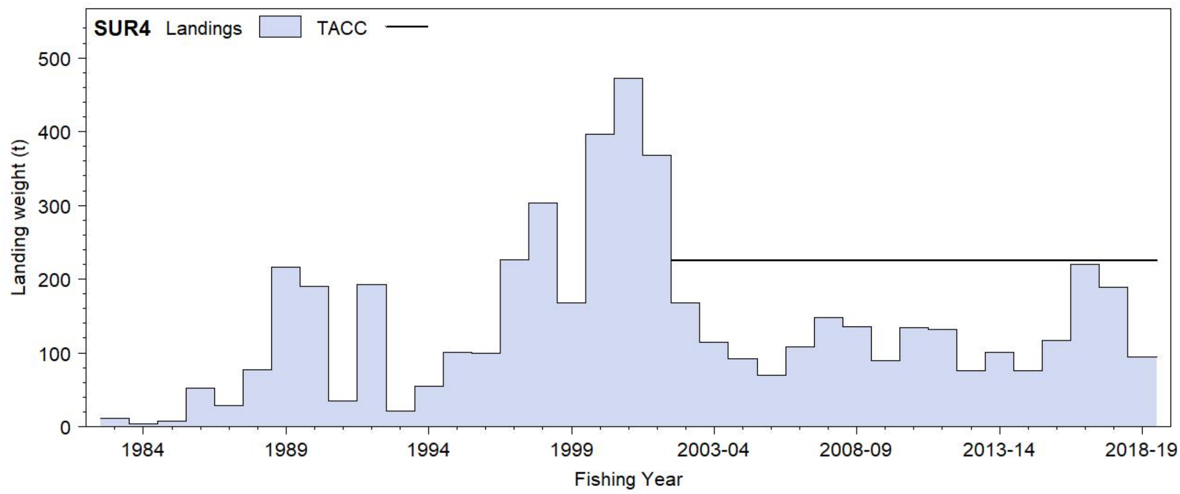


Figure 1: Reported commercial landings and TACC for the nine main SUR stocks. From top: SUR 1B (Hauraki Gulf, Bay of Plenty), SUR 2A (East Coast) and SUR 2B (Wairarapa, Wellington). Note that these figures do not show data prior to entry into the QMS for SUR 1A to SURB 2B and SUR 7A to SUR 7B. [Continued next page]





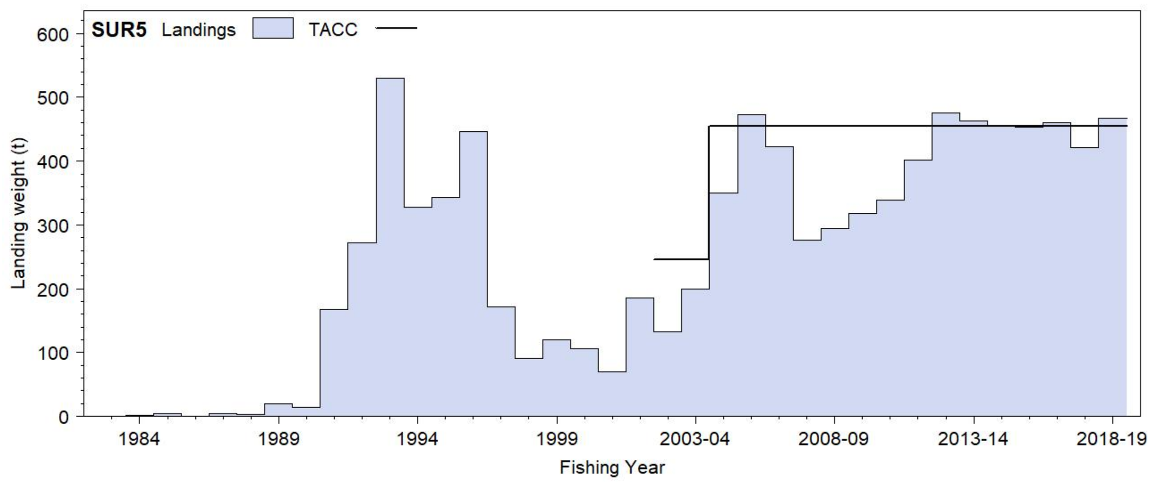
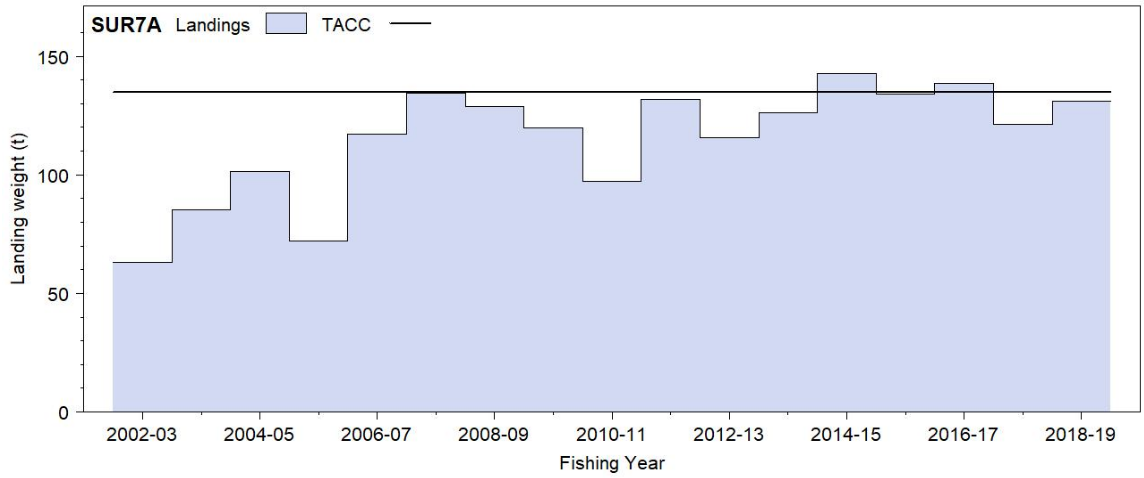


Figure 1 [Continued]: Reported commercial landings and TACC for the nine main SUR stocks. From top:, SUR 3 (South East Coast), SUR 4 (South East Chatham Rise) and SUR 5 (Southland). [Continued on next page].



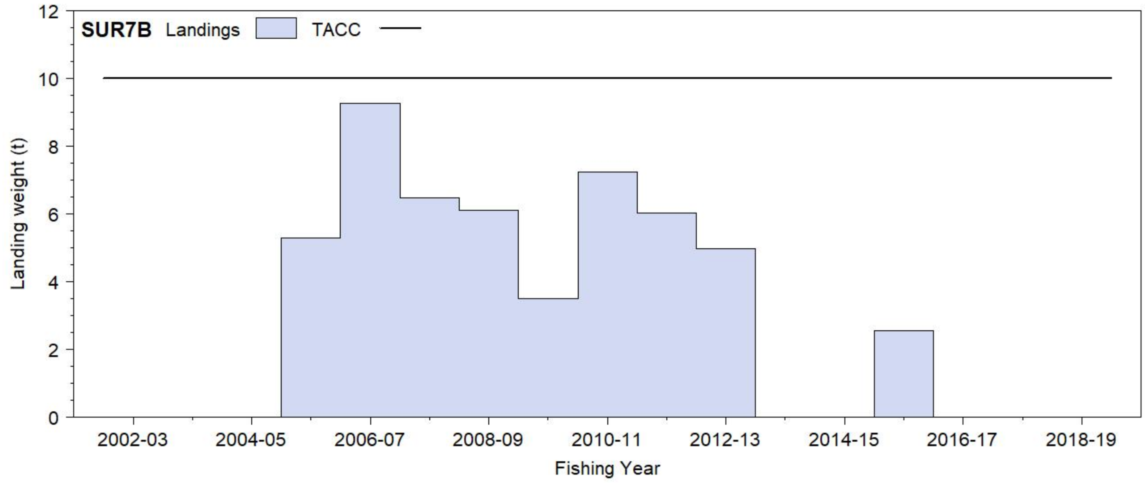


Figure 1 [Continued]: Reported commercial landings and TACC for the nine main SUR stocks. From top: SUR 7A (Challenger Nelson Marlborough) and SUR 7B (Challenger Westland). Note that these figures do not show data prior to entry into the QMS for SUR 1A to SURB 2B and SUR 7A to SUR 7B.

1.2 Recreational fisheries

Recreational catch was estimated using telephone-diary surveys in 1993–94, 1996 (Fisher & Bradford 1998, Bradford 1998) and 2000 (Boyd & Reilly 2002, Boyd et al 2004) (Table 3). There are no estimates of recreational catch from the Chatham Islands. In many instances, insufficient kina were caught to provide reliable estimates of the error associated with the estimates of total harvest. The harvest estimates provided by these telephone-diary surveys are no longer considered reliable for various reasons. A Recreational Technical Working Group concluded that these harvest estimates should be used only with the following qualifications: a) they may be very inaccurate; b) the 1996 and earlier surveys contain a methodological error; and c) the 2000 and 2001 estimates are implausibly high for many important fisheries. In response to these problems and the cost and scale challenges associated with onsite methods, a National Panel Survey was conducted for the first time throughout the 2011–12 fishing year. The panel survey used face-to-face interviews of a random sample of 30 390 New Zealand households to recruit a panel of fishers and non-fishers for a full year. The panel members were contacted regularly about their fishing activities and harvest information collected in standardised phone interviews. The panel survey was repeated in 2017–18. Harvest estimates for kina (in numbers) are given in Table 3 (from Wynne-Jones et al 2014, no estimates of mean weight were available from boat ramp surveys, Hartill & Davey 2015, Wynne-Jones et al 2019).

For the early telephone-diary surveys, catches in numbers were converted to catch in tonnes by assuming an average whole weight of 248.3 g per kina based on equal proportions across a size range 60–110 mm TD and a test diameter-weight relationship ($W = (6.27\times10^{-4})TD^{2.88}$) from Dusky Sound (unpublished data). These estimates of catch in tonnes should be considered as indicative only and may be very inaccurate. No estimates of mean weight were available to convert catches in numbers from the national panel survey to catch in tonnes.

Table 3: Estimates of recreational harvest of kina using telephone-diary surveys (1993–94, 1996, and 2000 surveys) and the national panel surveys (2011–12 and 2017-18).

Area	Number (thousands)	CV	Catch (t)*
1993–94 (telephone-diary)			
East Northland	109	0.60	27.1
Hauraki Gulf	14	-	3.5
Bay of Plenty	648	0.49	160.9
SUR 1	801	0.41	198.9
SUR 9	30	0.72	7.4
1996 (telephone-diary)			
SUR 1	316	0.24	78.5
SUR 2	61	-	15.1
SUR 3	12	-	3.0
SUR 5	20	-	5.0
SUR 7	2	-	0.5
SUR 8	43	-	10.7
SUR 9	30	-	7.4
2000 (telephone-diary)			
SUR 1	1 793	0.35	445.2
SUR 2	1 026	0.57	254.7
SUR 3	8	0.58	2.0
SUR 5	70	1.01	17.4
SUR 7	2	1.01	0.5
SUR 8	85	0.85	21.1
SUR 9	82	0.67	20.4
2011–12 (national panel survey)			
SUR 1	2 019	0.86	-
SUR 2	107	0.32	-
SUR 3	12	0.59	-
SUR 5	10	0.73	-
SUR 7	12	0.67	-
SUR 8	61	0.43	-
SUR 9	58	0.62	-
SUR total	2 279	0.73	-
2017–18 (national panel survey)			
SUR 1	296	0.21	-
SUR 2	181	0.24	-
SUR 3	5	0.68	-
SUR 5	10	0.44	-
SUR 7	2	0.95	-
SUR 8	34	0.38	-
SUR 9	12	0.85	-
SUR total	540		-

*Data as numbers caught supplied by Ngai Tahu Development Corporation. Catch in kilograms was estimated using the conversion rules described in the paragraph above.

1.3 Customary non-commercial fisheries

There is an important customary non-commercial harvest of kina by Maori for food. Limited quantitative information on the level of customary take is available from Fisheries New Zealand. These numbers are likely to be an underestimate of customary harvest as only the catch in numbers and kilograms are reported in the table below (Table 4).

1.4 Illegal catch

There is qualitative data to suggest significant illegal, unreported, unregulated (IUU) activity in this Fishery.

1.5 Other sources of mortality

Although there is no minimum legal size for kina, some incidental mortality is likely because roe quality (recovery rate and colour) is commonly assessed by opening ‘test’ kina underwater. These animals are not subsequently landed. There are no estimates of the magnitude to this incidental mortality.

Table 4: Fisheries New Zealand records of customary harvest of kina (reported as weight (kg) and numbers), since 1998-99. – no data. [Continued next page]

	SUR 1A				SUR 1B			
	Weight (kg)		Numbers		Weight (kg)		Numbers	
Fishing year	Approved	Harvested	Approved	Harvested	Approved	Harvested	Approved	Harvested
1998–99	–	–	–	–	–	–	–	–
1999–00	–	–	–	–	–	–	–	–
2000–01	–	–	–	–	–	–	–	–
2001–02	–	–	–	–	–	–	–	–
2002–03	–	–	–	–	–	–	–	–
2003–04	–	–	–	–	–	–	1 200	750
2004–05	–	–	–	–	–	–	400	210
2005–06	–	–	–	–	1 790	1 040	–	–
2006–07	850	850	7 300	7 300	12 055	9 785	6 025	5 475
2007–08	2 890	2 890	6 900	6 900	11 225	9 285	12 230	10 130
2008–09	3 290	3 290	1 900	1 900	11 540	8 940	10 524	9 924
2009–10	1 760	1 760	1 400	1 400	11 615	8 995	9 500	7 750
2010–11	3 570	3 570	–	–	26 582	20 142	21 890	19 050
2011–12	9 575	8 775	900	600	4 990	2 900	1 450	1 400
2012–13	9 704	9 210	2 300	2 170	4 325	3 460	400	400
2013–14	610	610	3 900	3 900	480	360	–	–
2014–15	–	–	–	–	16 495	15 265	2 700	2 150
2015–16	–	–	–	–	5 550	3 950	1 260	383
2016–17	–	–	–	–	1 885	1 175	5 950	3 173
2017–18	–	–	–	–	260	80	8 175	5 000
2018–19	–	–	–	–	2 120	1 883	2 820	1 645

	SUR 2A				SUR 2B			
	Weight (kg)		Numbers		Weight (kg)		Numbers	
Fishing year	Approved	Harvested	Approved	Harvested	Approved	Harvested	Approved	Harvested
1998–99	–	–	200	200	–	–	–	–
1999–00	–	–	2 350	460	–	–	–	–
2000–01	–	–	–	–	–	–	–	–
2001–02	–	–	100	80	–	–	–	–
2002–03	–	–	–	–	–	–	–	–
2003–04	–	–	–	–	–	–	1 350	1 350
2004–05	–	–	600	440	–	–	900	900
2005–06	–	–	7 500	4 940	–	–	200	200
2006–07	–	–	55 806	41 546	–	–	–	–
2007–08	–	–	60 546	46 599	–	–	–	–
2008–09	–	–	54 050	46 427	–	–	18 055	14 940
2009–10	–	–	17 100	13 640	–	–	2 700	1 510
2010–11	–	–	71 950	66 222	–	–	–	–
2011–12	–	–	120 160	87 639	–	–	–	–
2012–13	–	–	127 090	101 162	–	–	–	–
2013–14	–	–	132 715	98 129	–	–	–	–
2014–15	–	–	63 410	52 181	–	–	200	130
2015–16	–	–	20 030	16 072	–	–	460	420
2016–17	–	–	50 400	33 483	–	–	–	–
2017–18	–	–	11 400	5 950	–	–	–	–
2018–19	–	–	32 870	12 785	–	–	–	–

	SUR 3				SUR 4			
	Weight (kg)		Numbers		Weight (kg)		Numbers	
Fishing year	Approved	Harvested	Approved	Harvested	Approved	Harvested	Approved	Harvested
1998–99	–	–	–	–	–	–	–	–
1999–00	–	–	–	–	–	–	–	–
2000–01	–	–	–	–	–	–	–	–
2001–02	–	–	2 070	819	–	–	–	–
2002–03	–	–	650	150	–	–	–	–
2003–04	–	–	–	–	–	–	–	–
2004–05	–	–	–	–	–	–	–	–
2005–06	–	–	1 075	401	–	–	–	–
2006–07	–	–	2 020	1 417	–	–	–	–
2007–08	–	–	4 880	4 134	–	–	–	–
2008–09	–	–	3 099	968	–	–	–	–
2009–10	–	–	1 600	1 283	–	–	460	429
2010–11	–	–	17 170	16 092	–	–	–	–
2011–12	–	–	3 660	2 436	17	17	–	–
2012–13	–	–	5 600	4 629	–	–	–	–
2013–14	–	–	3 850	1 160	–	–	90	88
2014–15	–	–	1 910	1 382	–	–	40	40
2015–16	–	–	3 006	2 265	–	–	162	102
2016–17	–	–	1 805	1 570	–	–	310	310
2017–18	–	–	300	192	24	24	125	125
2018–19	–	–	–	–	50	50	–	–

Table 4 [Continued[

	SUR 5				SUR 7A			
	Weight (kg)		Numbers		Weight (kg)		Numbers	
Fishing year	Approved	Harvested	Approved	Harvested	Approved	Harvested	Approved	Harvested
1998–99	–	–	–	–	–	–	–	–
1999–00	–	–	–	–	–	–	–	–
2000–01	–	–	730	520	–	–	–	–
2001–02	–	–	4 810	4 039	–	–	–	–
2002–03	–	–	3 440	2 255	–	–	–	–
2003–04	–	–	–	–	–	–	–	–
2004–05	–	–	–	–	–	–	–	–
2005–06	–	–	700	700	–	–	–	–
2006–07	–	–	260	260	50	10	–	–
2007–08	–	–	7 715	7 715	–	–	1 220	960
2008–09	–	–	7 450	7 125	–	–	1 570	1 198
2009–10	–	–	2 380	1 706	–	–	2 170	2 040
2010–11	–	–	300	300	–	–	–	–
2011–12	–	–	2 659	2 659	–	–	–	–
2012–13	–	–	5 680	5 680	–	–	–	–
2013–14	–	–	1 000	910	–	–	–	–
2014–15	–	–	–	–	–	–	–	–
2015–16	–	–	3 840	3 170	–	–	–	–
2016–17	–	–	2 500	2 410	–	–	–	–
2017–18	–	–	2 150	2 150	–	–	–	–
2018–19	–	–	–	–	–	–	–	–

	SUR 7B				SUR 8			
	Weight (kg)		Numbers		Weight (kg)		Numbers	
Fishing year	Approved	Harvested	Approved	Harvested	Approved	Harvested	Approved	Harvested
1998–99	–	–	–	–	–	–	–	–
1999–00	–	–	–	–	–	–	–	–
2000–01	–	–	–	–	–	–	–	–
2001–02	–	–	–	–	–	–	–	–
2002–03	–	–	–	–	–	–	–	–
2003–04	–	–	–	–	–	–	–	–
2004–05	–	–	–	–	–	–	–	–
2005–06	–	–	–	–	–	–	–	–
2006–07	–	–	250	250	–	–	–	–
2007–08	–	–	–	–	–	–	–	–
2008–09	–	–	–	–	–	–	–	–
2009–10	–	–	–	–	–	–	–	–
2010–11	–	–	–	–	–	–	–	–
2011–12	–	–	–	–	–	–	–	–
2012–13	–	–	–	–	–	–	300	80
2013–14	–	–	–	–	–	–	–	–
2014–15	–	–	–	–	–	–	–	–
2015–16	–	–	–	–	–	–	–	–
2016–17	–	–	70	70	–	–	–	–
2017–18	–	–	–	–	–	–	–	–
2018–19	–	–	–	–	–	–	300	150

	SUR 9			
	Weight (kg)		Numbers	
Fishing year	Approved	Harvested	Approved	Harvested
1998–99	–	–	–	–
1999–00	–	–	–	–
2000–01	–	–	–	–
2001–02	–	–	–	–
2002–03	–	–	–	–
2003–04	–	–	–	–
2004–05	–	–	–	–
2005–06	–	–	–	–
2006–07	–	–	–	–
2007–08	50	50	–	–
2008–09	–	–	1 400	900
2009–10	100	80	–	–
2010–11	120	120	–	–
2011–12	350	320	–	–
2012–13	40	40	3 150	3 150
2013–14	400	280	500	380
2014–15	80	80	–	–
2015–16	–	–	–	–
2016–17	–	–	–	–
2017–18	–	–	–	–
2018–19	–	–	–	–

2. BIOLOGY

The biology and ecology of kina has been extensively studied; this literature has most recently been reviewed by Barker (2001). *Evechinus chloroticus* is found throughout New Zealand and the sub-Antarctic Islands. Kina has an annual reproductive cycle which culminates in spawning between November and March (Dix 1970, Walker 1984, McShane et al 1994a, 1996, Lamare & Stewart 1998, Lamare 1998). Size at maturity appears to vary considerably and may be as small as 30 mm and as large as 75 mm TD (Dix 1970, Barker et al 1998). In Dusky Sound, kina are reproductively mature at 50–60 mm T.D. (McShane et al 1996). Within these seemingly consistent patterns in the seasonality of the reproductive cycle there are many differences in the gonad size at small spatial scales.

Settlement is likely to be vary between years and appears to differ among locations and habitats (Dix 1972, Walker 1984). Laboratory work has shown that kina larval mortality increased with increasing concentrations of suspended sediment at realistic concentrations (Phillips & Shima 2006). In the field, but not in the laboratory, development abnormalities were found associated with suspended sediment concentrations, this suggests the importance of other environmental factors associated with terrestrial runoff (Schwarz et al 2006). Juvenile settlement and mortality has also been observed to increase with sediment at realistic concentrations in a size-specific manner in the laboratory; this agrees with juvenile patterns of distribution observed in the field (Walker 2007). Few small kina were observed in any of the surveys in Dusky Sound (McShane et al 1993). These results suggest that the productivity of stocks in Fiordland may be low and that recruitment over-fishing is a real possibility.

There is relatively little information available on the interactions between kina and its predators and competitors. Although a wide range of fish and invertebrates eat kina, there is limited evidence that these species control or limit populations of kina in Fiordland. Work in a marine reserve, where large predators such as reef fishes and crayfish are abundant, indicates that predators can control numbers of kina surviving the transition from crevice-bound to open substratum grazing (Cole & Keuskamp 1998, Babcock et al 1999). Babcock et al (1999) have drawn a direct link between the increases in snapper and crayfish populations and the long-term decline in kina populations in the Leigh Marine Reserve. There is however, no evidence that high kina densities limit rock lobster populations (Andrew & MacDiarmid 1991). It is likely, however, that changes in the abundance of kina, and the consequent changes in habitat representation, are part of a complex set of interacting processes, including but not exclusively, increased predation.

Kina compete with a range of invertebrate herbivores, including paua. There is no published evidence that high densities of kina limit paua populations in Fiordland. McShane (1997) reported that paua are abundant in Dusky Sound, and in Chalky and Preservation Inlets, but are rare in the fjords.

Lamare & Mladenov (2000) estimate that kina grow 8–10 mm in their first year of life. Growth rates will vary considerably depending on local conditions but kina may take 8–9 years to reach 100 mm TD, and very large individuals may reach ages of more than 20 years (Lamare & Mladenov 2000).

3. STOCKS AND AREAS

There appear to be few genetic differences in kina populations from Leigh (North Auckland) and Stewart Island (Mladenov et al 1997) which suggests that there is at least some mixing among populations. There is no direct evidence that populations of kina at the Chatham Islands differ genetically from those on the mainland, nor is there evidence that “populations” of kina at the Chatham Islands are dependent on the dispersal of larvae from the mainland.

4. STOCK ASSESSMENT

Although there is a wealth of information on the biology and ecology of this species (see Barker 2001 for reviews), there is relatively little that can be used to assess the status of exploited stocks. There have been no assessments of sustainable yield nor are there estimates of biomass or trends in relative abundance for any Fishstock (Annala 1995).

4.1 Estimates of fishery parameters and abundance

Andrew (2001) reported catch rates from both dive and dredge fisheries but advised caution in the interpretation of catch rate information of sedentary invertebrates, like kina, gathered at broad spatial scales.

Indices of relative abundance using timed swims have been reported for Ariel Reef in SUR 2 (Anderson & Stewart 1993), Chatham Islands (Schiel et al 1995, Naylor & Andrew 2002), and D'Urville Island and Arapawa Island in SUR 7 (McShane et al 1994a). Numerous surveys of kina have been done over the last 30 years in fished areas, mostly by university-based researchers (e.g. Dix 1970, Choat & Schiel 1982, Schiel et al 1995, Cole & Keuskamp 1998, Babcock et al 1999, Wing et al 2001). Naylor & Andrew (2002) reported a range of densities for kina around Chatham Island from 0.17/m^2 (northwest Chatham Island) to 1.6/m^2 (south east Chatham Island). These were generally lower than estimates made in the mid 1990s by Schiel et al (1995) (0.2/m^2 to 6/m^2). By contrast, even lower kina densities of around 0.1/m^2 were reported by McShane et al (1994a) for both Arapawa and D'Urville Island. Dix (1970) reported much higher mean relatively high densities of kina ranging from 2.2/m^2 in Queen Charlotte Sound to 6/m^2 at Kaikōura.

4.2 Biomass estimates

McShane & Naylor (1993) reported biomass estimates of 2500 and 500 t respectively for D'Urville and Arapawa Islands (SUR 7), presumably based on an expansion of density estimates reported in McShane et al (1994a) by an area estimate, however, the methods are not detailed.

Biomass was estimated for Dusky Sound and Chalky Inlet (SUR 5) prior to Dusky Sound being opened as an experimental fishery in May 1993 (McShane & Naylor 1991, 1993). Productivity and biomass was to be estimated by depletion methods but this was unsuccessful because only 133 t of the projected 1000 t was caught (McShane et al 1994b) and this catch was insufficient to cause a measurable change in the estimated biomass of kina.

4.3 Yield estimates and projections

MCY has not been estimated for any SUR fishstock. Within SUR 5, an *MCY* estimate of sustainable yield within Dusky Sound and Chalky Inlet was reported in Annala (1995). This estimate used Method 1 of Annala (1995) for new fisheries based on surveys done by McShane & Naylor (1991, 1993) and an estimate of a reference fishing mortality derived from McShane et al (1994a). The estimated annual sustainable yield of 275 t for these two areas has never been harvested because they are closed to commercial fishing except under special permit.

CAY has not been estimated for any SUR fishstock.

5. STATUS OF THE STOCKS

For all Fishstocks it is not known if current catch levels or TACCs are sustainable, or if they are at levels which will allow the stocks to move towards a size that will support sustainable yields.

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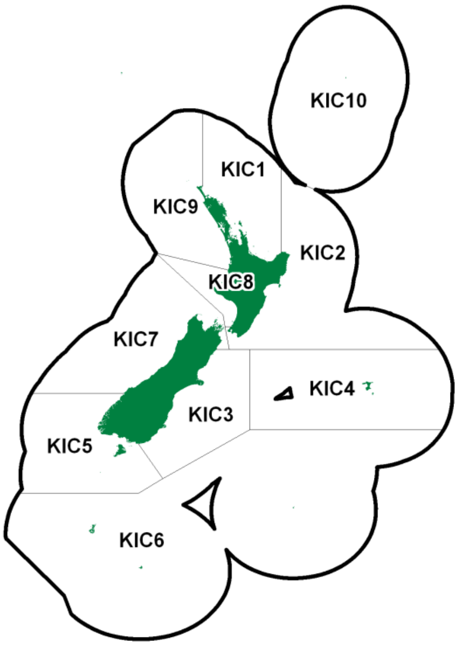
KING CRAB (KIC)

(*Lithodes aotearoa*, *Neolithodes brodiei*)



Lithodes aotearoa

Neolithodes brodiei

1. FISHERY SUMMARY

1.1 Commercial fisheries

King crabs (*Lithodes aoteroa* and *Neolithodes brodiei*) were introduced into the Quota Management System on 1 April 2004 with a combined TAC of 90 t and TACC of 90 t (Table 1). There are no allowances for customary, recreational, or other sources of mortality. The fishing year is from 1 April to 31 March and commercial catches are measured in greenweight. The two crabs are relatively distinct, and are found at different depths, but may be confused with other species of *Lithodes*.

Table 1: TACCs and reported landings (t) of king crab by Fishstock from 1993–94 to 2018–19. [Continued on next page]

Fishing	KIC 1		KIC 2		KIC 3		KIC 4		KIC 5	
year	Landings	TACC	Landings	TACC	Landings	TACC	Landings	TACC	Landings	TACC
1993–94	0	-	0.12	-	0.06	-	0	-	0	-
1994–95	0	-	0	-	0	-	0	-	0	-
1995–96	0	-	0	-	0.06	-	0	-	0	-
1996–97	0	-	0.08	-	0	-	0	-	0	-
1997–98	0	-	0	-	0	-	0	-	0	-
1998–99	0	-	0	-	0	-	0	-	0	-
1999–00	0	-	0	-	0.02	-	0	-	0	-
2000–01	0	-	0	-	0	-	0	-	0	-
2001–02	0.14	-	0.26	-	0	-	0	-	0	-
2002–03	0.01	-	0.01	-	0	-	0	-	0.03	-
2003–04	0		0		0.01		0.01		0	
2004–05	0.01	10	0.08	10	0.12	10	0.02	10	0.03	10
2005–06	0	10	0.21	10	0.12	10	0.18	10	0.03	10
2006–07	0	10	0.04	10	0.24	10	0.9	10	0.13	10
2007–08	0.08	10	0.41	10	0.21	10	1.46	10	0.07	10
2008–09	0.01	10	0.19	10	0.24	10	1.57	10	0.07	10
2009–10	0	10	0.2	10	0.35	10	1.49	10	0.03	10
2010–11	0.02	10	0.18	10	0.25	10	1.9	10	0.14	10
2011–12	0	10	2.48	10	0.07	10	0.02	10	0.04	10
2012–13	0	10	3.76	10	0.13	10	0.02	10	0.11	10
2013–14	0	10	10.31	10	0.11	10	0.12	10	0.33	10
2014–15	0.01	10	8.09	10	0.12	10	0.02	10	0.09	10
2015–16	0	10	2.08	10	0.08	10	0.04	10	0.04	10

Table 1 [Continued]

Fishing year	KIC 1 Landings	KIC 1 TACC	KIC 2 Landings	KIC 2 TACC	KIC 3 Landings	KIC 3 TACC	KIC 4 Landings	KIC 4 TACC	KIC 5 Landings	KIC 5 TACC
2016–17	0.02	10	0.03	10	0.05	10	0.29	10	0.02	10
2017–18	0.01	10	0.02	10	0.08	10	0.05	10	0.05	10
2018–19	0	10	0.02	10	0.45	10	0.05	10	0.41	10

Fishing year	KIC 6 Landings	KIC 6 TACC	KIC 7 Landings	KIC 7 TACC	KIC 8 Landings	KIC 8 TACC	KIC 9 Landings	KIC 9 TACC	Total Landings	Total TACC
1993–94	0	-	0	-	0	-	0	-	0.12	-
1994–95	0	-	0	-	0	-	0	-	0	-
1995–96	0	-	0	-	0	-	0	-	0.10	-
1996–97	4.00	-	0	-	0	-	0	-	4.10	-
1997–98	0	-	0	-	0	-	0	-	0	-
1998–99	0.03	-	0	-	0	-	0	-	0.01	-
1999–00	0.04	-	0	-	0.07	-	0	-	0.12	-
2000–01	0.06	-	0	-	0	-	0	-	0.04	-
2001–02	0.03	-	0	-	0	-	0	-	0.45	-
2002–03	0.05	-	0	-	0	-	0	-	0.06	-
2003–04	0.46		0		0		0		0.48	
2004–05	0.57	10	0	10	0	10	0	10	0.83	90
2005–06	0.51	10	0	10	0	10	0	10	1.05	90
2006–07	0.31	10	0	10	0	10	0.02	10	1.62	90
2007–08	0.49	10	0.08	10	0	10	0	10	2.82	90
2008–09	0.42	10	0.06	10	0	10	0.06	10	2.56	90
2009-10	0.34	10	0	10	0	10	0	10	2.47	90
2010–11	1.04	10	0	10	0.2	10	0.03	10	3.73	90
2011–12	0.34	10	0	10	0	10	0	10	2.98	90
2012–13	0.14	10	0	10	0	10	0.04	10	4.16	90
2013–14	0.70	10	0	10	0	10	0	10	11.61	90
2014–15	0.50	10	0.01	10	0	10	0	10	8.84	90
2015–16	0.27	10	0	10	0	10	0.01	10	2.51	90
2016–17	0.21	10	0	10	0	10	0	10	0.63	90
2017–18	0.85	10	0.01	10	0	10	0	10	1.07	90
2018–19	0.74	10	0	10	0	10	0.01	10	1.66	90

*In 1995–96 and 1998–99, 47 kg and 1 kg of LMU were landed respectively, but no FMA was assigned to the landings. In 1996–97, 24 kg of NEB was landed but no FMA was assigned to this landing. These reported landings by species are included in the total landings for KIC in those years.

Landings have been reported from all QMAs, however these landings are small and may not reflect the actual catch. Most of the landed catch has been reported under the aggregated code KIC, although there are a few records by species (i.e., *L. aotearoa* [LMU] and *N. brodiei* [NEB]) mainly by the fisheries observers.

Most of the reported landings have come from KIC 2 from 2011–12 to 2015–16, which was fished under a special permit during that time; catches of 2.15 tonnes in 2013–14 and 2.3 tonnes in 2014–15 were taken under special permit. A special permit was also issued for KIC 6 in the 1996–97 fishing year (Table 1). Target fishing is by potting, although small quantities of crabs are taken as bycatch in fisheries such as orange roughy and squid. Figure 1 shows the historical landings and TACC for KIC 2. There was no target fishery between 2015–16 and 2018–19.

1.2 Recreational fisheries

There are no records of recreational use of these crabs and, because of their depth range, recreational catch is unlikely.

1.3 Customary non-commercial fisheries

There are no known records of customary use of these crabs and, because of their depth range, customary take is unlikely.

1.4 Illegal catch

There is no known illegal catch of these crabs.

1.5 Other sources of mortality

There is no quantitative information on other sources of mortality, although the crabs are sometimes taken as bycatch in orange roughy and squid fishing.

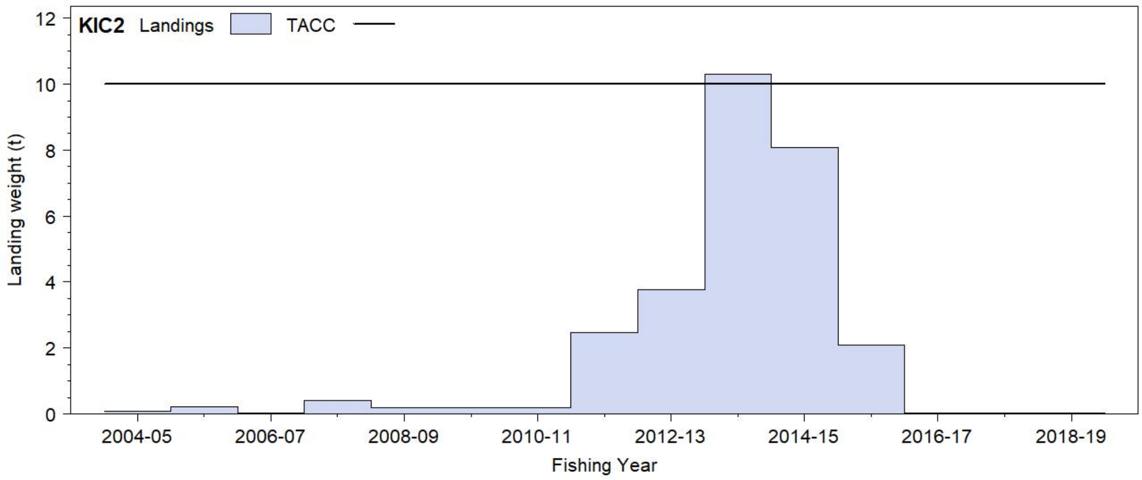


Figure 1: Reported commercial landings and TACC for KIC 2 (east coast North Island). Note that this figure does not show data prior to entry into the QMS and does not include the catch taken under special permits.

2. BIOLOGY

King crabs belong to the infra order Anomura, and differ from true crabs (Brachyura) in that the last pair of walking legs is reduced and folded inside the carapace.

L. aotearoa is a large, pear-shaped, dark purplish-red or brick red crab that has been found at depths between 120 m and 700 m, from the east coast of Northland to southern parts of the Campbell Plateau. It is a circumpolar, Southern Ocean species growing so large that the distance between the tips of the second legs can reach 1.25 m. The carapace width in males of this species may exceed 200 mm. Females are smaller.

N. brodiei is also pear-shaped and typically a uniform brick to bright red colour. It is widely distributed from the Three Kings Islands to the Campbell Plateau, where it occurs on soft and rocky bottom between about 800 m and 1100 m. Carapace width in this species is up to about 180 mm.

King crabs are thought to aggregate for protection during breeding and moulting. Migrations between shallow and deep waters also probably occur in response to moulting and mating, at least in near-shore populations. They occur mainly on soft substrates but have also been found on rocky bottoms. They are probably omnivorous, although animal food (sessile, sedentary, and mobile invertebrates, and small fish), including dead material, is their predominant food. Their principal predators are fish and seals.

Sexes are separate in all species of king crabs and they appear to be seasonal spawners, probably spawning in summer or autumn.

3. STOCKS AND AREAS

For management purposes stock boundaries are based on FMAs, however, there is currently no biological or fishery information which could be used to identify stock boundaries.

4. STOCK ASSESSMENT

4.1 Estimates of fishery parameters and abundance

There are no estimates of fishery parameters or abundance for any king crab fishstock.

4.2 Biomass estimates

There are no biomass estimates for any king crab fishstock.

4.3 Yield estimates and projections

There are no estimates of *MCY* and *CAY* for any king crab fishstock.

5. STATUS OF THE STOCKS

There are no estimates of reference or current biomass for any king crab fishstock.

6. FOR FURTHER INFORMATION

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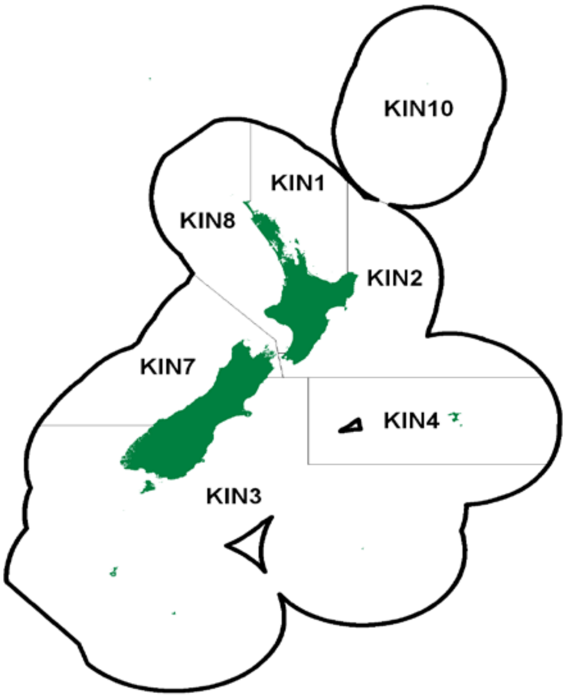
KINGFISH (KIN)

(*Seriola lalandi*)
Haku



1. FISHERY SUMMARY

Kingfish were introduced into the QMS on 1 October 2003. Current allowances, TACCs, and TACs are given in Table 1.

Table 1: Recreational and customary non-commercial allowances, TACCs, and TACs by Fishstock (t), as at 1 October 2019.

Fishstock	Recreational Allowance	Customary non-commercial Allowance	Other sources of fishing related mortality	TACC	TAC
KIN 1	459	76	47	91	673
KIN 2	65	18	24	63	170
KIN 3	6	4	1	6	17
KIN 4	1	1	0	1	3
KIN 7	20	2	4	15	41
KIN 8	31	9	7	45	92
KIN 10	1	0	0	1	2

1.1 Commercial fisheries

Historical estimated and recent reported kingfish landings and TACCs are shown in Tables 2 and 3, while Figure 1 shows the historical and recent landings and TACC values for the main kingfish stocks. Commercial landings of kingfish have been reported since the 1930s, with landings peaking at 144 t in 1940-41 before dropping to 11–41 t per annum between the mid-1940s and mid-1960s (Figure 1, Table 2). Landings increased from the late-1960s, exceeding 200 t per annum from the early 1970s, and reaching 532 t in 1992–93. Walsh et al (2003) note that landings for 1985 to 1988 are likely to be underestimated because of the change from the FSU to QMS reporting systems.

In the mid-1980s the commercial targeting of kingfish was restricted to certain methods and only fishers with 'kingfish' designated on their fishing permits could target the species (Walsh et al 2003). In the Auckland Fishery Management Area (FMAs 1 and 9), kingfish could be targeted by pole, troll, longline, and set net. After 1988, no new targeting permits were issued for kingfish. Although kingfish could be taken as bycatch, only fishers who had been granted targeting rights before 1988 could continue to target kingfish. In 1992 a moratorium was imposed on the catching of all non-QMS species. Fishers could only continue to target a non-QMS species if they held a target authorisation for that species as at September 1992 and they had taken the species at least once in the previous two years.

A minimum legal size (MLS) of 65 cm was established for kingfish in October 1993. This restriction applied to kingfish taken by all methods except trawling between 1993 and 2000. In December 2000, the Minister of Fisheries revoked the trawl MLS exemption (Walsh et al 2003).

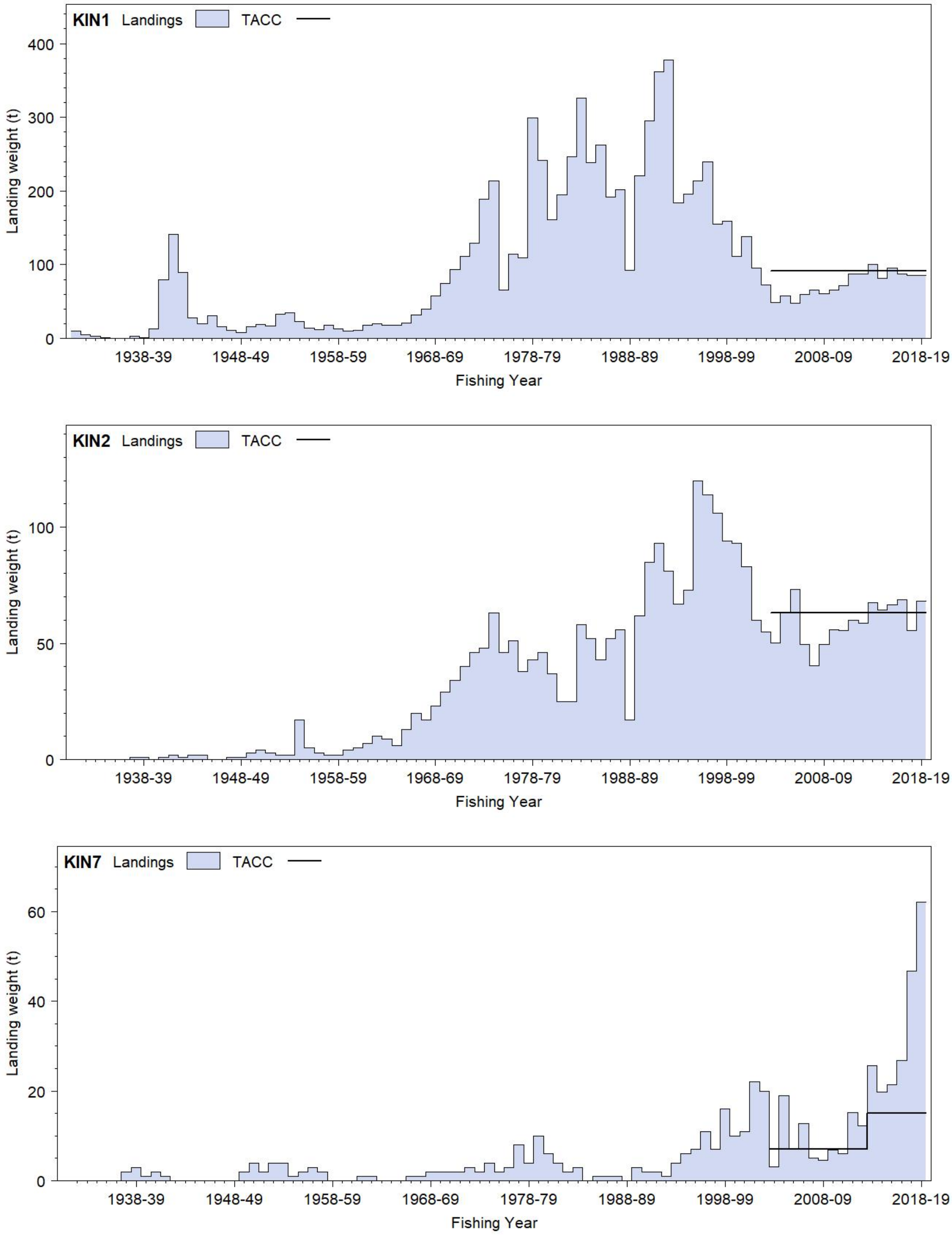


Figure 1: Reported commercial landings and TACC for the four largest KIN stocks. From top to bottom: KIN 1 (Auckland East), KIN 2 (Central East) and KIN 7 (Challenger). [Continued on next page]

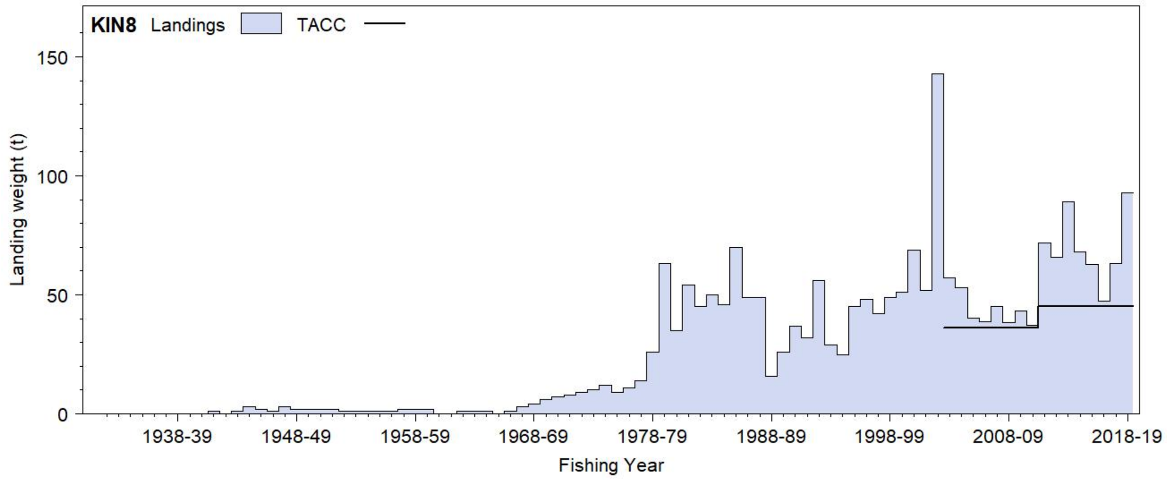


Figure 1 [Continued]: Reported commercial landings and TACC for the four largest KIN stocks. KIN 8 (Central Egmont).

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

Year	KIN 1	KIN 2	KIN 8	Year	KIN 1	KIN 2	KIN 8
1931–32	10	0	0	1957	18	2	2
1932–33	5	0	0	1958	13	2	2
1933–34	3	0	0	1959	10	4	2
1934–35	1	0	0	1960	11	5	0
1935–36	0	0	0	1961	18	7	0
1936–37	0	0	0	1962	20	10	1
1937–38	3	1	0	1963	18	9	1
1938–39	1	1	0	1964	18	6	1
1939–40	13	0	0	1965	21	13	0
1940–41	80	1	0	1966	32	20	1
1941–42	141	2	1	1967	40	17	3
1942–43	90	1	0	1968	58	23	4
1943–44	28	2	1	1969	75	29	6
1944	20	2	3	1970	93	34	7
1945	31	0	2	1971	111	40	8
1946	16	0	1	1972	129	46	9
1947	11	1	3	1973	189	48	10
1948	8	1	2	1974	214	63	12
1949	16	3	2	1975	66	46	9
1950	19	4	2	1976	114	51	11
1951	17	3	2	1977	109	38	14
1952	33	2	1	1978	299	43	26
1953	35	2	1	1979	242	46	63
1954	23	17	1	1980	161	37	35
1955	14	5	1	1981	195	25	54
1956	12	3	1	1982	247	25	45

Notes:
1. The 1931–1943 years are April–March but from 1944 onwards are calendar years.
2. Data up to 1985 are from fishing returns: data from 1986 to 1990 are from Quota Management Reports.
3. Data for the period 1931 to 1982 are based on reported landings by harbour and are likely to be underestimated as a result of under-reporting and discarding practices. Data includes both foreign and domestic landings.

The main fishing areas for kingfish are the east (KIN 1 and KIN 2) and west coast (KIN 8) of the North Island of New Zealand (Table 2). In recent years an increasing amount of landings have been taken off the west coast of the South Island (KIN 7). Of the peak landings of 532 t 1992–93, 71% was from KIN 1. From 1993–94 to 2002–03 the reported landings of kingfish decreased substantially in both KIN 1 and KIN 2. Possible reasons for this decrease include: the effect of the October 1993 introduction of a MLS of 65 cm on all methods other than trawl; changes in fishing patterns in the snapper and trevally target set net, trawl, and bottom longline fisheries (that were responsible for most of the non-target catch of kingfish); decreased target fishing for kingfish; and set net area closures in FMA 1 from October 1993.

The TACs set for kingfish stocks from 1 October 2003 were based on a 20% reduction in average landings in KIN 1, KIN 2, and KIN 8. Commercial catches in KIN 1 were substantially below the TACC from 2003–04 to 2010–11 and have been around the TACC since then. Except for 2005–06, landings in KIN 2 also remained at or below the TACC until 2012–13, but have exceeded the TACC in five of the six subsequent years. In KIN 8 landings dropped to just above the TACC from 2005–06 to 2010–11 but have typically been substantially above the TACC since then. Landings in KIN 7 and KIN 3 have increased substantially since 2011–12, with landings in KIN 7 exceeding the TACC of 15 t by 47 t in 2018–19.

Set net, bottom trawl, and bottom longline accounted for 36%, 33%, and 15% respectively of the kingfish commercial catch on average from 1983–84 to 1999–2000 (Walsh et al 2003). Targeting of kingfish has been largely restricted to the set net fishery. Set netting was responsible for most of the commercial catch of kingfish in the 1990s, but set net catches decreased substantially from 2000. Bottom longline catches have been largely restricted to KIN 1, primarily as a bycatch of the snapper target fishery.

Table 3: Reported landings (t) of kingfish by area (QMA) from 1983–84 to 2018–19. From 1986–87 to 2000–01, total landings are from LFRRs and landings by QMA are from CLRs prorated to the LFRR total. Totals include landings not attributed to the listed QMAs. MHR data from 2001–present. [Continued on next page]

Year	KIN 1		KIN 2		KIN 3		KIN 4	
	Landing	TACC	Landing	TACC	Landing	TACC	Landing	TACC
1983–84*	326	–	58	–	11	–	0	–
1984–85*	239	–	52	–	8	–	0	–
1985–86*	262	–	43	–	4	–	0	–
1986–87	192	–	52	–	9	–	0	–
1987–88	202	–	56	–	9	–	0	–
1988–89	92	–	17	–	4	–	0	–
1989–90	221	–	62	–	2	–	0	–
1990–91	295	–	85	–	6	–	< 1	–
1991–92	362	–	93	–	4	–	< 1	–
1992–93	378	–	81	–	4	–	0	–
1993–94	184	–	67	–	2	–	< 1	–
1994–95	196	–	73	–	2	–	0	–
1995–96	214	–	120	–	2	–	< 1	–
1996–97	240	–	114	–	7	–	< 1	–
1997–98	155	–	106	–	2	–	< 1	–
1998–99	159	–	94	–	3	–	< 1	–
1999–00	111	–	93	–	4	–	< 1	–
2000–01	138	–	83	–	4	–	< 1	–
2001–02	95	–	60	–	2	–	< 1	–
2002–03	73	–	55	–	1	–	0	–
2003–04	49	91	50	63	1	1	< 1	1
2004–05	58	91	63	63	1	1	0	1
2005–06	48	91	73	63	< 1	1	0	1
2006–07	60	91	50	63	1	1	0	1
2007–08	66	91	40	63	< 1	1	< 1	1
2008–09	61	91	50	63	< 1	1	< 1	1
2009–10	66	91	56	63	< 1	1	< 1	1
2010–11	71	91	55	63	< 1	1	< 1	1
2011–12	87	91	60	63	< 1	1	< 1	1
2012–13	88	91	59	63	2	1	<1	1
2013–14	100	91	67	63	1	1	<1	1
2014–15	81	91	64	63	1	1	<1	1
2015–16	95	91	67	63	2	1	<1	1
2016–17	88	91	69	63	3	1	<1	1
2017–18	85	91	55	63	4	1	<1	1
2018–19	86	91	68	63	8	6	<1	1

Table 3 [Continued]

Year	KIN 7 Landings	KIN 7 TACC	KIN 8 Landings	KIN 8 TACC	KIN 10 Landings	KIN 10 TACC	Total Landings	Total TACC
1983–84*	3	–	50	–	0	–	448	–
1984–85*	< 1	–	46	–	0	–	345	–
1985–86*	1	–	70	–	0	–	380	–
1986–87	1	–	49	–	0	–	356	–
1987–88	1	–	49	–	0	–	373	–
1988–89	< 1	–	16	–	0	–	460	–
1989–90	3	–	§26	–	< 1	–	428	–
1990–91	2	–	§37	–	< 1	–	448	–
1991–92	2	–	§32	–	9	–	512	–
1992–93	1	–	§56	–	< 1	–	532	–
1993–94	4	–	29	–	< 1	–	288	–
1994–95	6	–	25	–	< 1	–	302	–
1995–96	7	–	45	–	< 1	–	380	–
1996–97	11	–	48	–	6	–	427	–
1997–98	7	–	42	–	1	–	326	–
1998–99	16	–	49	–	< 1	–	323	–
1999–00	10	–	51	–	0	–	270	–
2000–01	11	–	69	–	< 1	–	304	–
2001–02	22	–	52	–	0	–	231	–
2002–03	20	–	143	–	0	–	292	–
2003–04	3	7	57	36	0	1	160	200
2004–05	19	7	53	36	0	1	195	200
2005–06	7	7	40	36	< 1	1	169	200
2006–07	13	7	39	36	0	1	161	200
2007–08	5	7	45	36	0	1	157	200
2008–09	5	7	38	36	0	1	154	200
2009–10	7	7	43	36	0	1	172	200
2010–11	6	7	37	36	0	1	171	200
2011–12	15	7	72	45	0	1	235	209
2012–13	12	7	66	45	0	1	226	209
2013–14	26	15	89	45	0	1	283	217
2014–15	20	15	68	45	0	1	235	217
2015–16	21	15	63	45	0	1	248	217
2016–17	27	15	48	45	0	1	235	217
2017–18	47	15	63	45	0	1	255	217
2018–19	62	15	93	45	0	1	317	222

* FSU data (Area unknown data prorated in proportion to recorded catch).
§ Some data included in FMA 1.

Kingfish were added to Schedule 6 of the Fisheries Act (1996) in October 2005 for all fishing methods except set net and in all areas. A special reporting code for Schedule 6 releases was introduced on 1 October 2006 to allow monitoring of releases. Kingfish released in accordance with Schedule 6 conditions and reported against this code are not counted against ACE. Use of Schedule 6 provisions to release kingfish alive was adopted from 2008 in KIN 8 and has been used in KIN 7 since 2012 as catches increased; Schedule 6 returns in KIN 7 have exceeded the retained catch since 2016 (Table 4). Use of Schedule 6 provisions is more recent in KIN 1 and is associated with a decision in parts of the bottom longline fishery to only retain fish that exceed the recreational MLS of 75 cm.

Table 4: Groomed landings (t) of kingfish by area (QMA) from 2006–07 to 2018–19 by destination. Landing code 'L' represents normal landings to a licensed fish receiver, code 'X' indicates returns to the sea under Schedule 6, and 'Other' includes all other non-intermediate landing codes.

Fishing year	KIN 1 L	KIN 1 X	KIN 1 Other	KIN 2 L	KIN 2 X	KIN 2 Other	KIN 3 L	KIN 3 X	KIN 3 Other	KIN 7 L	KIN 7 X	KIN 7 Other	KIN 8 L	KIN 8 X	KIN 8 Other
2006–07	62	0	1	50	0	0	1	0	0	12	0	1	37	0	3
2007–08	67	0	2	43	0	0	0	0	0	8	0	1	44	10	2
2008–09	62	0	2	52	0	0	0	0	0	4	0	1	36	1	3
2009–10	68	0	2	56	0	0	1	0	0	5	1	1	39	13	5
2010–11	70	0	2	55	0	0	1	0	0	5	1	1	34	8	4
2011–12	90	0	2	59	1	0	1	0	0	13	4	3	64	36	7
2012–13	87	0	2	56	0	0	1	0	0	8	4	4	63	44	8
2013–14	99	0	2	69	3	0	1	0	0	22	11	5	83	17	7
2014–15	80	1	2	64	7	0	1	1	1	15	12	5	63	9	6
2015–16	95	30	4	67	1	0	2	1	1	16	29	6	58	29	6
2016–17	87	50	4	69	6	0	3	1	2	21	21	4	42	36	7
2017–18	84	70	5	55	8	3	3	0	1	41	100	9	55	61	7

2018–19	81	34	5	66	6	3	6	2	2	59	103	11	88	101	7

1.2 Recreational fisheries

Kingfish is highly regarded by recreational fishers in New Zealand for its sporting attributes and as a table fish. Kingfish are most often caught by recreational fishers from private boats and from charter boats but are also a prized catch for spearfishers and shore-based game fishers. Kingfish (defined as southern yellowtail kingfish) are recognised internationally as a sport fish, and kingfish caught in New Zealand waters hold 34 of the 36 International Gamefish Association World Records.

1.2.1 Management controls

The main methods used to manage recreational harvests of kingfish are minimum legal size limits (MLS), method restrictions, and daily bag limits. Fishers can retain and land up to three kingfish as part their daily bag limit. An increased MLS to 75 cm (from 65 cm) for recreationally caught kingfish was introduced on 15 January 2004.

Many clubs, competitions, and charter boats have implemented a voluntary limit of one kingfish retained per person per day, and a number of gamefish clubs have also adopted a minimum size limit of 100 cm for kingfish. A high proportion of private and charter recreational catch is released (Holdsworth et al 2016b)

1.2.2 Tag and release

A voluntary recreational tagging programme has released 23 684 kingfish in New Zealand (1975 to 2019). Anglers feel they are contributing to research and conservation of stocks, while still getting recognition of their catch. The research objectives are to collect detailed information on released fish to help characterise the fishery and collect growth and movement information from recaptured fish. There have been 1608 tagged kingfish recaptured in New Zealand (1977 to 2019), with an average of 36 recaptures (and 679 releases) per year over the last 10 years (Table 5) (Holdsworth & Saul 2019).

Most kingfish are caught close to their release location, even after many years. Ninety four percent of recaptures for fish at liberty for 30 days or more were within 100 nautical miles of the release point (Figure 2). The proportion of recaptured kingfish at distances (over 100 nautical miles) increases after 3 years. Although kingfish are also capable of extensive movements, with three trans-Tasman recaptures recorded, few recaptures are made outside of the QMAs in which the fish were released.

Table 5: The number of kingfish tagged and recaptured by year for the last 10 years.

	2009–10	2010–11	2011–12	2012–13	2013–14	2014–15	2015–16	2016–17	2017–18	2018–19
Releases	1 381	1 123	613	761	649	723	607	598	546	509
Recaptures	46	54	44	38	31	30	28	31	23	32

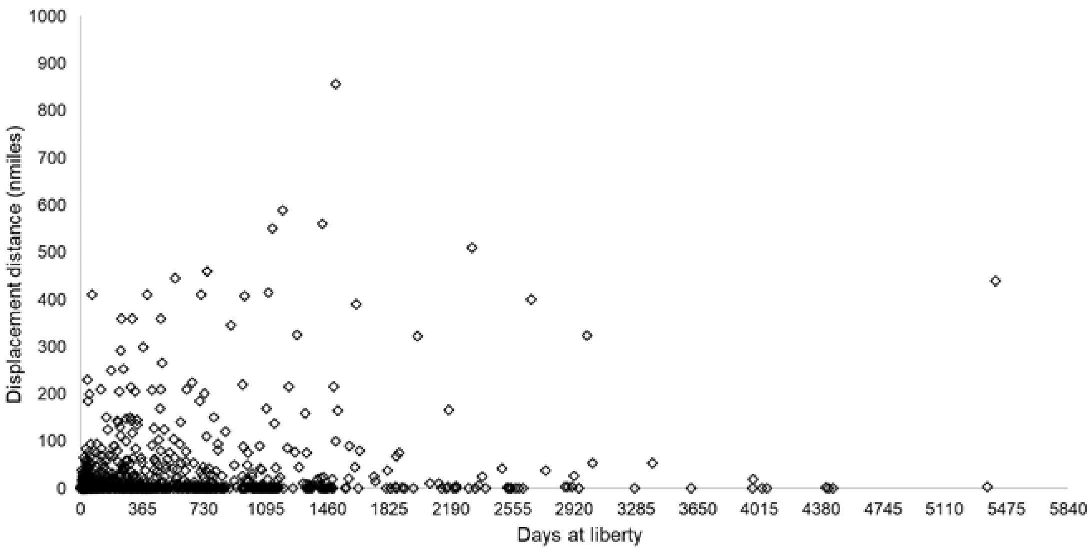


Figure 2: Kingfish straight line distance from release location by days at liberty 1977 to 2018.

1.2.3 Estimates of recreational harvest

Recreational catch 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 kingfish were calculated using an offsite approach, the offsite regional telephone and diary survey approach. Estimates for 1996 came from a national telephone and diary survey (Bradford 1998). Another national telephone and diary survey was carried out in 2000 (Boyd & Reilly 2002) and a rolling replacement of diarists in 2001 (Boyd & Reilly 2004 allowed estimates for a further year (population scaling ratios and mean weights from 2000 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 catch after a trip sometimes overstated their catch 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 for many species, 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 boat 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 and optimised to estimate snapper harvests in the Hauraki Gulf in 2003–04. It was then extended to survey the wider SNA 1 fishery in 2004–05 and to provide estimates for other species, including kingfish. The PELWG (Pelagic Working Group) indicated that the kingfish estimate should be considered with considerable caution due to the limited overlap between this method's sampling technique and the fisheries for kingfish, e.g., the target fisheries for kingfish are often in offshore areas from launches which were not sampled by the boat ramp survey. For this reason, the results from this survey have not been accepted or included in the working group report at this time.

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 development and implementation of a national panel survey for the 2011–12 fishing year and repeated in 2017–18 (Wynne-Jones et al 20014, 2019). The panel surveys used face-to-face interviews of a random sample of 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 catch information collected in standardised phone interviews. Note that the national panel survey estimate does not include recreational harvest taken under s111 general approvals on commercial vessels. The estimates of harvest from the 2011–12 panel survey were compared with direct estimates (using onsite surveys) for key stocks in FMA 1 (Edwards & Hartill 2015) and are considered reliable.

The point estimates of recreational harvest for KIN 1, KIN 7, and KIN 8 in 2012 and 2018 were above the allowances; recreational harvests in KIN 2 increased from 2012 to 2018 and exceeded the allowance in 2018.

Table 6: Recreational harvest estimates for kingfish stocks. The telephone/diary surveys ran from December to November but are denoted by the January calendar year. The national panel surveys 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). (Source: Tierney et al 1997, Bradford 1997, Bradford 1998, Boyd & Reilly 2002, Boyd et al 2004, Wynne-Jones et al 2014).

Stock	Year	Method	Number of fish	Total weight (t)	CV
KIN 1	1992	Telephone/diary	186 000	260	–
	1994	Telephone/diary	180 000	#228	0.09
	1996	Telephone/diary	194 000	234	0.07
	2000	Telephone/diary	127 000	800	0.18
	2001	Telephone/diary	109 000	683	0.17
	2012	Panel survey	52 056	535	0.13
	2018	Panel survey	69 473	571	0.16
KIN 2	1992	Telephone/diary	68 000	92	–
	1994	Telephone/diary	62 000	78	0.18
	1996	Telephone/diary	67 000	70	0.11
	2000	Telephone/diary	25 000	138	0.38
	2001	Telephone/diary	21 000	113	0.33
	2012	Panel survey	4 025	41	0.24
	2018	Panel survey	9 602	79	0.28
KIN 7	1992	Telephone/diary	10 000	20	–
	1994	Telephone/diary	–	–	–
	1996	Telephone/diary	9 000	13	0.19
	2000	Telephone/diary	2 000	11	0.55
	2001	Telephone/diary	1 000	9	0.86
	2012	Panel survey	2 079	21	0.38
	2018	Panel survey	3 289	27	0.25
KIN 8	1992	Telephone/diary	6 000	#8	–
	1994	Telephone/diary	–	–	–
	1996	Telephone/diary	2 000	#3	–
	2000	Telephone/diary	9 000	65	0.45
	2001	Telephone/diary	14 000	108	0.46
	2012	Panel survey	6 252	63	0.25
	2018	Panel survey	6 672	55	0.22

#No harvest estimate available in the survey report; estimate presented is calculated as average fish weight for all years and areas by the number of fish estimated caught.

1.3 Customary non-commercial fisheries

Kingfish is an important traditional food fish for Maori, but no quantitative information on the level of Maori customary non-commercial catch is available. The extent of the traditional fisheries for kingfish in the past is described by the Muriwhenua Fishing Report (Waitangi Tribunal 1988). Because of the coastal distribution of the species and its inclination to strike lures, it is likely that historically Maori caught considerable numbers of kingfish.

1.4 Illegal catch

There is no known illegal catch of kingfish.

1.5 Other sources of mortality

The extent of any other sources of mortality is unknown, however, handling mortality for sub-MLS size fish is likely to occur in both the recreational (sub 75 cm) and commercial (sub 65 cm) fisheries. Recreational fishers also release a large proportion of legal-size kingfish, and the use of Schedule 6 provisions to return legal-size kingfish to the sea if they are likely to survive has increased in commercial fisheries since 2010.

2. BIOLOGY

In New Zealand, kingfish are predominantly found around the northern half of the North Island but also occur from 29° to 46° S, Kermadec Islands to Foveaux Strait (Francis 1988), and to depths of 200 m. Kingfish are large predatory fish with adults exceeding one and a half metres in length. They usually occur in schools ranging from a few fish to well over a hundred fish. Kingfish tend to occupy a semi-pelagic existence and occur mainly in open coastal waters, preferring areas of high current and or tidal flow adjacent to rocky outcrops, reefs, and pinnacles. However, kingfish are not restricted to these habitats and are sometimes caught or observed in open sandy bottom areas and within shallow enclosed bays.

Estimates of age have been derived from opaque-zone counts in sagittal otolith thin sections. Estimates of kingfish von Bertalanffy growth parameters were also derived from recreational tagging data and otoliths collected from the eastern Bay of Plenty. Estimates of K and L_∞ were similar being 0.128 and 130 cm from the otolith age data and 0.130 and 142 cm from the tagging increment data, respectively (Table 7). The hard-structure ageing techniques have yet to be validated for New Zealand kingfish, although the position of the first annulus has been validated using regular samples of 0+ year old fish from a fish aggregating device (Holdsworth et al 2013; Francis et al 2005).

A Bayesian analysis of length and maturity data suggests that the length of 50% maturity is 97 cm in females and 83 cm in males (McKenzie et al 2014).

Estimates of M ranged from 0.20–0.25, however, these estimates are thought to represent an upper bound because the samples were taken from an exploited population.

Available biological parameters relevant to stock assessment are given in Table 7.

Table 7: Estimates of biological parameters.

Fishstock		**Estimate**		**Source**
2. Weight = a(length)^b (Weight in g, length in cm fork length).				
		Both Sexes		
		a	b	
KIN 1		0.03651	2.762	Walsh et al (2003)

3. von Bertalanffy growth parameters

Females			Males			Combined			
L_∞	k	t_0	L_∞	k	t_0	L_∞	k	t_0	
Bay of Plenty (2002)									
135.79	0.119	-0.976	123.81	0.137	-0.911	130.14	0.128	-0.919	McKenzie et al (2014)
East Northland (2010)									
124.48	0.232	-0.890	113.69	0.279	-0.790				Holdsworth et al (2013)
Bay of Plenty (2010)									
125.63	0.211	-0.987	119.32	0.226	-0.976				Holdsworth et al (2013)

3. STOCKS AND AREAS

Kingfish are widespread, occurring in temperate waters around South Australia, Japan, South Africa, and the western coast of the Americas (British Columbia to Chile) (Walsh et a. 2003). Although previously considered a single species, Martinez-Takeshita et al (2015) suggest that southern hemisphere kingfish should be considered a separate species, and that “a combination of dynamics in the sub-tropical and temperate regions permits a low-level of connectivity among *S. lalandi* sampled in South Africa, New Zealand, and Chile”.

Within New Zealand, a study based on meristic characters and parasite loads suggests two stocks of kingfish off the west and east coasts (Smith et al 2004). These stocks are contained within the Tasman Current on the west coast and the East Auckland Ccurrent and East Cape Current on the east coast, with little mixing between them. The east coast stock may be further subdivided into northeast and Hawkes Bay stocks based on limited exchange from tagging studies and parasite marker prevalence.

Tagging results suggest that most adult kingfish do not move outside local areas, with many tag returns close to the release site (Figure 2). However, some tagged kingfish have been found to move very long distances; there are validated reports of New Zealand tagged kingfish being caught in Australian waters and Australian tagged kingfish being recaptured in New Zealand waters.

In addition to the results from tagging studies, the age structure of recreational catches (Holdsworth et al 2016a) suggests that kingfish off the East Northland/Hauraki Gulf region and in the Bay of Plenty/East Cape region may comprise separate stocks.

4. STOCK ASSESSMENT

4.1 CPUE analyses

Standardised CPUE analyses were developed for KIN 1, 2, 7, and 8 during 2019 and 2020. Statutory catch, effort, and landings data from the commercial fisheries were used to develop indices for the mixed-target inshore bottom trawl fisheries in the Bay of Plenty and East Northland sub-areas of KIN 1, and for KIN 2 and KIN 8. Indices were also developed for the snapper-target bottom longline fishery in East Northland, and the offshore mid-water trawl fishery that targets jack mackerels in KIN 7 and KIN 8 off the western North Island and north-western South Island (from trips where an observer was present on the vessel). Additional indices were developed for the midwater fishery in KIN 7 and 8 from trips where an observer was present on the vessel, and for the recreational fisheries in the KIN 1 sub-areas using ramp survey data.

Indices using data from kingfish catches reported from amateur charter vessels were also considered but were rejected by the Working Group because (i) the recorded catches included fish returned to the sea without distinguishing returns of fish above and below the MLS, (ii) kingfish were targeted on features, where they aggregated, and CPUE was likely to be hyperstable, and (iii) charter boats targeting SNA mostly caught small kingfish.

In KIN 2, 7, and 8, and the bottom trawl fisheries in KIN 1, the proportion of the trip-level landed catches represented in aggregated event-level catch estimates can be low, especially where reporting used the CELR or TCEPR forms where estimated catches are limited to the top five species by weight per event. As a result, the CPUE analyses for the trawl fisheries used trip-level data where kingfish landings were modelled using covariates that were trip-level summaries of the effort data. These included number of tows, modal statistical area, mean hours per tow, mean bottom depth, and mean headline height and, for the midwater fishery in KIN 7 and 8, the proportion of jack mackerel target tows. Delta-lognormal models were fitted to the trip-level catch and effort data from bottom trawl fishers operating in East Northland, the Bay of Plenty, and KIN 2, and a delta-gamma model was fitted to KIN 8 bottom trawl trips. For the midwater fishery in KIN 7 and 8 there were few trips without kingfish landings and a lognormal model of positive catches was fitted. Analyses were restricted to the period after kingfish was introduced to the QMS and, in the case of the midwater trawl fishery, data were only used from trips where an observer was present on the vessel.

For the East Northland bottom longline fishery, the working group noted that kingfish was a valuable bycatch of the snapper longline fishery and that they appeared to have been consistently reported in estimated catches and landings since the QMS catch-effort data systems were introduced in the 1990 fishing year. As a result, four indices were prepared for this fishery: (i) a daily level index with the fine scale data available since 2008 aggregated to match the previous CELR-resolution data, and landings allocated to events using the approach of Starr (2007); (ii) a trip level index using landings data and aggregated effort data; (iii) an event level index using data from the LTCER form from 2008 onwards and landings allocated to events; and (iv) an index that was restricted to trips with a single set.

For the observed trips from the midwater trawl fishery in KIN 7 and 8, modelling used tow-level data and a delta-lognormal model was fitted using tow-level covariates.

Negative-binomial GLMMs were fitted to the number of fish caught during recreational bait-fishing trips recorded in the ramp survey data. Data were aggregated to location-month-target strata and the covariates offered to the models were: location, month, target species (KIN or SNA), number of events, mean fishers per event, and mean event duration. Location was included as a random effect. Separate trip-level models fitted to recreational fishing trips where the fishing method was reported as jigging and trolling were also presented to the working group. The indices derived from jigging and trolling models were more variable than the bait-fishing index because of lower numbers of surveyed events. Jigging and trolling are usually used to target kingfish aggregations on features, and there is believed to be a degree of learned hook avoidance associated with these catch methods.

A key consideration in the working group's evaluation of the resulting series and indices of relative abundance was the size composition of the kingfish catch in each fishery. Aggregated observer data (Figure 3) indicated that the bottom trawl fisheries primarily catch immature kingfish, whereas the midwater trawl fishery catches both juvenile and adult fish. No observer data were available from the bottom longline fishery, but packing data were used to examine the weight composition of kingfish landed from this fishery (Figure 4). This indicates that the bottom longline fishery also catches adult fish. The working group concluded that the bottom trawl indices were best regarded as indices of immature kingfish, whereas the midwater trawl and bottom longline indices included adult fish and were the better indices for the kingfish populations in the areas for which these indices are available.

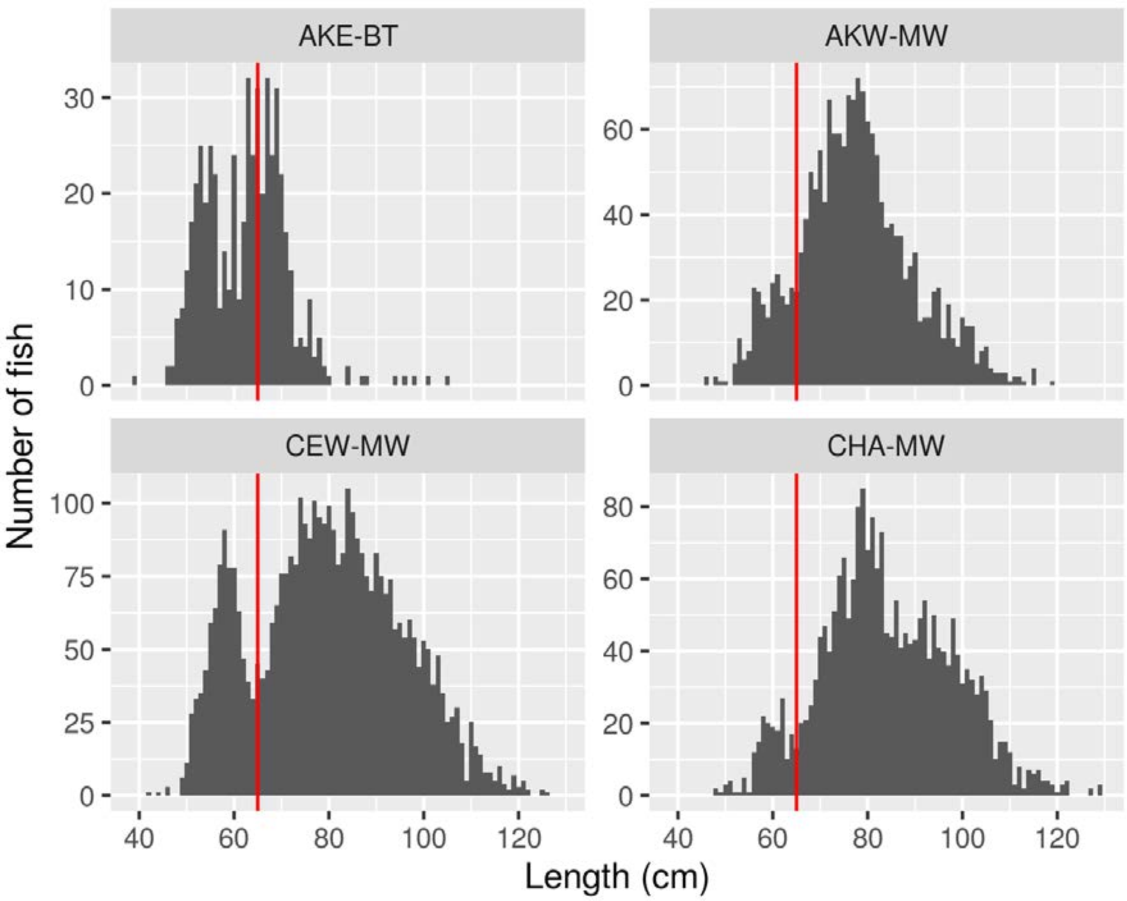


Figure 3: Raw aggregate length-frequency distributions for kingfish by area and method for kingfish using observer data collected from 2000–01 onwards, for strata where at least 200 fish were sampled. The red vertical line indicates the minimum legal size of kingfish for the commercial fishery.

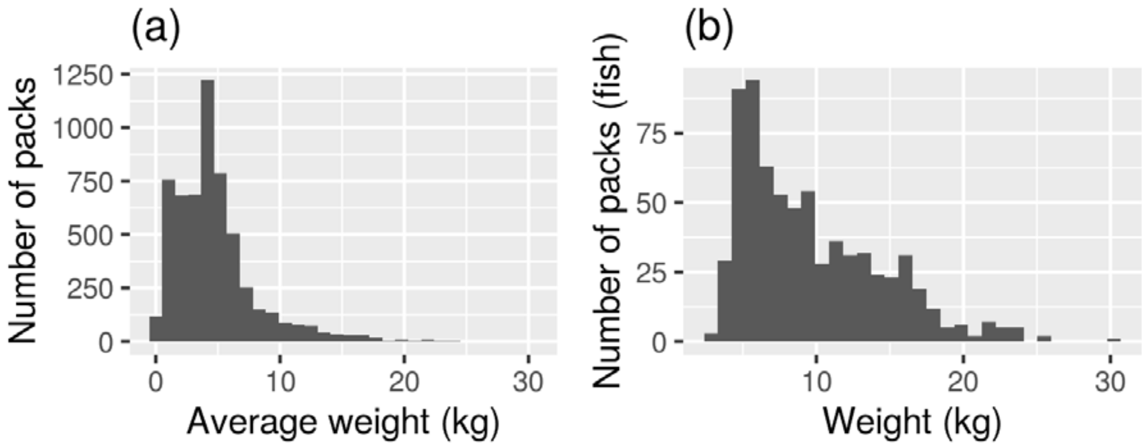


Figure 4: Weight frequency of (a) all kingfish and (b) single kingfish packed from the East Northland bottom longline fishery by Leigh Fisheries Limited between 2010 and 2016.

The different treatments of data from the East Northland bottom longline fishery result in similar indices (Figure 5), and indices from all three East Northland fisheries show a significant increase since 2010 (Figure 6) despite significant inter-annual variability in the longline index in this period. In the Bay of Plenty, the bottom trawl index increases consistently from 2004 to 2016 before declining somewhat to 2019 (Figure 7), whereas the recreational bait fishing index shows an increasing trend, but considerable year to year variation.

The trip based index from the statutory catch and effort data for the midwater trawl fishery in KIN 7 and 8 and the tow based observer index show similar trends (Figure 8), whereas the index from the KIN 8 bottom trawl fishery demonstrates a more cyclic pattern for much of the period before showing a rapid increase in 2018 and 2019.

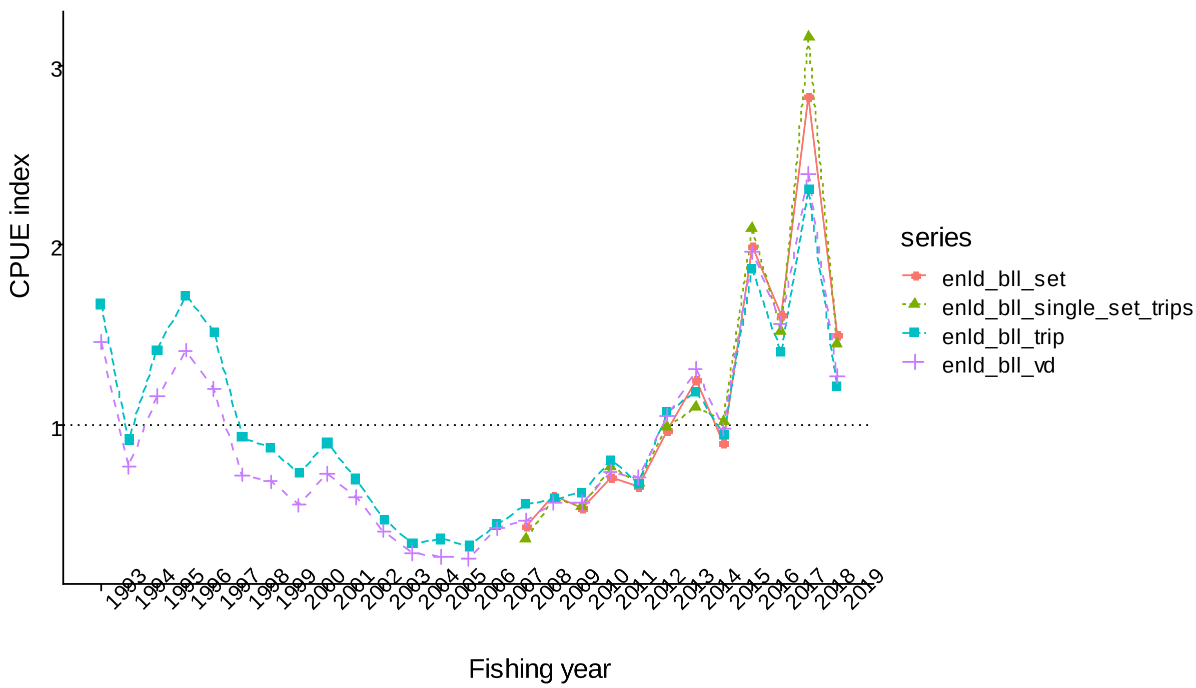


Figure 5: CPUE indices for the East Northland bottom longline fishery.

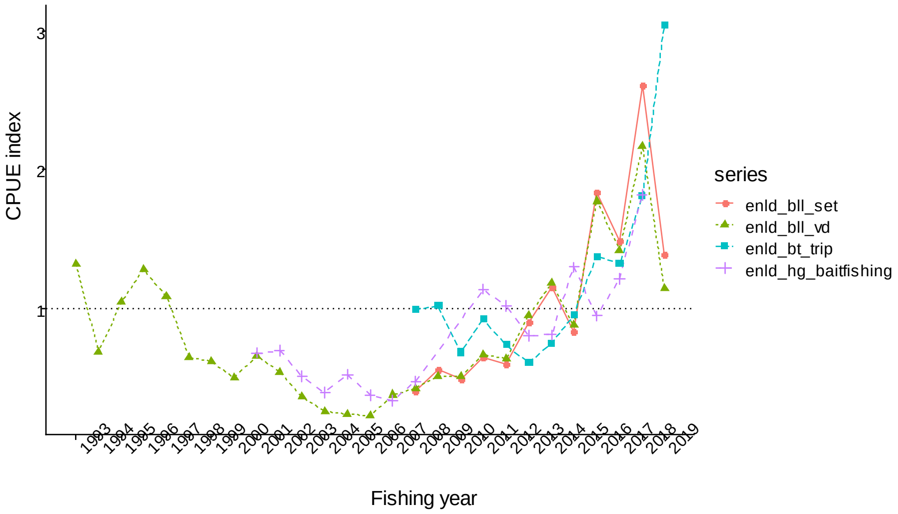


Figure 6: CPUE indices for the different East Northland fisheries.

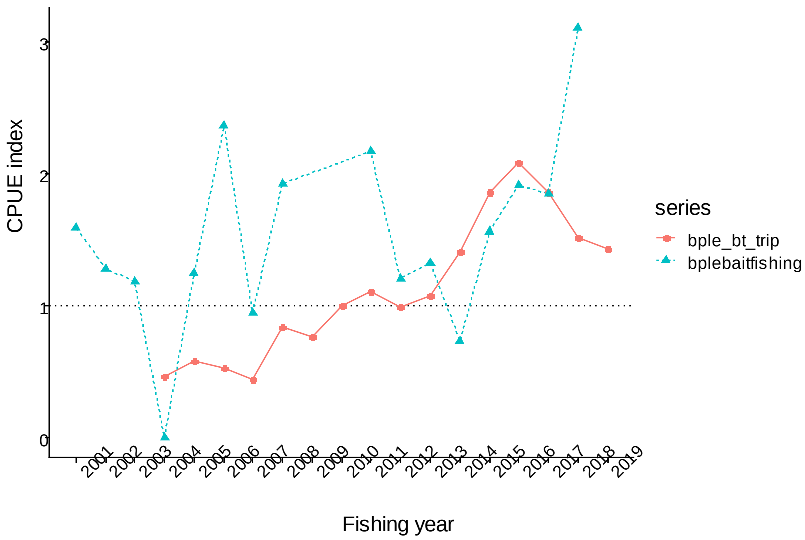


Figure 7: CPUE indices for the two Bay of Plenty fisheries.

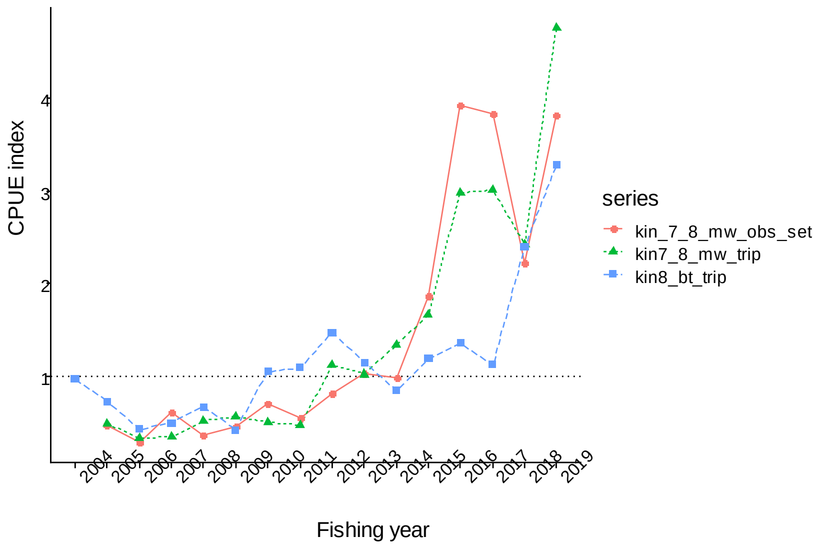


Figure 8: CPUE indices for the west coast North Island fisheries.

The bottom trawl indices of immature kingfish (Figure 9) share a general increasing trend from 2008 to 2017 but differ in detail. From 2016/2017 the indices from the Bay of Plenty and KIN 2 fisheries have declined whereas the indices from East Northland and KIN 8 show a large increase. However, although the Bay of Plenty and KIN 2 indices show similar trends from 2012 onwards, they show different trends from 2004 to 2011. Likewise, the East Northland and KIN 8 indices are similar from 2014 onwards, but their trends differ prior to this.

The indices for the commercial fisheries that take adult kingfish (the midwater trawl fishery in KIN 7 and 8, and the East Northland bottom longline fishery Figure 10) show similar patterns over the period they have in common, with a general increase from 2006 to 2019, although there is a notable divergence in 2019 with a downward fluctuation in the East Northland BLL index whereas the KIN 7&8 midwater trawl index continues to increase. The extended index for the East Northland BLL fishery indicates that abundance had previously declined over the period from 1993 to 2006.

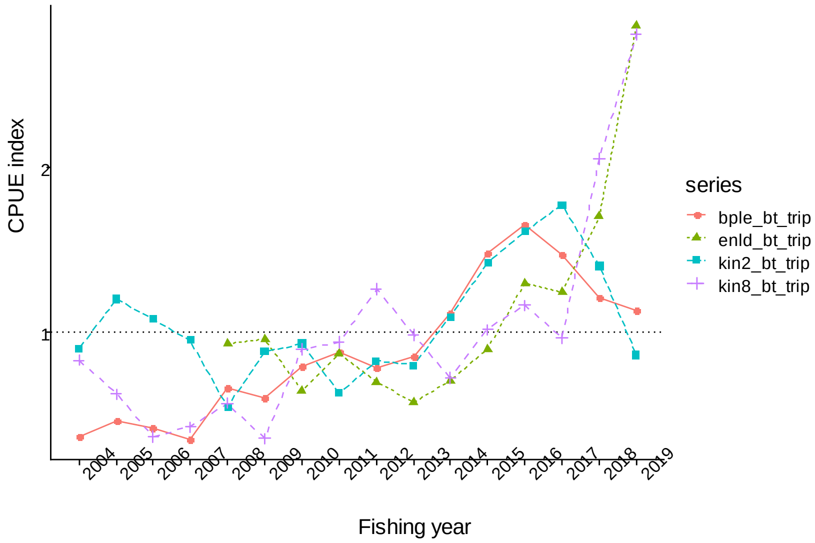


Figure 9: CPUE indices for immature kingfish from bottom trawl fisheries.

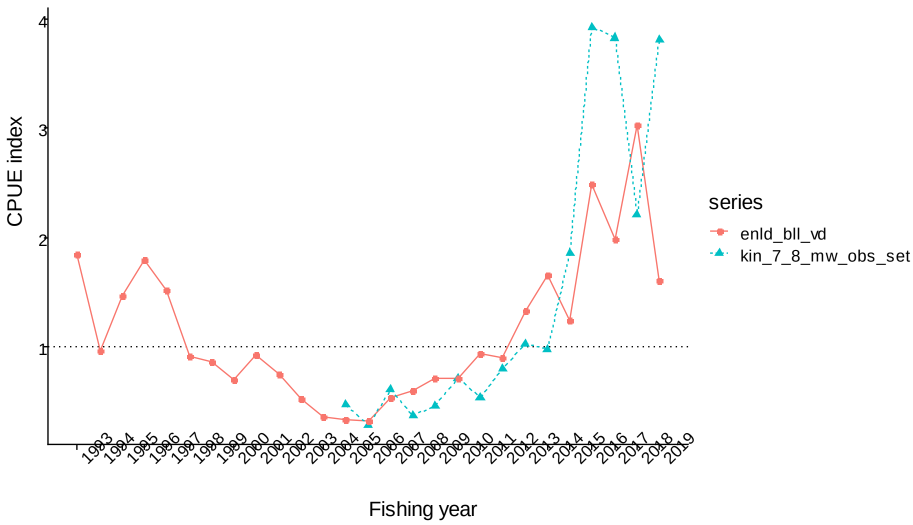


Figure 10: CPUE indices for immature and adult kingfish from the east and west coasts of the North Island.

Establishing B_{MSY} compatible reference points

The working group accepted the trip-level bottom longline index as the primary index of abundance for KIN 1 (East Northland) and the observer data based tow-level model for KIN 7 and KIN 8. Most of the available CPUE series start in the early 2000s and show steeply increasing trends in abundance for all areas. With the lack of stable periods of high catch and abundance, the working group concluded that the only defendable approach to determining reference points was to choose stable periods of low abundance early in the series as representing soft limits.

4.2 Catch at age sampling (KIN 1)

The age composition of the KIN 1 target recreational charter boat fleet catch was sampled in 2010–11 and in 2014–15 for the purpose of estimating total mortality (*Z*). Sampling was stratified into two regions, East Northland and Bay of Plenty, and two strata based on distance from the shore: inshore on the North Island continental shelf (< 200m) and around four offshore islands and pinnacles. Representative samples of kingfish over the MLS were obtained from the offshore Bay of Plenty and inshore East Northland with 831 and 863 kingfish measured over 75 cm in these two strata in 2014–15 (Table 8). Sampling was less successful in the inshore Bay of Plenty and the offshore East Northland but deemed usable by the Inshore Working Group.

All kingfish were measured and recorded per trip on participating vessels. Age length keys were developed using otoliths from retained fish. Bay of Plenty offshore samples in 2010–11 included more old fish than those from inshore (Holdsworth et al 2013). The Bay of Plenty offshore age distribution in 2014–15 was similar to that observed from the Bay of Plenty in 2010–11, although more older fish were evident in the 2014–15 sample. In 2014–15 there was a mode at age 5 in East Northland and age 6 in Bay of Plenty (Figure 11).

Table 8: Number of kingfish lengths and otolith sets collected in 2014–15 from the recreational fishery.

	KIN measured >75 cm	Otoliths collected	Otoliths used in the age-length-key
Inshore Bay of Plenty	211	57	212
Offshore Bay of Plenty	831	156	
Inshore EN/HGU	863	217	271
Offshore East Northland	318	55	

The Inshore Working Group agreed there was no valid method for combining inshore and offshore age frequencies by region for the purpose of estimating regional total mortality (Z), recommending instead that total mortality estimates be derived solely from the offshore age frequencies.

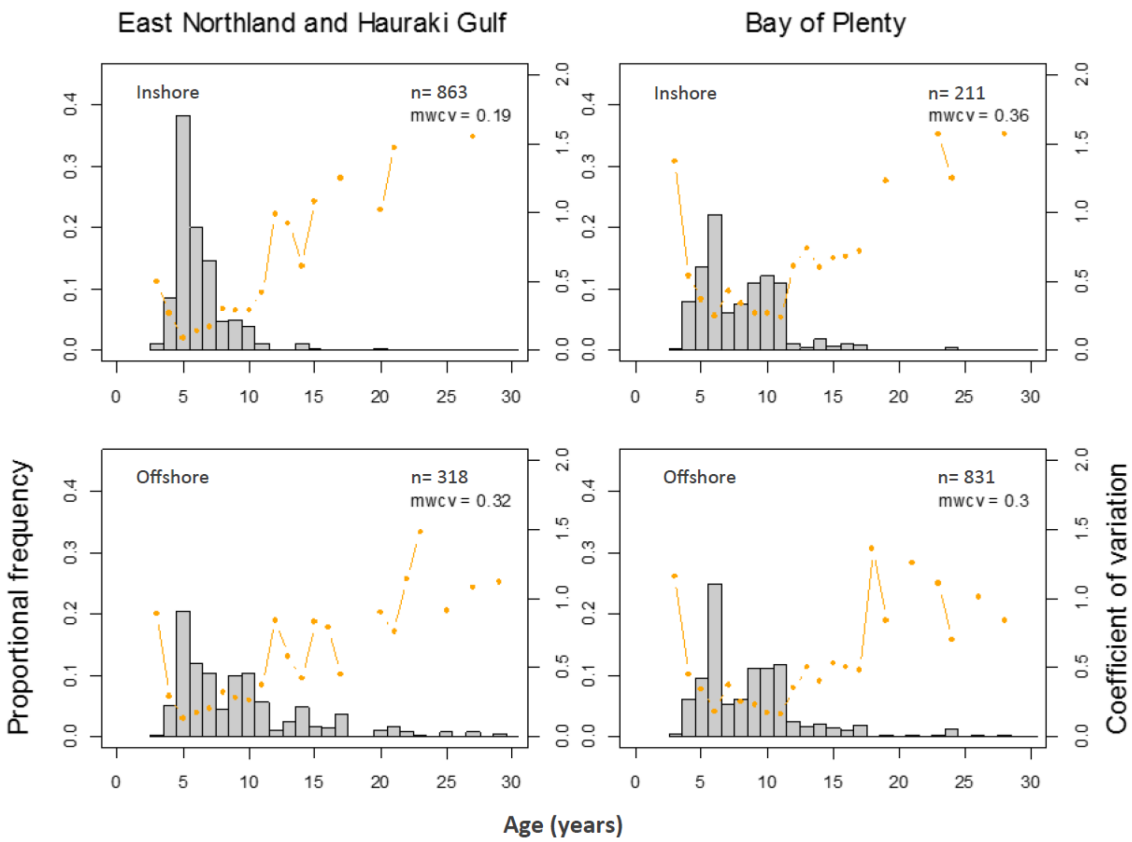


Figure 11: Kingfish age composition by region for inshore and offshore samples in 2014–15.

Total mortality estimates for offshore areas ranged from 0.19 to 0.25 for 2014–15 (Table 9). The $F_{SB40\%}$ target reference point for kingfish is 0.1, as derived by SSB/R methods (Holdsworth et al 2013). Assuming an instantaneous natural mortality rate (*M*) of 0.2, the target total mortality (Z) rate for kingfish is 0.3. None of the 2014–15 derived *Z* estimates given in Table 9 are higher than 0.3, suggesting that overfishing of kingfish in offshore areas of the Bay of Plenty and East Northland was unlikely. Although movement has been recorded between inshore and offshore areas, the relationship between these areas is unknown.

Table 9: Total mortality (*Z*) estimates for KIN 1 sub-regions as derived from catch-curve analysis (Chapman & Robson) of recreational charter boat catch-at-age data by fishing year, assuming 6 years is the age at full recruitment. The offshore estimate for the Bay of Plenty in 2009–10 was for the White Island area only and the offshore estimate for Northland in 2014–15 was for the Three Kings area only. Bootstrap CVs are shown in parentheses. EN/HG is East Northland/Hauraki Gulf, BoP is Bay of Plenty.

	EN/HG		BoP	
Sub-Region	2009–10	2014–15	2009–10	2014–15
Inshore	0.87 (0.12)	0.49 (0.08)	0.50 (0.14)	0.29 (0.09)
Offshore	–	0.19 (0.08)	0.30 (0.14)	0.25 (0.07)

4.3 Biomass estimates

Few kingfish are encountered in trawl surveys because they are capable of swimming faster the nets, suggesting that trawling is not a suitable method for monitoring changes in kingfish abundance. Kingfish are amenable to mark-recapture studies. However, up to now, tagging studies have been conducted solely to describe kingfish movement patterns and to estimate growth. Data from these programmes are inadequate to estimate stock biomass because tag releases and recoveries are voluntary, not systematic.

4.4 Other factors

It was recognised that if the increases in abundance represented a regime shift, or a significant change in productivity levels, with an associated increase in B_0, then the use of historical levels of relative abundance to establish a soft limit may not be appropriate.

4.5 Future research considerations

CPUE analyses

- Further investigation of the implications of modelling catch-effort data aggregated to trip levels vs finer scale data is needed, along with consideration of the range of descriptors that can be constructed for trip models (including weighting by catch). Consideration should also be given to the choice of modal values for area and month, and investigation of alternatives such as where fisheries spend the most time vs where the influence is greatest.
- Further consider the benefits/pitfalls of smoothing CPUE indices (and alternative smoothing methods) when generating reference points from partial quantitative stock assessments. Consider the period where smoothing is the most needed or appropriate, which will generally be the recent period, because this enables better interpretations of current stock status relative to reference periods when recent CPUE indices are fluctuating, and it may be more appropriate to calculate simple moving averages over recent years.
- Revisit the bottom longline CPUE for the Bay of Plenty; although the spatial extent of this fishery may be limited, it may be the best option for an index that monitors immature and adult fish in this area.
- Full catch histories by area (recreational and commercial) are required to estimate the relative exploitation rate.
- Consider finer scale information (particularly spatial information) on fishing effort patterns in the East Northland commercial longline fishery; however such information is only available from 2004–05.

Catch curve analysis

- Sensitivity analyses to determine the effect of progressively increasing the age of full recruitment on the estimates should be conducted.
- Improved data to better understand inshore–offshore movements should be collected.

General

- Develop full catch (removals) histories, including those for recreational fisheries.
- The CPUE based on charter boat catch and effort forms should be improved by reporting released kingfish less than the MLS separately from larger released kingfish.
- For KIN 7&8, there are observer length-frequency data, and some otoliths have been collected, in addition to an accepted CPUE index. The length-frequency and ageing data should be fully analysed with a view toward evaluating the feasibility of conducting a fully quantitative stock assessment in the future.
- Scaled observer length-frequency data, and confirmation of sampling representativeness, would also be informative in their own right.

5. STATUS OF THE STOCKS

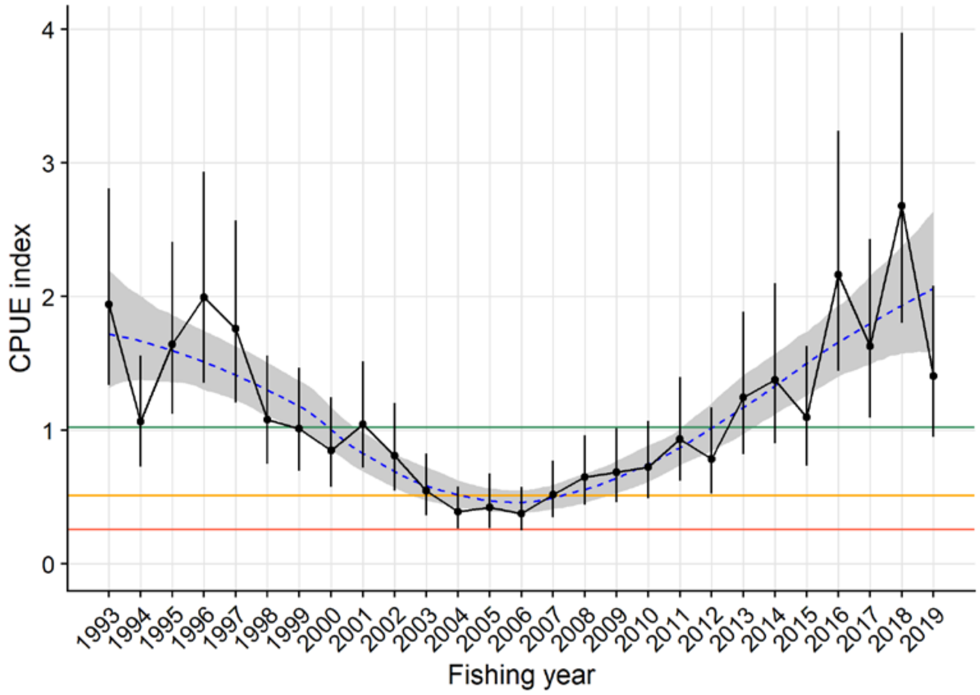
Stock Structure Assumptions

Meristic characteristics and parasite loads suggest that there are two stocks of kingfish off the west and east coasts. Extensive, opportunistic mark-recapture programmes indicate that most kingfish are recaptured close to the site of release, regardless of time at liberty, and there is little movement between the east and west coasts of the North Island. The age structure of recreational catches suggests that kingfish off East Northland/Hauraki Gulf and in the Bay of Plenty/East Cape regions may comprise separate stocks, consistent with movement patterns recorded from tagging studies. There is broad similarity in CPUE trends for East Northland and the west coast (KIN 7 and 8). Recruitment indices have shown similar trends for East Northland and the west coast, and the Bay of Plenty and FMA 2 since 2012.

For assessment purposes it is assumed that New Zealand kingfish comprise several biological stocks: East Northland, Bay of Plenty & KIN 2; KIN 7 & KIN 8. KIN 3 and KIN 4 are not considered here.

- **KIN 1 – East Northland/Hauraki Gulf**

Stock Status	
Year of Most Recent Assessment	2020
Assessment Runs Presented	Standardised CPUE from the East Northland bottom longline fishery (trip index)
Reference Points	Target: 40% B_0, interpreted as twice the smoothed mean CPUE for the period 2003–2007 Soft Limit: Mean smoothed CPUE from 2003–2007 Hard Limit: 50% of the soft limit Overfishing threshold: Twice the relative exploitation rate in 2003–2007
Status in relation to Target	Likely (> 60%) to be above the target
Status in relation to Limits	Very Unlikely (< 10%) to be below both the soft and hard limits
Status in relation to Overfishing	Unknown

Historical Stock Status Trajectory and Current Status-

Standardised catch per unit effort (CPUE) index for KIN 1 ENLD from bottom longlining targeting snapper, relative to the agreed reference points, and a loess smooth the values from which were used to define the reference period.

Fishery and Stock Trends	
Recent Trend in Biomass or Proxy	CPUE decreased from 1993 to 2006 and then increased to 2018. The index has shown greater year to year variation since 2015 and it decreased in 2019.
Recent Trend in Fishing Mortality or Proxy	In 2016, total mortality estimates from catch curve analyses indicated that *F* was unlikely to be at or below $F_{SB40\%}$ in inshore areas but likely to be at or below $F_{SB40\%}$ in offshore areas
Other Abundance Indices	The bait fishing (fishing with bait) index for the recreational fishery shows a similar long-term trend to the bottom longline index.
Trends in Other Relevant Indicators or Variables	An index for immature fish using data from the bottom trawl fishery declined from 2008 to 2014 before increasing.

Projections and Prognosis	
Stock Projections or Prognosis	As the index for immature kingfish shows a substantial increase in the last three years, it is anticipated that the recruited stock will continue to increase at current catch levels.
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 commence	Unlikely (< 40%)

Assessment Methodology and Evaluation		
Assessment Type	Level 2 – Partial Quantitative Stock Assessment	
Assessment Method	Standardised CPUE based on a delta-lognormal index from bottom longline	
Assessment dates	Latest assessment: 2020	Next assessment: Unknown
Overall assessment quality rank	1 – High Quality	
Main data inputs (rank)	Commercial catch and effort data Ramp survey data used to generate a secondary index of abundance Observer length frequency data used to interpret indices of abundance Packing data used to interpret indices of abundance	1 – High Quality 2 – Medium or Mixed Quality: spatial coverage is an issue 2 – Medium or Mixed Quality: data is not fully representative 2 – Medium or Mixed Quality: a detailed analysis of these data has not been completed
Data not used (rank)	N/A	
Changes to Model Structure and Assumptions	CPUE analyses were performed rather than catch curve analysis	
Major Sources of Uncertainty	It is unknown if all fish above the MLS returned to the sea are reported using the destination code X; such returns may be higher than reported	

Qualifying Comments
It was recognised that if the increases in abundance represented a regime shift, or a significant change in productivity levels, with an associated increase in B_0, then the use of historical levels of relative abundance to establish a soft limit may not be appropriate. The method of smoothing the CPUE trajectory may need further development and should be interpreted with caution. The bottom longline fishery catches immature and adult fish and so is not an index solely of the spawning stock biomass.

Fishery Interactions
Commercial kingfish catch is almost all bycatch in fisheries for other species.

- **KIN 1 – Bay of Plenty and KIN 2**

Stock Status	
Year of Most Recent Assessment	2016 with recruitment indices added in 2020
Assessment Runs Presented	Total mortality estimates from catch curve analysis for Inshore BPLE and Offshore BPLE Recruitment index of abundance based on bottom trawl CPUE
Reference Points	Target: $F_{SB40\%}$ (current estimate is $F_{SB40\%}$ = 0.1) Soft Limit: 20% B_0 Hard Limit: 10% B_0 Overfishing threshold: $F_{SB40\%}$
Status in relation to Target	Inshore BPLE: *F* in 2016 was Likely (> 60%) to be at or below the target Offshore BPLE: *F* in 2016 was Likely (> 60%) to be at or below the target

Status in relation to Limits	Soft Limit: Unknown for both Inshore BPLE and Offshore BPLE Hard Limit: Unknown for both Inshore BPLE and Offshore BPLE
Status in relation to Overfishing	Inshore BPLE: Overfishing is Unlikely (< 40%) to be occurring Offshore BPLE: Overfishing is Unlikely (< 40%) to be occurring

Historical Stock Status Trajectory and Current Status-

Fishery and Stock Trends	
Recent Trend in Biomass or Proxy	Unknown
Recent Trend in Fishing Intensity or Proxy	*F* appeared to have declined between 2010 and 2016 for Inshore BPLE and Offshore BPLE (although White Island was the only BPLE area assessed in 2010); likely to have been low for the decade to 2016 in all BPLE areas
Other Abundance Indices	The bait fishing index for the recreational fishery in the Bay of Plenty shows significant inter-annual fluctuations but has a generally increasing trend from 2001 to 2019.
Trends in Other Relevant Indicators or Variables	The CPUE indices for immature fish from the bottom trawl fisheries in the Bay of Plenty and KIN 2 show a steady increase from 2004 to 2016, before declining to 2019.

Projections and Prognosis	
Stock Projections or Prognosis	Catch curve analysis from catch sampling in 2014–15 indicated that total mortality was low for both the inshore and offshore regions, with fishing mortality below natural mortality and close to the target. The indices for immature fish are above average from 2013 to 2019 so the stock is expected to increase in the short term.
Probability of Current Catch or TACC causing Biomass to remain below or to decline below Limits	Soft Limit: Unknown for both inshore and offshore areas Hard Limit: Unknown for both inshore and offshore areas
Probability of Current Catch or TACC causing Overfishing to continue or to commence	Unlikely (< 40%) for both inshore and offshore areas

Assessment Methodology and Evaluation		
Assessment Type	Level 2 - Partial Quantitative Stock Assessment	
Assessment Method	Estimates of total mortality using Chapman-Robson estimator	
Assessment dates	Latest assessment: 2016 (the 2020 update added recruit series for BoP and KIN 2)	Next assessment: 2021
Overall assessment quality rank	1 – High Quality	
Main data inputs (rank)	Commercial catch and effort data Age structure of recreational catch in 2014–15 - Instantaneous rate of natural mortality (*M*) of 0.20 based on a maximum age of 23 years. - Age at 50% maturity (6 yr) - Age at MLS (4 yr) - Growth rate	1 – High Quality 1 – High Quality 1 – High Quality 1 – High Quality 1 – High Quality 1 – High Quality
Data not used (rank)	N/A	

Changes to Model Structure and Assumptions	-
Major Sources of Uncertainty	- Uncertainty in the estimate of *M* - Uncertain relationship between inshore and offshore areas; available data do not support much movement of inshore fish to offshore areas. Information from KIN 2 recreational catch at age is limited to the northern part of the QMA

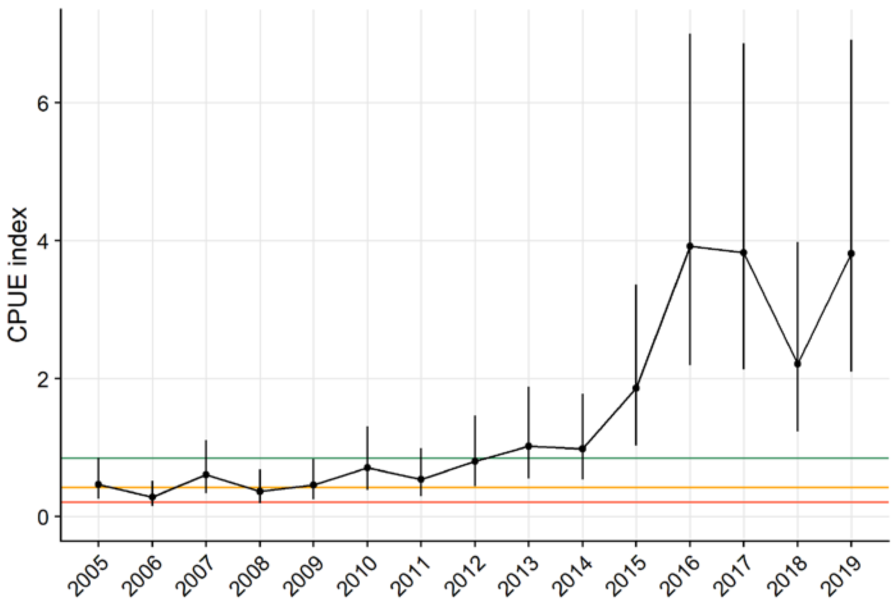
Qualifying Comments
The Z estimates are unweighted by relative catch by method (bait, jig) and area. The selectivity of the two capture methods differs substantially. The indices from the bottom trawl fisheries do not provide indices of abundance for the whole population

Fishery Interactions
Commercial kingfish catch is almost all bycatch in fisheries for other species.

- **KIN 7 and KIN 8**

Stock Status	
Year of Most Recent Assessment	2020
Assessment Runs Presented	Standardised CPUE from observer tow data in the jack mackerel target mid-water trawl fishery
Reference Points	Target: 40% B_0, interpreted as twice the mean CPUE in the period 2005–2009 Soft Limit: Mean CPUE from 2005–2009 Hard Limit: 50% of the soft limit Overfishing threshold: Twice the relative exploitation rate in 2005– 2009
Status in relation to Target	Very Likely (> 90%) to be at or above the target
Status in relation to Limits	Very Unlikely (< 10%) to be below both the soft and hard limits
Status in relation to Overfishing	Unknown

Historical Stock Status Trajectory and Current Status-



Standardised catch per unit effort (CPUE) index for KIN 7 and KIN 8 from mid-water trawling targeting jack mackerel (observer tow-level index), relative to the agreed reference points.

Fishery and Stock Trends	
Recent Trend in Biomass or Proxy	CPUE increased considerably from 2006/2007 to 2016 and has been relatively stable at a high level since.
Recent Trend in Fishing Mortality or Proxy	-
Other Abundance Indices	-
Trends in Other Relevant Indicators or Variables	An index for immature fish using data from the bottom trawl fishery fluctuates without trend from 2004 to 2014 before increasing with a particularly strong increase in 2018 and 2019. Unscaled observer length-frequency data are indicative of strong recruitment in 2015.

Projections and Prognosis	
Stock Projections or Prognosis	As there are indications of recent high recruitment it is anticipated that the spawning stock will increase at current catch levels, and the vulnerable biomass is expected to remain above target levels.
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 commence	Unknown

Assessment Methodology and Evaluation		
Assessment Type	Level 2 – Partial Quantitative Stock Assessment	
Assessment Method	Standardised CPUE based on a lognormal index from observed midwater trawl tows targeting jack mackerel	
Assessment dates	Latest assessment: 2020	Next assessment: Unknown
Overall assessment quality rank	1 – High Quality	
Main data inputs (rank)	Observer catch and effort data	1 – High Quality
	Commercial catch and effort data	1 – High Quality
	Observer length-frequency data	2 – Medium or Mixed Quality: data were unscaled
Data not used (rank)	N/A	
Changes to Model Structure and Assumptions	-	
Major Sources of Uncertainty	-	

Qualifying Comments
It was recognised that if the increases in abundance represented a regime shift or a temporary or permanent increase in productivity, with an associated increase in B_0, then the use of historical levels of relative abundance to establish a soft limit may not be appropriate.

Fishery Interactions
Commercial kingfish catch is almost all bycatch in fisheries for other species.

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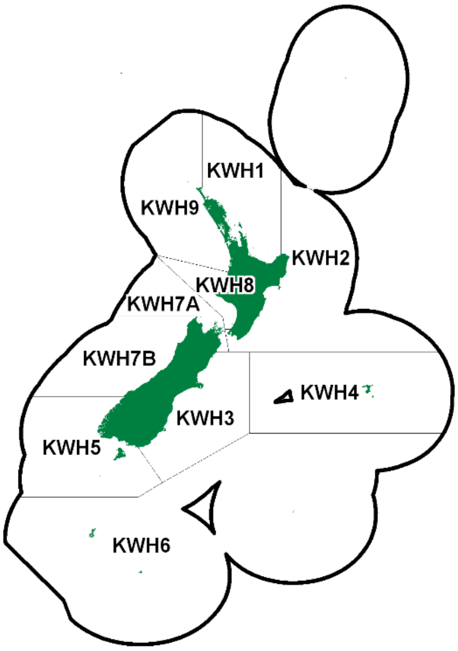
KNOBBED WHELK (KWH)

(*Austrofusus glans*)



1. FISHERY SUMMARY

Knobbed whelks (*Austrofusus glans*) were introduced into the Quota Management System on 1 October 2006. The fishing year is from 1 October to 30 September and commercial catches are measured in greenweight. TACs have been allocated in 10 QMAs (Table 1). This species is managed under Schedule 6 of the Fisheries Act for all stocks, which allows for them to be returned to where they were taken (as soon as practicable after being taken) providing they are likely to survive.

Table 1: Current TAC, TACC, and allowances for customary fishing, recreational fishing, and other sources of mortality for *Austrofusus glans*.

QMA	TAC (t)	TACC (t)	Customary fishing	Recreational fishing	Other sources of mortality
KWH1	3	1	1	1	0
KWH 2	3	1	1	1	0
KWH 3	5	3	1	1	0
KWH 4	8	6	1	1	0
KWH 5	3	1	1	1	0
KWH 6	4	2	1	1	0
KWH 7A	53	50	1	1	1
KWH 7B	3	1	1	1	0
KWH 8	3	1	1	1	0
KWH 9	3	1	1	1	0
Total	**88**	**67**	**10**	**10**	**1**

1.1 Commercial fisheries

Target fishing for knobbed whelks is by baited pots. Because economic returns for whelk fishing are poor, most of the historical catch is bycatch from oyster and scallop dredging and from bottom trawling. Due to the low value of this species it is likely that there is a high level of unreported discarded catch.

Landings shown in Table 2 for the period 1990–91 to 2005–06 were recorded under the generic code for whelks (WHE); however, the Ministry considers that in FMA 1, 2, 7, and 8 most reported landings were of the knobbed whelk *Austrofusus glans*. In FMA 3, 4, 5, and 6, the Ministry considers that about a third of reported landings were of the knobbed whelk, whereas the remainder were the large ostrich foot shell *Struthiolaria papulosa*.

Reported landings of knobbed whelk in FMA 1, FMA 2, and FMA 8 have been relatively low and variable since the 1990s and have been (largely or all) accounted for as bycatch. In FMA 7 in the early 1990s higher catches were reported as part of experimental fisheries in Golden Bay and Tasman Bay to provide stock assessment information in these areas (Tables 2 and 3). In the period 2011–12 to 2018–19 total reported landings averaged just 0.29 t, with just 0.02 t landed in 2018–19. Landings are split into two tables (before and after the 2006 fishing year) because reporting requirements changed when knobbed whelks entered the QMS.

Table 2: Reported landings (t) of whelks (WHE) by FMA from 1990–91 to 2005–06 from landing returns. See section 1.1 for an explanation of the proportion of WHE that are considered to be knobbed whelks.

Fishing year	FMA 1	FMA 2	FMA 3	FMA 4	FMA 5	FMA 6	FMA 7	FMA 8	FMA 9	Total
1990–91	0	0	0	0	0	0	44.976	0	0	44.976
1991–92	0	0	0	0	0	0	26.935	0	0	26.935
1992–93	0.021	0	0.018	0	0	0	1.762	0	0	1.801
1993–94	0	0.135	0	0	0	0	49.278	0	0	49.413
1994–95	0	0.707	0.545	0	0	0	21.458	0.593	0	23.303
1995–96	0	0.089	0.178	0	0	0	27.596	0	0	27.863
1996–97	0.002	0.174	0.144	0	0.003	0	8.959	0	0	9.282
1997–98	0	0	0.102	0.150	0	0	0.884	0	0	1.136
1998–99	0	0	0.223	2.205	2.470	0.150	0.570	0	0	5.618
1999–00	0	0	2.286	7.953	3.250	0.790	0.080	0	0	14.359
2000–01	0	0	10.467	17.497	3.538	4.765	0.141	0	0	36.408
2001–02	0	0	1.474	3.995	0.515	1.755	0.002	0	0	7.741
2002–03	0	0	0.212	0.020	0.004	0.780	0.077	0	0	1.093
2003–04	0.035	0	0.491	0	0	0.335	4.217	0	0	5.078
2004–05	0.008	0	0.021	0	0	0.335	0.234	0	0.047	0.639
2005–06	0	0	0.163	0	0	0	0.032	0	0	0.195

Table 3: Landings of Knobbed whelk (KWH) by QMA from 2006–07 to present from monthly harvest returns (MHR).

Fishing year	QMA 1	QMA 2	QMA 3	QMA 4	QMA 5	QMA 6	QMA 7A	QMA 7B	QMA 8	Total
2006–07	0.080	0	0.010	0	0	0	0.046	0	0	0.136
2007–08	0.077	0	0.006	0	0	0	9.174	0.104	0	9.361
2008–09	0.103	0	0.121	0	0	0.001	0.226	0.008	0	0.459
2009–10	0.088	0	0.053	0	0	0	18.500	0	0	18.614
2010–11	0.473	0.036	0	0	0	0	16.033	0	0	16.542
2011–12	0.721	0.070	0.088	0	0	0	0	0.008	0	0.887
2012–13	0.551	0	0.003	0	0.001	0	0	0.014	0	0.569
2013–14	0.116	0	0.159	0	0.002	0	0	0	0	0.277
2014–15	0.039	0	0.020	0	0	0	0	0	0.108	0.167
2015–16	0.011	0	0.031	0	0	0	0	0	0	0.032
2016–17	0	0	0.210	0	0	0	0	0	0	0.210
2017–18	0	0	0.140	0.020	0	0	0	0	0.010	0.170
2018–19	0	0	0.024	0	0	0	0	0	0	0.024

1.2 Recreational fisheries
There are no estimates of recreational catch.

1.3 Customary non-commercial fisheries
There are no estimates of current customary catch.

1.4 Illegal catch
There is no known illegal catch of this whelk.

1.5 Other sources of mortality
There is no information on other sources of mortality for this whelk.

2. BIOLOGY

The knobbed whelk *A. glans,* is a widely distributed gastropod found from low tide to about 600 m (Powell 1979). This carnivorous whelk grows up to 5 cm long and occurs throughout New Zealand where it is found on sandy/silt/mud substrate. There is very little published about the biology of this species; most references are identification notes or records of occurrence. It is a scavenger that buries in the substrate when not feeding. A wide variety of invertebrates including polychaetes, gastropods, and bivalves occur within the wide depth range of the knobbed whelk, but no interdependent relationships are documented with *A. glans*.

3. STOCKS AND AREAS

For management purposes stock boundaries are based on FMAs. There is no biological information on stock structure, recruitment patterns, or other biological characteristics which might indicate alternative stock boundaries.

4. STOCK ASSESSMENT

4.1 Estimates of fishery parameters and abundance

There are no estimates of fishery parameters or abundance for any knobbed whelk fishstock.

4.2 Biomass estimates

There are no biomass estimates for any knobbed whelk fishstock.

4.3 Yield estimates and projections

There are no estimates of *MCY* for any knobbed whelk fishstock.

There are no estimates of *CAY* for any knobbed whelk fishstock.

5. STATUS OF THE STOCKS

- **KWH 7A -** *Austrofusus glans*

Stock Status	
Year of Most Recent Assessment	No formal assessment done of any of the stocks
Assessment Runs Presented	–
Reference Points	Target: None Soft Limit: None Hard Limit: None Overfishing threshold: None
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 Unknown	

Fishery and Stock Trends	
Recent Trend in Biomass or Proxy	Unknown
Recent Trend in Fishing Mortality or Proxy	In 1990–96 the landings for KWH 7 averaged 28.7 t. However, since that time, landings have declined in this area to less than 19 t per year. Landings in all other Fishstocks have been variable but total catch across all Fishstocks has been less than 19 t per year since 2001–02.
Other Abundance Indices	–
Trends in Other Relevant Indicators or Variables	–

Projections and Prognosis	
Stock Projections or Prognosis	–
Probability of Current Catch or TACC causing Biomass to remain below or to decline below Limits	Soft Limit: Unknown Hard Limit: Unknown It is unknown what effect fishing to date has had on *Austrofusus glans* stocks

Probability of Current Catch or TACC causing Overfishing to continue or to commence	–

Assessment Methodology		
Assessment Type	–	
Assessment Method	–	
Assessment Dates	Latest assessment: –	Next assessment: –
Overall assessment quality rank	–	
Main data inputs (rank)	–	
Data not used (rank)	–	
Changes to Model Structure and Assumptions	–	
Major Sources of Uncertainty	–	

Qualifying Comments
–

Fishery Interactions
–

6. FOR FURTHER INFORMATION

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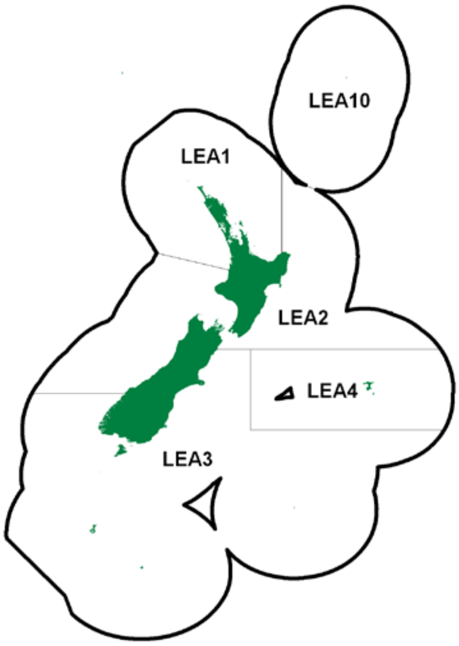
LEATHERJACKET (LEA)

(*Meuschenia scaber*)
Kokiri, Hiriri



1. FISHERY SUMMARY

Leatherjacket was introduced into the QMS on 1 October 2003. Current allowances, TACCs, and TACs are given in Table 1.

Table 1: Recreational and Customary non-commercial allowances (t), TACCs (t), and TACs (t) for leatherjacket by Fishstock.

Fishstock	Recreational Allowance	Customary Non-Commercial Allowance	Other sources of mortality	TACC	TAC
LEA 1	5	1	9	188	203
LEA 2	2	1	57	1 136	1 196
LEA 3	2	1	5	130	138
LEA 4	1	1	1	7	10
LEA 10	0	0	0	0	0
Total	10	4	72	1 431	1 517

1.1 Commercial fisheries

Nationally, very small landings were first reported in 1948. Most of the current leatherjacket catch is taken as a bycatch, and it is very likely that leatherjacket has always been primarily a bycatch species. From less than 2 t in the early 1960s, reported landings increased to 200–400 t in the mid-1970s, 1980s, and early 1990s (Table 2). It is possible actual catches were higher than reported prior to the 1970s, but that some catches were discarded without being reported due to low market demand in this period. Landings increased further in the late 1990s to around 1000 to 1300 t, but have decreased to less than 500 t since 2012–13 (Table 3). In 2018–19 320 t of leatherjacket were landed. On average over the last five years total landings have only been 23% of the total TACC.

Figure 1 shows the historical landings and TACC values for the main leatherjacket stocks. LEA 1 landings fluctuated around the TACC from the fishing year 2003–04 to 2012–13, but have since dropped to approximately half, with 97 t landed in 2018–19. LEA 2 landings have always been much lower than the TACC of 1136 t, with landings averaging 69 t from 2014–15 to 2018–19. LEA 3 landings exceeded the TACC during the fishing years 2008–09 to 2015–16, 2017–18, and again in 2018–19 153 t being landed.

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

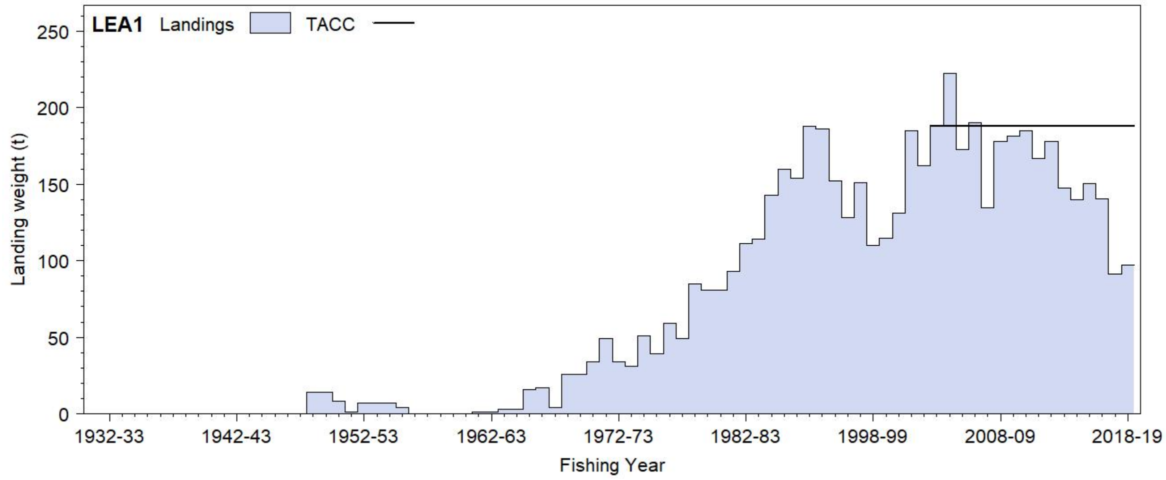
Year	LEA 1	LEA 2	LEA 3	LEA 4	Year	LEA 1	LEA 2	LEA 3	LEA 4
1931–32	0	0	0	0	1957	0	0	0	0
1932–33	0	0	0	0	1958	0	0	0	0
1933–34	0	0	0	0	1959	0	0	0	0
1934–35	0	0	0	0	1960	0	0	0	0
1935–36	0	0	0	0	1961	1	0	0	0
1936–37	0	0	0	0	1962	1	0	0	0
1937–38	0	0	0	0	1963	3	0	0	0
1938–39	0	0	0	0	1964	3	0	0	0
1939–40	0	0	0	0	1965	16	0	0	0
1940–41	0	0	0	0	1966	17	0	0	0
1941–42	0	0	0	0	1967	4	0	0	0
1942–43	0	0	0	0	1968	26	4	0	0
1943–44	0	0	0	0	1969	26	13	0	0
1944	0	0	0	0	1970	34	11	0	0
1945	0	0	0	0	1971	49	11	0	0
1946	0	0	0	0	1972	34	32	0	0
1947	0	0	0	0	1973	31	46	0	0
1948	14	0	0	0	1974	51	46	0	0
1949	14	0	0	0	1975	39	29	0	0
1950	8	0	0	0	1976	59	155	0	0
1951	1	0	0	0	1977	49	163	0	0
1952	7	0	0	0	1978	85	85	0	0
1953	7	0	0	0	1979	81	179	0	0
1954	7	0	0	0	1980	81	232	173	0
1955	4	0	0	0	1981	93	199	68	0
1956	0	0	0	0	1982	111	111	5	0

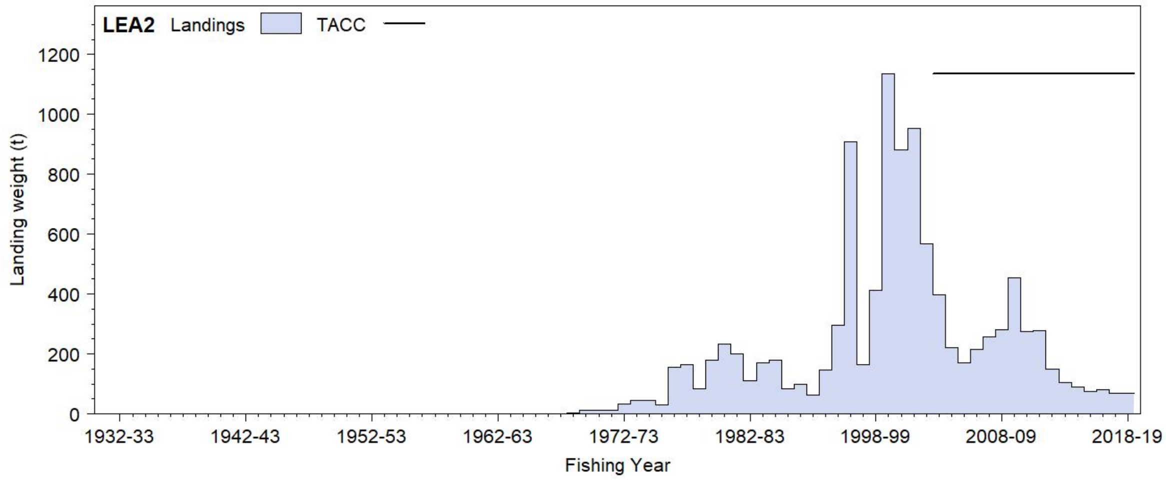
Notes:

1. The 1931–1943 years are April–March but from 1944 onwards are calendar years.
2. Data up to 1985 are from fishing returns: data from 1986 to 1990 are from Quota Management Reports.
3. Data for the period 1931 to 1982 are based on reported landings by harbour and are likely to be underestimated as a result of under-reporting and discarding practices. Data includes both foreign and domestic landings. Data were aggregated to FMA using methods and assumptions described by Francis & Paul (2013).

Table 3: Reported commercial landings (tonnes) of leatherjacket by Fishstock for the fishing years from 1989–90 to 2018–19. Landings for LEA 10 have not been shown as these were negligible and were rounded to zero.

Fishstock	LEA 1		LEA 2		LEA 3		LEA 4			
FMA (s)	1&9		2&8		3, 5 & 6		4		Total	
	Landings	TACC	Landings	TACC	Landings	TACC	Landings	TACC	Landings	TACC
1989–90	114	-	169	-	42	-	-	-	325	-
1990–91	143	-	178	-	61	-	-	-	382	-
1991–92	160	-	85	-	100	-	-	-	345	-
1992–93	154	-	98	-	41	-	-	-	293	-
1993–94	188	-	62	-	37	-	-	-	287	-
1994–95	186	-	148	-	50	-	-	-	384	-
1995–96	152	-	296	-	38	-	-	-	486	-
1996–97	128	-	908	-	70	-	-	-	1 106	-
1997–98	151	-	165	-	66	-	-	-	382	-
1998–99	110	-	413	-	30	-	-	-	553	-
1999–00	115	-	1 136	-	35	-	-	-	1 286	-
2000–01	131	-	880	-	41	-	-	-	1 052	-
2001–02	185	-	953	-	43	-	-	-	1 181	-
2002–03	162	-	568	-	67	-	0	-	797	-
2003–04	189	188	396	1 136	28	100	0	7	613	1 431
2004–05	223	188	221	1 136	56	100	< 1	7	500	1 431
2005–06	173	188	172	1 136	60	100	0	7	405	1 431
2006–07	191	188	215	1 136	49	100	0	7	454	1 431
2007–08	135	188	258	1 136	73	100	0	7	466	1 431
2008–09	178	188	282	1 136	122	100	0	7	582	1 431
2009–10	181	188	455	1 136	117	100	0	7	754	1 431
2010–11	185	188	276	1 136	112	100	< 1	7	573	1 431
2011–12	167	188	277	1 136	127	100	< 1	7	571	1 431
2012–13	178	188	150	1 136	114	100	0	7	442	1 431
2013–14	147	188	105	1 136	132	130	0	7	384	1 461
2014–15	140	188	91	1 136	143	130	0	7	374	1 461
2015–16	151	188	75	1 136	133	130	4	7	363	1 461
2016–17	141	188	80	1 136	122	130	0	7	343	1 461
2017–18	92	188	67	1 136	135	130	0	7	294	1 461
2018–19	97	188	70	1 136	153	130	0	7	320	1 461





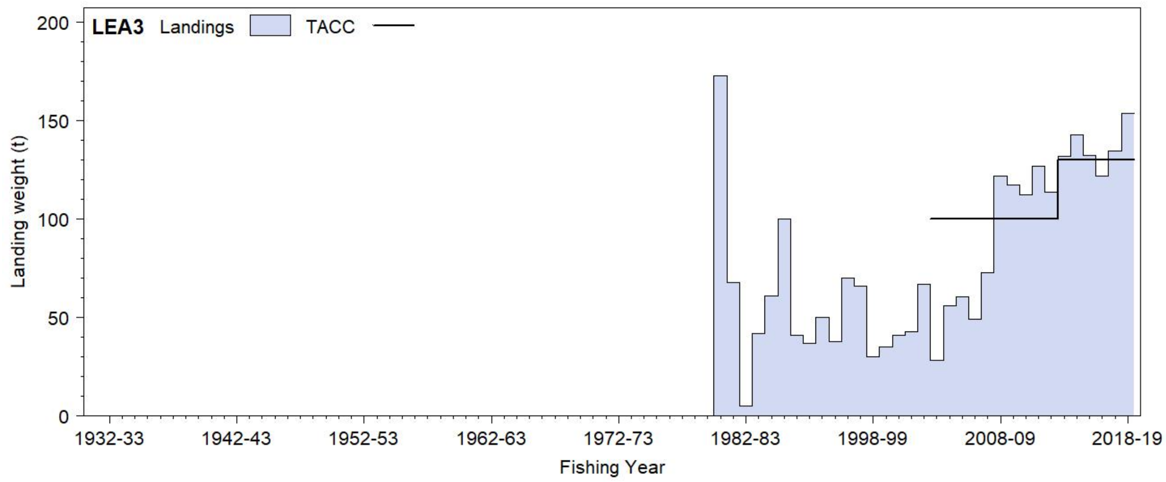


Figure 1: Reported commercial landings and TACCs for the main LEA stocks. From top to bottom: LEA 1 (Auckland), LEA 2 (Central), and LEA 3 (South East).

1.2 Recreational fisheries

Leatherjackets are seldom caught by hook and line but recreational fishers, especially in the northern region, take some leatherjacket by spear fishing, in rock lobster pots, and in set nets. No estimates of recreational harvest of leatherjacket were generated from the telephone/diary surveys conducted in 1994, 1996, and 2000 because so few were reported. A National Panel Survey was conducted for the first time throughout 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 (from Wynne-Jones et al 2014). The panel members were contacted regularly about their fishing activities and harvest information collected in standardised phone interviews. The national panel survey was repeated during the 2017–18 fishing year using very similar methods to produce directly comparable results (Wynne-Jones et al 2019). Recreational catch estimates from the two national panel surveys are given in Table 4. Note that national panel survey estimates do not include recreational harvest taken under s111 general approvals.

Table 4: Recreational harvest estimates (in numbers of fish) for leatherjacket stocks (Wynne-Jones et al 2014, 2019).

Stock	Year	Method	Number of fish	Total weight (t)	CV
LEA 1	2011–12	Panel survey	1 599	–	0.68
	2017–18	Panel survey	2 398	–	0.44
LEA 2	2011–12	Panel survey	831	–	0.58
	2017–18	Panel survey	178	–	0.81
LEA 3	2011–12	Panel survey	506	–	0.65
	2017–18	Panel survey	133	–	1.00

1.3 Customary non-commercial fisheries

There is no quantitative information available to allow the estimation of the amount of leatherjacket taken by customary non-commercial fishers.

2. BIOLOGY

The New Zealand leatherjacket (*Meuschenia scaber*) is present around much of New Zealand, but is most common in the north. Trawl survey records show it to be widespread over the inner shelf north of East Cape and Cape Egmont, in the South Taranaki Bight, in Tasman Bay and Golden Bay, Pegasus Bay, and the South Canterbury Bight, extending to depths below 100 m, but with greatest abundance at 10–60 m (Anderson et al 1998). It was less commonly caught along the east coast of the North Island south of East Cape, off the northeast South Island (Cook Strait to Pegasus Bay), northwest South Island (Cape Farewell to Cape Foulwind), and around the South Otago and Southland coast. It has not been taken by trawl off the west coast south of Cape Foulwind.

The New Zealand leatherjacket also occurs in Australia, from New South Wales to the southern coast of West Australia. In the Australian southeast trawl fishery, *Meuschenia scaber* is the main leatherjacket species caught (Yearsley et al 1999). It was once believed that two similar species of leatherjacket occurred in New Zealand – 'rough' and 'smooth' – but these are now considered to be a single species with variable colouring. Kokiri is the Maori name, but is not in common usage. 'Creamfish' is a New Zealand trade name for the processed (headed/gutted/skinned) product, rather than a name for the fish itself.

Leatherjacket usually occur near reefs and over rough seafloor, but may be found over sand or some distance above the bottom. Although not a schooling species, it does occur in small groups.

A recent study showed that fifty percent sexual maturity was attained at 19 cm and 1.5 y in the Hauraki Gulf, and there were not significant differences between sexes (Visconti et al 2017, 2018). Maximum age was 9.8 y for males and 18.1 y for females. Males defend territories and eggs are laid within nests on the seafloor from late winter to early summer (Ayling & Cox 1982, Milicich 1986, Visconti et al 2017, 2018).

3. STOCKS AND AREAS

3.1 Biomass estimates

There have been no biological studies directly relevant to the recognition of separate stocks.

The west coast South Island (WCSI) trawl survey probably monitors adult biomass and most of the survey catch comes from Tasman Bay and Golden Bay. The total biomass estimates are shown in

Figure 2. Biomass estimates have been relatively stable throughout the time series but increased substantially in 2019 to the time series high, with a CV of 19%.

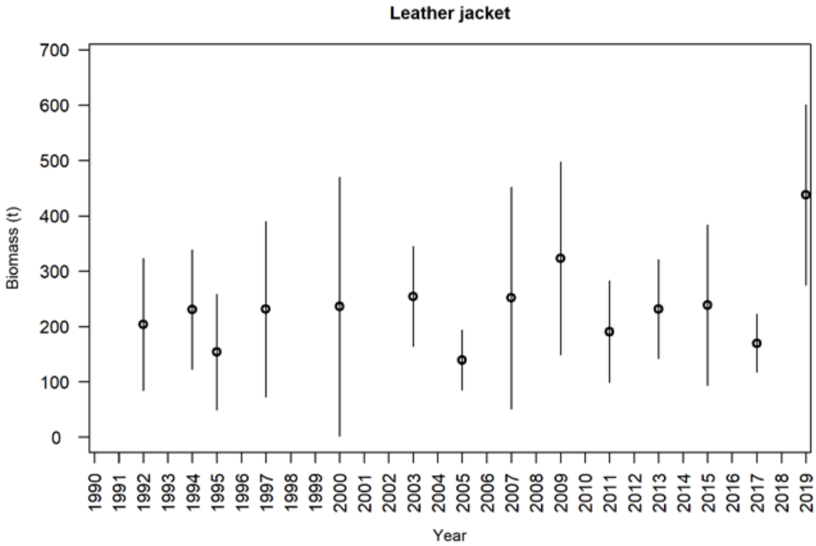


Figure 2: Leatherjacket biomass estimates from the WCSI inshore trawl survey time series. Error bars are ± two standard deviations.

East coast South Island (ECSI) winter trawl survey biomass estimates in the core strata (30–400 m) are not valid because so few fish were caught, and coefficients of variations are generally high ranging from 36 to 76% (mean = 55%, up to 2012), and biomass estimates, not routinely reported, are provided in Figure 3. Most of the biomass is captured in the 10–30 m depth indicating that the core plus shallow strata (10–400 m) is the only valid depth range within which to monitor leatherjacket biomass; although it is doubtful that these surveys index leatherjacket abundance because they are found more commonly over foul ground and hence not fully available to trawl gear (Beentjes & MacGibbon 2013).

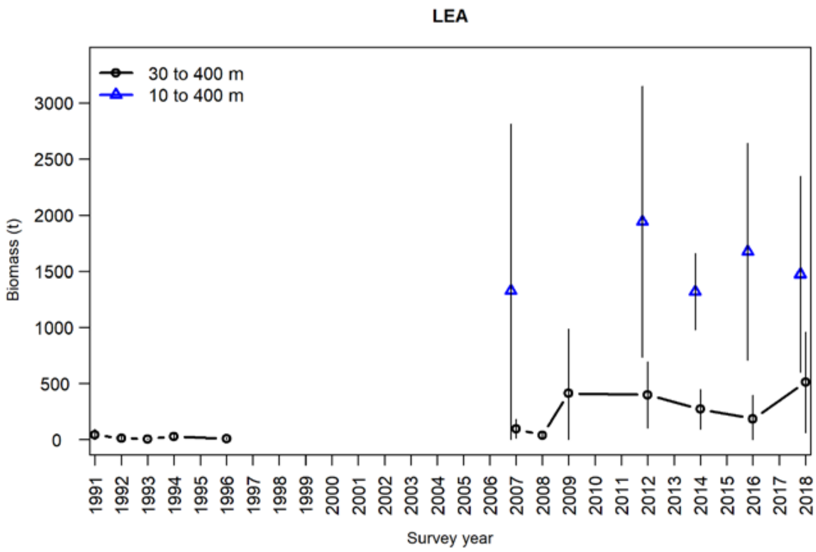


Figure 3: Leatherjacket total biomass for the ECSI winter surveys in core strata (30–400 m), and core plus shallow strata (10–400 m) in 2007, 2012, 2014, 2016, and 2018. Error bars are 2 Standard Deviations.

3.2 Length distributions

Leatherjacket were not caught in significant numbers in the ECSI winter surveys until 2007 when the shallow strata were included in the surveys. The length distributions in the core plus shallow strata (10–400 m) in 2007 and 2012 show at least three clear modes at about 10 cm, 16 cm, and 23 cm (combined males, females, and unsexed) (Beentjes & MacGibbon 2013). The core plus shallow strata survey is monitoring both pre-recruited cohorts, and fish in the recruited size range.

4. STOCK ASSESSMENT

There has been no scientific assessment of the maximum sustainable yield, reference, or current biomass of any of the leatherjacket stocks.

A characterisation and CPUE analysis for the LEA 3 fishery was undertaken by Langley (2013). Leatherjacket in LEA 3 are landed throughout the year, taken almost exclusively by bottom trawl gear in Statistical Areas 021–025 and 030 (Figure 4). Almost all of the LEA catch is taken in the 10–50 m depth range. The characterisation revealed that most of the increase in LEA 3 catch since 2005–06 is attributable to increased landings of leatherjacket catch from bottom trawls targeting spiny dogfish in Foveaux Strait (025).

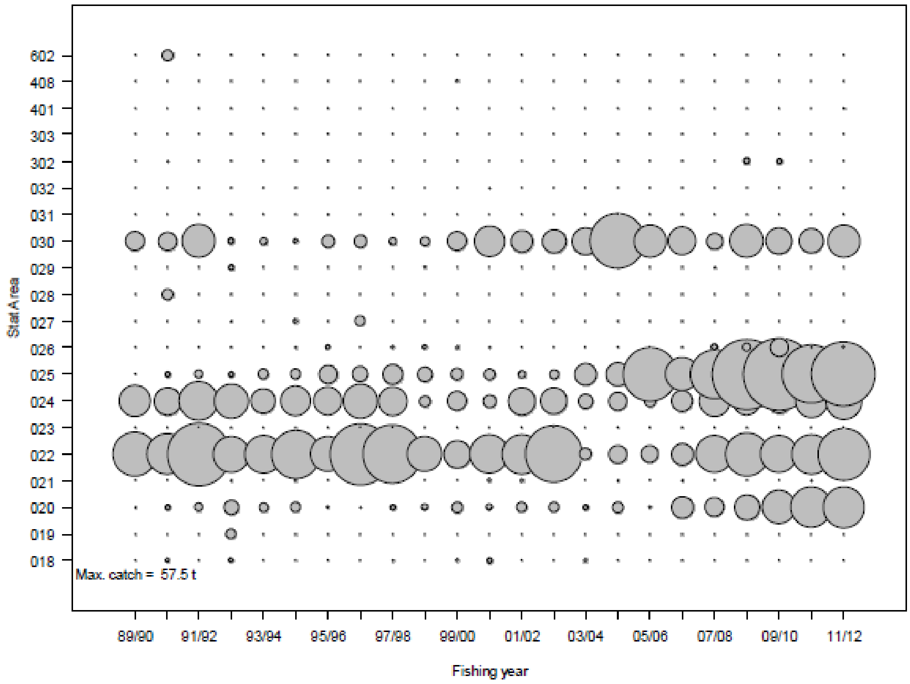


Figure 4: Distribution of reported catch for bottom trawl by Statistical Area in LEA 3 and fishing year from trips which landed leatherjacket in LEA 3 (Langley 2013).

A CPUE standardisation was undertaken using catch and effort data that included all trips that landed or targeted LEA 3, but did not include trips that did not catch LEA 3. Landed catch was assigned to effort records proportional to estimated catch, following the Starr (2007) methodology, with some refinements where the data were aggregated to CELR equivalent format (vessel/day/method/statistical area/target species) and then the records were defined as CELR equivalent. This method was somewhat problematic due to differences in the reliability of reporting of fishing location and target species between the CELR and TCER form types. The Foveaux Strait and Canterbury Bight fisheries were analysed separately. The Foveaux Strait analysis was rejected by the Working Group and is therefore not reported further.

The Canterbury Bight analysis was limited to the bottom trawl (BT) fishery in Statistical Areas 020 and 022, targeting a range of target species (RCO, BAR, FLA, ELE, TAR, WAR, and GUR). The dataset included trips where 1 kg or more of LEA 3 were landed. The analysis had large numbers of very small catches. Eight vessels accounted for 80% of the catch. The Working Group requested that the Canterbury Bight delta lognormal model targeting FLA, ELE, GUR from 2002 (Target FLA, GUR, ELE post QMS) be used because these are the years when the reporting is likely to be more reliable. There was an indication that CPUE from the Canterbury Bight fishery has increased since the early 2000s, and these indices were robust to some key assumptions. The index (Figure 5) showed that the CPUE remained low at the start of the series and then began to increase from 2007–08 to 2011–12. However, some concerns were raised about the low number of vessels in the analysis and the development of new markets for this species that may have increased targeting or retention of this species in recent years, suggesting that the index may not be reliable as an index of abundance.

The Working Group concluded that this analysis only pertains to the stock unit for the East Coast of the South Island; is the best available information on the stock abundance at this stage, but trawl survey data may provide better information in the medium and long term; and that this is a Level 2 assessment and should be given a medium or mixed (2) overall assessment quality rank.

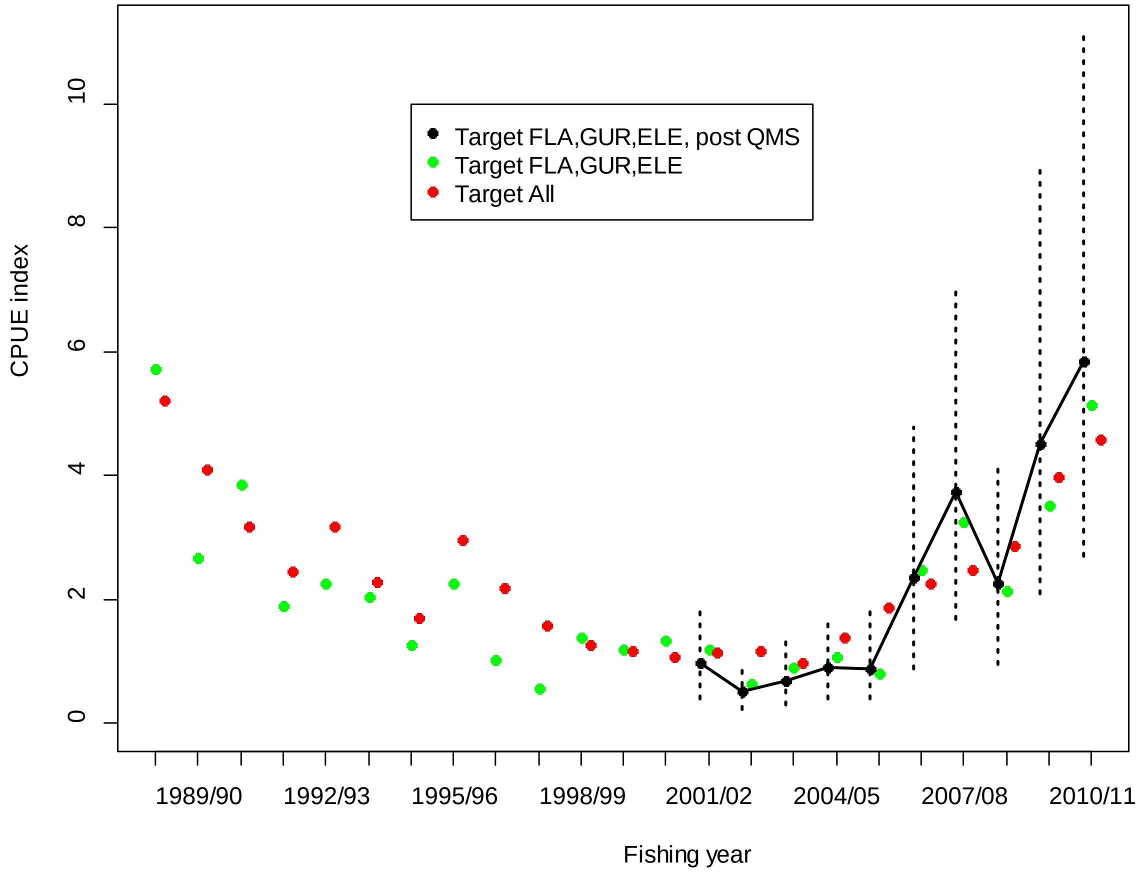


Figure 5: A comparison of three standardised CPUE indices for leatherjacket on the East Coast South Island Langley (2013).

5. STATUS OF THE STOCK

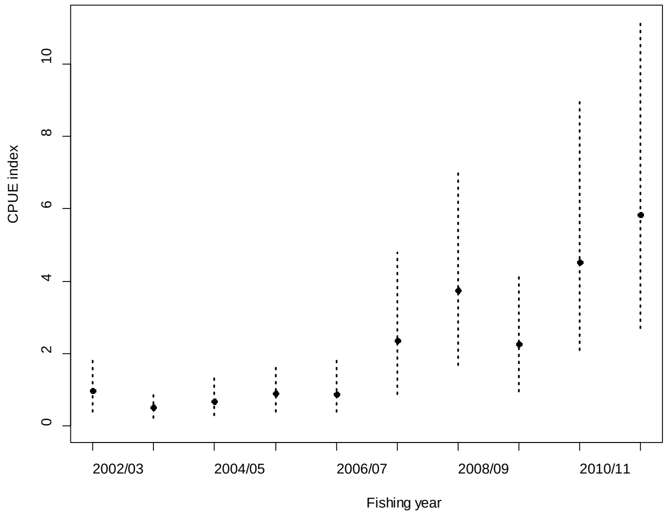
Stock Structure Assumptions

Stock structure is unknown but for management purposes the QMA boundaries are assumed to represent the stock boundaries for this species. There are two distinct areas of catch distribution within LEA 3 (Foveaux Strait and East Coast South Island) and these may represent distinct biological stocks.

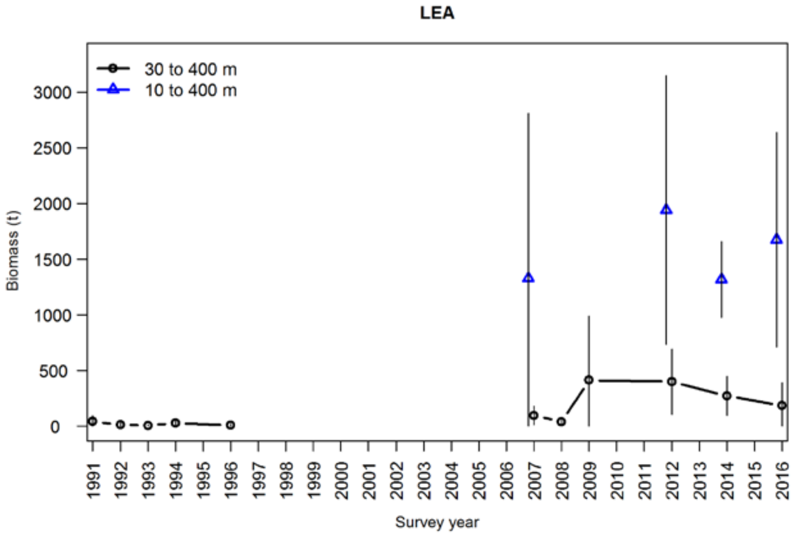
- **LEA 3 (**East Coast South Island only**)**

Stock Status	
Year of Most Recent Assessment	2013
Assessment Runs Presented	CPUE: Target FLA, GUR, ELE post QMS
Reference Points	Target: 40% B_0 Soft Limit: 20% B_0 Hard Limit: 10% B_0 Overfishing threshold: F_{MSY}
Status in relation to Target	Unknown
Status in relation to Limits	Soft Limit: Unknown Hard Limit: Unlikely (< 40%)
Status in relation to Overfishing	Unknown

Historical Stock Status Trajectory and Current Status



The 2013 standardised CPUE index for leatherjacket on the East Coast South Island.



Biomass and 95% confidence intervals (total biomass only) for leatherjacket caught by the ECSI trawl survey core strata (30–400), and core plus shallow strata (10–400 m).

Fishery and Stock Trends	
Recent Trend in Biomass or Proxy	CPUE remained low at the start of the series (2002) and then began to increase from 2007–08 to 2011–12. The biomass index from the East Coast South Island trawl survey 30–400 m strata has increased since 2008.
Recent Trend in Fishing Intensity or Proxy	Unknown because new markets for this species may have increased targeting or retention in recent years.
Other Abundance Indices	-
Trends in Other Relevant Indicators or Variables	-

Projections and Prognosis	
Stock Projections or Prognosis	Unknown
Probability of Current Catch or TACC causing Biomass to remain below or to decline below Limits	Soft Limit: Unknown Hard Limit: Unknown
Probability of Current Catch or TACC causing Overfishing to continue or to commence	Unknown

<table>
<tr><th colspan="3">Assessment Methodology and Evaluation</th></tr>
<tr><td>Assessment Type</td><td colspan="2">Level 2 - Partial Quantitative Stock Assessment</td></tr>
<tr><td>Assessment Method</td><td colspan="2">Standardised CPUE</td></tr>
<tr><td>Assessment Dates</td><td>Latest assessment: 2013</td><td>Next assessment: Unknown</td></tr>
<tr><td>Overall assessment quality rank</td><td colspan="2">2 - Medium or Mixed Quality: CPUE may be compromised by the low number of vessels in the analysis and trends in targeting or retention of leatherjacket; the trawl survey has only covered the entire habitat since 2007.</td></tr>
<tr><td>Main data inputs (rank)</td><td>- catch and effort data from bottom trawl sets targeting FLA, GUR and ELE

- trawl survey biomass index</td><td>2 - Medium or Mixed Quality: few vessels in analysis

2 - Medium or Mixed Quality: limited years with full coverage of LEA area</td></tr>
<tr><td>Data not used (rank)</td><td>- Foveaux Strait CPUE index

- Trawl survey biomass estimates from the 10–400 m strata.</td><td>3 – Low Quality: based on only a single vessel that has recently started targeting LEA
3 – Low Quality: confidence intervals large and only two data points</td></tr>
<tr><td>Changes to Model Structure and Assumptions</td><td colspan="2">New model</td></tr>
<tr><td>Major sources of Uncertainty</td><td colspan="2">The low number of vessels in the analysis and new markets for this species may have increased targeting or retention in recent years. Trends in CPUE may therefore be a result of changes in reporting and retention rather than abundance.
Total trawl survey biomass estimates for the entire survey area (10–400 m) have large confidence intervals.</td></tr>
</table>

Qualifying Comments
-

Fishery Interactions
Leatherjacket are landed in fisheries targeting RCO, BAR, FLA, ELE, TAR, WAR and GUR, but are most commonly caught in FLA, GUR and ELE target bottom trawl sets. Some concerns have been raised about catch being taken in “hay paddocks”; these are polychaete worm beds that are biologically sensitive, habitat forming areas, which appear to be diminishing in areal extent as a consequence of disturbance from bottom trawling. Interactions with other species are currently being characterised.

Research Needs
Fishery characterisations that include interviews with fishers and processors are required to assess the degree to which changes in fishing practices and economic drivers may have influenced CPUE trends. Trawl surveys need to continue to include the shallow strata in order to monitor the abundance of leatherjacket on the east coast of the South Island.

Reported landings and TACCs by Fishstock for the 2018–19 fishing year are summarised in Table 5.

Table 5: Summary of TACCs (t) and reported landings (t) of leatherjacket for the most recent fishing year.

Fishstock		FMA	2018–19 Actual TACC	2018–19 Reported landings
LEA 1	Auckland (East) (West)	1, &9	188	97
LEA 2	Central (East) (West), Challenger	2,7&8	1 136	70
LEA 3	South east (coast), Southland, Sub-Antarctic	3, 4, 5 & 6	130	153
LEA 4	South east (Chatham)		7	0
Total			1 461	320

6. FURTHER INFORMATION

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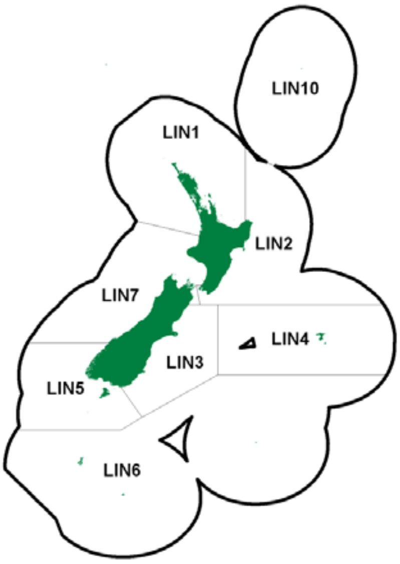
LING

(*Genypterus blacodes*)
Hoka



1. FISHERY SUMMARY

Ling was introduced into the Quota Management System on 1 October 1986. TACs, TACCs, and allowances as of 1 October 2019 are given in Table 1.

Table 1: TACs (t), TACCs (t) and allowances (t) for ling.

Fishstock	Recreational Allowance	Customary non-commercial Allowance	Other sources of mortality	TACC	TAC
LIN 1	40	20	3	400	463
LIN 2	–	–	–	982	–
LIN 3	0	0	0	2 060	2 060
LIN 4	0	0	0	4 200	4 200
LIN 5	1	1	97	4 735	4 834
LIN 6	0	0	85	8 505	8 590
LIN 7	1	2	68	3 387	3 458
Total	42	22	–	23 182	22 493

1.1 Commercial fisheries

Ling was introduced into the Quota Management System (QMS) on 1 October 1986. Ling are widely distributed through the middle depths (200–800 m) of the New Zealand EEZ, particularly south of latitude 40° S. From 1975 to 1980 there was a substantial longline fishery on the Chatham Rise (and to a lesser extent in other areas) carried out by Japanese and Korean longliners. Since 1980 ling have been caught by large trawlers, both domestic and foreign owned, and by small domestic longliners and trawlers. In the early 1990s the domestic fleet was increased by the addition of several larger longliners with autoline equipment, resulting in a large increase in the catches of ling off the east and south of South Island (LIN 3, 4, 5, and 6). Following the fishing year 2000–01 there was a declining trend in catches taken by longline vessels in most areas, offset, to some extent, by increased trawl landings.

The principal grounds for smaller domestic vessels are off the west coast of South Island (WCSI) and the east coast of both main islands south of East Cape. For the large trawlers the main sources of ling are Puysegur Bank and the slope of the Stewart-Snares shelf and waters in the Auckland Islands area, and the Chatham Rise, primarily as bycatch of target fisheries for hoki. Longliners fish mainly in LIN 3, 4, 5, and 6.

Under the Adaptive Management Programme (AMP), the TACC for LIN 1 was increased to 400 t from 1 October 2002, and it remained at this level when LIN 1 was removed from the AMP on 30 September 2009. In a proposal for the 1994–95 fishing year, TACCs for LIN 3 and 4 were increased to 2810 t and

5720 t, respectively. These stocks were removed from the AMP from 1 October 1998, with TACCs maintained at the increased level. However, from 1 October 2000, the TACCs for LIN 3 and 4 were reduced to 2060 t and 4200 t, respectively. From 1 October 2004, the TACCs for LIN 5 and LIN 6 were increased by about 20% to 3595 t and 8505 t, respectively, and the LIN 5 was increased by a further 10% (to 3955 t) from 1 October 2013. From 1 October 2009, the TACC for LIN 7 was increased from 2225 t to 2474 t, and further increased to 3080 t from 1 October 2013. All other TACC increases since 1986–87 in all stocks are the result of quota appeals. From 1 October 2018, a TACC of 4735 t applies for LIN 5, and from 1 October 2019 a TACC of 3387 t has been set for LIN 7.

In 2018–19, landings from Fishstocks LIN 4 and LIN 6 were substantially under-caught relative to their TACCs; the LIN1, LIN 2, LIN 3, and LIN 7 catch was just under the TACCs; and the LIN 5 TACC was slightly over-caught. Reported landings for the main QMAs from 1931 to 1982 are given in Table 2, reported landings by nation from 1975 to 1987–88 are given in Table 3, and reported landings by Fishstock from 1983–84 onwards are given in Table 4. Figure 1 shows the historical landings and TACC values for the main LIN stocks.

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

Year	LIN 1	LIN 2	LIN 3	LIN 4	Year	LIN 1	LIN 2	LIN 3	LIN 4
1931–32	0	0	11	0	1957	0	34	175	0
1932–33	0	63	14	0	1958	0	43	178	0
1933–34	0	146	59	0	1959	0	39	157	0
1934–35	0	217	70	0	1960	0	26	196	0
1935–36	0	146	124	0	1961	0	25	230	0
1936–37	0	133	103	0	1962	1	27	211	0
1937–38	0	91	320	0	1963	1	17	213	0
1938–39	0	66	280	0	1964	1	20	223	0
1939–40	0	40	320	0	1965	1	21	195	0
1940–41	1	85	286	0	1966	5	52	141	0
1941–42	0	64	308	0	1967	7	40	106	0
1942–43	0	54	254	0	1968	7	55	88	0
1943–44	0	83	264	0	1969	5	52	154	0
1944	0	103	224	0	1970	6	67	167	0
1945	1	122	199	0	1971	4	49	203	0
1946	0	153	348	0	1972	6	37	522	6
1947	0	203	474	0	1973	18	73	1 425	0
1948	0	120	403	0	1974	9	102	575	42
1949	0	108	402	0	1975	3	70	1 770	15
1950	0	84	352	0	1976	2	60	1 567	14
1951	0	60	230	0	1977	9	100	1 149	466
1952	0	69	235	0	1978	24	144	487	0
1953	0	62	212	0	1979	82	228	799	246
1954	0	75	208	0	1980	114	205	265	182
1955	0	48	160	0	1981	208	429	427	444
1956	0	27	155	0	1982	320	625	924	435

Year	LIN 5	LIN 6	LIN 7	Year	LIN 5	LIN 6	LIN 7
1931–32	1	0	0	1957	8	0	19
1932–33	2	0	35	1958	15	0	28
1933–34	1	0	67	1959	13	0	27
1934–35	1	0	94	1960	21	0	19
1935–36	1	0	66	1961	20	0	19
1936–37	1	0	61	1962	13	0	16
1937–38	1	0	57	1963	14	0	11
1938–39	24	0	37	1964	16	0	13
1939–40	16	0	26	1965	24	0	13
1940–41	21	0	46	1966	16	0	17
1941–42	22	0	40	1967	14	0	36
1942–43	24	0	29	1968	11	0	42
1943–44	19	0	40	1969	10	0	23
1944	13	0	46	1970	14	0	51
1945	13	0	80	1971	20	1	37
1946	9	0	78	1972	22	0	33
1947	24	0	96	1973	23	0	41
1948	24	0	66	1974	335	44	82
1949	20	0	67	1975	1 513	344	224
1950	29	0	61	1976	2 630	0	1 739
1951	16	0	34	1977	1 683	0	2 810
1952	16	0	36	1978	2 515	391	240
1953	19	0	34	1979	4 400	1 431	454
1954	7	0	44	1980	4 064	933	928
1955	6	0	27	1981	3 576	636	1 020
1956	4	0	15	1982	2 109	317	1 208

Table 3: Reported landings (t) from 1975 to 1987–88. Data from 1975 to 1983 from MAF; data from 1983–84 to 1985–86 from FSU; data from 1986–87 to 1987–88 from QMS. –, no data available.

Fishing year	New Zealand			Foreign Licensed					Grand total
				Longline	Trawl				
	Domestic	Chartered	Total	(Japan + Korea)	Japan	Korea	USSR	Total	
1975*	486	0	486	9 269	2 180	0	0	11 499	11 935
1976*	447	0	447	19 381	5 108	0	1 300	25 789	26 236
1977*	549	0	549	28 633	5 014	200	700	34 547	35 096
1978–79#	657	24	681	8 904	3 151	133	452	12 640	13 321
1979–80#	915	2 598	3 513	3 501	3 856	226	245	7 828	11 341
1980–81#	1 028	–	–	–	–	–	–	–	–
1981–82#	1 581	2 423	4 004	0	2 087	56	247	2 391	6 395
1982–83#	2 135	2 501	4 636	0	1 256	27	40	1 322	5 958
1983†	2 695	1 523	4 218	0	982	33	48	1 063	5 281
1983–84§	2 705	2 500	5 205	0	2 145	173	174	2 491	7 696
1984–85§	2 646	2 166	4 812	0	1 934	77	130	2 141	6 953
1985–86§	2 126	2 948	5 074	0	2 050	48	33	2 131	7 205
1986–87§	2 469	3 177	5 646	0	1 261	13	21	1 294	6 940
1987–88§	2 212	5 030	7 242	0	624	27	8	659	7 901

* Reported by calendar year.
\# Reported April 1 to March 31(except domestic vessels, which reported by calendar year).
† Reported April 1 to Sept 30 (except domestic vessels, which reported by calendar year).
§ Reported Oct 1 to Sept 30.

Table 4: Reported landings (t) of ling by Fishstock from 1983–84 to 2018–19 and actual TACCs (t) from 1986–87 to 2018–19. Estimated landings for LIN 7 from 1987–88 to 1992–93 include an adjustment for ling bycatch of hoki trawlers, based on records from vessels carrying observers. QMS data from 1986-present. [Continued on next page]

Fishstock	LIN 1		LIN 2		LIN 3		LIN 4		LIN 5	
FMA (s)	1 & 9		2		3		4		5	
	Landings	TACC	Landings	TACC	Landings	TACC	Landings	TACC	Landings	TACC
1983–84*	141	–	594	–	1 306	–	352	–	2 605	–
1984–85*	94	–	391	–	1 067	–	356	–	1 824	–
1985–86*	88	–	316	–	1 243	–	280	–	2 089	–
1986–87	77	200	254	910	1 311	1 850	465	4 300	1 859	2 500
1987–88	68	237	124	918	1 562	1 909	280	4 400	2 213	2 506
1988–89	216	237	570	955	1 665	1 917	232	4 400	2 375	2 506
1989–90	121	265	736	977	1 876	2 137	587	4 401	2 277	2 706
1990–91	210	265	951	977	2 419	2 160	2 372	4 401	2 285	2 706
1991–92	241	265	818	977	2 430	2 160	4 716	4 401	3 863	2 706
1992–93	253	265	944	980	2 246	2 162	4 100	4 401	2 546	2 706
1993–94	241	265	779	980	2 171	2 167	3 920	4 401	2 460	2 706
1994–95	261	265	848	980	2 679	2 810	5 072	5 720	2 557	3 001
1995–96	245	265	1 042	980	2 956	2 810	4 632	5 720	3 137	3 001
1996–97	313	265	1 187	982	2 963	2 810	4 087	5 720	3 438	3 001
1997–98	303	265	1 032	982	2 916	2 810	5 215	5 720	3 321	3 001
1998–99	208	265	1 070	982	2 706	2 810	4 642	5 720	2 937	3 001
1999–00	313	265	983	982	2 799	2 810	4 402	5 720	3 136	3 001
2000–01	296	265	1 105	982	2 330	2 060	3 861	4 200	3 430	3 001
2001–02	303	265	1 034	982	2 164	2 060	3 602	4 200	3 295	3 001
2002–03	246	400	996	982	2 529	2 060	2 997	4 200	2 939	3 001
2003–04	249	400	1 044	982	1 990	2 060	2 618	4 200	2 899	3 001
2004–05	283	400	936	982	1 597	2 060	2 758	4 200	3 584	3 595
2005–06	364	400	780	982	1 711	2 060	1 769	4 200	3 522	3 595
2006–07	301	400	874	982	2 089	2 060	2 113	4 200	3 731	3 595
2007–08	381	400	792	982	1 778	2 060	2 383	4 200	4 145	3 595
2008–09	320	400	634	982	1 751	2 060	2 000	4 200	3 232	3 595
2009–10	386	400	584	982	1 718	2 060	2 026	4 200	3 034	3 595
2010–11	438	400	670	982	1 665	2 060	1 572	4 200	3 856	3 595
2011–12	384	400	504	982	1 292	2 060	2 305	4 200	3 649	3 595
2012–13	383	400	579	982	1 475	2 060	2 181	4 200	3 610	3 595
2013–14	380	400	673	982	1 442	2 060	2 373	4 200	3 935	3 955
2014–15	374	400	673	982	1 325	2 060	2 246	4 200	3 924	3 955
2015–16	422	400	702	982	1 440	2 060	2 659	4 200	3 868	3 955
2016–17	404	400	1 022	982	1 808	2 060	2 565	4 200	3 356	3 955
2017–18	415	400	1 106	982	2 171	2 060	2 636	4 200	4 034	3 955
2018–19	383	400	938	982	2 016	2 060	2 044	4 200	4 846	4 735

Table 4 [Continued]

Fishstock	LIN 6		LIN 7			LIN 10			Total
FMA (s)	6		7 & 8			10			
	Landings	TACC	Reported Landings	Estimated Landings	TACC	Landings	TACC	Landings§	TACC
1983–84*	869	–	1 552	–	–	0	–	7 696	–
1984–85*	1 283	–	1 705	–	–	0	–	6 953	–
1985–86*	1 489	–	1 458	–	–	0	–	7 205	–
1986–87	956	7 000	1 851	–	1 960	0	10	6 940	18 730
1987–88	1 710	7 000	1 853	1 777	2 008	0	10	7 901	18 988
1988–89	340	7 000	2 956	2 844	2 150	0	10	8 404	19 175
1989–90	935	7 000	2 452	3 171	2 176	0	10	9 028	19 672
1990–91	2 738	7 000	2 531	3 149	2 192	< 1	10	13 506	19 711
1991–92	3 459	7 000	2 251	2 728	2 192	0	10	17 778	19 711
1992–93	6 501	7 000	2 475	2 817	2 212	< 1	10	19 065	19 737
1993–94	4 249	7 000	2 142	–	2 213	0	10	15 961	19 741
1994–95	5 477	7 100	2 946	–	2 225	0	10	19 841	22 111
1995–96	6 314	7 100	3 102	–	2 225	0	10	21 428	22 111
1996–97	7 510	7 100	3 024	–	2 225	0	10	22 522	22 113
1997–98	7 331	7 100	3 027	–	2 225	0	10	23 145	22 113
1998–99	6 112	7 100	3 345	–	2 225	0	10	21 034	22 113
1999–00	6 707	7 100	3 274	–	2 225	0	10	21 615	22 113
2000–01	6 177	7 100	3 352	–	2 225	0	10	20 552	19 843
2001–02	5 945	7 100	3 219	–	2 225	0	10	19 561	19 843
2002–03	6 283	7 100	2 918	–	2 225	0	10	18 903	19 978
2003–04	7 032	7 100	2 926	–	2 225	0	10	18 760	19 978
2004–05	5 506	8 505	2 522	–	2 225	0	10	17 189	21 977
2005–06	3 553	8 505	2 479	–	2 225	0	10	14 184	21 977
2006–07	4 696	8 505	2 295	–	2 225	0	10	16 102	21 977
2007–08	4 502	8 505	2 282	–	2 225	0	10	16 264	21 977
2008–09	2 977	8 505	2 223	–	2 225	0	10	13 137	21 977
2009–10	2 414	8 505	2 446	–	2 474	0	10	12 609	22 226
2010–11	1 335	8 505	2 800	–	2 474	0	10	12 337	22 226
2011–12	2 047	8 505	2 771	–	2 474	0	10	12 953	22 226
2012–13	3 102	8 505	3 010	–	2 474	0	10	14 339	22 226
2013–14	3 221	8 505	3 200	–	3 080	0	10	15 224	23 192
2014–15	3 115	8 505	3 343	–	3 080	0	10	15 002	23 192
2015–16	2 222	8 505	3 340	–	3 080	0	10	14 654	23 192
2016–17	2 473	8 505	3 428	–	3 080	0	10	15 056	23 192
2017–18	4 846	8 505	3 487	–	3 080	0	10	18 694	23 192
2018–19	3 706	8 505	3 059	–	3 080	0	10	16 992	21 192

* FSU data.
§ Includes landings from unknown areas before 1986–87, and areas outside the EEZ since 1995–96.

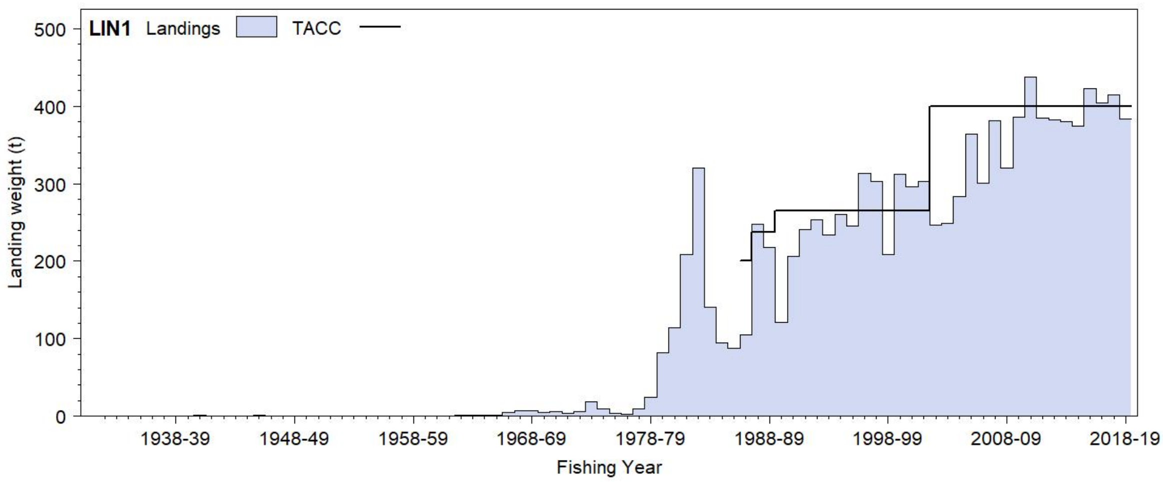


Figure 1: Reported commercial landings and TACC for the seven main LIN stocks. LIN 1 (Auckland East).
[Continued on next page]

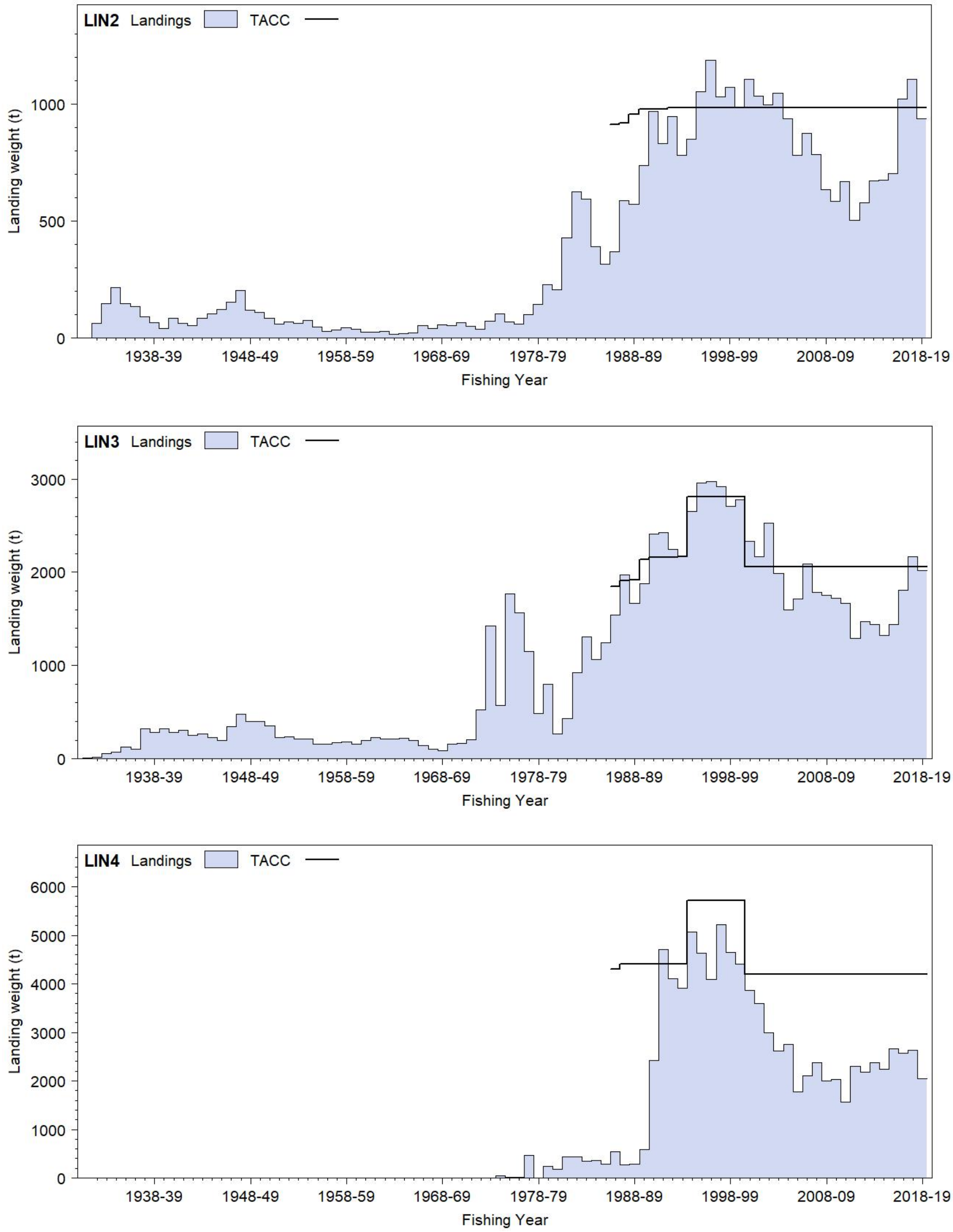


Figure 1 [Continued]: Reported commercial landings and TACC for the seven main LIN stocks. From top to bottom: LIN 2 (Central East), LIN 3 (South East Coast), and LIN 4 (South East Chatham Rise). [Continued on next page]

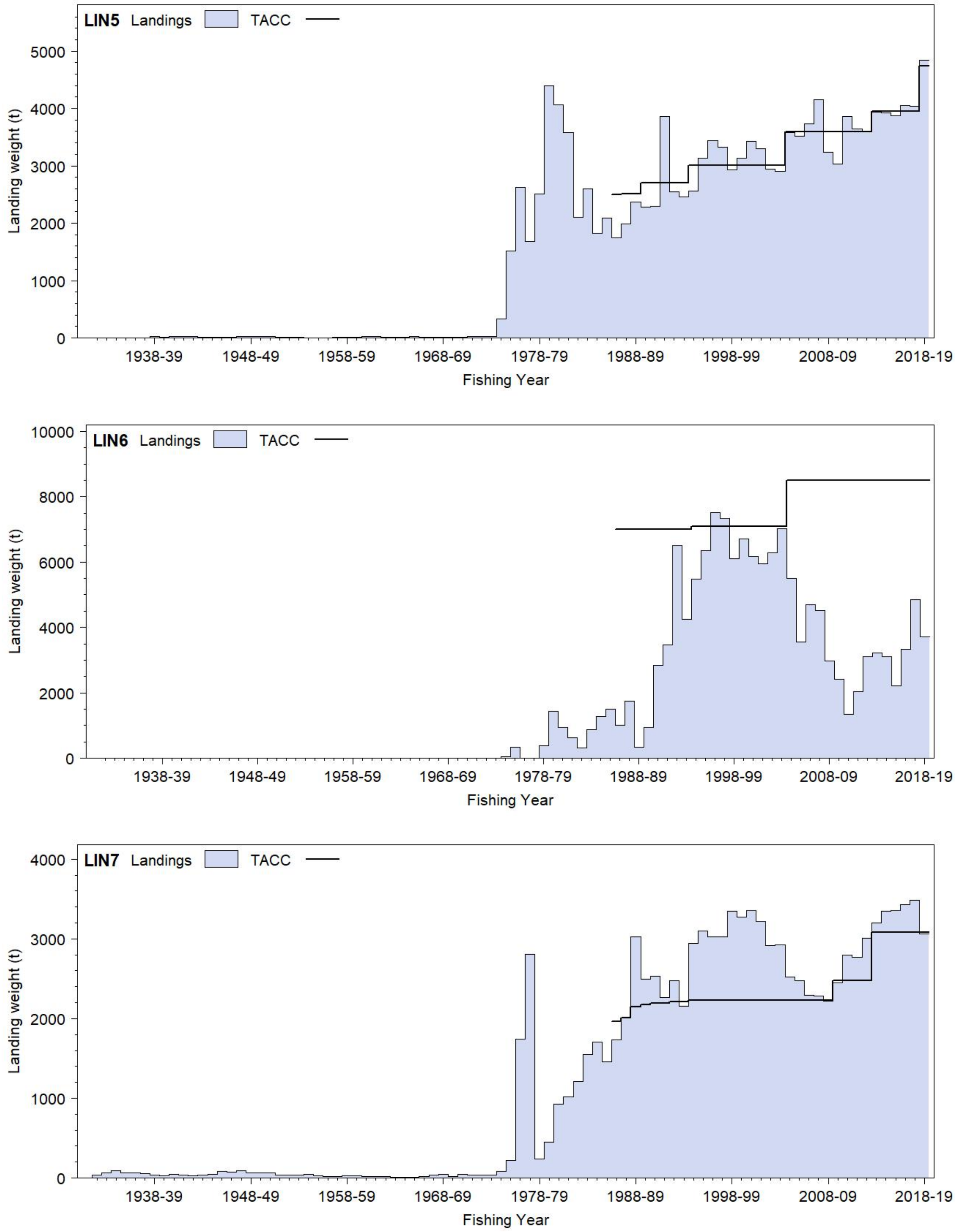


Figure 1 [Continued]: Reported commercial landings and TACC for the seven main LIN stocks. From top to bottom: LIN 5 (Southland), LIN 6 (Sub-Antarctic), and LIN 7 (Challenger).

1.2 Recreational fisheries

The 1993–94 North region recreational fishing survey (Bradford 1996) estimated the annual recreational catch from LIN 1 as 10 000 fish (CV 0.23). With a mean weight likely to be in the range of 1.5 to 4 kg, this equates to a harvest of 15–40 t. Recreational catch was recorded from LIN 1, 5, and 7 in the 1996 national diary survey. The estimated harvests (LIN 1, 3000 fish; LIN 5, less than 500; LIN 7, less than 500) were too low to provide reliable estimates.

The harvest estimates provided by telephone/diary surveys between 1993 and 2001 are no longer considered reliable for various reasons. A Recreational Technical Working Group concluded that these harvest estimates should be used only with the following qualifications: a) they may be very inaccurate; b) the 1996 and earlier surveys contain a methodological error; and c) the 2000 and 2001 estimates are implausibly high for many important fisheries. In response to these problems and the cost and scale challenges associated with onsite methods, a National Panel Survey was conducted for the first time throughout 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 (Wynne-Jones et al 2014). The panel members were contacted regularly about their fishing activities and harvest information collected in standardised phone interviews. The national panel survey was repeated during the 2017–18 fishing year using very similar methods to produce directly comparable results (Wynne-Jones et al 2019). In 2011–12, only three fishers reported catching ling in LIN 1 (4 trips) and only four fishers reported catching ling in LIN 2 (5 trips). In 2017–18, only two fishers reported catching ling in LIN 2 (2 trips), one fisher reported catching ling in LIN 3 (1 trip), and three fishers reported catching ling in LIN 7 (3 trips). Estimates of total nationwide catch were 1334 and 320 fish in 2011–12 and 2017–18, respectively, both with wide CVs. Note that national panel survey estimates do not include recreational harvest taken under s111 general approvals.

1.3 Customary non-commercial fisheries

Quantitative information on the level of Māori customary non-commercial take is not available. Ling bones have been recovered from archaic middens throughout the South Island and southern North Island, and on Chatham Island (Leach & Boocock 1993). In the South Island and Chatham Island, ling comprised about 4% (by number) of recovered fish remains.

1.4 Illegal catch

It is believed that up to the mid-1990s some ling bycatch from the west coast hoki fishery was not reported. Estimates of total catch including non-reported catch are given in Table 4 for LIN 7. It is believed that in recent years, some catch from LIN 7 has been reported against other ling stocks (probably LIN 3, 5, and 6). The likely levels of misreporting are moderate, being about 250–400 t in each year from 1989–90 to 1991–92 (Dunn 2003).

1.5 Other sources of mortality

The extent of any other sources of mortality is unknown.

2. BIOLOGY

The maximum age recorded for New Zealand ling is 46 years, although only 0.5% of successfully aged ling have been older than 30 years. A growth study of ling from five areas (west coast South Island, Chatham Rise, Bounty Plateau, Campbell Plateau, and Cook Strait) showed that females grew significantly faster and reached a greater size than males in all areas, and that growth rates were significantly different between areas. Ling grow fastest in Cook Strait and slowest on the Campbell Plateau (Horn 2005).

M was initially estimated from the equation $M = \log_e 100/\text{maximum age}$, where maximum age is the age to which 1% of the population survives in an unexploited stock. The mean M calculated from five samples of age data was 0.18 (range = 0.17–0.20) (Horn 1993). However, a review of M, and results of modelling conducted in 2007, suggested that this parameter may vary between stocks (Horn 2008). The M for Chatham Rise ling was estimated to be lower than 0.18, whereas for Cook Strait and west coast South Island the value was potentially higher than 0.18. M was evaluated again in 2017 (Edwards 2017). In the new study all available life-history data were re-analysed and sex-specific M values derived. For a variety of reasons female M values were estimated with much greater confidence than those for males, the results for females being: West Coast South Island 0.15; Cook Strait 0.12; Chatham Rise 0.13; Sub-Antarctic 0.16. However, all credibility intervals overlapped such that assuming a common value of 0.14 in all areas was also credible. M has been estimated in assessment model runs for some stocks (see section 4).

Ling in spawning condition have been reported in a number of localities throughout the EEZ (Horn 2005, 2015). Time of spawning appears to vary between areas: August to October on the Chatham Rise; September to December on Campbell Plateau and Puysegur Bank; September to February on the Bounty Plateau; July to September off west coast South Island and in Cook Strait. Little is known about the distribution of juveniles until they are about 40 cm total length, when they begin to appear in trawl samples over most of the adult range.

Ling appear to be mainly bottom dwellers, feeding on crustaceans such as *Munida* and scampi and also on fish, with commercial fishing discards being a significant dietary component (Dunn et al 2010). However, they may at times be caught well above the bottom, for example when feeding on hoki during the hoki spawning season.

Biological parameters relevant to the stock assessment are shown in Table 5.

Table 5: Estimates of biological parameters. See section 3 for definitions of Fishstocks.

1. Natural mortality (*M*)

	Both sexes
FMA	
All stocks	0.18

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

	Female		Male		Combined		Area
FMA	a	b	a	b	a	b	
LIN 3&4	0.00114	3.318	0.001	3.354	–	–	Chatham Rise
LIN 5&6	0.00128	3.303	0.00208	3.19	–	–	Southern Plateau
LIN 6B	0.00114	3.318	0.001	3.354	–	–	Bounty Plateau
LIN 7WC	0.000934	3.368	0.001146	3.318	0.00104	3.318	West Coast S.I.
LIN 7CK	0.000934	3.368	0.001146	3.318	–	–	Cook Strait

3. von Bertalanffy growth parameters

	Female			Male			Combined			Area
FMA	K	t_0	L_{∞}	K	t_0	L_{∞}	K	t_0	L_{∞}	
LIN 3&4	0.083	–0.74	156.4	0.127	–0.70	113.9	–	–	–	Chatham Rise
LIN 5&6	0.124	–1.26	115.1	0.188	–0.67	93.2	–	–	–	Southern Plateau
LIN 6B	0.101	–0.53	146.2	0.141	0.02	120.5	–	–	–	Bounty Plateau
LIN 7WC	0.078	–0.87	169.3	0.067	–2.37	159.9	0.07	-1.5	168.5	West Coast S.I.
LIN 7CK	0.097	–0.54	163.6	0.08	–1.94	158.9	–	–	–	Cook Strait

3. STOCKS AND AREAS

A review of ling stock structure (Horn 2005) examined diverse information from studies of morphometrics, genetics, growth, population age structures, and reproductive biology and behaviour, and indicated that there are at least five ling stocks, i.e., west coast South Island, Chatham Rise, Cook Strait, Bounty Plateau, and the Southern Plateau (including the Stewart-Snares shelf and Puysegur Bank). Stock affinities of ling north of Cook Strait are unknown, but spawning is known to occur off Northland, Cape Kidnappers, and in the Bay of Plenty.

4. STOCK ASSESSMENT

LIN 1 was previously managed and assessed under the Adaptive Management Programme, and the stocks on the east and west coasts (LIN 1E and LIN 1W) have been assessed separately. An updated CPUE analysis for the eastern part of the stock (LIN 1E) was attempted in 2020 but was not accepted as an index of abundance due to sparse data, the influence of vessels with particularly low catch rates in the early part of the series, and inconsistent trends in different statistical areas. A CPUE analysis for the ling target bottom longline fishery in LIN 2 was conducted in 2014. The stock assessments for two ling stocks (LIN 3&4, Chatham Rise; LIN 5&6, Sub-Antarctic) were updated in 2015. Assessments for other stocks were updated in 2007 (LIN 6B, Bounty Plateau, with a CPUE update in 2014), 2013

(LIN 7CK, Cook Strait), or 2017 (LIN 7WC, west coast South Island). All assessments (excluding LIN 1 and LIN 2) were updated using a Bayesian stock model implemented using the general-purpose stock assessment program CASAL (Bull et al 2012).

Catch histories by stock and fishery are presented in Table 6, and other model input parameters are shown in Table 7. Estimates of relative abundance from standardised CPUE analyses (Table 8) and trawl surveys (Table 9) are also presented below.

Table 6: Estimated catch histories (t) for LIN 2 (ECNI), LIN 3&4 (Chatham Rise), LIN 5&6 (Campbell Plateau), LIN 6B (Bounty Platform), LIN 7WC (WCSI section of LIN 7), and LIN 7CK (Cook Strait). Landings have been separated by fishing method (trawl or line), and, for the LIN 5&6 line fishery, by pre-spawning (Pre) and spawning (Spn) season.

Year	**LIN 2**		**LIN 3&4**		**LIN 5&6**			**LIN 6B**	**LIN 7WC**		**LIN 7CK**	
	trawl	line	trawl	line	trawl	line Pre	line Spn	line	trawl	line	trawl	line
1972	–	–	0	0	0	0	0	0	0	0	0	0
1973	–	–	250	0	500	0	0	0	85	20	45	45
1974	–	–	382	0	1 120	0	0	0	144	40	45	45
1975	–	–	953	8 439	900	118	192	0	401	800	48	48
1976	–	–	2 100	17 436	3 402	190	309	0	565	2 100	58	58
1977	–	–	2 055	23 994	3 100	301	490	0	715	4 300	68	68
1978	–	–	1 400	7 577	1 945	494	806	10	300	323	78	78
1979	–	–	2 380	821	3 707	1 022	1 668	0	539	360	83	83
1980	–	–	1 340	360	5 200	0	0	0	540	305	88	88
1981	–	–	673	160	4 427	0	0	10	492	300	98	98
1982	–	–	1 183	339	2 402	0	0	0	675	400	103	103
1983	–	–	1 210	326	2 778	5	1	10	1 040	710	97	97
1984	–	–	1 366	406	3 203	2	0	6	924	595	119	119
1985	–	–	1 351	401	4 480	25	3	2	1 156	302	116	116
1986	–	–	1 494	375	3 182	2	0	0	1 082	362	126	126
1987	–	–	1 313	306	3 962	0	0	0	1 105	370	97	97
1988	–	–	1 636	290	2 065	6	0	0	1 428	291	107	107
1989	–	–	1 397	488	2 923	10	2	9	1 959	370	255	85
1990	85	134	1 934	529	3 199	9	4	12	2 205	399	362	121
1991	162	185	2 563	2 228	4 534	392	97	33	2 163	364	488	163
1992	110	299	3 451	3 695	6 237	566	518	908	1 631	661	498	85
1993	97	381	2 375	3 971	7 335	1 238	474	969	1 609	716	307	114
1994	96	397	1 933	4 159	5 456	770	486	1 149	1 136	860	269	84
1995	97	398	2 222	5 530	5 348	2 355	338	396	1 750	1 032	344	70
1996	149	350	2 725	4 863	6 769	2 153	531	381	1 838	1 121	392	35
1997	168	269	3 003	4 047	6 923	3 412	614	340	1 749	1 077	417	89
1998	148	387	4 707	3 227	6 032	4 032	581	395	1 887	1 021	366	88
1999	169	257	3 282	3 818	5 593	2 721	489	563	2 146	1 069	316	216
2000	166	286	3 739	2 779	7 089	1 421	1 161	991	2 247	923	317	131
2001	216	344	3 467	2 724	6 629	818	1 007	1 064	2 304	977	258	80
2002	212	366	2 979	2 787	6 970	426	1 220	629	2 250	810	230	171
2003	124	344	3 375	2 150	7 205	183	892	922	1 980	807	280	180
2004	82	420	2 525	2 082	7 826	774	471	853	2 013	814	241	227
2005	54	335	1 913	2 440	7 870	276	894	49	1 558	871	200	282
2006	45	365	1 639	1 840	6 161	178	692	43	1 753	666	129	220
2007	87	425	2 322	1 880	7 504	34	651	236	1 306	933	107	189
2008	37	457	2 350	1 810	6 990	329	821	503	1 067	1 170	115	110
2009	49	394	1 534	2 217	5 225	276	432	232	1 089	1 009	108	39
2010	37	409	1 484	2 257	4 270	864	313	1	1 346	1 063	74	14
2011	51	426	1 191	2 046	4 404	567	169	51	1 733	1 011	115	67
2012	57	288	1 407	2 190	4 384	934	376	2	1 744	976	96	47
2013	44	317	1 113	2 543	6 234	135	340	3	1 915	1 045	104	106
2014	78	337	1 340	2 250	5841	785	247	265	1 420	1 190	71	71
2015	68	385	1 064	1 608	6176	611	229	23	1 561	1 157	68	63
2016	69	386	936	2 189	5228	440	190	220	1 669	1 149	52	81
2017					5816	633	153		1 998	1 187		
2018									1 940	1 230		
2019									1 487	1 347		

Table 7: Input parameters for the assessed stocks.

Parameter	LIN 3&4	LIN 5&6	LIN 6B	LIN 7WC	LIN 7CK
Stock-recruitment steepness	0.84	0.84	0.9	0.84	0.9
Recruitment variability CV	0.6	0.7	1.0	0.7	0.7
Ageing error CV	0.05	0.06	0.05	0.1	0.07
Proportion male at birth	0.5	0.5	0.5	0.5	0.5
Proportion of mature that spawn	1.0	1.0	1.0	1.0	1.0
Maximum exploitation rate (U_{max})	0.6	0.6	0.6	0.6	0.6

Maturity ogives (from Horn 2005)

Age	3	4	5	6	7	8	9	10	11	12	13	14	15
LIN 3&4 (and assumed for LIN 6B)													
Male	0.0	0.027	0.063	0.14	0.28	0.48	0.69	0.85	0.93	0.97	0.99	1.00	1.0
Female	0.0	0.001	0.003	0.006	0.014	0.033	0.08	0.16	0.31	0.54	0.76	0.93	1.0
LIN 5&6													
Male	0.0	0.00	0.10	0.30	0.50	0.80	1.00	1.00	1.00	1.0			
Female	0.0	0.00	0.05	0.10	0.30	0.50	0.80	1.00	1.00	1.0			
LIN 7WC (and assumed for LIN7CK)													
Male	0.0	0.015	0.095	0.39	0.77	0.94	1.00	1.00	1.00	1.0			
Female	0.0	0.004	0.017	0.06	0.18	0.39	0.65	0.85	0.94	1.0			
Combined	0.0	0.010	0.056	0.23	0.48	0.67	0.83	0.93	0.97	1.0			

Table 8: Standardised CPUE indices (with CVs) for the ling line and trawl fisheries. Year refers to calendar year, sp=spawning fishery, nsp=non-spawning fishery. [Continued on next page]

	LIN 2 line		LIN 3&4 line		LIN 5&6 line (sp)		LIN 5&6 line (nsp)		LIN 6B line	
Year	CPUE	CV	CPUE	CV	CPUE	CV	CPUE	CV	CPUE	CV
1991	–	–	1.67	0.06	–	–	–	–	–	–
1992	1.64	0.09	2.43	0.06	1.03	0.13	1.15	0.1	1.74	0.15
1993	1.40	0.08	1.73	0.05	1.76	0.09	1.16	0.11	1.41	0.13
1994	1.55	0.09	1.65	0.05	1.59	0.1	1.02	0.09	0.95	0.16
1995	1.54	0.07	1.68	0.05	1.26	0.08	1.44	0.08	1.24	0.13
1996	1.34	0.07	1.31	0.05	1.33	0.11	1.05	0.08	1.15	0.12
1997	1.29	0.07	0.88	0.04	1.27	0.08	1.3	0.06	0.92	0.14
1998	1.27	0.07	0.90	0.05	1.15	0.07	1.1	0.06	1.06	0.12
1999	1.13	0.07	0.80	0.04	1.03	0.09	0.74	0.06	1.07	0.11
2000	0.80	0.07	0.93	0.05	1.07	0.1	0.86	0.07	0.95	0.10
2001	0.60	0.08	0.93	0.04	1.29	0.08	1.03	0.09	0.76	0.11
2002	0.97	0.08	0.77	0.04	1.36	0.09	0.99	0.13	0.69	0.11
2003	0.88	0.07	0.85	0.05	1.49	0.1	0.64	0.17	0.78	0.10
2004	1.07	0.07	0.81	0.04	0.78	0.11	0.71	0.07	0.74	0.16
2005	1.00	0.08	0.85	0.04	1.02	0.08	0.71	0.11	–	–
2006	0.88	0.07	0.74	0.05	1.46	0.11	0.78	0.14	–	–
2007	0.95	0.07	0.81	0.04	1.19	0.11	0.76	0.45	–	–
2008	0.85	0.07	1.04	0.04	1.27	0.1	0.75	–	–	–
2009	0.89	0.08	0.73	0.04	1.03	0.14	0.92	0.17	–	–
2010	0.90	0.07	0.84	0.04	2.05	0.19	1.18	0.09	–	–
2011	0.82	0.06	0.65	0.04	0.69	0.18	0.76	0.1	–	–
2012	0.56	0.07	0.79	0.05	1.04	0.14	0.99	0.08	–	–
2013	0.65	0.08	0.80	0.07	1.1	0.15	0.9	–	–	–
2014					0.87	0.16	0.84	0.09		
2015					0.65	0.16	0.84	0.08		
2016					0.58	0.16	0.52	0.1		
2017					0.64	0.27	0.72	0.09		

	LIN 7WC line		LIN 7CK line		LIN 7CK trawl		LIN 7WC trawl	
Year	CPUE	CV	–	–	CPUE	CV	CPUE	CV
1987	0.34	0.07	–	–	–	–	0.58	0.07
1988	0.7	0.06	–	–	–	–	1.01	0.06
1989	1.45	0.07			–	–	1.43	0.07
1990	1.39	0.06	1.29	0.15	–	–	1.37	0.06
1991	0.77	0.07	1.44	0.13	–	–	0.88	0.07
1992	0.82	0.08	1.43	0.11	–	–	0.95	0.08
1993	0.96	0.08	1.11	0.11	–	–	1.10	0.07
1994	0.74	0.06	0.90	0.11	1.25	0.05	0.94	0.06
1995	1.14	0.07	0.83	0.12	1.16	0.04	1.29	0.07
1996	1.28	0.05	0.97	0.13	1.12	0.04	1.71	0.05
1997	1.24	0.06	1.32	0.18	1.00	0.04	1.62	0.06
1998	1.23	0.05	0.83	0.15	1.01	0.04	1.32	0.05
1999	1.69	0.04	1.54	0.18	1.02	0.03	1.60	0.04
2000	0.96	0.04	1.45	0.19	1.27	0.04	1.22	0.04
2001	0.99	0.04	1.27	0.18	1.46	0.04	0.98	0.04
2002	1.26	0.04	2.04	0.11	1.27	0.05	1.22	0.04
2003	0.67	0.05	1.66	0.10	1.27	0.04	0.70	0.05
2004	1.28	0.04	1.45	0.09	1.13	0.04	1.21	0.04
2005	0.95	0.04	1.16	0.10	1.18	0.04	0.83	0.04
2006	0.71	0.04	0.97	0.15	1.10	0.05	0.77	0.04
2007	0.53	0.06	0.70	0.12	0.73	0.06	0.57	0.06

Table 8 [Continued]

	LIN 7WC line		LIN 7CK line		LIN 7CK trawl		LIN 7WC trawl	
Year	**CPUE**	**CV**	**–**	**–**	**CPUE**	**CV**	**CPUE**	**CV**
2008	0.55	0.06	0.82	0.22	0.90	0.06	0.57	0.06
2009	0.42	0.06	0.60	0.28	0.44	0.07	0.54	0.06
2010	0.80	0.06	0.35	0.30	0.44	0.07	0.75	0.06
2011	1.05	0.05	0.22	0.30	0.23	0.09	1.10	0.05
2012	0.97	0.04					0.88	0.05
2013	1.04	0.03					0.98	0.03
2014	0.96	0.03					0.94	0.03
2015	1.06	0.03					1.09	0.03
2016	1.44	0.03					1.32	0.03
2017	1.05	0.03						
2018	1.30	0.03						
2019	1.26	0.03						

4.1 LIN 1

In October 2002, the TACC for LIN 1 was increased from 265 t to 400 t within an Adaptive Management Plan (AMP). Reviews of the LIN 1 AMP were carried out in 2007 and 2009. The AMP programme was discontinued by the Minister of Fisheries in 2009–10. Updates of LIN 1 CPUE analyses were carried out in 2013, 2017, and 2020. The early CPUE analysis were given a reduced data quality ranking; in 2020 the Inshore Working Group concluded that the CPUE analyses did not provide a reliable index of abundance.

4.1.1 Fishery characterisation

- Around two thirds of LIN 1 landings come from the LIN target bottom longline fishery with most of the remainder from a mixed target bottom trawl fishery. The proportion of the catch taken by longline increased in 2005.
- The ling longline fishery has operated consistently in the Bay of Plenty (primarily Statistical Areas 009 and 010). Longline catches increased in East Northland from the mid-1990s, then off the west coast of the North Island from 2008.
- The majority of bottom trawl catches are taken in Statistical Areas 008 to 010, although there have been significant bottom trawl catches of ling off the west coast of the North Island in Areas 045 to 047. There were substantial ling bycatches made by trawl off the North Island west coast from 1996–97 to 2000–01 in the gemfish fishery (which has since ceased).
- Target bottom trawl catches of LIN 1 have increased since 2005 and represent about a third of trawl catches. Bycatch in the gemfish trawl fishery was important from the mid-1990s to early 2000s. Prior to 1995, bycatch of ling in the scampi fishery represented the majority of ling trawl catches, and, though the volume has reduced, the scampi fishery remains a consistent part of the LIN 1 trawl fishery. Ling catches in the hoki target trawl fishery have increased since 2010.
- The bottom longline landings of LIN 1 are taken mainly in the final two months of the fishing year, probably due to the economics of the vessels switching from tuna longlining to cleaning up available quota at the end of the fishing year. Bottom trawl catches of ling tend to be more evenly distributed across the year and reflect the fishing patterns of the diverse trawl targets, such as scampi which is also a consistent fishery over the entire year. Both of the major fishing methods which take ling have sporadic seasonal patterns, reflecting the small landings in most years and the bycatch nature of many of the fisheries, although the ling target longline fishery has operated more consistently since 2005.
- The depth distribution of ling catches in the trawl fisheries show two main depths associated with the target species. Most ling are caught in the scampi/hoki/ling fishery at about 400 m depth, but some are taken in the tarakihi/snapper/barracouta/trevally fisheries around 100 m depth. Bottom longline depth records indicate that target ling fishing (as well as target bluenose fishing) takes place at even deeper depths, with most of the records at between 500 and 600 m.

4.1.2 Abundance indices

A variety of different CPUE analyses have been carried out for LIN 1 (see Starr & Kendrick 2017) but no indices are currently accepted.

Table 9: Biomass indices (t) and estimated coefficients of variation (CV). [Continued on next page]

Fishstock	Area	Vessel	Trip code	Date	Biomass	CV (%)
LIN 3	ECSI (winter)	*Kaharoa*	KAH9105*	May–Jun 1991	1 009	35
			KAH9205*	May–Jun 1992	525	17
			KAH9306*	May–Jun 1993	651	27
			KAH9406*	May–Jun 1994	488	19
			KAH9606*	May–Jun 1996	488	21
			KAH0705*	May–Jun 2007	283	17
			KAH0806*	May–Jun 2008	351	22
			KAH0905*	May–Jun 2009	262	19
			KAH1207*	May–Jun 2012	265	21
LIN 3 & 4	Chatham Rise	*Tangaroa*	TAN9106	Jan–Feb 1992	8 930	5.8
			TAN9212	Jan–Feb 1993	9 360	7.9
			TAN9401	Jan 1994	10 130	6.5
			TAN9501	Jan 1995	7 360	7.9
			TAN9601	Jan 1996	8 420	8.2
			TAN9701	Jan 1997	8 540	9.8
			TAN9801	Jan 1998	7 310	8.0
			TAN9901	Jan 1999	10 310	16.1
			TAN0001	Jan 2000	8 350	7.8
			TAN0101	Jan 2001	9 350	7.5
			TAN0201	Jan 2002	9 440	7.8
			TAN0301	Jan 2003	7 260	9.9
			TAN0401	Jan 2004	8 250	6.0
			TAN0501	Jan 2005	8 930	9.4
			TAN0601	Jan 2006	9 300	7.4
			TAN0701	Jan 2007	7 800	7.2
			TAN0801	Jan 2008	7 500	6.8
			TAN0901	Jan 2009	10 620	11.5
			TAN1001	Jan 2010	8 850	10.0
			TAN1101	Jan 2011	7 030	13.8
			TAN1201	Jan 2012	8 098	7.4
			TAN1301	Jan 2013	8 714	10.1
			TAN1401	Jan 2014	7 489	7.2
			TAN1601	Jan 2016	10 201	7.2
LIN 5 & 6	Southern Plateau	*Amaltal Explorer*	AEX8902*	Oct–Nov 1989	17 490	14.2
			AEX9002*	Nov–Dec 1990	15 850	7.5
LIN 5 & 6	Southern Plateau (summer)	*Tangaroa*	TAN9105	Nov–Dec 1992	24 090	6.8
			TAN9211	Nov–Dec 1992	21 370	6.2
			TAN9310	Nov–Dec 1993	29 750	11.5
			TAN0012	Dec 2000	33 020	6.9
			TAN0118	Dec 2001	25 060	6.5
			TAN0219	Dec 2002	25 630	10.0
			TAN0317	Nov–Dec 2003	22 170	9.7
			TAN0414	Nov–Dec 2004	23 770	12.2
			TAN0515	Nov–Dec 2005	19 700	9.0
			TAN0617	Nov–Dec 2006	19 640	12.0
			TAN0714	Nov–Dec 2007	26 492	8.0
			TAN0813	Nov–Dec 2008	22 840	9.5
			TAN0911	Nov–Dec 2009	22 710	9.6
			TAN1117	Nov–Dec 2011	23 178	11.8
			TAN1215	Nov–Dec 2012	27 010	11.3
			TAN1412*	Nov–Dec 2014	30 010	7.7
			TAN1614*	Nov-Dec 2016	26 656	16.0
LIN 5 & 6	Southern Plateau (autumn)	*Tangaroa*	TAN9204	Mar–Apr 1992	42 330	5.8
			TAN9304	Apr–May 1993	37 550	5.4
			TAN9605	Mar–Apr 1996	32 130	7.8
			TAN9805	Apr–May 1998	30 780	8.8
LIN 7WC	WCSI	*Tangaroa*	TAN0007	Aug 2000	1 861	17.3
			TAN1210	Aug 2012	2 169	14.8
			TAN1308	Aug 2013	2 000	18.4
			TAN1608	Aug 2016	1 635	12.7
			TAN1807	Jul—Aug 2018	1 682	18.3
LIN 7WC	WCSI	*Kaharoa*	KAH9204*	Mar–Apr 1992	280	19
			KAH9404*	Mar–Apr 1994	261	20
			KAH9504*	Mar–Apr 1995	373	16
			KAH9701*	Mar–Apr 1997	151	30
			KAH0004*	Mar–Apr 2000	95	46
			KAH0304*	Mar–Apr 2003	150	33
			KAH0503*	Mar–Apr 2005	274	37
			KAH0704*	Mar–Apr 2007	180	27
			KAH0904*	Mar–Apr 2009	291	37
			KAH1104*	Mar–Apr 2011	234	43

Table 9 [Continued]

Fishstock	Area	Vessel	Trip code	Date	Biomass
		KAH1305*	Mar–Apr 2013	405	44
		KAH1503*	Mar–Apr 2015	472	53

* Not used in the reported assessment.

4.2 East Coast North Island, (LIN 2, Statistical Areas 011–015)

In 2014 a catch-per-unit-effort (CPUE) analysis was conducted on data from the LIN 2 fishery (Roux 2015). Estimated catch data and effort data from bottom longliners that fished in FMA 2 Statistical Areas 011–015 (ECNI) targeting ling where there was a positive catch were used. The estimated catch and effort data were rolled up by vessel/day/statistical area after a filter was applied to individual fishing events to retain estimated catch from the top five species together with all effort.

A GLM model (model 1) was fitted using a core vessel fleet where individual vessels had to have fished for four or more years in the fishery and fished a minimum of 10 days per year. One auto-longlining vessel was excluded because it was an outlier in terms of numbers of hooks set and created patterns in the residuals.

The sensitivity of the CPUE time series was tested for a range of alternative sets of input data: vessels using very large numbers of hooks per day (over 10 000) were either included or excluded; changes in fishing power and fleet were minimised by fitting only the most recent time series (2000–2013); data from Statistical Area 016 (Cook Strait) were either included or excluded; and fitting was carried out with or without the use of interaction terms. An all-target model using bottom longline data that targeted or caught ling was also developed with 'target species' included as an explanatory variable. The GLM trend was robust to all sensitivities investigated.

The standardised CPUE index for ling from the ECNI demonstrates an initial decline consistent with the previous assessment (Horn 2004), followed by a period of stability (2002–2010) with lower CPUE in 2011–12 and 2012–13 (Figure 2). This pattern was consistent across all GLM scenarios examined.

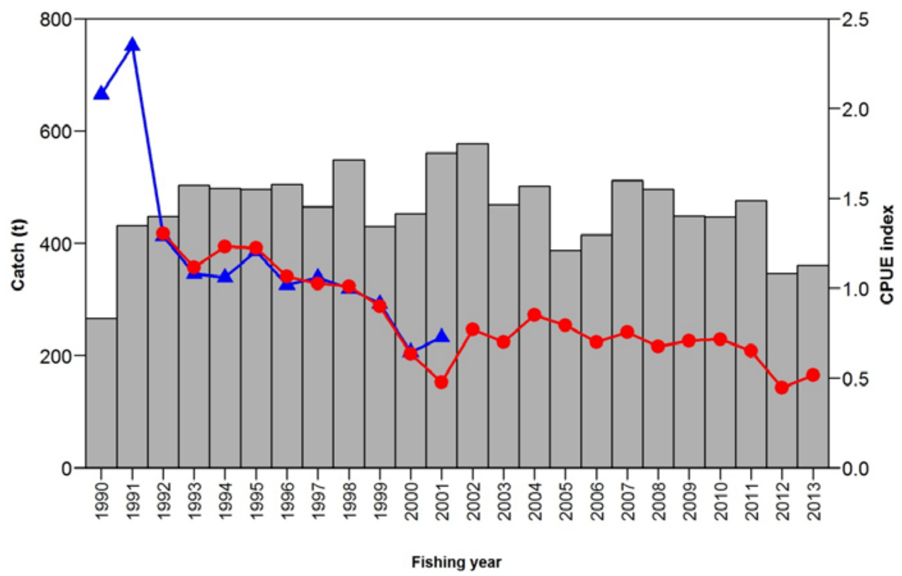


Figure 2: Estimated ling catch (bars) and standardised CPUE indices for LIN 2. Blue line and triangles from Horn (2004). Red line and circles for ECNI Statistical Areas 011–015 for core bottom longline vessels targeting ling, from Roux (2015). The two CPUE series were normalised to the overlapping fishing years (1992–2001).

4.3 Chatham Rise, LIN 3 & LIN 4

4.3.1 Model structure and inputs

The stock assessment for LIN 3&4 (Chatham Rise) was updated in 2019 (Holmes 2019). For final model runs, the full posterior distribution was sampled using Markov Chain Monte Carlo (MCMC) methods, based on the Metropolis-Hastings algorithm. Bounded estimates of spawning stock virgin (B_0) and current (B_{2019}) biomass were obtained. Year class strengths and fishing selectivity ogives were estimated in the model. Trawl fishery and research survey selectivity ogives were fitted as double normal curves; line fishery ogives were fitted as logistic curves. Selectivities were assumed constant over all years in each fishery/survey. Instantaneous natural mortality (*M*) was estimated as sex specific and constant at ages in the model. MCMCs were estimated using a burn-in length of 1×10^6 iterations, with every 1000th sample kept from the next 5×10^6 iterations (i.e., a final sample of length 5000 was taken from the Bayesian posterior).

For LIN 3&4, model input data included catch histories, biomass and sexed catch-at-age data from a summer trawl survey series, sexed catch-at-age from the trawl fishery, line fishery CPUE, and sexed catch-at-age from the line fishery (Table 10). Data used in the base case model are shown in bold. The catch history, biological input parameters, and estimates of relative abundance used in the model are shown in Tables 5–9. The stock assessment model partitioned the population into two sexes, and age groups 3 to 25 with age 25 being a plus group. The model's annual cycle is described in Table 11.

Table 10: LIN 3&4: Summary of the relative abundance series applied in the models, including source years (Years).

Data series	**Years**
Trawl survey proportion at age (*Amaltal Explorer,* Dec)	1990
Trawl survey biomass (*Tangaroa*, Jan)	**1992–2014, 2016, 2018**
Trawl survey proportion at age (*Tangaroa,* Jan), sexed	**1992–201, 2016, 2018**
CPUE (longline, all year)	1991–2018
Commercial longline proportion-at-age (Jun–Oct),unsexed	2002–09, 2013–2018
Commercial longline length-frequency (Jun–Oct), unsexed	1995–2002
Commercial longline proportion-at-age (Jun–Oct),sexed	**2002–09, 2013–2018**
Commercial longline length-frequency (Jun–Oct), sexed	1995–2002
Commercial trawl proportion-at-age (Oct–May), sexed	**1992, 1994–2018**

Table 11: LIN 3&4: Annual cycle of the stock model, showing the processes taking place at each time step, their sequence within each time step, and the available observations. Fishing and natural mortality that occur within a time step occur after all other processes, with half of the natural mortality for that time step occurring before and half after the fishing mortality.

					Observations	
Step	**Period**	**Processes**	***M***[1]	**Age**[2]	**Description**	**%*Z***[3]
1	Dec–Aug	Recruitment fisheries (line & trawl)	0.9	0.5	Trawl survey (summer)	0.2
					Line CPUE	0.5
					Line catch-at-age/length	
					Trawl catch-at-age	
2	Sep–Nov	Spawning and increment ages	0.1	0	–	

1. *M* is the proportion of natural mortality that was assumed to have occurred in that time step.
2. Age is the age fraction, used for determining length-at-age, that was assumed to occur by the start of that time step.
3. %*Z* is the percentage of the total mortality in the step that was assumed to have taken place at the time each observation was made.

The error distributions assumed were multinomial for the at-age data, and lognormal for all other data. The weight assigned to each data set was controlled by the error coefficient of variation (CV). The multinomial observation error CVs for the at-age data were adjusted using the reweighting procedure of Francis (2011). In a change to the previous assessment, additional process errors for the trawl survey biomass index and line fishery CPUE were estimated within the model, then fixed after a final adjustment to the at-age data weighting.

Most priors were intended to be uninformed and were specified with wide bounds. One exception was an informative prior for the trawl survey *q*. The prior on *q* for all the *Tangaroa* trawl surveys was estimated assuming that the catchability constant was a product of areal availability (0.5–1.0), vertical availability (0.5–1.0), and vulnerability between the trawl doors (0.03–0.40). The resulting (approximately lognormal) distribution had mean 0.13 and CV 0.70, with bounds assumed to be 0.02 to 0.30. Penalty functions were used to constrain the model so that any combination of parameters that did not allow the historical catch to be taken was strongly penalised. A penalty was applied to the estimates of year class strengths to encourage estimates that averaged to 1. Sensitivity runs showed p_male to be estimated at the prior mean of 0.5. It was deemed unnecessary to estimate p_male and the value was fixed at 0.5.

In all model runs, the catchability coefficients (q's) were estimated as free parameters, unless there were difficulties in MCMC convergence, in which case they were estimated as nuisance variables. The runs that included the longline CPUE had difficulty converging at MCMC. Natural mortality (M) was estimated separately by sex. A single sex M version of the base model was performed as a sensitivity run.

There is a conflict between the line fishery CPUE and the trawl survey biomass index, in which the line fishery biomass index declined between 1991 and 1997, but the trawl survey index remained relatively flat throughout. The base case model run (Base) used all the observational data (except the line fishery CPUE). This included the trawl survey biomass index because this was the most reliable index of abundance.

There was evidence that the longline fishery q had changed over time (Horn 2015). A sensitivity run (Longline) then included the line fishery CPUE, and excluded both the trawl survey biomass index and survey proportions at age information; this model is considered a 'worst case' scenario. Additional models included longline proportions at length data (removed for the base run) and tested the effect of putting an informed prior on survey catchability with higher initial mean q value of 0.6 (High q), but these models are not reported in detail here.

4.3.2 Model estimates

The fits to the biomass indices, and catch-at-age data were all reasonable, and almost indistinguishable between model runs. Estimated year class strengths were not widely variable, with all medians being between 0.5 and 2 (Figure 3). Ling are first caught by the trawl survey (age at full selectivity 4 years), then the trawl fishery (age 8 years), and then the line fishery (age 12–15 years). Selectivities for the trawl fishery and survey tended towards a logistic distribution (more so for males in the fishery, more so for females in the survey), although a double normal distribution was offered to allow for a descending right hand limb. Males were estimated to be less vulnerable than females to the trawl and longline fisheries. The estimated median M was 0.15 for females and 0.13 for males.

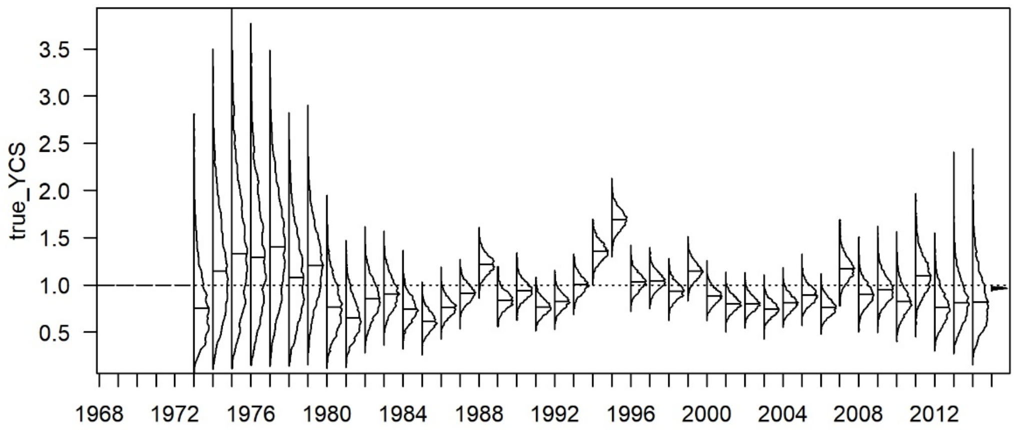


Figure 3: LIN 3&4: Estimated posterior distributions of year class strength for the base model. The horizontal line indicates a year class strength of one. Individual distributions show the marginal posterior distribution, with horizontal lines indicating the median.

Base case estimates indicated that it was unlikely that B_0 was lower than 100 000 t for this stock, or that biomass in 2019 was less than 45% of B_0 (Table 12, Figure 4). Annual exploitation rates (catch over vulnerable biomass) were estimated to be lower than 0.15 (often much lower) since 1979 (Figure 5). The sensitivity model based on the longline CPUE estimated lower virgin biomass (87 500–101 000 t), with current status estimated between 27 and 47% B_0. The two models had similar SSB trajectories after about 2000. The WG considered this run a worst case scenario, but it was not likely to be a reliable indication of decline because the changes in the fleet composition may be driving the observed changes in CPUE.

Table 12: LIN 3&4: Bayesian median and 95% credible intervals (in parentheses) of B_0 and B_{2019} (in tonnes, and as a percentage of B_0) for the Base model run, and the probability that B_{2019} is below 40% of B_0 from the Base model run.

Model run		B_0		B_{2019}		B_{2019} (% B_0)	P(40% B_0)
Base	111 067	(102 260–26 828)	62 800	(49 641–82 913)	56.5	(48.2–65.5)	0.001

The model indicated a relatively flat biomass trajectory since about 2009 (Figure 4). Annual landings from the LIN 3&4 stock have been less than 4600 t since 2004, markedly lower than the 6000–8000 t taken annually between 1992 and 2003. Biomass projections derived from this assessment are shown below (Section 4.9).

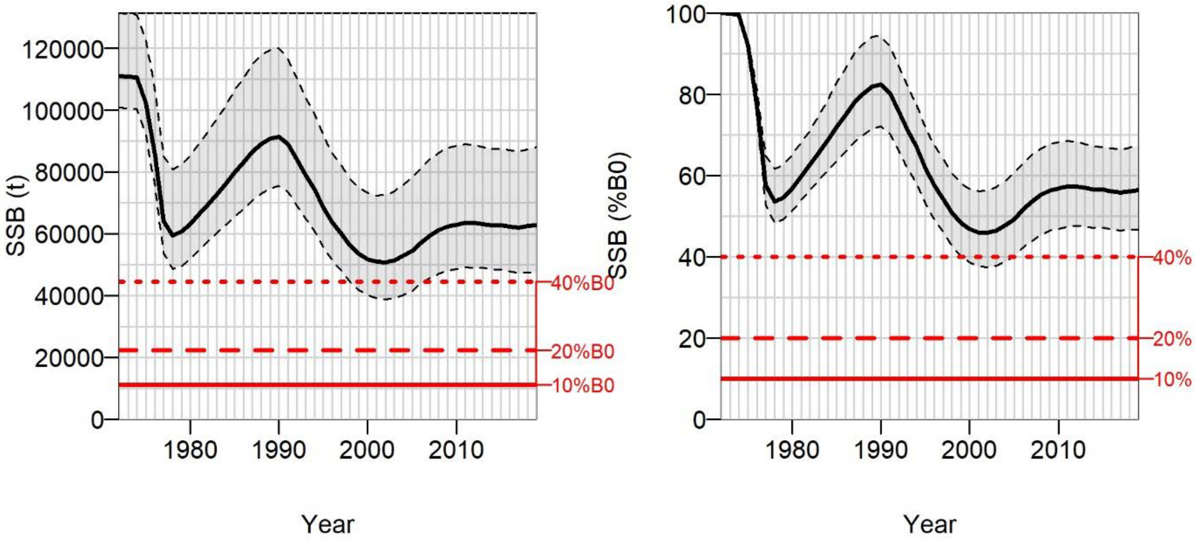


Figure 4: LIN 3&4 base model: Estimated median trajectories (with 95% credible intervals shown as dashed lines) for absolute biomass and biomass as a percentage of B_0.

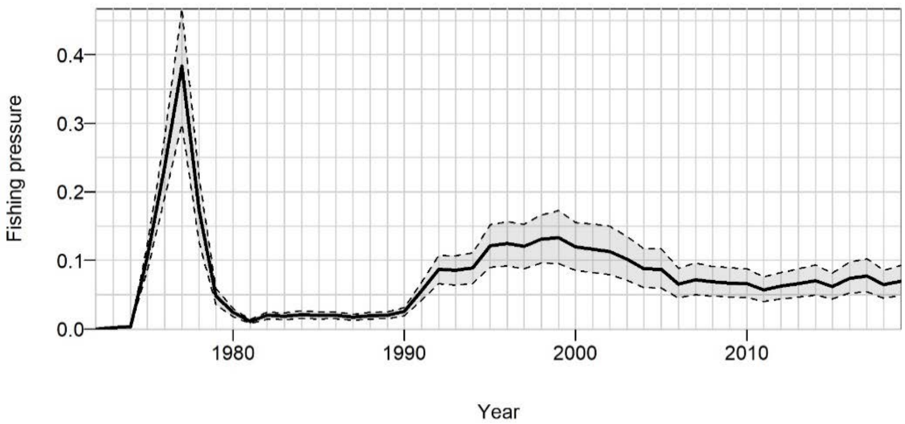


Figure 5: LIN 3&4 base model: Exploitation rates (catch over vulnerable biomass) with 95% credible intervals shown as dashed lines.

4.4 Sub-Antarctic, LIN 5 & LIN 6 (excluding Bounty Plateau)

4.4.1 Model structure and inputs

The stock assessment for LIN 5&6 (Sub-Antarctic) was updated in 2018 (Masi unpublished data). For final runs, the full posterior distribution was sampled using Markov chain Monte Carlo (MCMC) methods, based on the Metropolis-Hastings algorithm. Bounded estimates of spawning stock virgin (B_0) and current (B_{2018}) biomass were obtained. Year class strengths and fishing selectivity ogives were also estimated in the model. Trawl fishery selectivity ogives were fitted as double normal curves; line fishery and research survey ogives were fitted as logistic curves. Selectivities were assumed constant over all years in each fishery/survey.

MCMC chains with a total length of 4×10^6 iterations were constructed. A burn-in length of 1×10^6 iterations was used, with every 1000th sample taken from the final 3×10^6 iterations (i.e., a final sample of length 3000 was taken from the Bayesian posterior).

For LIN 5&6, model input data include catch histories, biomass, and catch-at-age data from summer and autumn trawl survey series, two line fishery CPUE series (from the spawning and home ground fisheries), catch-at-age from the spawning ground and home ground line fisheries, catch-at-age data from the trawl fishery, and estimates of biological parameters. A base case run is presented, which had a constant, estimated natural mortality with respect to age and a revised annual cycle for the spawn and non-spawn line fisheries. The stock assessment model partitions the population into two sexes and age groups 3 to 25 with a plus group. The base model's annual cycle is described in Table 13.

A summary of all observations used in this assessment and the associated time series is given in Table 14. Lognormal errors, with known CVs, were assumed for all relative biomass observations. The CVs available for those observations of relative abundance allow for sampling error only. However, additional variance, assumed to arise from differences between model simplifications and real world variation, was added to the sampling variance. The additional variance, termed process error, was fixed to 0.11 for the base model run, following the recommendations of Francis (2011). Multinomial errors were assumed for all age composition observations. The effective sample sizes for the composition samples were estimated following method TA1.8 as described in appendix A of Francis (2011).

Table 13: LIN 5&6. Annual cycle of the stock model, showing the processes taking place at each time step, their sequence within each time step, and the available observations. Fishing and natural mortality that occur within a time step occur after all other processes, with half of the natural mortality for that time step occurring before and half after the fishing mortality.

					Observations	
Step	**Period**	**Processes**	***M*[1]**	**Age[2]**	**Description**	**%*Z*[3]**
1	Dec–Aug	Trawl and Spawning fishery (line) fisheries Increment ages	0.33	0.0	Trawl survey (summer)	0.1
					Trawl survey (autumn)	0.5
					Trawl catch-at-age	0.7
					Line CPUE (spawning)	
					Line (spawning) catch-at-age	
	Sep–Nov	Recruitment	0.67		Line CPUE (non-spawn)	
2		Non-spawning (line) fishery		0.5	Line (non-spawn) catch-at-age	0.5

1. *M* is the proportion of natural mortality that was assumed to have occurred in that time step.
2. Age is the age fraction, used for determining length-at-age, that was assumed to occur in that time step.
3. %*Z* is the percentage of the total mortality in the step that was assumed to have taken place at the time each observation was made.

Table 14: LIN 5&6. Summary of the relative abundance series applied in the models, including source years (Years).

Data series	**Model Years**
Trawl survey biomass (*Tangaroa*, Nov–Dec)	1992–94, 2001–10, 2012–13, 2015, 2017
Trawl survey proportion at age (*Tangaroa*, Nov–Dec)	1992–94, 2001–10, 2012–13, 2015, 2017
Trawl survey biomass (*Tangaroa*, Mar–May)	1992–93, 1996, 1998
Trawl survey proportion at age (*Tangaroa*, Mar–May)	1992–93, 1996, 1998
CPUE (longline, spawning fishery)	1991–2017
CPUE (longline, non-spawning fishery)	1991–2017
Commercial longline proportion-at-age (spawning, Oct–Dec)	2000–08, 2010, 2017
Commercial longline proportion-at-age (non-spawn, Feb–Jul)	1999, 2001, 2003, 2005, 2009–12, 2014
Commercial trawl proportion-at-age (Sep–Apr)	1992–94, 1996, 1998, 2001–17

The assumed prior distributions used in the assessment are given in Table 15. Most priors were intended to be relatively uninformed and were specified with wide bounds. The exceptions were the choice of informative priors for the trawl survey *q*. The priors on *q* for all the *Tangaroa* trawl surveys were estimated assuming that the catchability constant was a product of areal availability (0.5–1.0), vertical availability (0.5–1.0), and vulnerability between the trawl doors (0.03–0.40). The resulting (approximately lognormal) distribution had mean 0.13 and CV 0.70, with bounds assumed to be 0.02 to 0.30.

Table 15: LIN 5&6. Assumed prior distributions and bounds for estimated parameters in the assessments. The parameters for lognormal priors are mean (in log space) and CV.

Parameter description	Distribution	Parameters		Bounds	
B_0	Uniform-log	–	–	50 000	800 000
Year class strengths	Lognormal	1.0	0.70	0.01	100
Trawl survey *q*	Lognormal	0.13	0.70	0.02	0.3
CPUE *q*	Uniform-log	–	–	1e-8	1e-3
Selectivities	Uniform	–	–	0	20–200[1]
M[2]	Uniform	–	–	0.01	0.6

1. A range of maximum values were used for the upper bound.
2. Constant, estimated natural mortality used in base model.

Penalty functions were used to constrain the model so that any combination of parameters that did not allow the historical catch to be taken was strongly penalised. A small penalty was applied to the estimates of year class strengths to encourage estimates that averaged to 1. The catch history, biological input parameters, and estimates of relative abundance used in the model are given in Tables 5–9.

4.4.2Model estimates

Description of the base model run reported is as follows:
The base case is considered to be a reference model, except process error for both summer and autumn trawl surveys was set to 0.11, a constant, estimated natural mortality with respect to age was applied, and a revised annual cycle for the spawn and non-spawn line fisheries was used.

Five sensitivities were investigated: (1) the updated 2015 model using free *q*'s (hereafter referred to as the reference model) (2) using nuisance *q*'s, (3) logistic selectivity ogive for longline spawn only, (4) doubled the mean of the prior for *q* for the trawl surveys, and (5) halved multinomial weightings associated with age composition estimates. An additional trial of fitting to CPUE was investigated, however this model was found to have potential structural issues. The MPD run with the CPUE index predicted % B_0 still above the 40% threshold, but the CPUE spawn index was not adequately reflecting abundance due to a decline in catch in recent years. Therefore, there was uncertainty as to the CPUE index being a reliable measure of abundance. From the five sensitivity runs trialled, MPD estimates of stock status were between 86–94% B_0.

Posterior distributions of year class strength estimates from the base case model run are shown in Figure 6; the distribution from the base case model differed little from the reference model. Year classes were generally weak from 1982 to 1992, strong from 1994 to 1996, 2005 to 2006, 2008, and 2010, and average since then. Overall, estimated year class strengths were not widely variable, with all medians being between 0.5 and 1.5. Consequently, biomass estimates for the stock declined through the 1990s, but have exhibited an upturn during the last 17 years (Figure 7). The biomass trajectory from the base case model was little different to that derived from the reference model.

Biomass estimates for the stock appear very healthy, with estimated current biomass from three reported models at 88–90% of B_0 (Figure 7, Table 16). Annual exploitation rates (catch over vulnerable biomass) were low (less than 0.05) in all years as a consequence of the high estimated stock size in relationship to the level of relative catches (Figure 8).

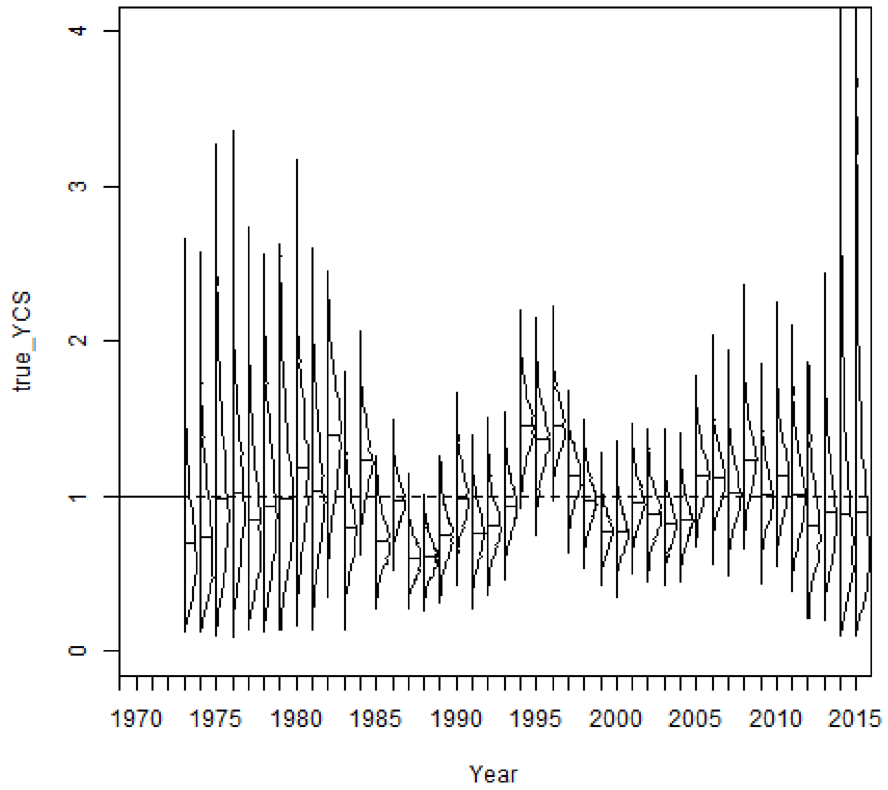


Figure 6: LIN 5&6. Estimated posterior distributions of year class strength from the base case run. The horizontal line indicates a year class strength of one. Individual distributions show the marginal posterior distribution, with horizontal lines indicating the median.

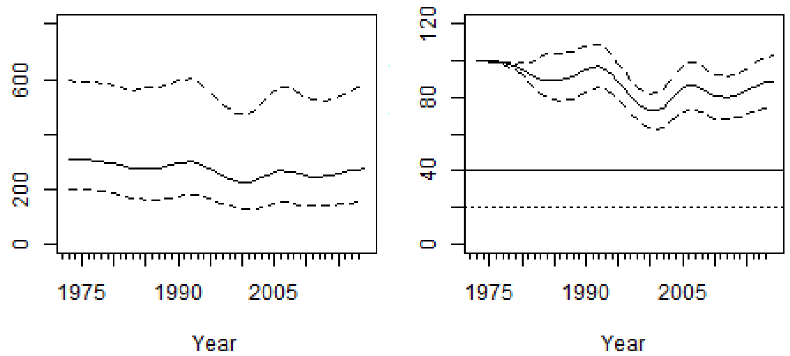


Figure 7: LIN 5&6 base model. Estimated median trajectories (with 95% credible intervals shown as dashed lines) for absolute biomass and biomass as a percentage of B_0. The management target of 40% B_0 is represented as a solid line and the dashed line is the soft limit (20% B_0).

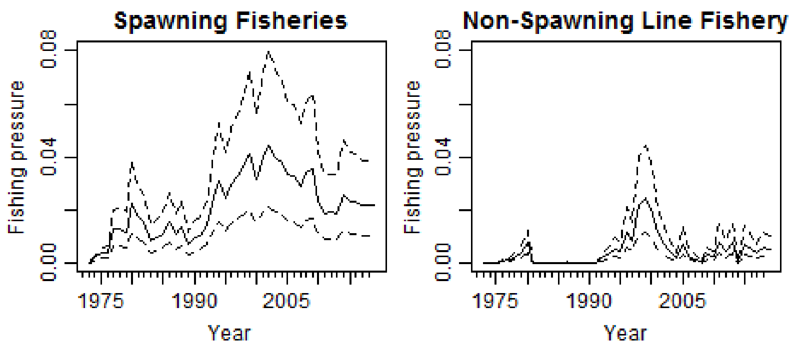


Figure 8: LIN 5&6 base model. Exploitation rates (catch over vulnerable biomass) with 95% credible intervals shown as dashed lines.

Table 16: LIN 5&6. Bayesian median and 95% credible intervals (in parentheses) of B_0 and B_{2018} (in tonnes), and B_{2018} as a percentage of B_0, and the probability that B_{2018} is above 40% of B_0 from the Base model, Reference model, and Base model with nuisance *q*'s.

Model run	B_0		B_{2018}		B_{2018} (% B_0)		P(40% B_0)
Base case model	305 306	(206 265–568 452)	271 900	(164 127–498 668)	88.4	(75.4 –101.1)	0.000
Reference model	278 469	(185 556–507 129)	253 822	(142 119–508 076)	90.3	(74.1–104.7)	0.000
Nuisance *q*'s model	373 544	(233 061–657 266)	339 627	(190 132–638 935)	91.4	(79.4–103.1)	0.000

Resource survey and fishery selectivity ogives were relatively tightly defined. The survey ogive suggested that ling were fully selected by the research gear at about age 7–9. Estimated fishing selectivities indicated that ling were fully selected by the trawl fishery at about age 9 years, and by the line fisheries at about age 12–16.

The assessments indicated a biomass trough about 1999, and some recovery since then. Although estimates of current and virgin stock size are very imprecise, it is most unlikely that B_0 was lower than 200 000 t for this stock, and it is very likely that current biomass is greater than 70% of B_0. Biomass projections derived from this assessment are shown below (section 4.9).

4.5 Bounty Plateau, LIN 6B (Bounty Plateau only)

4.5.1 Model structure and inputs

The stock assessment for the Bounty Plateau stock (part of LIN 6) was updated in 2007 (Horn 2007b). For final runs, the full posterior distribution was sampled using Markov chain Monte Carlo (MCMC) methods, based on the Metropolis-Hastings algorithm. Bounded estimates of spawning stock virgin (B_0) and current (B_{2006}) biomass were obtained. Year class strengths and fishing selectivity ogives were also estimated in the model. Line fishery ogives were fitted as logistic curves.

MCMC chains were constructed using a burn-in length of $5{\times}10^5$ iterations, with every 1000th sample taken from the next 10^6 iterations (i.e., a final sample of length 1000 was taken from the Bayesian posterior).

For LIN 6B, model input data include catch histories, line fishery CPUE, catch-at-age, and catch-at-length from the line fishery, and estimates of biological parameters. In the absence of sufficient stock-specific data, maturity ogives were assumed to be the same as for LIN 3&4, a stock with comparable growth parameters to LIN 6B. Only a base case model run is presented. The stock assessment model partitions the population into two sexes and age groups 3 to 35 with a plus group. There is one fishery (longline) in the stock. The model's annual cycle is described in Table 17.

Lognormal errors, with observation-error CVs, were assumed for all relative biomass, proportions-at-age, and proportions-at-length observations. Additional process error was estimated in MPD runs of the model (Table 18) and fixed in all subsequent runs.

The assumed prior distributions used in the assessment are given in Table 19. All priors were intended to be relatively uninformed, and were estimated with wide bounds.

Table 17: LIN 6B. Annual cycle of the stock model, showing the processes taking place at each time step, their sequence within each time step, and the available observations. Fishing and natural mortality that occur within a time step occur after all other processes, with half of the natural mortality for that time step occurring before and half after the fishing mortality.

					Observations	
Step	Period	Processes	M[1]	Age[2]	Description	$\%Z$[3]
1	Dec–Sep	Recruitment	0.9	0.5	Line CPUE	0.5
		fisher y (line)			Line catch-at-age/length	0.5
2	Oct–Nov	increment ages	0.1	0	–	

1. M is the proportion of natural mortality that was assumed to have occurred in that time step.
2. Age is the age fraction, used for determining length-at-age that was assumed to occur in that time step.
3. $\%Z$ is the percentage of the total mortality in the step that was assumed to have taken place at the time each observation was made.

Table 18: LIN 6B. Summary of the relative abundance series applied in the models, including source years (Years), and the estimated process error (CV) added to the observation error.

Data series	Years	Process error CV
CPUE (longline, all year)	1992–2004	0.15
Commercial longline length-frequency (Nov–Feb)	1996, 2000–04	0.50
Commercial longline proportion-at-age (Dec–Feb)	2000–01, 2004	0.40

Table 19: LIN 6B. Assumed prior distributions and bounds for estimated parameters for the assessments. The parameters are mean (in log space) and CV for lognormal.

Parameter description	Distribution	Parameters		Bounds	
B_0	uniform-log	–	–	5 000	100 000
Year class strengths	lognormal	1	0.7	0.01	100
CPUE *q*	uniform-log	–	–	1.00E-08	1.00E-03
Selectivities	uniform	–	–	0	20–200*
Process error CV	uniform-log	–	–	0.001	2

Penalty functions were used to constrain the model so that any combination of parameters that did not allow the historical catch to be taken was strongly penalised. A small penalty was applied to the estimates of year class strengths to encourage estimates that averaged to 1.

The catch history, biological input parameters, and estimates of relative abundance used in the model are shown in Tables 5–9.

4.5.2 Model estimates

Only a base case model run was completed.

Posterior distributions of year class strength estimates from the base case model run are shown in Figure 9.

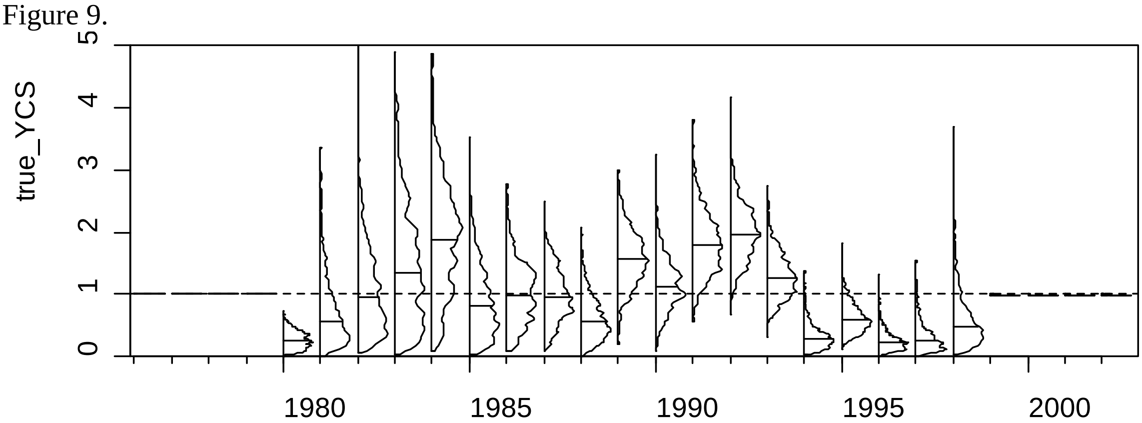


Figure 9: LIN 6B. Estimated posterior distributions of year class strength from the base case run. The horizontal line indicates a year class strength of one. Individual distributions show the marginal posterior distribution, with horizontal lines indicating the median.

The assessment was driven largely by the catch-at-age and catch-at-length series from the line fishery; the first two years of CPUE data were not well fitted. Biomass estimates are listed in Table 20 and the biomass trajectory is shown in Figure 10. The assessment indicates a declining biomass throughout the history of the fishery. Estimates of current and virgin stock size are not well known, but current biomass is very likely to be above 50% of B_0.

Table 20: LIN 6B. Bayesian median and 95% credible intervals (in parentheses) of B_0 and B_{2006} (in t), and B_{2006} as a percentage of B_0 for the base case model run.

Model run	B_0	B_{2006}	B_{2006} (% B_0)
Base case	13 570 (10 850–19 030)	8 330 (4 860–14 730)	61 (45–79)

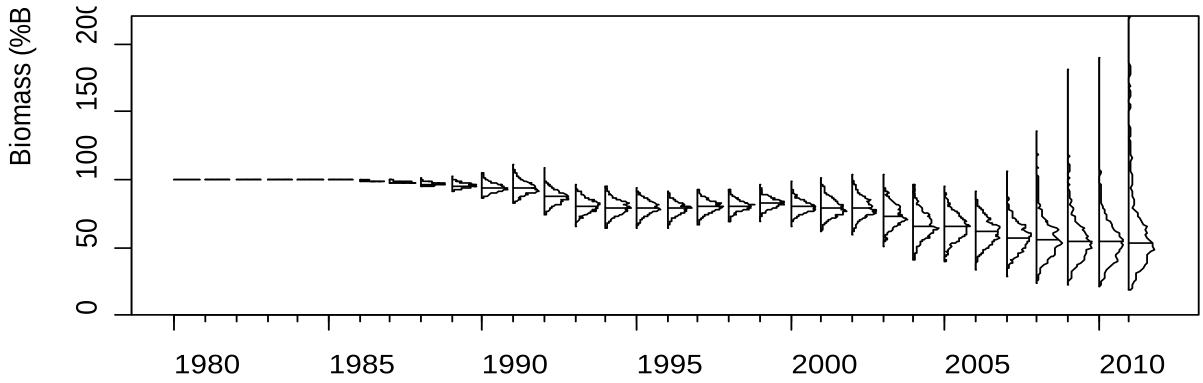


Figure 10: LIN 6B. Estimated posterior distributions of biomass trajectories as a percentage of B_0, from the base case model run (including 5-year projections through to 2011 with assumed constant annual catch of 400 t). Distributions are the marginal posterior distribution, with horizontal lines indicating the median.

Biomass projections derived from this assessment are shown below (section 4.9).

4.6 West coast South Island, LIN 7WC

4.6.1 Model structure and inputs

The stock assessment for LIN 7WC (west coast South Island) was updated in 2020. The assessment model partitioned the population into age groups 3 to 28 with a plus group, and immature and mature fish, with no sex in the partition. The model's annual cycle is described in Table 21.

The reported model runs were developed following the investigation of numerous previous model runs. These evaluated the sensitivity of the model fit to assumptions about indices of abundance, natural mortality rate, trawl survey and fishery selectivity ogives, and weights assigned to different observational data sets.

Table 21: LIN 7WC. Annual cycle of the stock model, showing the processes taking place at each time step, their sequence within each time step, and the available observations. Fishing and natural mortality that occur within a time step occur after all other processes, with half of the natural mortality for that time step occurring before and half after the fishing mortality.

					Observations	
Step	**Period**	**Processes**	M[1]	**Age**[2]	**Description**	**%Z**[3]
1	Oct–May	Recruitment fishery (line)	0.75	0.5	Line catch-at-age	0.5
2	Jul–Sep	fishery (trawl)	0.25	0.8	Trawl catch-at-age Trawl CPUE Trawl survey biomass and catch at age	0.5
3	End of Sep	Increment ages	0	0		

1. M is the proportion of natural mortality that was assumed to have occurred in that time step.
2. Age is the age fraction, used for determining length-at-age, that was assumed to occur in that time step.
3. %Z is the percentage of the total mortality in the step that was assumed to have taken place at the time each observation was made.

Year class strengths and fishing selectivity ogives were estimated in the model. The longline fishery and mature fish research trawl survey selectivity ogives were assumed to be logistic. The selectivity of immature fish by the research trawl survey was estimated as a capped logistic curve. Commercial trawl fishery selectivity ogive was set as a double normal function.

Two analyses were carried to test the sensitivity of the results of the LIN 7 stock assessment (base case) to some of the assumptions (Table 22): models 2 and 3 were used to investigate the effect of using alternative indices of abundance into the assessment; models 4 and 5 assessed the effect of using different values of natural mortality.

Table 22: LIN 7WC. Settings of the models exploring the sensitivity of the base case stock assessment to the index of abundance (columns) and the value of natural mortalities (rows).

	Indices of abundance		
Natural mortality (per year)	**Survey**	**Survey + CPUE**	**CPUE**
0.14	Model 4		
0.18	Base case	Model 2	Model 3
0.22	Model 5		

The full posterior distributions of the parameters of the base case model and model 15 were sampled using Markov chain Monte Carlo (MCMC) methods, based on the Metropolis-Hastings algorithm. Bounded estimates of spawning stock virgin (B_0) and current (B_{2020}) biomass were obtained. Four MCMC chains were constructed using a burn-in length of 2×10^6 iterations, with every 2000th sample taken from the next 6×10^6 iterations (i.e., four final samples of length 2000 each were taken from the Bayesian posterior totally 8000 samples to describe the posterior distributions of the models parameters). Visual inspections of the chains were used to determine the acceptability of the MCMC procedure. The final model runs (section 4.6.2) were considered acceptable for providing management advice.

For LIN 7WC, available data to model the fishery included catch histories, trawl fishery CPUE, extensive catch-at-age data from the trawl fishery, sparse catch-at-age data from the line fishery, biomass estimates, and proportion-at-age from *Tangaroa* surveys in 2000, 2012, 2013, 2016, and 2018 and estimates of constant biological parameters (Table 23). A line fishery CPUE series was available, but was rejected as unlikely to be indexing stock abundance. The *Kaharoa* inshore trawl survey biomass estimates and proportion-at-length estimates were not considered to be useful because they have been rejected in previous sittings of the DWWG because few ling older than age nine were caught in surveys, and inclusion of the data made negligible contribution to the estimation of model parameters.

The error distributions assumed were multinomial for the proportions-at-age and lognormal for all other data. Biomass indices had assumed CVs set equal to the sampling CV plus an additional process error of 0.4, estimated following Francis (2011). The multinomial observation error effective sample sizes for the trawl fishery at-age data were adjusted using the reweighting procedure of Francis (2011). An *ad hoc* procedure was used for the at-age data from the line fishery and *Tangaroa* survey at-age data, giving the line fishery a relatively low weighting and the trawl survey a relatively high weighting.

Table 23: LIN 7WC. Summary of the relative abundance and stock composition series applied in the models, including source years (Years).

Data series	Years
CPUE (hoki trawl, Jun–Sep)	1987–2019
Commercial trawl proportion-at-age (Jun–Sep)	1991, 1994–2008, 2012–2019
Commercial longline proportion-at-age	2003, 2006, 2007, 2012, 2015
Trawl survey biomass (*Tangaroa*, Jul)	2000, 2012–13, 2016, 2018
Trawl survey age data	2000, 2012–13, 2016, 2018

The assumed prior distributions used in the assessment are given in Table 24. Most priors were intended to be relatively uninformed and were specified with wide bounds. The prior for the survey q was informative and was estimated using the Sub-Antarctic ling survey priors as a starting point (see section 4.4.1) because the survey series in both areas used the same vessel and fishing gear. However, the WCSI survey area in the 200–650 m depth range in strata 0004 A–C and 0012 A–C comprised 6619 km^2; seabed area in that depth range in the entire LIN 7 WC biological stock area (excluding the Challenger Plateau) is estimated to be about 20 100 km^2. So, because biomass from only 33% of the WCSI ling habitat was included in the indices, the Sub-Antarctic prior on μ was modified accordingly (i.e., $0.13 \times 0.33 = 0.043$), and the bounds were also reduced from [0.02, 0.30] to [0.01, 0.20]. Priors for survey selectivity parameters, both immature and mature ling, and trawl fishery were changed from uninformed to informed because of lack of convergence in the MCMC. The prior for those parameters was set to a lognormal distribution with mean set at the estimate from a log-likelihood minimisation fit and coefficient of variation of 0.2. The prior distributions for the longline fishery selectivity parameters were assumed to be uniform.

Table 24: LIN 7WC. Assumed prior distributions and bounds for parameters estimated in the models. For lognormal distributions the figures are the log-space mean and the CV, and for normal distributions the figures are the mean and standard deviation.

Parameter description	Distribution	Parameters		Bounds	
B_0	uniform-log	–	–	10 000	500 000
Year class strengths	lognormal	1.0	0.7	0.01	100
Tangaroa survey *q*	lognormal	0.043	0.70	0.001	1
CPUE *q*	uniform-log	–	–	1e-8	1e-3
Trawl fishery selectivity par 1	Lognormal	10	0.2	1	30
Trawl fishery selectivity par 2	Lognormal	5.5	0.2	1	30
Trawl survey selectivity immature par 1	Lognormal	2.8	0.2	1	30
Trawl survey selectivity immature par 2	Lognormal	0.77	0.2	0.1	30
Trawl survey selectivity immature par 3	Lognormal	0.03	0.2	0.001	0.20
Trawl survey selectivity mature par 1	Lognormal	13.6	0.2	1	30
Trawl survey selectivity mature par 2	Lognormal	7.2	0.2	1	30
Longline fishery selectivity	uniform	–	–	0	30–200*

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

Penalty functions were used to constrain the model so that any combination of parameters that did not allow the historical catch to be taken was strongly penalised. A small penalty was applied to the estimates of year class strengths to encourage estimates that averaged to 1.

The catch history, biological input parameters, and estimates of relative abundance used in the model are shown in Tables 5–9.

4.6.2 Model estimates

The results of the sensitivity analyses showed that the stock assessment model is not sensitive to using alternative indices of abundance. Spawning stock biomass estimates do vary as a function of the magnitude of natural mortality assumed in the model in a predictable way: the best estimate of *M* is 0.18. Of the five models presented in this section, only two were brought to MCMC. Those two models estimated the median virgin biomass to be equal between 55 000–56 000 t (Table 25), and the ling SSB to have declined by 2020 to approximately 50% of its virgin biomass (B_0) (Figure 11).

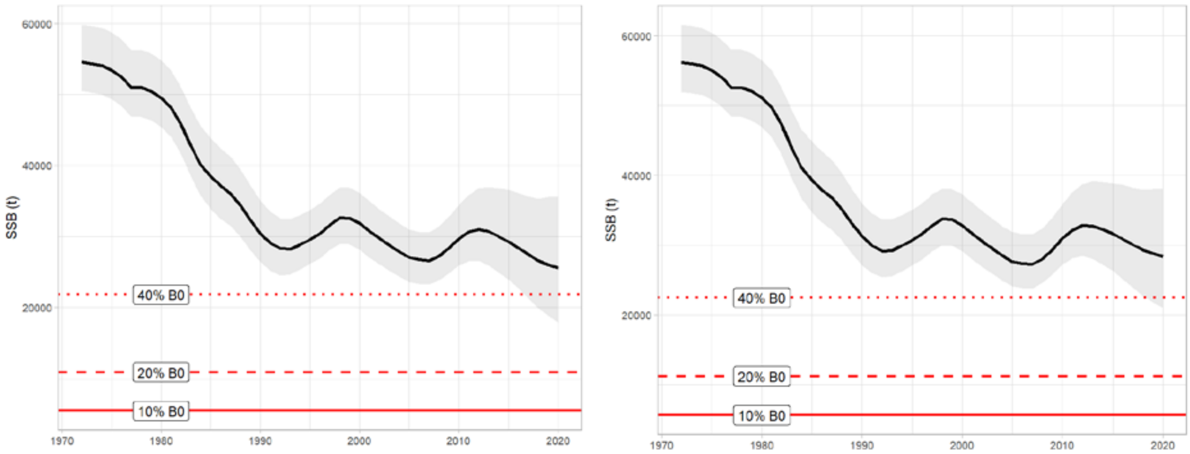


Figure 11: LIN 7WC. Estimated posterior distribution of the spawning stock biomass (SSB in tonnes) trajectory and estimated virgin spawning stock biomass reference points (40%, 20%, and 10% B_0) for the base case model (left panel) and the model 2 (right panel). The solid black line represents the median values and the shaded areas the 95% confidence intervals.

Table 25: LIN 7WC. Bayesian median and 95% credible intervals (in parentheses) of B_0 and B_{2017} (in tonnes) and B_{2017} as a percentage of B_0 for all model runs.

Model run	B_0		B_{2020}		B_{2020} (% B_0)		$P(B_{2020} > 0.4B_0)$	$P(B_{2020} < 0.2B_0)$	$P(B_{2020} < 0.1B_0)$
Base case	54 546	(50 463–59833)	25 556	(17 877–35 527)	47	(35–60)	87	0	0
Adding CPUE index of abundance (model 2)	56 159	(51 964–61 580)	28 393	(21 034–38 047)	50	(40–62)	97	0	0

4.7 Cook Strait, LIN 7CK

4.7.1 Model structure and inputs

A stock assessment of ling in Cook Strait (LIN 7CK) was completed in 2013 (Dunn et al 2013). Because it is believed that the true *M* for the Cook Strait stock is higher than the 'default' value of 0.18, it was considered desirable to estimate *M* in the model, and so incorporate the effect of this uncertainty in *M* in the assessment. However, the simultaneous estimation of B_0 and *M* was not successful owing to the adoption of a multinomial likelihood (rather than lognormal) for proportions-at-age. Consequently, models with fixed *M* values were run, and although the age data were reasonably well fitted, the model failed to accurately represent declines in resource abundance that appear evident from CPUE values, which have been declining since 2001. As a consequence the model was considered unsuitable for the provision of management advice.

The last stock assessment for LIN 7CK (Cook Strait) accepted by the Working Group was completed in 2010 (Horn & Francis 2013), and it is reported here. The stock assessment model partitions the population into two sexes and age groups 3 to 25 with a plus group. The model's annual cycle is described in Table 26. Year class strengths and fishing selectivity ogives were also estimated in the model. Commercial trawl selectivity was fitted as double normal curves; line fishery ogives were fitted as logistic curves.

For final runs, the full posterior distribution was sampled using Markov chain Monte Carlo (MCMC) methods, based on the Metropolis-Hastings algorithm. Bounded estimates of spawning stock virgin (B_0) and current (B_{2008}) biomass were obtained. MCMC chains were constructed using a burn-in length of 4×10^6 iterations, with every 2000th sample taken from the next 20×10^6 iterations (i.e., a final sample of length 1000 was taken from the Bayesian posterior).

For LIN 7CK, model input data include catch histories, trawl and line fishery CPUE, extensive catch-at-age data from the trawl fishery, sparse catch-at-age data from the line fishery, and estimates of biological parameters. Initial modelling investigations found that the line CPUE produced implausible results; this series was rejected as a useful index. The base case used all catch-at-age data from the fisheries, and the trawl CPUE series. Instantaneous natural mortality was estimated in the model.

Lognormal errors, with observation-error CVs, were assumed for all CPUE and proportions-at-age observations. Additional process error, assumed to arise from differences between model simplifications and real world variation, was added to the sampling variance (Table 27).

Table 26: LIN 7CK. Annual cycle of the stock model, showing the processes taking place at each time step, their sequence within each time step, and the available observations. Fishing and natural mortality that occur within a time step occur after all other processes, with half of the natural mortality for that time step occurring before and half after the fishing mortality.

					Observations	
Step	**Period**	**Processes**	***M*[1]**	**Age[2]**	**Description**	**%*Z*[3]**
1	Oct–May	Recruitment fishery (line)	0.67	0.5	Line CPUE Line catch-at-age	0.5
2	Jun–Sep	increment ages fishery (trawl)	0.33	0	Trawl CPUE Trawl catch-at-age	0.5

1. *M* is the proportion of natural mortality that was assumed to have occurred in that time step.
2. Age is the age fraction, used for determining length-at-age, that was assumed to occur in that time step.
3. %*Z* is the percentage of the total mortality in the step that was assumed to have taken place at the time each observation was made.

Table 27: LIN 7CK. Summary of the available data including source years (Years), and the estimated process error (CV) added to the observation error.

Data series	Years	Process error CV
CPUE (hoki trawl, Jun–Sep)	1994–2009	0.2
Commercial trawl proportion-at-age (Jun–Sep)	1999–2009	1.1
Commercial longline proportion-at-age	2006–07	1.1

The assumed prior distributions used in the assessment are given in Table 28. Most priors were intended to be relatively uninformed and were specified with wide bounds.

Table 28: LIN 7CK: Assumed prior distributions and bounds for estimated parameters in the assessments. The parameters are mean (in log space) and CV for lognormal, and mean and standard deviation for normal.

Parameter description	Distribution	Parameters		Bounds	
B_0	uniform-log	–	–	2 000	60 000
Year class strengths	lognormal	1.0	0.9	0.01	100
CPUE q	uniform-log	–	–	1e-8	1e-2
Selectivities	uniform	–	–	0	20–200*
M	lognormal	0.18	0.16	0.1	0.3

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

Penalty functions were used to constrain the model so that any combination of parameters that did not allow the historical catch to be taken was strongly penalised. A small penalty was applied to the estimates of year class strengths to encourage estimates that averaged to 1.

The catch history, biological input parameters, and estimates of relative abundance used in the model are shown in Tables 5–9.

4.7.2 Model estimates

A single model was presented incorporating a catch history, trawl and line fishery catch-at-age, trawl CPUE series, with double-normal ogives for the trawl fishery and logistic ogives for the line fishery, and *M* estimated in the model.

Posterior distributions of LIN 7CK year class strength estimates from the base case model run are shown in Figure 12.

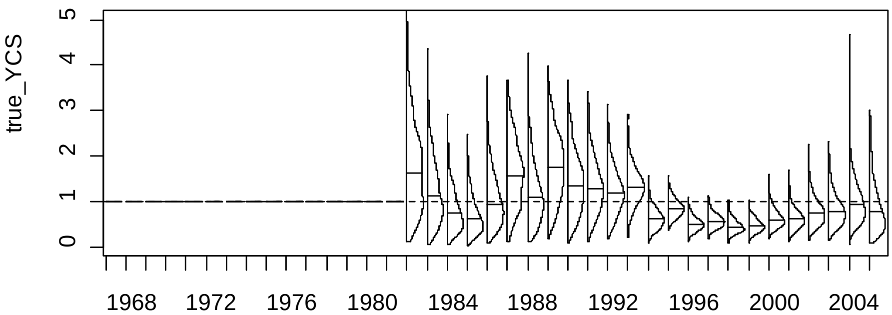


Figure 12: LIN 7CK. Estimated posterior distributions of year class strength. The horizontal line indicates a year class strength of one. Individual distributions show the marginal posterior distribution, with horizontal lines indicating the median.

The assessment is driven by the trawl fishery catch-at-age data and tuned by the trawl CPUE. Both input series contain information indicative of an overall stock decline in the last two decades. The confidence bounds around biomass estimates are wide (Table 29, Figure 13). Probabilities that current and projected biomass will drop below selected management reference points are shown in Table 30. Median *M* was estimated to be 0.24 (95% confidence interval 0.16–0.30). Estimates of biomass are very sensitive to small changes in *M*, but clearly there is information in the model encouraging an *M* higher than the ‘default’ value of 0.18. The model indicated a slight overall biomass decline to about 2000, followed by a much steeper decline from 2000 to 2010. Exploitation rates (catch over vulnerable biomass) were very low up to the late 1980s and have been low to moderate (up to about 0.12 y^{-1}) since then. Since the early 1990s, trawl fishing pressure has generally declined, whereas line pressure has generally increased.

Table 29: LIN 7CK. Bayesian median and 95% credible intervals (in parentheses) of B_0 and B_{2010} (in tonnes), and B_{2010} as a percentage of B_0 for all model runs.

Model run		B_0		B_{2010}		B_{2010} (%B_0)
Base case	8 070	(5 290–53 080)	4 370	(1 250–40 490)	54	(23–80)

Table 30: LIN 7CK. Probabilities that current (B_{2010}) and projected (B_{2015}) biomass will be less than 40%, 20%, or 10% of B_0. Projected biomass probabilities are presented for two scenarios of future annual catch (i.e., 220 t and 420 t).

Biomass	Management reference points		
	40% B_0	20% B_0	10% B_0
B_{2010}	0.248	0.006	0.000
B_{2015}, 220 t catch	0.179	0.010	0.000
B_{2015}, 420 t catch	0.328	0.094	0.019

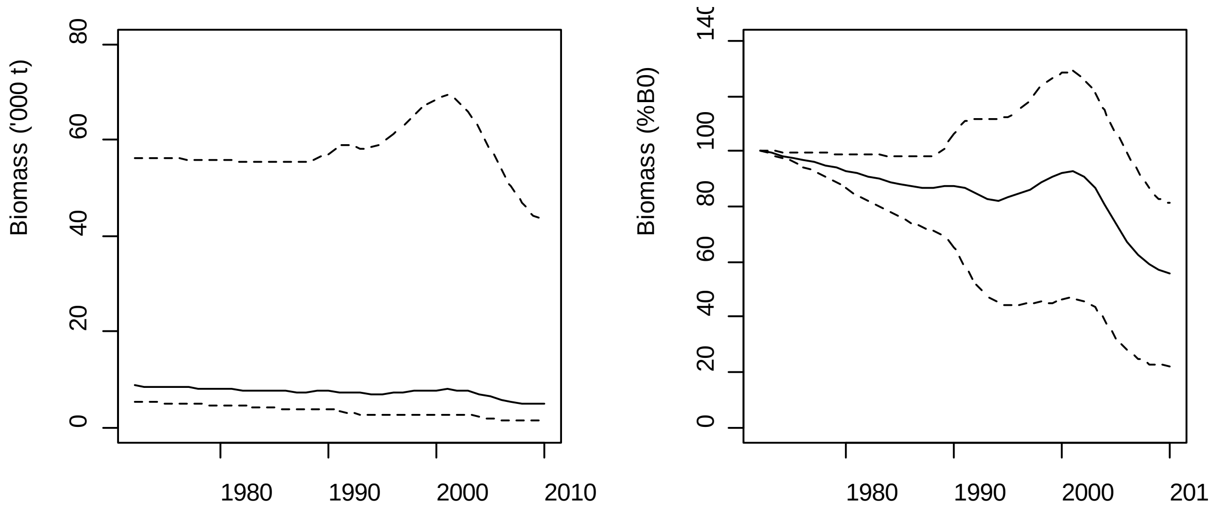


Figure 13: LIN 7CK. Estimated median trajectories (with 95% credible intervals shown as dashed lines) for absolute biomass and biomass as a percentage of B_0.

Estimates of biomass projections derived from this assessment are shown below (section 4.9).

4.8 Projections

Projections for LIN 6B from the 2006 assessment are shown in Table 31. The LIN 6B stock (Bounty Plateau) was projected to decline out to 2011, but probably still be higher than 50% of B_0. Projections out to 2015 for LIN 7CK indicated that biomass was likely to increase with future catches equal to recent previous catch levels, or decline slightly if catches were equal to the mean since 1990 (Table 32). New projections made in 2014 out to 2019 for LIN 3&4 and 5&6 are shown in Table 33. For LIN 3&4, stock size is likely to remain about the same assuming future catches equal to recent catch levels, or decrease to around 90% of the 2018 biomass by 2023 if catches reach the TACC. For LIN 5&6, the probability of B_{2019} being below 40% of B_0 is very small when assuming either one of two future annual catch scenarios (the recent catch level of 6650 t or the TACC of 12 100 t) (Table 34). Projections out to 2022 for LIN 7WC indicated that biomass was likely to remain about the same with future catches equal to the average of catch in 2012–2016 (2980 t), or if catches for LIN 7WC were to increase modestly (by around 10%, 3300 t) to the overall LIN 7 fishstock level (Table 35).

Table 31: LIN 6B. Bayesian median and 95% credible intervals (in parentheses) of projected B_{2011}, B_{2011} as a percentage of B_0, and B_{2011}/B_{2006} (%) for the 2006 base case.

Stock and model run		Future catch (t)	B_{2011}		B_{2011} (%B_0)		B_{2011}/B_{2006} (%)	
LIN 6B	Base	600	7 460	(2 950–18 520)	53	(26–116)	86	(51–168)

Table 32: LIN 7CK. Bayesian median and 95% credible intervals (in parentheses) of projected B_{2015}, B_{2015} as a percentage of B_0, and B_{2015}/B_{2010} (%) for the base case.

Stock and model run		Future catch (t)	B_{2015}		B_{2015} (%B_0)		B_{2015}/B_{2010} (%)	
LIN 7CK	Base	220	5 030	(1 310–43 340)	59	(24–97)	110	(82–158)
		420	4 320	(590–42 910)	52	(11–92)	95	(45–136)

Table 33: LIN 3&4. Bayesian median and 95% credible intervals (in parentheses) of projected B_{2024}, B_{2024} as a percentage of B_0, and B_{2024}/B_{2019}(%) for the base case runs. [Continued on next page]

Stock and model run		Future catch (t)		B_{2024}		B_{2024} (%B_0)		B_{2024}/B_{2019} (%)
LIN 3&4	Base (future YCS from all estimated YCS)	6 260	54 200	(37 500–81 500)	49	(37–63)	86	(75–98)
	Base (future YCS from last 10 YCS)	6 260	54 000	(37 000–81 600)	49	(36–63)	86	(75–98)
	Base (future YCS from all estimated YCS)	3 883	63 300	(46 600–90 400)	57	(56–70)	101	(92–111)
	Base (future YCS from last 10 YCS)	3 883	63 100	(46 400–90 200)	57	(46–70)	100	(91–111)

Table 34: LIN 5&6. Bayesian median and 95% credible intervals (in parentheses) of projected B_{2023}, B_{2023} as a percentage of B_0, and B_{2023}/B_{2018}(%) for the base case runs.

Stock and model run		Future catch (t)		B_{2024}		B_{2023} (%B_0)		B_{2023}/B_{2018} (%)
LIN 5&6	Base	6 650	269 600	(135 100–551 200)	86	(67–110)	97	(80–127)
		12 100	247 000	(120 400–553 600)	81	(58–106)	90	(72–123)

Table 35: LIN 7WC. Bayesian median and 95% credible intervals (in parentheses) of projected B_{2022}, B_{2022} as a percentage of B_0, and B_{2022}/B_{2017} (%) for the model runs.

Stock and model run		Future catch (t)		B_{2022}		B_{2022} (%B_0)		B_{2022}/B_{2016} (%)
LIN 7WC	Combined CPUE	2980	77 300	(37 800–185 500)	79	(56–106)	100	(83–126)
		3300	76 600	(35 500–183 700)	78	(54–104)	98	(80–123)
	Lognormal CPUE	2980	47 400	(21 600–97 300)	70	(41–100)	104	(81–134)
		3300	45 900	(20 700–96 900)	68	(37–97)	102	(77–133)
	Lognormal CPUE & M = 0.18	2980	38 100	(17 300–97 900)	57	(33–85)	100	(76–126)
		3300	36 400	(15 900–95 900)	54	(32–82)	97	(73–124)

5. STATUS OF THE STOCKS

Stock Structure Assumptions

Ling are assessed as six independent biological stocks, based on the presence of spawning areas and some differences in biological parameters between areas (Horn 2005).

The Chatham Rise biological stock comprises all of Fishstock LIN 4, and LIN 3 north of the Otago Peninsula. The Sub-Antarctic biological stock comprises all of Fishstock LIN 5, all of LIN 6 excluding the Bounty Plateau, and LIN 3 south of the Otago Peninsula. The Bounty Plateau (part of Fishstock LIN 6) holds another distinct biological stock. The WCSI biological stock occurs in Fishstock LIN 7 west of Cape Farewell. The Cook Strait biological stock includes those parts of Fishstocks LIN 7 and LIN 2 between the northern Marlborough Sounds and Cape Palliser. Ling around the northern North Island (Fishstock LIN 1) are assumed to comprise another biological stock, but there is no information to support this assumption. The stock affinity of ling in LIN 2 between Cape Palliser and East Cape is unknown.

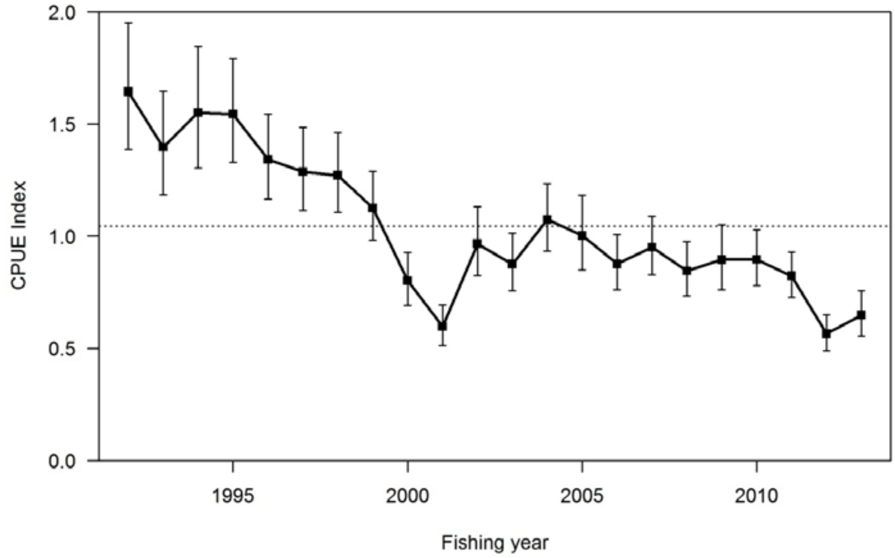
East and west coast LIN 1 are regarded as separate stocks, but no assessments are available for either stock.

- **East coast North Island (part of LIN 2, Statistical Areas 011–015)**

Stock Status	
Year of Most Recent Assessment	2014

Assessment Runs Presented	CPUE time series based on bottom longline ling target fishing
Reference Points	Target: 40% B_0 Soft Limit: 20% B_0 Hard Limit: 10% B_0 Overfishing threshold: F corresponding to 40% B_0
Status in relation to Target	Unknown. CPUE has declined by between about 50–60% since the start of the time series in 1992.
Status in relation to Limits	B_{2014} is Unlikely (< 40%) to be below the Soft Limit and Very Unlikely (< 10%) to be below the Hard Limit
Status in relation to Overfishing	Unknown

Historical Stock Status Trajectory and Current Status



Standardised CPUE index (± 95% CI) for bottom longline vessels targeting ling from the ECNI Statistical Areas 011–015 (1992–2013). The dashed horizontal line is the time series mean.

Fishery and Stock Trends	
Recent Trend in Biomass or Proxy	Biomass is estimated to have declined from 1992 by 50–60%.
Recent Trend in Fishing Intensity or Proxy	Unknown
Other Abundance Indices	-
Trends in Other Relevant Indicators or Variables	-

Projections and Prognosis (2014)	
Stock Projections or Prognosis	Unknown
Probability of Current Catch or TACC causing Biomass to remain below or to decline below Limits	Soft Limit: Unknown Hard Limit: Unknown
Probability of Current Catch or TACC causing Overfishing to continue or to commence	CPUE has declined while catches have been below the TACC. There is some probability that fishing at the TACC or current catch may lead to overfishing.

Assessment Methodology and Evaluation		
Assessment Type	Level 2 - Partial Quantitative Stock Assessment	
Assessment Method	Evaluation of a CPUE time series from 1992–2013 for bottom longliners targeting ling in statistical areas 11–15.	
Assessment Dates	Latest assessment: 2014	Next assessment: Unknown
Overall assessment quality rank	1 – High Quality	

Main data inputs (rank)	- Bottom longline effort & estimated catch	1 – High Quality
Data not used (rank)	N/A	
Changes to Model Structure and Assumptions	-	
Major Sources of Uncertainty	- It is assumed that the longline CPUE time series tracks the entire biomass of ling in this stock. - The boundaries of this biological stock, particularly towards Cook Strait, are uncertain.	

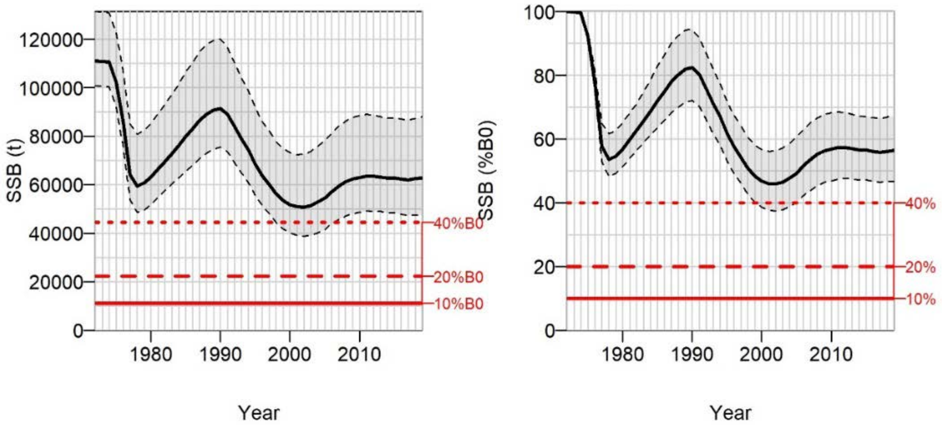
Qualifying Comments
-

Fishery Interactions
Ling are often taken as bycatch in hoki target trawl fisheries in this region. The main bycatch species of hoki-hake-ling-silver warehou-white warehou target fisheries are rattails, javelinfish, and spiny dogfish. Additional information on trawl bycatch can be found in the Environmental and Ecosystem Considerations section of the hoki plenary chapter. Model-based analysis of observer and effort data shows that, in the target line fisheries for ling across all stocks, the main bycatch species (those constituting over 1% of the observed catch) are: spiny dogfish, ribaldo, skates (smooth and rough), black cod, sea perch, pale ghost shark, red cod, and shovelnose dogfish. Incidental captures of protected species are reported for seabirds.

- **Chatham Rise (LIN 3 & 4)**

Stock Status	
Year of Most Recent Assessment	2019
Assessment Runs Presented	One base case
Reference Points	Management Target: 40% B_0 Soft Limit: 20% B_0 Hard Limit: 10% B_0 Overfishing threshold: $U_{40\%}$
Status in relation to Target	B_{2019} was estimated to be about 57% B_0; Very Likely (> 90%) to be above the target
Status in relation to Limits	B_{2019} is Exceptionally Unlikely (< 1%) to be below the Soft Limit and Exceptionally Unlikely (< 1%) to be below the Hard Limit
Status in relation to Overfishing	Overfishing is Very Unlikely (< 10%) to be occurring

Historical Stock Status Trajectory and Current Status



Trajectory over time of spawning biomass (absolute, and % B_0, with 95% credible intervals shown as broken lines) for the Chatham Rise ling stock from the start of the assessment period in 1972 to the most recent assessment in 2019, for the base case model run. Years on the x-axis are fishing year with "2010" representing the 2009–10 fishing year. Biomass estimates are based on MCMC results.

Fishery and Stock Trends	
Recent Trend in Biomass or Proxy	Biomass is very unlikely to have been below 40% B_0. Biomass is estimated to have been increasing or stable since 2003.
Recent Trend in Fishing Mortality or Proxy	Fishing pressure is estimated to have been constant since about 2008.
Other Abundance Indices	-
Trends in Other Relevant Indicators or Variables	Recruitment since about 2008 is estimated to have been fluctuating around the long-term average for this stock.

Projections and Prognosis (2019)	
Stock Projections or Prognosis	Current catch is unlikely to cause the stock to decline. Catches at level of the TACC are likely to cause the stock to decline to about 50% B_0 in 5 years.
Probability of Current Catch or TACC causing Biomass to remain below or to decline below Limits	Soft Limit: Exceptionally Unlikely (< 1%) at current catch Hard Limit: Exceptionally Unlikely (< 1%) at current catch Soft Limit: Exceptionally Unlikely (< 1%) at TACC Hard Limit: Exceptionally Unlikely (< 1%) at TACC
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 Stock Assessment	
Assessment Method	Age-structured CASAL model with Bayesian estimation of posterior distributions	
Assessment Dates	Latest assessment: 2019	Next assessment: 2021
Overall assessment quality rank	1 – High Quality	
Main data inputs (rank)	- Summer research trawl survey series, 1992-2014, 2016, 2018	1 – High Quality
	- Proportions-at-age data from the commercial fisheries and trawl survey	1 – High Quality
	- Line fishery CPUE series (annual indices since 1991): series not used in the base assessment model	2 – Medium or Mixed Quality: likely change in q over time
	- Estimates of biological parameters (but note that M was estimated in the models)	1 – High Quality
Data not used (rank)	*Kaharoa* ECSI trawl survey abundance index	3 – Low Quality: inadequate spatial coverage of the stock distribution
Changes to Model Structure and Assumptions	- Longline fishery proportions at length removed as data inputs. - Longline fishery proportions at age changed from combined sex to separated male and female. Natural mortality estimated by sex instead of combined over sexes.	
Major Sources of Uncertainty	- Lack of contrast in survey indices	

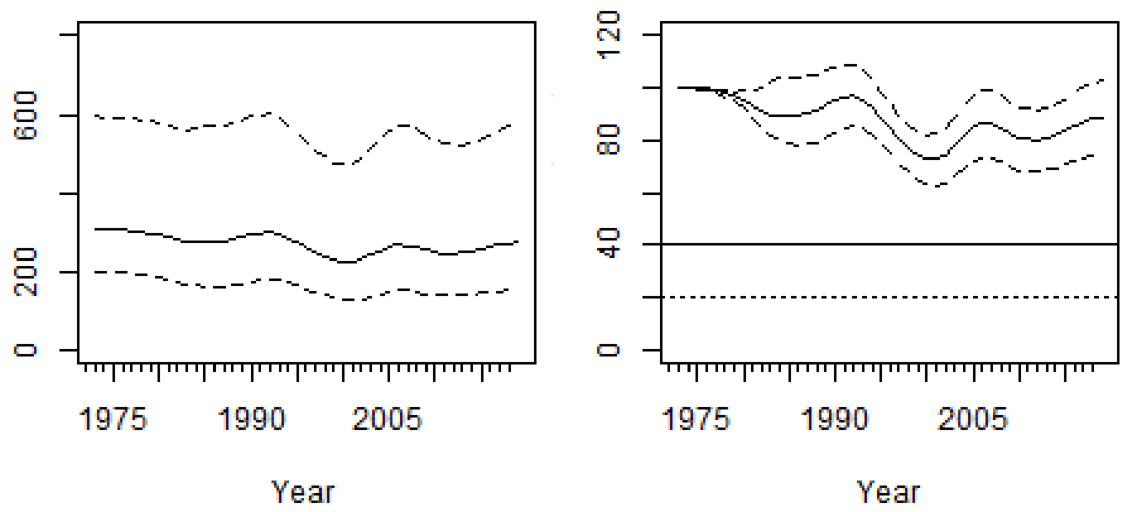
Qualifying Comments
-

Fishery Interactions
Ling are often taken as bycatch in hoki target trawl fisheries in this region. The main bycatch species of hoki-hake-ling-silver warehou-white warehou target fisheries are rattails, javelinfish, and spiny dogfish. Additional information can be found in the Environmental and Ecosystem Considerations section of the hoki plenary chapter. Model-based analysis of observer and effort data shows that, in the target line fisheries for ling across all stocks, the main bycatch species (those comprising over 1% of the observed catch) are: spiny dogfish, ribaldo, skates (smooth and rough), black cod, sea perch, pale ghost shark, red cod, and shovelnose dogfish. All these species are a significant part of the longline fishery bycatch on the Chatham Rise. Spiny dogfish is particularly represented in the bycatch, with estimated annual catches of 1000–2000 t.

- **Sub-Antarctic (LIN 5 & 6, excluding the Bounty Plateau)**

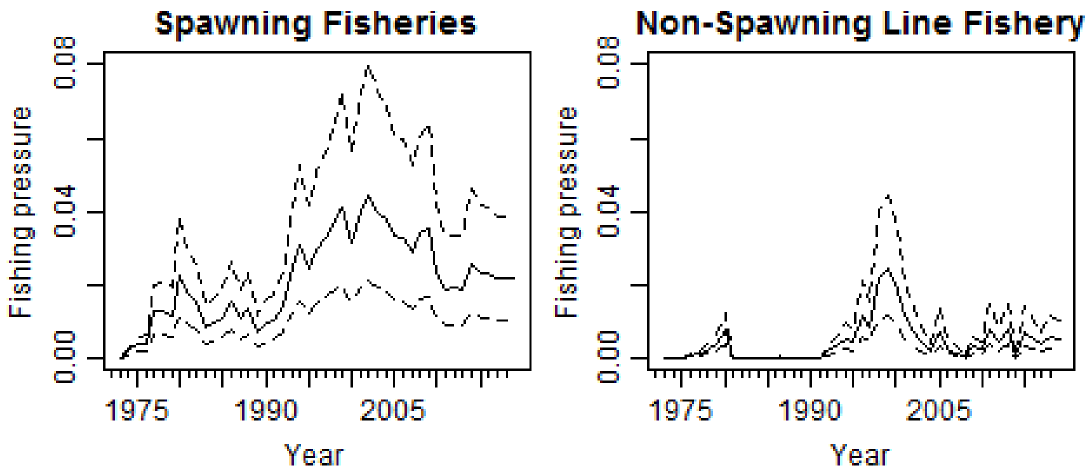
Stock Status	
Year of Most Recent Assessment	2018
Assessment Runs Presented	One base case
Reference Points	Management Target: 40% B_0 Soft Limit: 20% B_0 Hard Limit: 10% B_0 Overfishing threshold: $F_{40\%B0}$
Status in relation to Target	B_{2018} was estimated to be between 75% and 101% B_0; Virtually Certain (> 99%) to be above the target
Status in relation to Limits	B_{2018} is Exceptionally Unlikely (< 1%) to be below the Soft Limit and Exceptionally Unlikely (< 1%) to be below the Hard Limit
Status in relation to Overfishing	Overfishing is Exceptionally Unlikely (< 1%) to be occurring

Historical Stock Status Trajectory and Current Status



Trajectory over time of spawning biomass (absolute, and % B_0, with 95% credible intervals shown as broken lines) for the Sub-Antarctic ling stock from the start of the assessment period in 1972 to the most recent assessment in 2018, for the base case model run. Years on the x-axis are fishing year with "1990" representing the 1989–90 fishing year. Biomass estimates are based on MCMC results.

Fishery and Stock Trends	
Recent Trend in Biomass or Proxy	Biomass appears to have changed little in recent years.
Recent Trend in Fishing Mortality or Proxy	Fishing pressure is estimated to have been low, with little change.



LIN 5&6 base model: Exploitation rates (catch over vulnerable biomass) with 95% credible intervals shown as dashed lines.

Other Abundance Indices	-
Trends in Other Relevant Indicators or Variables	-

Projections and Prognosis	
Stock Projections or Prognosis	Stock status is unlikely to change over the next 5 years at recent catch levels or the level of the TACC (i.e., 12 100 t).
Probability of Current Catch or TACC causing Biomass to remain below or to decline below Limits	Soft Limit: Exceptionally Unlikely (< 1%) at current catch or catches at the level of the catch limit Hard Limit: Exceptionally Unlikely (< 1%) at current catch or TACC
Probability of Current Catch or TACC causing Overfishing to continue or to commence	Exceptionally Unlikely (< 1%)

Assessment Methodology and Evaluation		
Assessment Type	Level 1 - Full Quantitative Stock Assessment	
Assessment Method	Age-structured CASAL model with Bayesian estimation of posterior distributions	
Assessment Dates	Latest assessment: 2018	Next assessment: 2021
Overall assessment quality rank	1 – High Quality	
Main data inputs (rank)	- Summer and autumn *Tangaroa* trawl survey series	1 – High Quality
	- Proportions-at-age data from the commercial fisheries and trawl surveys	1 – High Quality
	- Estimates of biological parameters (but note that *M* was estimated in the models)	1 – High Quality
Data not used (rank)	- Line fishery CPUE series (annual indices since 1991).	2 – Medium Quality: uncertainty in its ability to index abundance

Changes to Model Structure and Assumptions	- *M* was estimated as a constant - The annual cycle of the model and fishery catches were aligned - Free q's were used instead of nuisance q's
Major Sources of Uncertainty	- The lack of contrast in the summer trawl series (the main relative abundance series) makes it difficult to accurately estimate the upper bound of past and current biomass.

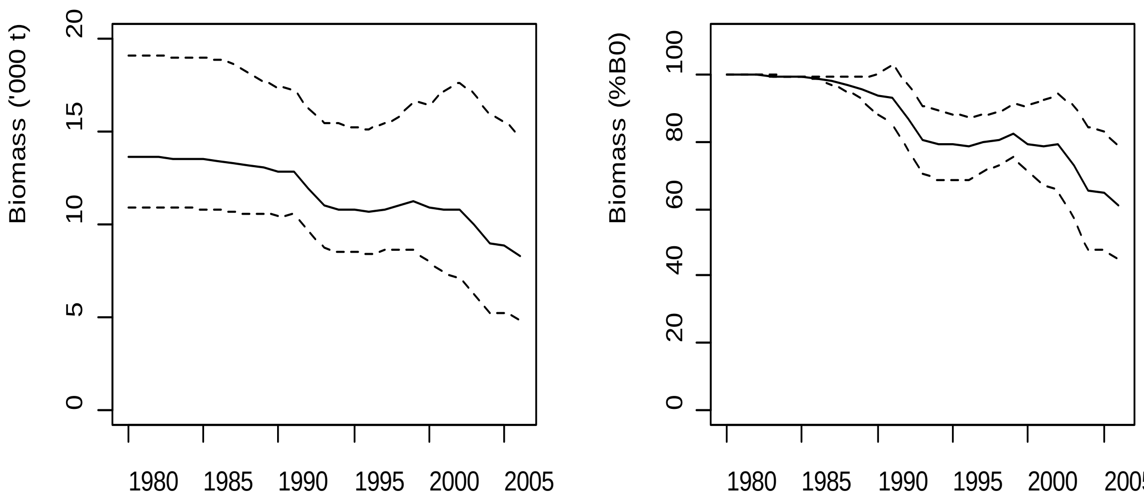
Qualifying Comments
The current assessment assumes that LIN 5 and LIN 6 (except Bounty Islands LIN 6B) are a single biological stock.

Fishery Interactions
Ling are often taken as bycatch in hoki target trawl fisheries in this region. The main bycatch species of hoki-hake-ling-silver warehou-white warehou target trawl fisheries are rattails, javelinfish, and spiny dogfish. Additional information can be found in the Environmental and Ecosystem Considerations section of the hoki plenary. Model-based analysis of observer and effort data shows that, in the target line fisheries for ling across all stocks, the main bycatch species (those comprising over 1% of the observed catch) are: spiny dogfish, ribaldo, skates (smooth and rough), black cod, sea perch, pale ghost shark, red cod, and shovelnose dogfish.

- **Bounty Plateau (part of LIN 6)**

Stock Status	
Year of Most Recent Assessment	2006
Assessment Runs Presented	A single model run
Reference Points	Management Target: 40% B_0 Soft Limit: 20% B_0 Hard Limit: 10% B_0 Overfishing threshold: Not defined
Status in relation to Target	B_{2006} was estimated to be 61% B_0; Very Likely (> 90%) to be at or above the target
Status in relation to Limits	B_{2006} 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	-

Historical Stock Status Trajectory and Current Status



Trajectory over time of spawning biomass (absolute, and % B_0, with 95% credible intervals shown as broken lines) for the Bounty Plateau ling stock from the start of the assessment period in 1980 to the most recent assessment in 2006. Years on the x-axis are fishing year with "1995" representing the 1994–95 fishing year. Biomass estimates are based on MCMC results.

Fishery and Stock Trends	
Recent Trend in Biomass or Proxy	Median estimates of biomass are unlikely to have been below 61% B_0. Biomass is estimated to have been declining since 1999.
Recent Trend in Fishing Mortality or Proxy	Fishing pressure is estimated to have been low, but erratic, since 1980.
Other Abundance Indices	-
Trends in Other Relevant Indicators or Variables	Recruitment was above average in the early 1990s, but below average in the late 1990s. No estimates of recruitment since 1999 are available.

Projections and Prognosis (2006)	
Stock Projections or Prognosis	Stock status is predicted to continue declining slightly over the next 5 years at a catch level equivalent to the average since 1991 (i.e., 600 t per year).
Probability of Current Catch or TACC causing Biomass to remain below or to decline below Limits	Note that there is no specific TACC for the Bounty Plateau stock. Soft Limit: Very Unlikely (< 10%) Hard Limit: Very Unlikely (< 10%)
Probability of Current Catch or TACC causing Overfishing to continue or to commence	-

Assessment Methodology and Evaluation		
Assessment Type	Level 1 - Full Quantitative Stock Assessment	
Assessment Method	Age-structured CASAL model with Bayesian estimation of posterior distributions	
Assessment Dates	Latest assessment: 2006	Next assessment: Unknown
Overall assessment quality rank	1 – High Quality	
Main data inputs (rank)	- Proportions-at-age data from the commercial line fishery - Line fishery CPUE series (annual indices since 1992) - Estimates of biological parameters	1 – High Quality 3 – Low Quality: fishery-dependent with possible changes in q over time 1 – High Quality
Data not used (rank)	N/A	
Changes to Model Structure and Assumptions	- No significant changes since the previous assessment	
Major Sources of Uncertainty	- There are no fishery-independent indices of relative abundance, so the assessment is driven largely by the line fishery CPUE series. - Stock projections are based on a constant future catch of 600 t per year. However, historic catches from this fishery have fluctuated widely, so future catches could be markedly different from 600 t per year.	

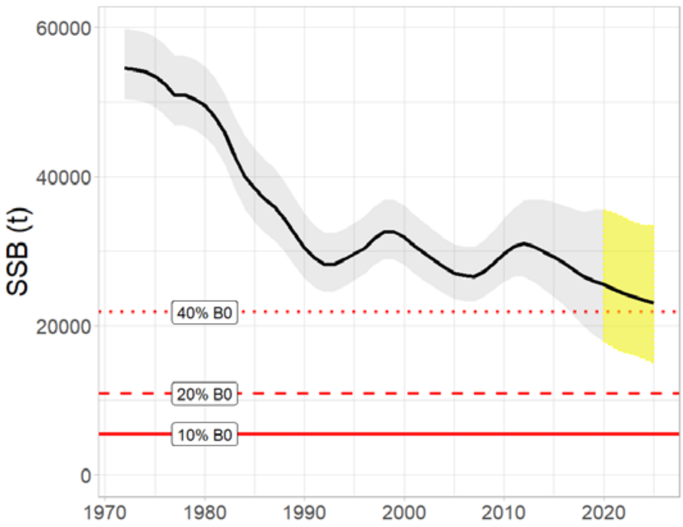
Qualifying Comments
There is no separate TACC for this stock; it is part of the LIN 6 Fishstock that has a TACC of 8505 t.

Fishery Interactions
Target line fisheries for ling have the main bycatch species of spiny dogfish, ribaldo, skates (smooth and rough), sea perch, and sharks (school shark and shovelnose dogfish).

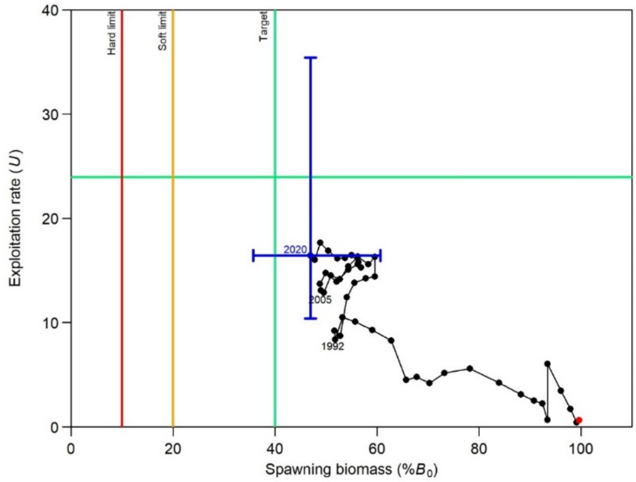
- **West coast South Island (LIN 7)**

Stock Status	
Year of Most Recent Assessment	2020
Assessment Runs Presented	One base case
Reference Points	Target: 40% B_0 Soft Limit: 20% B_0 Hard Limit: 10% B_0 Overfishing threshold: $U_{40\%B0}$
Status in relation to Target	B_{2020} was estimated to be about 47% B_0. Likely (> 60%) to be at or above the target
Status in relation to Limits	B_{2020} is Very Unlikely (< 10%) to be below the Soft Limit and Exceptionally Unlikely (< 1%) to be below the Hard Limit
Status in relation to Overfishing	Overfishing is Unlikely (< 40%) to be occurring

Historical Stock Status Trajectory and Current Status



Trajectory over time of relative spawning biomass (with 95% credible intervals in grey) for the base case model for the WCSI ling stock from the start of the assessment period in 1972 to the most recent assessment in 2020 and projected to 2025 (in yellow). Years on the x-axis are fishing year with "1990" representing the 1989–90 fishing year. Biomass estimates are based on MCMC results.



Trajectory over time of exploitation rate (*U*) and spawning biomass (% B_0), for the LIN 7 base model from the start of the assessment period in 1974 (represented by a red point), to 2020 (in blue). The red vertical line at 10% B_0 represents the hard limit, the orange line at 20% B_0 is the soft limit, and green lines are the %B_0 target (40% B_0) and the corresponding exploitation rate (U_{40}). Biomass and exploitation rate estimates are medians from MCMC results. The blue cross represents the limits of the 95% confidence intervals of estimated the ratio of the SSB to B_0 and exploitation rate in 2020.

Fishery and Stock Trends	
Recent Trend in Biomass or Proxy	Biomass is estimated to have slowly declined since 2012.
Recent Trend in Fishing Intensity or Proxy	Exploitation rates have been increasing bout are well below the overfishing threshold.
Other Abundance Indices	Inclusion of the trawl fishery CPUE led to the same conclusions.
Trends in Other Relevant Indicators or Variables	-

Projections and Prognosis	
Stock Projections or Prognosis	Stock status is declining but Likely (> 60%) to remain above the target over the next 5 years at the current TACC.
Probability of Current Catch or TACC causing Biomass to remain below or to decline below Limits	At TACC Soft Limit: Very Unlikely (< 10%) Hard Limit: Exceptionally Unlikely (< 1%)
Probability of Current Catch or TACC causing Overfishing to continue or to commence	About as Likely as Not (40–60%)

Assessment Methodology and Evaluation		
Assessment Type	Level 1 - Full Quantitative Stock Assessment	
Assessment Method	Age-structured CASAL model with Bayesian estimation of posterior distributions	
Assessment Dates	Latest assessment: 2020	Next assessment: 2023
Overall assessment quality rank	1 – High Quality	
Main data inputs (rank)	- Catch history - Abundance index from WCSI trawl surveys - Proportions at age data from the commercial fisheries and trawl surveys - Estimates of fixed biological parameters	1 – High Quality 1 – High Quality 1 – High Quality 1 – High Quality
Data not used (rank)	- Abundance index from the commercial trawl hoki-hake-ling target fishery CPUE - Commercial line fishery CPUE - *Kaharoa* trawl survey abundance index	1 – High Quality: used in sensitivity 3 – Low Quality: does not track stock biomass 3– Low Quality: inadequate spatial coverage of the stock distribution
Changes to Model Structure and Assumptions	-time step added to place the age increment at the end of the year cycle -changed survey and trawl fishery selectivity to improve the behaviour of the model at MCMC	
Major Sources of Uncertainty	- There is a lack of contrast in the biomass indices to inform the absolute level of biomass. - Although the catch history used in the assessment has been corrected for some misreported catch (see Section 1.4), it is possible that additional misreporting exists. -Age data do not track cohorts well.	

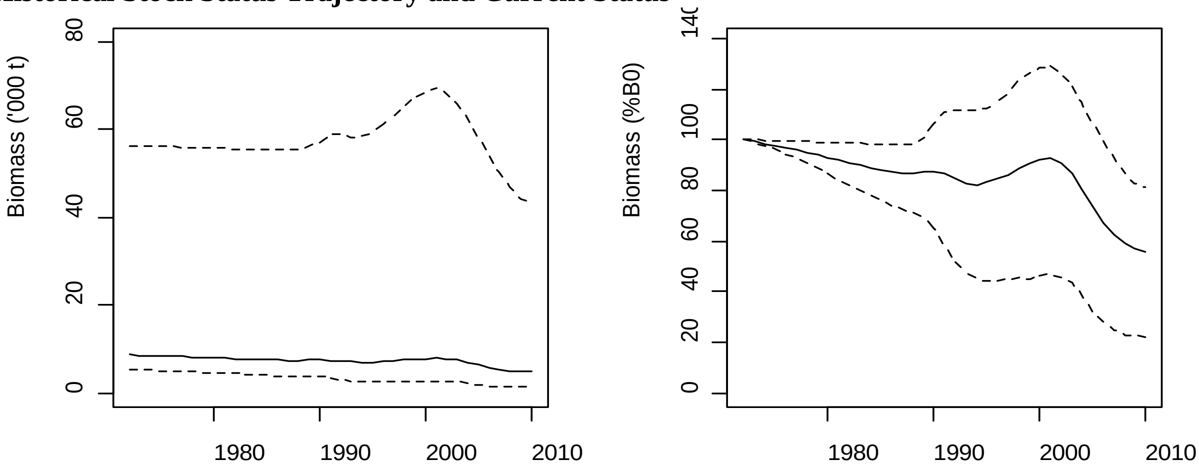
Qualifying Comments
- Longline age data may not be representative of fishery

Fishery Interactions
Ling are often taken as a bycatch in hoki target trawl fisheries in this region. The main bycatch species of hoki-hake-ling-silver warehou-white warehou target trawl fisheries are rattails, javelinfish, and spiny dogfish. Additional information can be found in the Environmental and Ecosystem Considerations section of the hoki plenary. Model-based analysis of observer and effort data shows that, in the target line fisheries for ling across all stocks, the main bycatch species (those comprising over 1% of the observed catch) are: spiny dogfish, ribaldo, skates (smooth and rough), black cod, sea perch, pale ghost shark, red cod, and shovelnose dogfish.

- **Cook Strait (LIN 2 [Statistical Area 016] & part of LIN 7)**

Stock Status	
Year of Most Recent Assessment	2010 (an assessment in 2013 was rejected)
Assessment Runs Presented	A base case.
Reference Points	Target: 40% B_0. Soft Limit: 20% B_0. Hard Limit: 10% B_0. Overfishing threshold: F corresponding to 40% B_0
Status in relation to Target	B_{2010} was estimated to be 54% B_0; Likely (> 60%) to be at or above the target.
Status in relation to Limits	B_{2010} is Exceptionally Unlikely (< 1%) to be below the Soft Limit and Exceptionally Unlikely (< 1%) to be below the Hard Limit.
Status in relation to Overfishing	Overfishing is Very Unlikely (< 10%) to be occurring.

Historical Stock Status Trajectory and Current Status



Trajectory over time of spawning biomass (absolute, and % B_0, with 95% credible intervals shown as broken lines) for the Cook Strait ling stock from the start of the assessment period in 1972 to the most recent assessment in 2010. Years on the x-axis are fishing year with "1990" representing the 1989–90 fishing year. Biomass estimates are based on MCMC results.

Fishery and Stock Trends	
Recent Trend in Biomass or Proxy	Biomass is estimated to have been declining since 1999, but is unlikely to have dropped below 30% B_0.
Recent Trend in Fishing Intensity or Proxy	Overall fishing pressure is estimated to have been relatively constant since the mid-1990s, but has trended down for trawl and up for line.
Other Abundance Indices	–
Trends in Other Relevant Indicators or Variables	Recruitment from 1995 to 2006 was low relative to the long-term average for this stock. There are no estimates for the more recent year classes.

Projections and Prognosis	
Stock Projections or Prognosis	Stock status is predicted to improve slightly over the next 5 years at a catch level equivalent to that since 2006 (i.e., 220 t per year), or remain relatively constant at a catch equivalent to the mean since 1990 (i.e., 420 t per year).
Probability of Current Catch or TACC causing Biomass to remain below or to decline below Limits	Note that there is no specific TACC for the Cook Strait stock. Soft Limit: Catch 220 t, Very Unlikely (< 10%); Catch 420 t, Very Unlikely (< 10%) Hard Limit: Catch 220 t, Exceptionally Unlikely (< 1%); Catch 420 t, 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 Stock Assessment	
Assessment Method	Age-structured CASAL model with Bayesian estimation of posterior distributions	
Assessment Dates	Latest assessment: 2010	Next assessment: 2020
Overall assessment quality rank	3 – Low Quality: The only accepted relative abundance series (trawl fishery CPUE) was not well fitted. A subsequent assessment in 2013 was rejected by the Working Group.	
Main data inputs (rank)	- Proportions-at-age data from the commercial trawl fishery	1 – High Quality
	- Proportions-at-age data from the commercial line fishery	3 – Low Quality: not representative of entire fishery
	- Trawl fishery CPUE series (annual indices since 1994)	2 – Medium or Mixed Quality: not well-fitted by model
	- Estimates of biological parameters	1 – High Quality
Data not used (rank)	Line fishery CPUE	3 – Low quality: does not track stock biomass
Changes to Model Structure and Assumptions	- No significant changes since the previous assessment.	
Major Sources of Uncertainty	- There are no fishery-independent indices of relative abundance. It is not known if the trawl CPUE series is a reliable abundance index. - The stock structure of Cook Strait ling is uncertain. While ling in this area are almost certainly biologically distinct from the WCSI and Chatham Rise stocks, their association with ling off the lower east coast of the North Island is unknown. - It is possible that trawl selectivity has varied over time, resulting in poor fits to some age classes in some years. - Line fishery selectivity is based on only two years of catch-at-age data from the auto longline fishery. No information is available from the ‘hand-baiting’ line fishery. - The model is moderately sensitive to small changes in M, and M is poorly estimated.	

Qualifying Comments
There is no separate TACC for this stock; it comprises parts of Fishstocks LIN 7 and LIN 2.

Fishery Interactions
Ling are often taken as a bycatch in hoki target trawl fisheries in this region. The main bycatch species of hoki-hake-ling-silver warehou-white warehou target trawl fisheries are rattails, javelinfish, and spiny dogfish. Additional information can be found in the Environmental and Ecosystem Considerations section of the hoki plenary. Model-based analysis of observer and effort data shows that, in the target line fisheries for ling across all stocks, the main bycatch species (those comprising over 1% of the observed catch) are: spiny dogfish, ribaldo, skates (smooth and rough), black cod, sea perch, pale ghost shark, red cod, and shovelnose dogfish.

6. FUTURE RESEARCH

A review of the ling stock structure for LIN 2 should be completed before further assessments are conducted for this QMA.

7. FOR FURTHER INFORMATION

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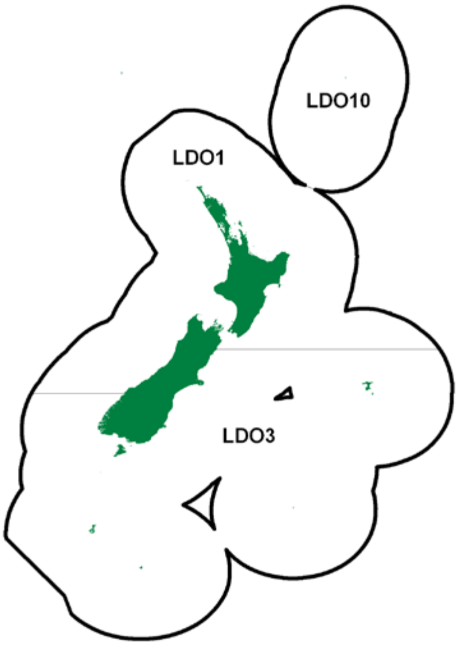
LOOKDOWN DORY (LDO)

(Cyttus traversi)



1. FISHERY SUMMARY

Lookdown dory was introduced into the Quota Management System (QMS) on 1 October 2004 with the allowances, TACs and TACCs in Table 1. It is currently managed as three stocks: LDO 1 which comprises FMAs 1–2 and 7–9; LDO 3 which comprises FMAs 3–6; and LDO 10 (Kermadec region).

Table 1: Recreational and customary non-commercial allowances, TACCs and TACs, by Fishstock, for lookdown dory.

Fishstock	Recreational Allowance	Customary non-commercial Allowance	TACC	TAC
LDO 1	0	0	168	168
LDO 3	0	0	614	614
LDO 10	0	0	1	1
Total	0	0	783	783

1.1 Commercial fisheries

Reliable landings data are available from 1989–90 onwards, after the introduction of Catch Landing Returns (CLRs) in the previous year (Table 2). Annual landings are also available from Licensed Fish Receiver Returns (LFRRs), and these agree well with CLR figures in most years (within 10%), but differ by 20–27% in 4 of the 12 years with comparable data (Table 2). Total landings (CLR) have increased steadily from 127 t in 1989–90 to 760 t in 2001–02. Estimated catch as a percentage of recorded landings were moderate in the early 1990s at 60–70%, but subsequently declined to around 30%. Lookdown dory will often not be included within the top five species in a trawl haul, but the reason for the declining percentage of landings recorded as catch is unknown.

Since entering the QMS, landings in LDO 1 slightly exceeded the TACC in 2005-06 and 2007-08; by an average of 30 t in 2012-13 to 2014-15; and by 76 t in 2017-18 (Table 3). The TACC in LDO 3 has never been caught. This probably reflects the reduction in the size of the trawl fishery on the Chatham Rise where the greatest proportion of lookdown dory has been taken as bycatch. No landings have been reported from LDO 10. Figure 1 shows the historical landings and TACC values for LDO 1 and LDO 3.

There is a seasonal pattern of catch of lookdown dory on the west coast South Island in relation to target fishing for spawning hoki and hake in winter. Catches elsewhere are also dependent on fishing activity in target fisheries but, other than a slight decline in winter months in relation to the shift in area of operation of the hoki fleet, they tend to be less seasonal.

Table 2: Reported landings and estimated catch (t) of lookdown dory by fishing year from 1989-90 to 2001-02. Also, percentage of landings recorded as catch in the catch effort databases.

Year	Landings (CLR)	Landings (LFRR)	Estimated catch (t)	% of CLR landings recorded as estimated catch
1989–90	127	161	80	63
1990–91	164	182	105	64
1991–92	249	216	177	71
1992–93	275	264	159	58
1993–94	188	226	117	62
1994–95	283	277	125	44
1995–96	260	276	107	41
1996–97	354	426	173	49
1997–98	564	557	265	47
1998–99	625	640	228	36
1999–00	637	605	215	34
2000–01	694	504	157	23
2001–02	760	-	254	33

-, data not available

Table 3: Reported domestic landings (t) of lookdown dory by Fishstock and TACC from 2004–05 to 2018–19.

Fishstock		LDO 1		LDO 3		LDO 10		
FMA		1,2,7,8&9		3,4,5&6		10		Total
	Landings	TACC	Landings	TACC	Landings	TACC	Landings	TACC
2004–05	110	168	272	614	0	1	382	783
2005–06	180	168	290	614	0	1	470	783
2006–07	147	168	284	614	0	1	431	783
2007–08	174	168	256	614	0	1	430	783
2008–09	144	168	315	614	0	1	459	783
2009–10	161	168	274	614	0	1	435	783
2010–11	165	168	216	614	0	1	380	783
2011–12	153	168	229	614	0	1	382	783
2012–13	185	168	309	614	0	1	494	783
2013–14	204	168	256	614	0	1	460	783
2014–15	207	168	357	614	0	1	564	783
2015–16	166	168	342	614	0	1	507	783
2016–17	160	168	339	614	0	1	499	783
2017–18	244	168	320	614	0	1	564	783
2018–19	133	168	287	614	0	1	420	783

Lookdown dory is generally caught by bottom trawling in depths of 200 to 800 m mainly as bycatch in the hoki fishery, but also in a variety of other target fisheries such as barracouta, hake, ling, scampi, squid and jack mackerel. A small amount of target fishing is reported from FMA 7. Most of the landings have historically come from FMA 3 (east coast South Island), FMA 4 (Chatham Rise), and FMA 7 (west coast South Island) (Table 4). Landings from around the North Island have been restricted mostly to a few tonnes each year from FMAs 1, 2, 8 and 9. In FMA 5 (Southland) and FMA 6 (Sub-Antarctic) landings averaged 28 t and 25 t respectively in 1999-00 to 2003-04. 123 kg of lookdown dory were reported to have been caught from outside the New Zealand EEZ in the 2012–13 fishing year.

Table 4: Reported historic landings (rounded to nearest tonne) of lookdown dory by FMA and fishing year 1989–90 to 2003–04.

Year	FMA 1	FMA 2	FMA 3	FMA 4	FMA 5	FMA 6	FMA 7	FMA 8	FMA 9	FMA 10
1989–90	2	1	40	20	12	2	51	-	-	-
1990–91	3	4	46	59	10	11	33	< 1	-	-
1991–92	1	2	96	75	17	3	55	-	-	-
1992–93	1	4	63	112	10	2	83	-	-	-
1993–94	< 1	2	62	50	4	3	67	-	< 1	-
1994–95	1	6	73	108	7	3	85	-	< 1	-
1995–96	2	4	99	78	11	3	62	-	< 1	-
1996–97	7	10	108	110	11	7	100	< 1	< 1	-
1997–98	5	8	159	272	11	25	82	-	< 1	-
1998–99	3	3	161	295	21	17	124	< 1	10	-
1999–00	3	5	161	295	21	17	124	< 1	10	-
2000–01	2	6	203	318	24	25	111	< 1	4	-
2001–02	10	10	181	331	26	28	170	3	2	-
2002–03	8	8	261	365	48	32	167	1	2	-
2003–04	13	8	135	210	22	24	113	3	1	-

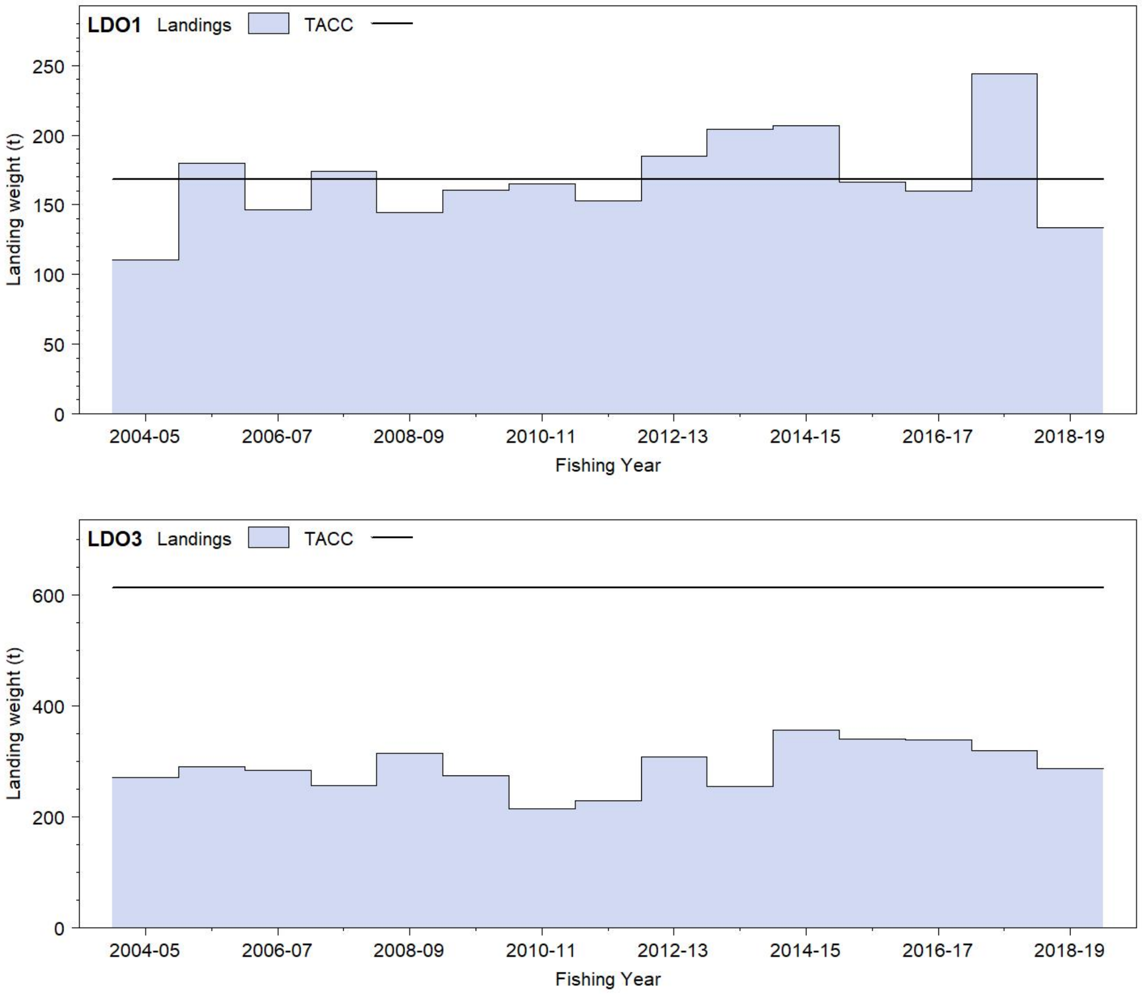


Figure 1: Reported commercial landings and TACC for the two main LDO stocks. Left to right: LDO 1 (Challenger, Central, Auckland), and LDO 3 (South East Chatham Rise, South East Coast, Sub Antarctic, Southland). Note that this figure does not show data prior to entry into the QMS.

1.2 Recreational fisheries
There is no quantitative information on recreational harvest levels of lookdown dory. Due to the offshore location and depth distribution of lookdown dory recreational catch is thought to be negligible.

1.3 Customary non-commercial fisheries
An estimate of current catch is not available but given the offshore location and depth distribution of lookdown dory customary non-commercial catch is thought to be negligible.

1.4 Illegal catch
Estimates of illegal catch are not available.

1.5 Other sources of mortality
There is no quantitative information on the level of other sources of mortality.

2. BIOLOGY

Lookdown dory (*Cyttus traversi*) belongs to the family Zeidae. This family includes 13 species in seven genera distributed among the Atlantic and Pacific Oceans and the Mediterranean Sea. Lookdown dory also occurs in Australian waters, mostly east and south of Tasmania (where it is known as king dory), and also in South Africa. It is widely distributed throughout New Zealand waters with most records from the Chatham Rise. The geographical and depth distribution of immature (less than 33 cm) fish is similar to that of adults (Hurst et al 2000).

It is one of the less abundant members of a loosely associated group of about 23 common species, which together form the upper slope assemblage of New Zealand’s continental shelf (Francis et al 2002). The main species in this group are hoki, javelin fish, ling, pale ghostshark, sea perch, hake, and longnose spookfish (chimaerid). It was identified as a key species characterising the demersal fish community 350–550 m on the Chatham Rise (Bull et al 2001).

Juveniles are found in surface waters up to a length of approximately 12 cm (May & Maxwell 1986), at which stage a metamorphosis occurs associated with the transition from a pelagic to a demersal habitat (James 1976). Adults are most common between 400 to 600 m, but have a wide depth range, from 50 to 1200 m (Anderson et al 1998). Immature fish less than 33 cm have a similar geographical and depth distribution to adults (Hurst et al 2000, O’Driscoll et al 2003). The main prey of lookdown dory are natant decapod crustaceans, followed by euphausid, mysid, galatheid, and nephropsid crustaceans, and fish (Clark & King 1989, Forman & Dunn, 2010). Lookdown dory is likely to be prey of larger fish and have occasionally been recorded in the stomachs of large ling.

Trawl survey catch distribution across the Chatham Rise is fairly even, with females ranging from 10 to 55 cm total length, and males ranging from 10 to 45 cm. Lookdown dory show early signs of ripening to spawn in the January surveys (Livingston et al 2002). Catch distribution across the Sub-Antarctic is patchier than across the Chatham Rise, particularly during autumn surveys (O’Driscoll & Bagley 2001). Lookdown dory appear to grow larger in the Sub-Antarctic than on the Chatham Rise with females ranging from 12 to 60 cm total length, and males ranging from 12 to 45 cm.

There are no known aggregations or migrations associated with spawning lookdown dory. Around the North Island, female lookdown dory were reported to mature at about 35 cm (May & Maxwell 1986). Ripe specimens are usually seen in autumn and winter but have also been observed in summer (Clark & King 1989). Livingston et al (2002) reported early signs of ripening in January Chatham Rise trawl surveys. Observer records from the east coast South Island and Chatham Rise show that ripe females are more common in summer months and spent females are more common in winter (MacGibbon et al 2012). Females on the west coast South Island are mostly resting, immature or spent in winter. Although most spawning takes place in autumn and winter it is likely that it is not a discrete event but occurs over much of the year. Research data from other areas are sparse, but show the presence of fish in spawning condition in most months of the year.

Although there are no published studies of validated age and growth of lookdown dory, preliminary work in Australia suggests that this species may live to over 30 years (Stewart & Smith 1992). Tracey et al (2007) attempted to use lead-radium techniques to validate ageing by zone counts of otoliths but were unsuccessful. Based on unvalidated zone counts, they observed maximum ages of 38 and 25 years for males and females respectively for New Zealand lookdown dory from the Chatham Rise. Von Bertalanffy growth parameters are given in Table 5 and length-weight parameters are given in Table 6.

Table 5: Summary of von Bertalanffy growth parameters for Chatham Rise lookdown dory. Source : Tracey et al 2007. NB : Ageing in this study used unvalidated methods.

Sex	N	L_∞	SE	95% CI	K	SE	95% CI	t_0	SE	95% CI
All	382	50.72	2.53	(45.75, 55.68)	0.058	0.007	(0.044, 0.073)	-3.53	0.67	(-4.84, -2.21)
Males	191	38.78	1.68	(35.49, 42.06)	0.074	0.011	(0.053, 0.095)	-4.28	0.87	(-5.97, -2.57)
Females	191	69.94	5.71	(58.75, 81.13)	0.039	0.006	(0.027, 0.051)	-3.90	0.72	(-5.31, -2.49)

Table 6: Length-weight parameters for Chatham Rise and Sub-Antarctic lookdown dory.

Fishstock				Estimate	Source
1.Weight = a(length)b	(Weight in g, length in cm total length)				
FMA 3 & 4	Females		Males		Tracey et al (2007)
	a	b	a	b	
	0.022	2.98	0.025	2.96	
FMA 5 & 6			Sexes combined		Bagley et al (unpublished data)
			a	b	
			0.022	3.02	

3. STOCKS AND AREAS

A catch-effort characterisation carried out in 2010 (MacGibbon et al 2012) identified three main fishing areas where lookdown dory are caught. These are the east coast South Island (FMA 3), Chatham Rise (FMA 4), and west coast South Island (FMA 7). It was found that these are still the main relevant fishing areas when this work was updated in 2012 (Ballara 2014).

There is little information on stock structure, recruitment patterns, or other biological characteristics on which to base any biological fishstock boundaries. MacGibbon et al (2012) found that both sexes grow to a larger size in the Sub-Antarctic compared with the Chatham Rise suggesting the possibility of different stocks. There is also a difference in abundance between males and females in both areas with females nearly always outnumbering males (Figure 2).

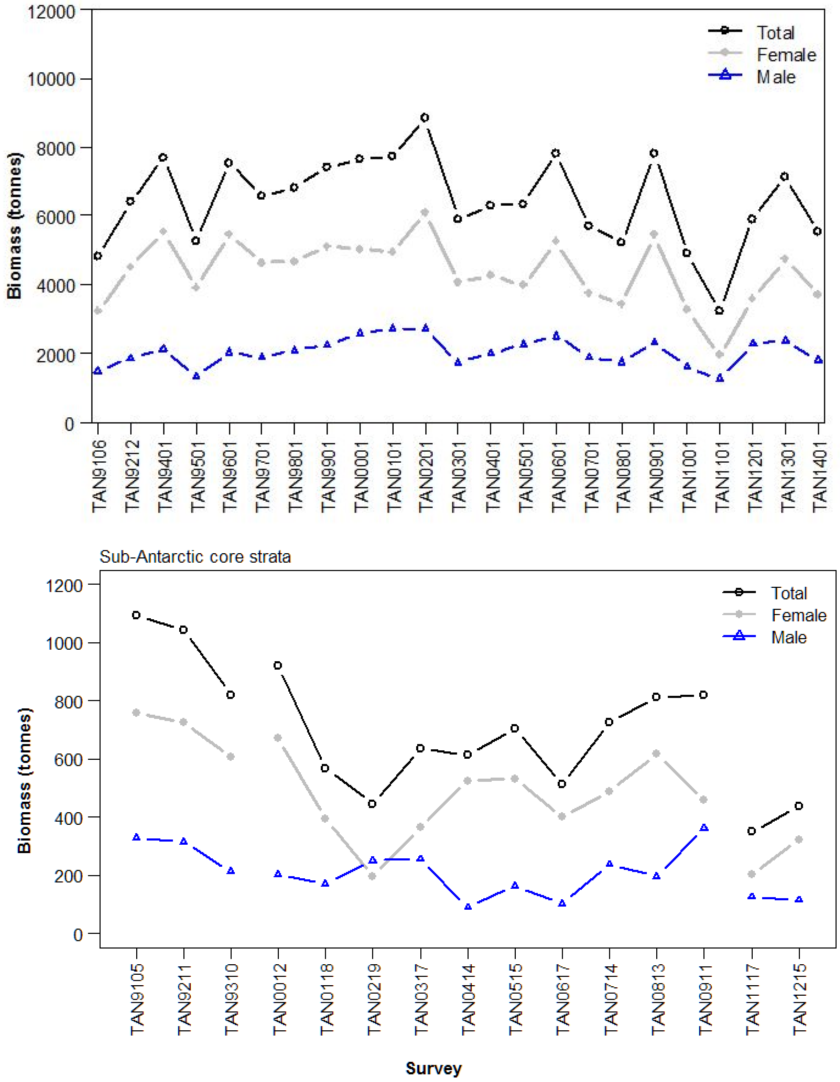


Figure 2: Doorspread biomass estimates of lookdown dory by sex from the Chatham Rise 1991 to 2014 (upper) and Sub-Antarctic 1991 to 1993 and 2000 to 2012 (lower), from *Tangaroa* surveys.

4. STOCK ASSESSMENT

In December 2013 the Middle Depths Working Group agreed that for the west coast South Island (FMA 7, which accounts for the vast majority of the LDO 1 catch), acceptable methods of monitoring abundance are relative biomass estimates from the west coast South Island winter trawl survey carried out by R.V. *Tangaroa.* Catch-per-unit-effort indices from daily processed commercial catches and from the scientific observer programme were also accepted as indices of abundance for the west coast of the South Island.

The Middle Depths Working Group agreed in February 2011 that relative biomass estimates of lookdown dory from middle depth trawl surveys on the Chatham Rise and the Sub-Antarctic were suitable for monitoring major changes in lookdown dory abundance for LDO 3. Standardised CPUE indices from a mixed target species trawl fishery on the ECSI and Chatham Rise area were not accepted by the Working Group.

4.1 Estimates of fishery parameters and abundance

Lookdown dory biomass is usually in the top 10 species on the Chatham Rise and CVs are relatively precise (usually less than 15%) (Table 7). Females have consistently comprised more of the biomass than males (Figure 2). Biomass indices on the Sub-Antarctic have higher but still acceptable CVs (generally less than 30%). Relative biomass has been lower in the last two surveys. Biomass indices from the west coast South Island are considerably lower than those for the Chatham Rise and Sub-Antarctic but are still thought to be reliable measures of abundance.

Table 7: Biomass indices (t) and coefficients of variation (CV) for lookdown dory from *Tangaroa* trawl surveys (Assumptions: areal availability, vertical availability and vulnerability = 1). NB: estimates are for the core strata only for the respective time series. [Continued on next page]

Trip code	Date	Reference	Biomass (t)	% CV
Chatham Rise*				
TAN9106	Dec 1991–Feb 1992	Horn (1994a)	4 797	5.6
TAN9212	Dec 1992–Feb 1993	Horn (1994b)	6 439	5.2
TAN9401	Jan 1994	Schofield & Horn (1994)	7 664	7.2
TAN9501	Jan–Feb 1995	Schofield & Livingston (1995)	5 270	6.5
TAN9601	Dec 1995–Jan 1996	Schofield & Livingston (1996)	7 540	8
TAN9701	Jan 1997	Schofield & Livingston (1997)	6 568	7.6
TAN9801	Jan 1998	Bagley & Hurst (1998)	7 019	6
TAN9901	Jan 1999	Bagley & Livingston (2000)	7 417	8.2
TAN0001	Dec 1999–Jan 2000	Stevens et al (2001)	7 655	7
TAN0101	Dec 2000–Jan 2001	Stevens & Livingston (2002)	7 713	6.5
TAN0201	Dec 2001–Jan 2002	Stevens & Livingston (2003)	8 821	11.1
TAN0301	Dec 2002–Jan 2003	Livingston et al (2004)	5 853	7
TAN0401	Dec 2003–Jan 2004	Livingston & Stevens (2005)	6 304	8
TAN0501	Dec 2004–Jan 2005	Stevens & O’Driscoll (2006)	6 351	9.3
TAN0601	Dec 2005–Jan 2006	Stevens & O’Driscoll (2007)	7 818	8.5
TAN0701	Dec 2006–Jan 2007	Stevens et al (2008)	5 714	7.7
TAN0801	Dec 2007–Jan 2008	Stevens et al (2009a)	5 230	9.3
TAN0901	Dec 2008–Jan 2009	Stevens et al (2009b)	7 789	8.7
TAN1001	Jan 2010	Stevens et al (2011)	4 896	9.7
TAN1101	Jan 2011	Stevens et al (2012)	3 257	21.4
TAN1201	Jan 2012	Stevens et al (2013)	5 913	13.2
TAN1301	Jan 2013	Stevens et al (2014)	7 141	11
TAN1401	Jan 2014	Stevens et al (2015)	5 560	6.9
Sub-Antarctic				
TAN0012	Nov–Dec 2000	O’Driscoll et al (2001)	877	15.2
TAN0118	Nov–Dec 2001	O’Driscoll & Bagley (2003a)	566	19.7
TAN0219	Nov–Dec 2002	O’Driscoll & Bagley (2003b)	446	22.1
TAN0317	Nov–Dec 2003	O’Driscoll & Bagley (2004)	636	23.7
TAN0414	Nov–Dec 2004	O’Driscoll & Bagley (2006a)	614	27.9
TAN0515	Nov–Dec 2005	O’Driscoll & Bagley (2006b)	703	19.1
TAN0617	Nov–Dec 2006	O’Driscoll & Bagley (2008)	509	35.3

Table7 [Continued]

Trip code	Date	Reference	Biomass (t)	% CV
Sub-Antarctic				
TAN0714	Nov–Dec 2007	Bagley et al (2009)	725	20
TAN0813	Nov–Dec 2008	O'Driscoll & Bagley (2009)	811	24.7
TAN0911	Nov–Dec 2009	Bagley & O'Driscoll (2012)	820	25.1
TAN1117	Nov–Dec 2011	Bagley et al 2013	327	34.9
TAN1215	Nov–Dec 2012	Bagley & et al 2014	436	29.1
WCSI core				
TAN0007	Jul–Aug 2000	O'Driscoll et al (2004)	169	14.4
TAN1210	Jul–Aug 2012	O'Driscoll et al (2013) Ballara, S.L.;	155	11.9
TAN1310	Aug 2013	O'Driscoll et al (2014) Ballara, S.L.;	198	11.7
WCSI all				
TAN1210	Jul–Aug 2012	O'Driscoll et al (2013) Ballara, S.L.;	181	10.8
TAN1310	Aug 2013	O'Driscoll et al (2014) Ballara, S.L.;	228	12.1

Length frequency distributions of Chatham Rise lookdown dory suggest that recruitment is variable (MacGibbon et al, 2012, Ballara, 2014). Generally, when a strongly recruiting year class is present, the male length frequencies are often bimodal and females show two or three modes. Length frequency plots show that females are usually more numerous than males with a mean ratio for the time series of 1.15 females to every male (range 0.98–1.52). Males don't grow as large as females, with few males growing larger than 40 cm.

Length frequency distributions from the summer Sub-Antarctic series are less informative and no tracking of cohorts is possible. Overall, scaled population numbers are much lower for both sexes here than on the Chatham Rise but, again, females are more numerous than males with a mean ratio for the time series of 1.8 females for every male (range 0.55–3.9). Females also grow to a larger size than males and both sexes grow to a larger size on the Sub-Antarctic than on the Chatham Rise, which suggests that it may be a separate biological stock. This could also potentially be due to real differences in fishing pressure.

CPUE indices for lookdown dory on the WCSI were developed using the daily processed catch data and a smaller subset of observed vessels in the hoki and hake target fisheries. Both series show a similar trend, flat since 1995 (Figures 3 and 4).

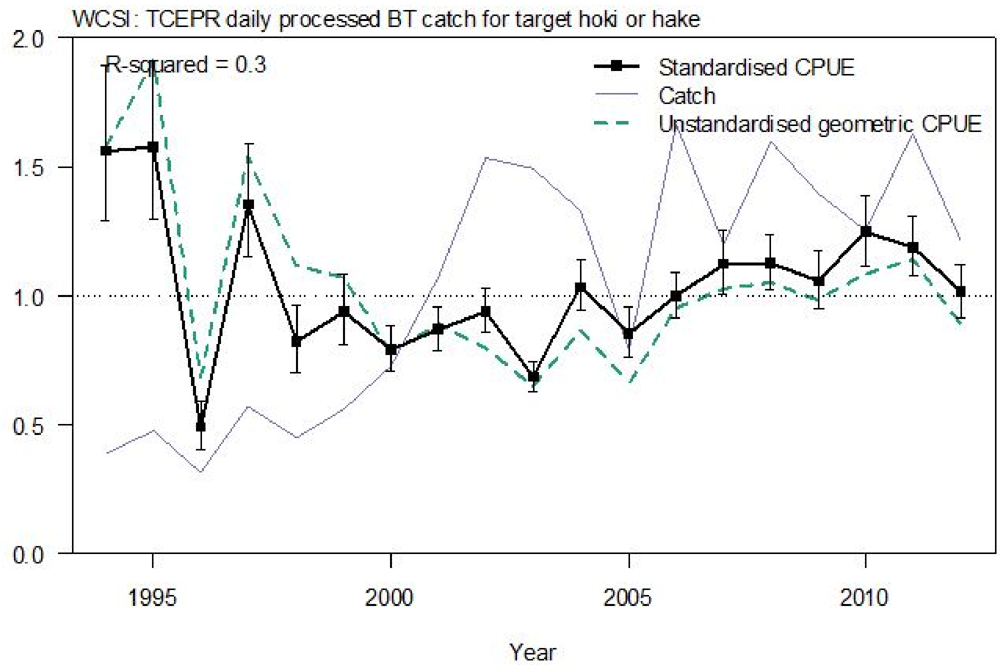


Figure 3: Log normal CPUE indices for WCSI daily processed catch, bottom trawl target hoki or hake, showing catches (scaled to same mean as indices), and lognormal standardised and un-standardised indices. Bars indicate 95% confidence intervals. Year defined as June–September.

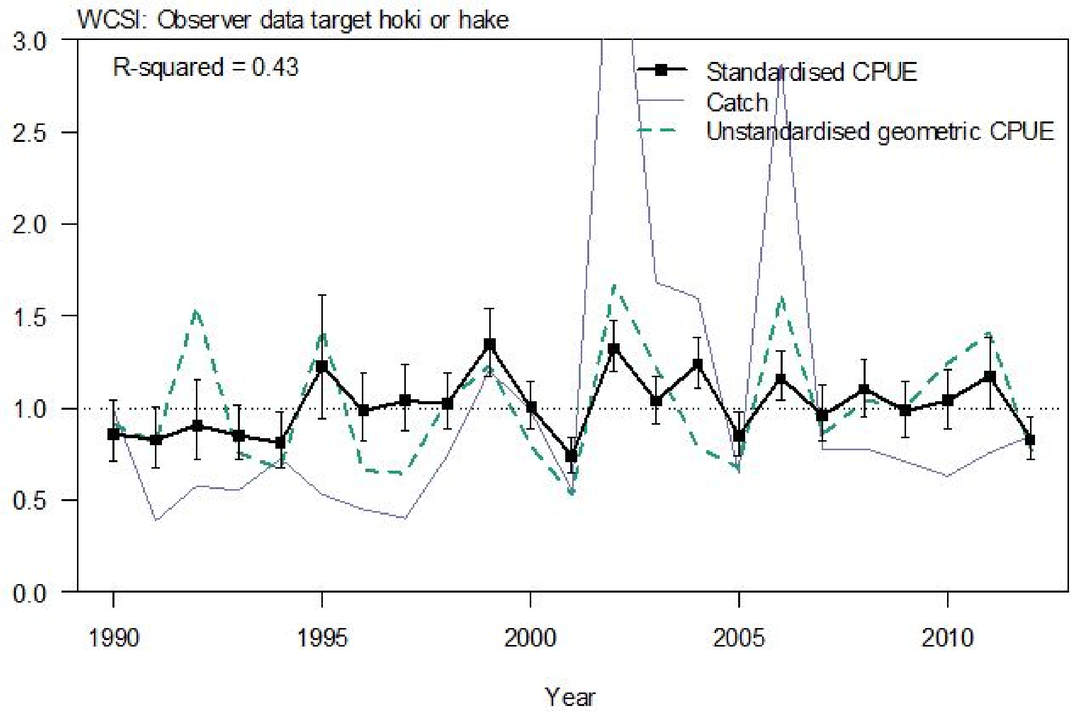


Figure 4: CPUE lognormal indices for WCSI observer programme data, target hoki or hake, bottom and midwater trawl, showing catches (scaled to same mean as indices), and lognormal standardised and un-standardised indices. Bars indicate 95% confidence intervals. Year defined as June–September.

4.2 Yield estimates and projections

MCY cannot be estimated.

CAY cannot be estimated.

4.4 Other yield estimates and stock assessment results

No information is available.

5. STATUS OF THE STOCK

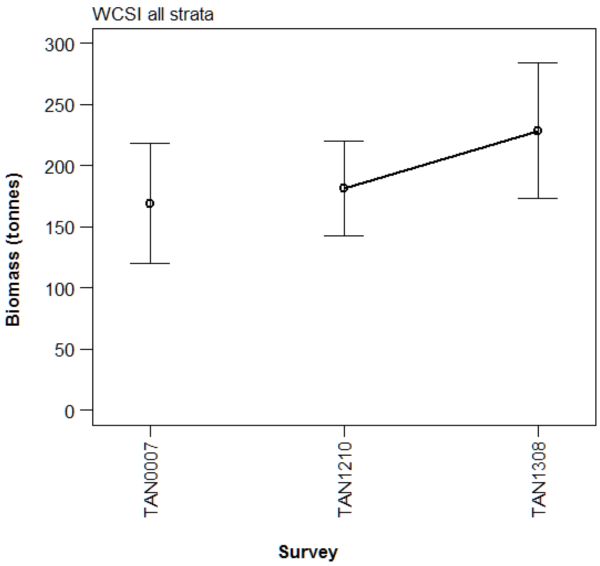
There are no known sustainability concerns in the lookdown dory fishery. For LDO 1, the area which accounts for the vast majority of the lookdown dory catch is thought to be well monitored by trawl surveys which are currently too short to suggest any pattern, but CPUE indices suggest that abundance has been stable since the mid-1990s. For LDO 3, trawl surveys on the Chatham Rise and Sub-Antarctic indicate abundance has fluctuated in both areas

LDO 1

- **LDO 1 (west coast South Island, west and east coast North Island)**

Stock Status	
Year of Most Recent Assessment	2013
Assessment runs presented	-
Reference Points	Target: Not established but 40% B_0 assumed Soft Limit: 20% B_0 Hard Limit: 10% B_0 Overfishing threshold: -
Status in relation to Target	Unknown
Status in relation to Limits	Unknown for Soft limit Unlikely (< 40%) to be below the Hard Limit
Status in relation to Overfishing	-

Historical Stock Status Trajectory and Current Status



Doorspread biomass estimates for lookdown dory (error bars are ± two standard deviations) from the winter WCSI *Tangaroa* surveys 2000, and 2012–2013.

Fishery and Stock Trends	
Recent Trend in Biomass or Proxy	Within LDO 1, FMA 7 biomass indices from the trawl survey time series are similar for 2000 and 2012, with an increase in 2013. This time series is only three points, but is thought to cover an appropriate depth and geographical range for lookdown dory. CPUE indices have been relatively flat since the mid-1990s.
Recent Trend in Fishing Mortality or Proxy	Unknown
Other Abundance Indices	-
Trends in Other Relevant Indicators or Variables	-

Projections and Prognosis	
Stock Projections or Prognosis	Stock size is unlikely (< 40%) to change much at current catch levels in FMA 7.
Probability of Current Catch or TACC causing Biomass to remain below or to decline below Limits	Soft Limit: Unknown Hard Limit: Unlikely (< 40%)
Probability of Current Catch or TACC causing Overfishing to continue or to commence	-

Assessment Methodology		
Assessment Type	Level 2: Partial quantitative stock assessment	
Assessment Method	Evaluation of agreed CPUE indices and trawl survey indices thought to index abundance within FMA 7 of LDO 1. The vast majority of the LDO 1 catch is taken in FMA 7, catches in other areas of LDO 1 are minor.	
Assessment dates	Latest assessment: 2013	Next assessment: Unknown
Overall assessment quality rank	-	
Main data inputs (rank)	-	
Data not used (rank)	-	
Changes to Model Structure and Assumptions	-	
Major Sources of Uncertainty	-	

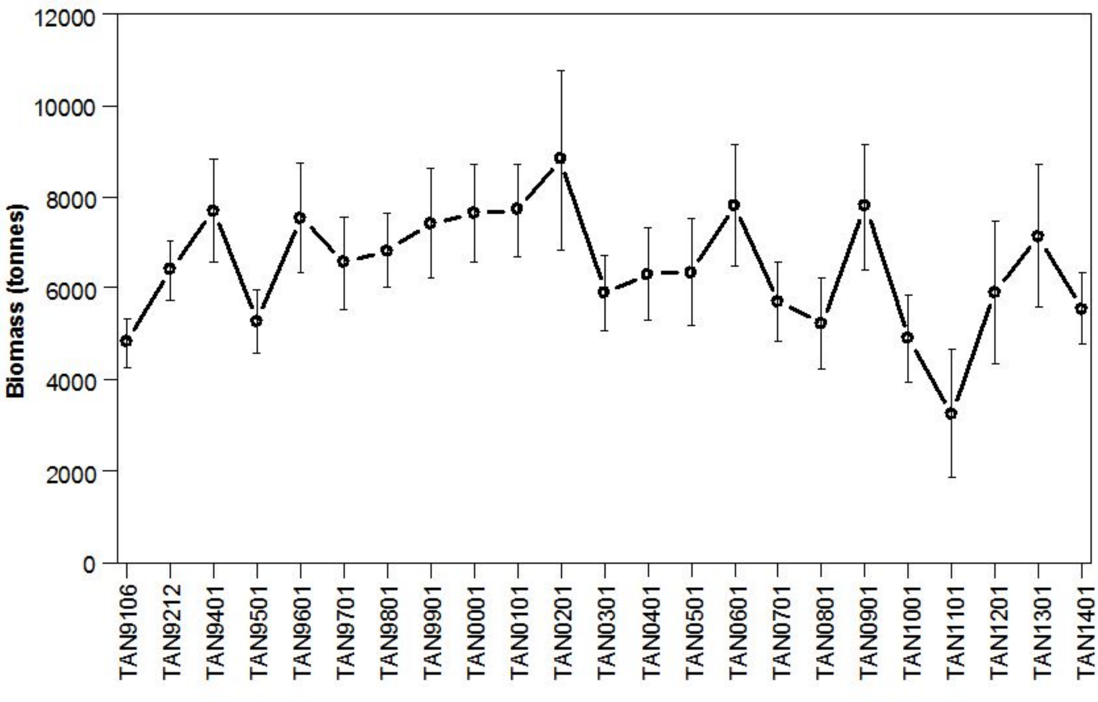
Qualifying Comments

Fishery Interactions
In LDO 1, lookdown dory are taken primarily as bycatch in the bottom trawl west coast South Island hoki and hake target fisheries. Smaller catches are reported by midwater trawl. Interactions are the same as those for the hoki fishery. The east coast North Island scampi fishery also catches lookdown dory. A variety of other target fisheries also report catching lookdown dory but in very small amounts. A small amount of lookdown dory is targeted on the west coast of the South Island by smaller trawlers.

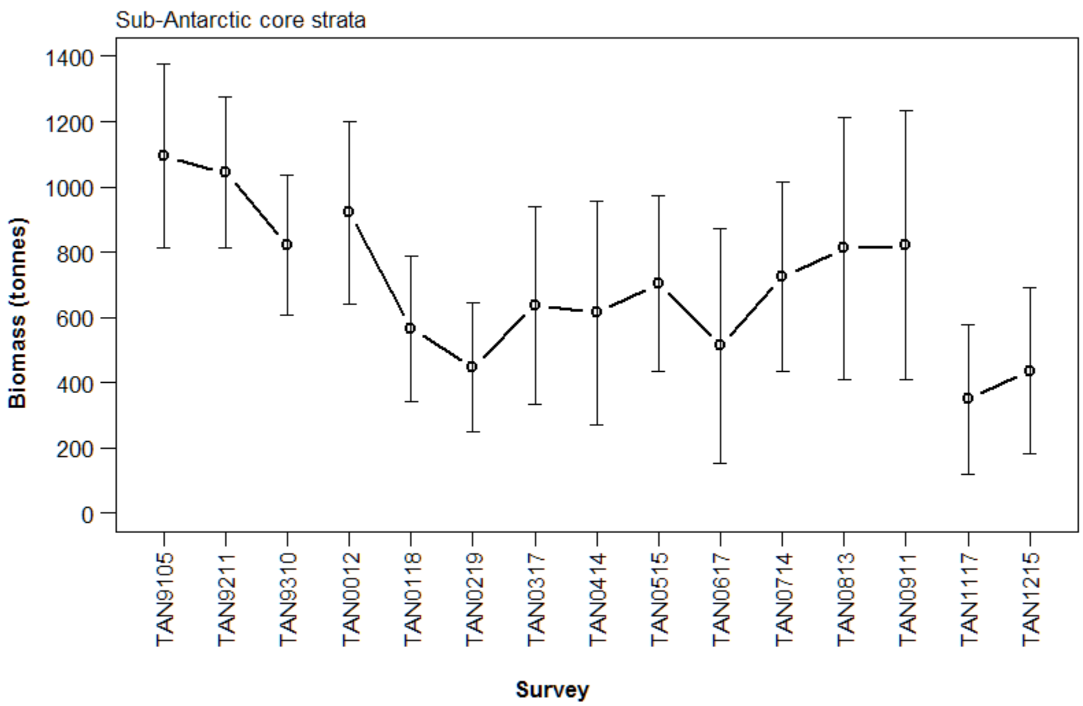
LDO 3 (Chatham Rise & Sub-Antarctic)

Stock Status	
Year of Most Recent Assessment	2013
Reference Points	Target: Not established but 40% B_0 assumed Soft Limit: 20% B_0 Hard Limit: 10% B_0 Overfishing threshold: -
Status in relation to Target	Unknown
Status in relation to Limits	Unknown for Soft limit Unlikely (< 40%) to be below the Hard Limit
Status in relation to Overfishing	-

Historical Stock Status Trajectory and Current Status



Doorspread biomass estimates of lookdown dory (error bars are ± two standard deviations) from the Chatham Rise, from *Tangaroa* surveys from 1991 to 2013.



Doorspread biomass estimates of lookdown dory (error bars are ± two standard deviations) from the Sub-Antarctic, from *Tangaroa* surveys from 1991 to 1993, 2000 to 2009, and 2011–12.

Fishery and Stock Trends	
Recent Trend in Biomass or Proxy	Within LDO 3, FMAs 3 & 4 biomass indices have been fairly flat throughout the time series of Chatham Rise trawl surveys with the exception of 2010 and 2011 which show a decline. The 2012–14 surveys are more in line with previous years. For FMAs 5 & 6 biomass indices from the Sub-Antarctic series declined to 2002, steadily increased until 2009, and has dropped to the lowest estimates in the time series in 2011 and 2012.
Recent Trend in Fishing Intensity or Proxy	Unknown
Other Abundance Indices	-
Trends in other Relevant Indicators or Variables	-

Projections and Prognosis	
Stock Projections or Prognosis	Stock size is Unlikely (< 40%) to change much at current catch levels in FMAs 5 & 6.
Probability of Current Catch or TACC causing Biomass to remain below or to decline below Limits	Soft Limit: Unknown Hard Limit: Unlikely (< 40%)
Probability of Current Catch or TACC causing Overfishing to continue or to commence	-

Assessment Methodology		
Assessment Type	Level 2: Partial quantitative stock assessment	
Assessment Method	Evaluation of agreed trawl survey indices thought to index FMA 3 & 4, and FMA 5 & 6 abundance	
Assessment Dates	Latest assessment: 2013	Next assessment: unknown

Overall assessment quality rank	-	
Main data inputs (rank)	-	
Data not used (rank)	-	
Changes to Model Structure and Assumptions	-	
Major Sources of Uncertainty	-	

Qualifying Comments
There is some indication that lookdown dory on the Chatham Rise may be a different stock to the Sub-Antarctic (i.e. different maximum sizes, evidence of some spawning activity in the Sub-Antarctic, as well as more extensively on the Chatham Rise)

Fishery Interactions
In LDO 3 lookdown dory are mainly caught as bycatch in the hoki target bottom trawl fishery but also in many other middle depth fisheries. Interactions are the same as those for the hoki fishery.

7. FOR FURTHER INFORMATION

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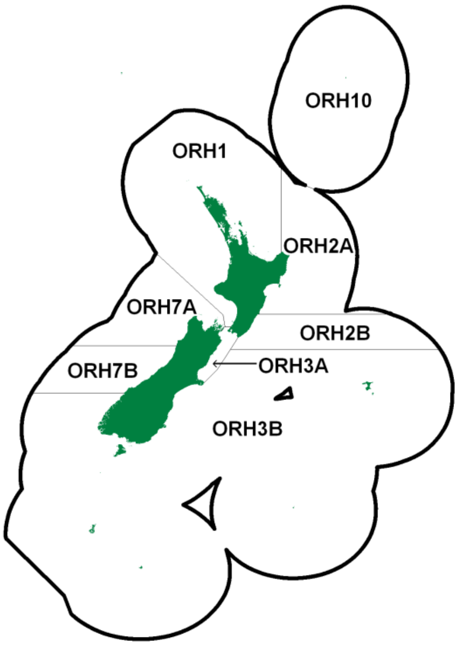
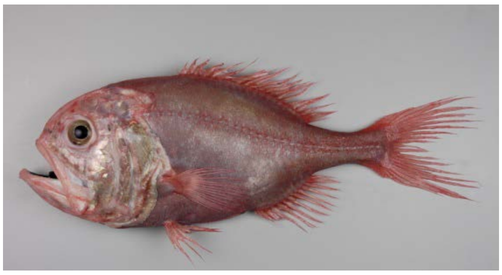
ORANGE ROUGHY (ORH)

(*Hoplostethus atlanticus*)





1. INTRODUCTION

Orange roughy was introduced into the Quota Management System (QMS) on 1 October 1986. The main orange roughy fisheries have been treated separately for assessment and management purposes, and individual reports have been produced for each of six areas consisting of one or more stocks as follows:

1. Northern North Island (ORH 1)
    - Mercury-Colville stock
    - Other stocks
2. Cape Runaway to Banks Peninsula (ORH 2A, 2B, & 3A)
    - East Cape stock
    - Mid-East Coast stock
3. Chatham Rise and Puysegur (ORH 3B)
    - Northwest Chatham Rise stock
    - East and South Chatham Rise stock
    - Puysegur stock
    - Other minor stocks or subareas
4. Challenger Plateau (ORH 7A)
5. West coast South Island (ORH 7B)
6. Outside the EEZ
    - Lord Howe
    - Northwest Challenger
    - Louisville
    - West Norfolk
    - South Tasman

Recent orange roughy stock assessments have been conducted for the Mid-East Coast (2014 with a preliminary update in 2018), Northwest Chatham Rise (2018), East and South Chatham Rise (2020 update of 2017 assessment), Challenger Plateau (2019), Puysegur (2017) and ORH 7B (a preliminary assessment in 2020). These assessments used a similar approach and have relied on the use of ageing data and acoustic surveys of spawning plumes. The methods common to these assessments are described later in this introduction.

2. BIOLOGY

Orange roughy inhabit depths between 700 m and at least 1500 m within the New Zealand EEZ. They are most abundant between about 800 m and 1200 m. Their maximum depth range is unknown.

Orange roughy are slow-growing, long-lived fish. On the basis of otolith ring counts and radiometric isotope studies, orange roughy may live up to 120–130 years. Age determination from otolith rings has been validated by length-mode analysis for juveniles up to four years of age (Mace et al 1990), and adult ages have been validated using radiometric techniques in a study by Andrews & Tracey (2003).

Orange roughy otoliths have a marked transition zone in banding which is believed to be associated with the onset of maturity (Francis & Horn 1997). The estimates of transition-zone maturity range from 23 to 31.5 years for fish from various New Zealand fishing grounds (Horn et al 1998, Seafood Industry Council/NIWA unpublished data). However, spawning fish appear to be an older subset of the transition-zone mature fish as evidenced by the older ages and the larger sizes of fish caught on the spawning grounds. The age at which 50% of fish are spawning was estimated in the 2014 stock assessment models to range from 32–41 years (Cordue 2014a). Orange roughy in New Zealand waters reach a maximum size of about 50 cm standard length (SL), and 3.6 kg in weight, but the maximum size appears to vary among local populations. Average size is around 35 cm SL, although there is variation between areas.

Spawning occurs once each year between June and early August in several areas within the New Zealand EEZ, from the Bay of Plenty in the north, to the Auckland Islands in the south. Spawning occurs in dense aggregations at depths of 700–1000 m and is often associated with bottom features such as pinnacles and canyons. Spawning fish are also found outside the EEZ on the Challenger Plateau, Lord Howe Rise, and Norfolk Ridge to the west, and the Louisville Ridge to the east.

Fecundity is relatively low, with females carrying on average about 40 000–60 000 eggs. The eggs are large (2–3 mm in diameter), are fertilised in the water column, and then drift upwards towards the surface and remain planktonic until they hatch close to the bottom after about 10 days. Details of larval biology are poorly known.

Orange roughy juveniles are first available to bottom trawls at age about 6 months, when they exhibit a mean length of about 2 cm. Juveniles have been found in large numbers in only one area, at a depth of 800–900 m about 150 km east of the main spawning ground on the north Chatham Rise.

Orange roughy also form aggregations outside the spawning period, presumably for feeding. Their main prey species include mesopelagic and benthopelagic prawns, fish and squid, with other organisms such as mysids, amphipods and euphausiids occasionally being important.

Natural mortality (M) has been estimated to be 0.045 yr^{-1}. This was based on otolith age data from a 1984 research survey of the Chatham Rise that used an estimation technique based on mean age. A similar estimate was obtained in 1998 from a lightly fished population in the Bay of Plenty.

Biological parameters used in the following assessments (Tables 1 and 2) were estimated by Doonan (1994) with modifications of A_r, A_m, S_r, and S_m for the 1998 stock assessment meetings by Francis & Horn (1997), Horn et al (1998), and Doonan et al (1998), and further modifications for the 2006 assessment by Hicks (2006).

Biases in reading ages from otoliths were identified, leading to a recommendation by reviewers of orange roughy workshops in October 2005 and February 2006 that no age data should be used in assessments until the biases were quantified and corrected. Stemming from this recommendation, a new ageing methodology was developed for orange roughy in 2007, associated with an international ageing workshop for this species (Tracey et al 2007). In the 2014 stock assessments, age-frequency data were only used if the otoliths had been read using the new ageing protocol.

It is believed that ages derived from otoliths collected during the 1984 and 1990 trawl surveys of the

East Chatham Rise, which were aged under the old NIWA protocol do not contain serious biases. The single-sex growth curve, the length-weight parameters and the maturity ogive based on transition zones, which are all based on ageing using the old-protocol data are still believed to be valid. The estimates of these biological parameters (Table 1) were used for both the East Chatham Rise and the Northwest Chatham Rise stock assessments, although the otoliths used were collected from the East Chatham Rise only (of which most were from the Spawning Box). The transition-zone maturity estimates are not used in current stock assessments as maturity was estimated in each of the models.

Table 1: Biological parameters as used for orange roughy assessments. -, not estimated.

Parameter	Symbol	Male	Female	Both sexes
Natural mortality	M	-	-	0.045 yr^{-1}
Age of recruitment	A_r (a_{50})	-	-	$=A_m$
Gradual recruitment	S_r (a_{to95})	-	-	$=S_m$
Age at maturity	A_m (a_{50})	-	-	Table 2
Gradual maturity	S_m (a_{to95})	-	-	Table 2
von Bertalanffy parameters				
- Chatham Rise (default)	L_∞	36.4 cm	38.0 cm	-
- Northwest Chatham Rise	L_∞	-	-	37.78 cm
- East Chatham Rise	L_∞	-	-	37.78 cm
- Ritchie Bank	L_∞	-	-	37.63 cm
- Challenger Plateau	L_∞	33.4 cm	35.0 cm	-
- All areas (default)	k	0.070 yr^{-1}	0.061 yr^{-1}	-
- Northwest Chatham Rise	k	-	-	0.059 yr^{-1}
- East Chatham Rise	k	-	-	0.059 yr^{-1}
- Ritchie Bank	k	-	-	0.065 yr^{-1}
- All areas (default)	t_0	-0.4 yr	-0.6 yr	-
- East Chatham Rise	t_0	-	-	-0.491
- Northwest Chatham Rise	t_0	-	-	-0.491
- Ritchie Bank	t_0	-	-	-0.5
Length-weight parameters				
- default	a	-	-	0.0921
- East and Northwest Chatham Rise	a			0.0800
- default	b	-	-	2.71
- East and Northwest Chatham Rise	b			2.75
Recruitment steepness		-	-	0.75

Table 2: Estimates of A_m and S_m by area for New Zealand orange roughy from transition zone observations.

	A_m			S_m		
Area	**M**	**F**	**Both sexes**	**M**	**F**	**Both sexes**
Chatham Rise (default)	-	-	29	-	-	3
Northwest Chatham Rise	-	-	28.51	-	-	4.56
East Chatham Rise	-	-	28.51	-	-	4.56
Ritchie Bank	-	-	31.5	-	-	7.11
Challenger Plateau	-	-	23	-	-	3
Puysegur Bank	-	-	27	-	-	3
Bay of Plenty	26	27	-	4	5	-

3. ENVIRONMENTAL AND ECOSYSTEM CONSIDERATIONS

The tables and accompanying text in this section were updated for the 2020 Fishery Assessment Plenary. A more detailed summary from an issue-by-issue perspective is available in the 2018 Aquatic Environment & Biodiversity Annual Review (Fisheries New Zealand 2019, https://www.mpi.govt.nz/dmsdocument/34854-aquatic-environment-and-biodiversity-annual-review-aebar-2018-a-summary-of-environmental-interactions-between-the-seafood-sector-and-the-aquatic-environment).

3.1 Role in the ecosystem

Orange roughy are the dominant demersal fish at depths of 750–1100 m on the north and east Chatham

Rise, the east coast of the North Island south of about East Cape, and the Challenger Plateau (Clark et al 2000; Doonan & Dunn 2011; Tracey et al 1990). An analysis of New Zealand demersal fish assemblages using research trawl data showed that orange roughy was the most frequently occurring species (found in more than 40 % of tows) in the mid slope assemblage (Francis et al 2002). Fishing has reduced the abundance of orange roughy since the 1980s, and the effects of removing, for example, an average of about 18 000 t per year from ORH 3B between 1979–80 and 2009–10 are largely unknown. There are likely to have been ecosystem implications (Tracey et al 2012).

3.1.1 Trophic interactions

The main prey species of orange roughy include mesopelagic and benthopelagic prawns, fish and squid, with other organisms such as mysids, amphipods and euphausiids occasionally being important (Rosecchi et al 1988). Koslow (1997) showed that orange roughy have a faster metabolism than deepwater fishes that are typically dispersed over the flat seafloor, and their food consumption is higher. Ontogenetic shifts occur in their feeding preferences with the smaller fish (up to 20 cm) feeding on crustaceans, and larger fish (31 cm and above) feeding on teleosts and cephalopods (Stevens et al 2011). Relative proportions of the three prey groups were similar between areas. Bulman & Koslow (1992) found that teleosts were more important than crustaceans by weight in the prey of Australian orange roughy, and that this dominance increased in adult-sized fish. Dunn & Forman (2011) inferred from diet analysis that juveniles feed more on the benthos compared with the benthopelagic foraging of adults. Where they co-occur, orange roughy and black oreo may compete for teleost and crustacean prey.

Predators of orange roughy are likely to change with fish size. Larger smooth oreo, black oreo and orange roughy were observed with healed soft flesh wounds, typically in the dorso-posterior region. Wound shape and size suggest they may be caused by one of the deepwater dogfishes (Dunn et al 2010). Giant squid and sperm whales have also been found to prey on orange roughy (Gaskin & Cawthorn 1967, Jereb & Roper 2010).

3.1.2 Ecosystem Indicators

Tuck et al (2009, 2014) used data from the Sub-Antarctic and Chatham Rise middle-depth trawl surveys to derive indicators of fish diversity, size, and trophic level. However, fishing for orange roughy occurs mostly deeper than the depth range of these surveys and is only a small component of fishing in the areas considered by Tuck et al (2009, 2014).

3.2 Non-target fish and invertebrate bycatch

Anderson et al (2017) summarised the bycatch of orange roughy and oreo trawl fisheries from 2001–02 to 2014–15. For orange roughy trawls since 2001–02, orange roughy accounted for 85% of the total observed catch and the remainder comprised mainly smooth oreo (7%), black oreo (1.6%), hoki (0.6%), and cardinalfish (0.3%). More than 700 species or species groups were recorded by observers, including various deepwater dogfishes (2%), morid cods (1%), rattails (<1%), and slickheads (0.5%). Total annual bycatch between 2001–02 and 2009–10 ranged from 3090 t to 6075 t per year and declined to less than 1100 in subsequent years following decline in catch in the fishery. Total annual discards also decreased over time, from about 2120 t in 2001–02 to about 184 t in 2013–14 and were almost entirely of non-QMS or invertebrate species (rattails, shovelnose dogfish, and other deepwater dogfishes, all discarded at a rate of 50% or more). From 2001–02 to 2014–15, the overall discard fraction value was 0.07 kg (range of 0.02-0.13 kg) and tended to be lower in recent years.

Invertebrate species are caught in low numbers in the orange roughy fishery (Anderson et al 2017). Squid (mostly warty squid, *Onykia* spp., 0.15%) were the largest component of invertebrate catch, followed by various groups of coral (0.12%), echinoderms (mainly starfish, 0.03%), and crustaceans (mainly king crabs, family Lithodidae, 0.01%). Tracey et al (2011) analysed the distribution of nine groups of protected corals based on bycatch records from observed trawl effort from 2007–08 to 2009–10, primarily from 800–1000 m depth. For the orange roughy target fishery, about 10% of observed tows in FMAs 4 and 6 included coral bycatch, but a higher proportion of tows in northern waters included coral (28% in FMA 1, 53% in FMA 9, Tracey et al 2011).

Finucci et al (2019) analysed bycatch trends in deepwater fisheries, including orange roughy trawl, from

1990–91 until 2016–17. They found that the most common bycatch species by weight (t) were smooth oreo (*Pseudocyttus maculatus*, SSO), black oreo (BOE), and unspecified sharks (SHA). Moreover, among the 557 bycatch species examined, 94 showed a decrease in catch over time (29 were statistically significant) and 62 showed an increase (14 were significant). The species showing the greatest decline were dark ghost shark (*Hydrolagus novaezealandiae*, GSH), black oreo (*Allocyttus niger*, BOE), and lanternshark (*Etmopterus* sp., ETM), while the greatest increases were found for longnose velvet dogfish (*Centroscymnus crepidater*, CYP), Portuguese dogfish (*Centroscymnus coelolepis*, CYL), and Owston's dogfish (*Centroscymnus owstonii*, CYO).

3.3 Incidental Capture of Protected Species (seabirds, mammals, and protected fish)

For protected species, capture estimates presented here include all animals recovered to the deck (alive, injured or dead) of fishing vessels but do not include any cryptic mortality (e.g., seabirds struck by a warp but not brought on board the vessel, Middleton & Abraham 2007, Brothers et al 2010).

3.3.1 Marine mammal interactions

Trawlers targeting orange roughy, oreo, and black cardinalfish occasionally catch New Zealand fur seal (which were classified as "Not Threatened" under the New Zealand Threat Classification System in 2010, Baker et al 2016; Baker et al 2019). Between 2002–03 and 2007–08, there were 15 observed captures of New Zealand fur seal in orange roughy, oreo, and black cardinalfish trawl fisheries. There has been one observed capture in the period between 2008–09 and 2017–18, during which time the average level of annual observer coverage was 26.7% (Table 3). Corresponding mean annual estimated captures in this period ranged 0–3 (mean 1.25) based on statistical capture models (Thompson et al 2013; Abraham et al 2016). All observed fur seal captures occurred in the Sub-Antarctic region.

Table 3: Number of tows by fishing year and observed and model-estimated total NZ fur seal captures in orange roughy, oreo, and cardinalfish trawl fisheries, 2002–03 to 2017–18. No. Obs, number of observed tows; % obs, percentage of tows observed; Rate, number of captures per 100 observed tows, % inc, percentage of total effort included in the statistical model. Estimates are based on methods described in Abraham et al (2016), available via https://data.dragonfly.co.nz/psc. Estimates from 2002–03 to 2015–16 are based on data version 2018v1.

				Observed		Estimated	
	Tows	No.obs	%ob	Captures	Rate	Capture	95%c.i.
2002–03	8 871	1 383	15.6	0	0.0	4	0–13
2003–04	8 005	1 262	15.8	2	0.2	10	3–26
2004–05	8 425	1 619	19.2	4	0.2	15	6–32
2005–06	8 289	1 358	16.4	2	0.1	11	4–25
2006–07	7 368	2 324	31.5	2	0.1	3	2–7
2007–08	6 730	2 811	41.8	5	0.2	8	5–14
2008–09	6 134	2 372	38.7	0	0.0	2	0–8
2009–10	6 011	2 135	35.5	0	0.0	3	0–9
2010–11	4 178	1 205	28.8	0	0.0	4	0–11
2011–12	3 654	922	25.2	0	0.0	1	0–5
2012–13	3 098	346	11.2	0	0.0	0	0–3
2013–14	3 606	434	12.0	0	0.0	1	0–4
2014–15	3 812	978	25.7	1	0.1	2	1–4
2015–16	4 083	1 421	34.8	0	0.0	1	0–3
2016–17	3 972	1 226	30.9	0	0.0		
2017–18	3 744	903	24.1	0	0.0		

3.3.2 Seabird interactions

Annual observed seabird capture rates in the orange roughy, oreo and cardinalfish trawl fisheries have ranged from 0 to 0.9 per 100 tows between 2002–03 and 2017–18 (Table 4). The average observed capture rate in deepwater trawl fisheries (including orange roughy, oreo and cardinalfish) for the period from 2002–03 to 2017–18 is about 0.31 birds per 100 tows, a very low rate relative to other New Zealand trawl fisheries, e.g. for scampi (4.43 birds per 100 tows) and squid (13.79 birds per 100 tows) over the same years.

Table 4: Number of tows by fishing year and observed seabird captures in orange roughy, oreo, and cardinalfish trawl fisheries, 2002–03 to 2017–18. No. obs, number of observed tows; % obs, percentage of tows observed; Rate, number of captures per 100 observed tows. Estimates are based on methods described in Abraham et al (2016) and Abraham & Richard (2017, 2018) and available via http://www.fish.govt.nz/en-nz/Environmental/Seabirds/. Estimates from 2002–03 to 2017–18 are based on data version 2019v1.

	Fishing effort			Observed captures		Estimated captures	
	Tows	No. obs	% obs	Captures	Rate	Mean	95% c.i.
2002–03	8 870	1 382	15.6	0	0.0	34	20–52
2003–04	8 007	1 262	15.8	3	0.2	32	19–47
2004–05	8 427	1 619	19.2	7	0.4	43	28–62
2005–06	8 291	1 359	16.4	8	0.6	39	25–55
2006–07	7 379	2 324	31.5	1	0.0	20	10–31
2007–08	6 731	2 811	41.8	7	0.2	23	14–33
2008–09	6 133	2 372	38.7	7	0.3	23	15–34
2009–10	6 012	2 132	35.5	19	0.9	35	27–46
2010–11	4 177	1 205	28.8	1	0.1	16	8–26
2011–12	3 655	923	25.3	2	0.2	12	6–21
2012–13	3 099	346	11.2	2	0.6	14	7–23
2013–14	3 608	434	12.0	2	0.5	16	8–26
2014–15	3 818	978	25.6	0	0.0	14	6–23
2015–16	4 084	1 421	34.8	4	0.3	14	8–22
2016–17	3 967	1 226	30.9	2	0.2	13	6–21
201718	3 748	903	24.1	4	0.4	16	9–25

Salvin's albatross was the most frequently captured albatross (46% of observed albatross captures) but seven other albatross species have been observed captured since 2002–03. Cape petrels were the most frequently captured other taxon (35% of other taxon observed caught not including albatross species, Table 5). Seabird captures in the orange roughy, oreo, and cardinalfish fisheries have been observed mostly around the Chatham Rise and off the east coast South Island. These numbers should be regarded as only a general guide on the distribution of captures because the observer coverage is not uniform across areas and may not be representative.

Table 5: Number of observed seabird captures in orange roughy, oreo, and cardinalfish fisheries, 2002–03 to 2017–18, by species and area. The risk category is an estimate of aggregate potential fatalities across trawl and longline fisheries relative to the Population Sustainability Thresholds, PST (from Richard & Abraham 2015 where full details of the risk assessment approach can be found). It is not an estimate of the risk posed by fishing for cardinal fish. These data are available via https://data.dragonfly.co.nz/psc, based on data version 2019v1.

Species	Risk Category	Chatham Rise	East Coast South Island	Fiordland	Sub-Antarctic	Stewart Snares Shelf	West Coast South Island	Total
Salvin's albatross	High	13	4	0	3	0	0	20
Southern Buller's albatross	High	3	0	1	0	0	0	4
Chatham Island albatross	High	7	0	0	1	0	0	8
New Zealand white-capped albatross	Medium	3	0	0	0	0	2	5
Gibson's albatross	High	1	0	0	0	0	0	1
Antipodean albatross	Medium	1	0	0	0	0	0	1
Northern royal albatross	Low	1	0	0	0	0	0	1
Southern royal albatross	Negligible	1	0	0	0	0	0	1
Albatrosses	-	0	2	0	0	0	0	2
Total albatrosses	-	**30**	**6**	**1**	**4**	**0**	**2**	**43**

Table 5[Continued]

Species	Risk Category	Chatham Rise	East Coast South Island	Fiordland	Sub-Antarctic	Stewart Snares Shelf	West Coast South Island	Total
Northern giant petrel	Medium	1	0	0	0	0	0	1
White-chinned petrel	Negligible	2	1	0	0	0	0	3
Grey petrel	Negligible	1	0	0	1	0	0	2
Sooty shearwater	Negligible	0	3	0	0	0	1	4
Common diving petrel	Negligible	2	0	0	0	0	0	2
White-faced storm petrels	Negligible	3	0	0	0	0	0	3
Cape petrel	-	8	1	0	0	0	0	9
Short-tailed shearwater	-	0	0	0	0	1	0	1
Petrels, prions and shearwaters	-	0	0	0	1	0	0	1
Total other birds	-	**17**	**5**	**0**	**2**	**1**	**1**	**26**

The deepwater trawl fisheries (including the cardinal fish target fishery) contributes to the total risk posed by New Zealand commercial fishing to seabirds (see Table 6). The two species to which the fishery poses the most risk are Chatham Island albatross and Salvin's albatross, with this suite of fisheries posing 0.06 and 0.022 respectively of Population Sustainability Threshold (PST) (Table 6). Chatham albatross and Salvin's albatross were assessed at high risk (Richard et al 2020).

Table 6: Risk ratio of seabirds predicted by the level two risk assessment for the orange roughy and all fisheries included in the level two risk assessment, 2006–07 to 2016-17, showing seabird species with a risk ratio of at least 0.001 of PST (from Richard et al 2017 and Richard et al 2020 where full details of the risk assessment approach can be found). The risk ratio is an estimate of aggregate potential fatalities across trawl and longline fisheries relative to the PBR. The DOC threat classifications are shown (Robertson et al 2017 at http://www.doc.govt.nz/documents/science-and-technical/nztcs19entire.pdf).

Species name	PST (mean)	Risk ratio: ORH, OEO, CDL target trawl*	Risk ratio: TOTAL	Risk category	DOC Threat Classification
Chatham Island albatross	428	0.060	0.28	High	At Risk: Naturally Uncommon
Salvin's albatross	3 460	0.022	0.65	High	Threatened: Nationally Critical
Northern giant petrel	337	0.005	0.15	Medium	At Risk: Naturally Uncommon
Northern Buller's albatross	1 640	0.002	0.26	Medium	At Risk: Naturally Uncommon
Black petrel	447	0.002	1.23	Very high	Threatened: Nationally Vulnerable
Antipodean albatross	369	0.002	0.17	Medium	Threatened: Nationally Critical
Gibson's albatross	497	0.002	0.31	High	Threatened: Nationally Critical
Northern royal albatross	723	0.001	0.05	Low	At Risk: Naturally Uncommon
Flesh-footed shearwater	1 450	0.001	0.49	High	Threatened: Nationally Vulnerable
Southern Buller's albatross	1 360	0.001	0.37	High	At Risk: Naturally Uncommon
Grey petrel	5 460	0.000	0.03	Negligible	At Risk: Naturally Uncommon
Common diving petrel	137 000	0.000	<0.01	Negligible	At Risk: Relict
New Zealand white-faced storm petrel	331 000	0.000	<0.01	Negligible	At Risk: Relict
New Zealand white-capped albatross	10 800	0.000	0.29	Medium	At Risk: Declining
Buller's shearwater	56 200	0.000	<0.01	Negligible	At Risk: Naturally Uncommon
Westland petrel	351	0.000	0.54	High	At Risk: Naturally Uncommon
Sooty shearwater	622 000	0.000	<0.01	Negligible	At Risk: Declining
Hutton's shearwater	14 900	0.000	<0.01	Negligible	At Risk: Declining
Otago shag	283	0.000	0.13	Medium	Threatened: Nationally Vulnerable
White-headed petrel	34 400	0.000	<0.01	Negligible	Not Threatened

*ORH, OEO, CDL from Richard et al 2017

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

3.3.3 Protected fish species interactions

Deepwater trawling for orange roughy and oreo typically exceeds the depth at which protected fish species are usually found. Fisheries-reported records include the capture of a basking shark (*Cetorhinus maximus*) in 2019, a species classified as “Endangered” by IUCN in 2013 and as “Threatened – Nationally Vulnerable” in 2016, under the New Zealand Threat Classification System (Duffy et al 2018). Basking shark has been a protected species in New Zealand since 2010, under the Wildlife Act 1953, and is also listed in Appendix II of the CITES convention.

However, basking sharks have been occasionally confused with bluntnose sixgill shark (*Hexanchus griseus*), a “Not Threatened” species according to the DOC latest assessment (Duffy et al 2018), and this report is being verified.

3.4 Benthic interactions

The spatial extent of seabed contact by trawl fishing gear in New Zealand’s EEZ and Territorial Sea has been estimated and mapped in numerous studies for trawl fisheries targeting deepwater species (Baird et al 2011, Black et al 2013, Black & Tilney 2015, Black & Tilney 2017, and Baird & Wood 2018) and species in waters shallower than 250 m (Baird et al 2015). The most recent assessments of the deepwater trawl footprint was for the period 2007–08 to 2016–17 (Baird & Mules 2019) and 1989–90 to 2017–18 (Baird & Mules 2020a).

Orange roughy, oreo, and cardinalfish are taken using bottom trawls and accounted for about 14% of all tows reported on TCEPR forms that fished on or close to the bottom between 1989–90 and 2004–05 (Baird et al 2011). During 1989–90 to 2015–16, about 128 000 orange roughy bottom trawls were reported on TCEPRs (Baird & Wood 2018): with between 5000 and at least 8000 tows reported most years up to 1999–2000; 3000–4500 annual tows between 2000–01 and 2009–10; and 1500–3000 tows a year during 2010–11 to 2015–16. The total footprint generated from these tows was estimated at about 34 725 km^2. This footprint represented coverage of 0.8% of the seafloor of the combined EEZ and the Territorial Sea areas; 2.4% of the ‘fishable area’, that is, the seafloor area open to trawling, in depths of less than 1600 m. For the 2016–17 fishing year, 2983 orange roughy bottom tows had an estimated footprint of 2700 km^2 which represented coverage of 0.1% of the EEZ and Territorial Sea and 0.2% of the fishable area (Baird & Mules 2019). The most recent footprint, for 2017–18, was estimated at 2590 km^2 based on 2816 tows (Baird & Mules 2020b).

The overall trawl footprint for orange roughy (1989–90 to 2015–16) covered 8% of the seafloor in 800–1000 m, 6% of 1000–1200 m seafloor, and 3% of the 1200–1600 m seafloor (Baird & Wood 2018). In 2017–18, the orange roughy footprint contacted 0.6%, 0.6%, and 0.1% of those depth ranges, respectively (Baird & Mules 2020b). Deepsea corals in the New Zealand region are abundant and diverse and, because of their fragility, are at risk from anthropogenic activities such as bottom trawling (Clark & O’Driscoll 2003, Clark & Rowden 2009, Williams et al 2010). All deepwater hard corals are protected under Schedule 7A of the Wildlife Act 1953. Baird et al (2013) mapped the likely coral distributions using predictive models and concluded that the fisheries that pose the most risk to protected corals are these deepwater trawl fisheries.

Tows are located in Benthic-optimised Marine Environment Classification (BOMEC, Leathwick et al 2012) classes J, K (mid-slope), M (mid-lower slope), N, and O (lower slope and deeper waters) (Baird & Wood 2012), and 94% were between 700 and 1200 m depth (Baird et al 2011). The BOMEC areas with the highest proportion of area covered by the orange roughy footprint were classes J (comprising mainly the Challenger Plateau and northern and southern slopes of the Chatham Rise) and N (deeper areas around the North Island and Chatham Rise). In 2017–18, the orange roughy footprint represented 0.65% of the 311 360 km^2 in class J and 0.1% of the 493 034 km^2 of class N (Baird & Mules 2020b).
Trawling for orange roughy, like trawling for other species, is likely to have effects on benthic community structure and function (e.g., Rice 2006) and there may be consequences for benthic productivity (e.g., Jennings et al 2001, Hermsen et al 2003, Hiddink et al 2006, Reiss et al 2009). These consequences are not considered in detail here but are discussed in the Aquatic Environment and Biodiversity Annual Review 2019 (Fisheries New Zealand 2020).

The New Zealand EEZ contains Benthic Protection Areas (BPAs) and seamount closures that are closed to bottom trawl fishing for the protection of benthic biodiversity. These combined areas include 28% of underwater topographic features (including seamounts), 52% of all seamounts over 1000 m elevation and 88% of identified hydrothermal vents.

3.5 Other considerations

Fishing during spawning may disrupt spawning activity or success. Morgan et al (1999) concluded that Atlantic cod (*Gadus morhua*) "exposed to a chronic stressor are able to spawn successfully, but there appears to be a negative impact of this stress on their reproductive output, particularly through the production of abnormal larvae". Morgan et al (1999) also reported that "Following passage of the trawl, a 300-m-wide "hole" in the [cod spawning] aggregation spanned the trawl track. Disturbance was detected for 77 min after passage of the trawl." There is no research on the disruption of spawning orange roughy by fishing in New Zealand.

3.5.2 Genetic effects

Fishing, environmental changes, including those caused by climate change or pollution, could alter the genetic composition or diversity of a species. There are no known studies of the genetic diversity of orange roughy from New Zealand. Genetic studies for stock discrimination are reported under "stocks and areas".

3.5.3 Habitat of particular significance to fisheries management

Habitat of particular significance for fisheries management (HPSFM) does not have a policy definition (MPI, 2013). Mace et al (1990) identified only one area of high abundance for juvenile orange roughy at 800–900 m depth about 150 km east of the main spawning ground on the north Chatham Rise. Orange roughy from 9 cm SL have also been located on the Challenger Plateau and O'Driscoll et al (2003) show other areas where immature fish are relatively common. Dunn et al (2009) showed that orange roughy juveniles are generally found close to the seabed, and in shallower water than the adults, starting off at depths of around 850–900 m and spreading deeper, and over a wider depth range, as they grow. Dunn & Forman (2011) also suggested that juveniles start on flat grounds shallower than the adults, that they shift deeper as they grow, and that seamounts and other features tend to be dominated by the largest orange roughy. It is not known if there are any direct linkages between the congregation of orange roughy around features and the corals found on those features. Bottom trawling for orange roughy has the potential to affect features of the habitat that could qualify as habitat of particular significance to fisheries management.

4. RECENT STOCK ASSESSMENTS

Stock assessments were undertaken for ORH 7A areas in 2019, for Puysegur in 2017, the Mid-east coast (MEC) and Northwest Chatham Rise (NWCR) in 2018, and the East and South Chatham Rise (ESCR) (update of 2017 assessment) and ORH 7B (preliminary) in 2020. In this section, the methods that were common to these stock assessments are described.

4.1 Methods

The methods used in recent orange roughy assessments were different from those used prior to 2014. The major differences were in the application of a more stringent data quality threshold, in model structure, and in the use of age data to estimate year class strengths.

4.1.1 Data quality and model structure

A high quality threshold was imposed on data before they were used in an assessment. This resulted in the exclusion of biomass estimates that had previously been used. In particular, CPUE indices were not used in any of the assessments because they were considered unlikely to be monitoring stock-wide abundance (e.g., non-spawning season catch rates from a single hill feature or complex within a large area cannot be monitoring stock wide abundance as the fishery would not have been sampling a large proportion of the stock; at best, such CPUE indices may index localised abundance; during the spawning season catches from a single hill or aggregation may be sampling a large proportion of the stock but the catch rates will depend on how the aggregation is fished rather than how much biomass is present). Also, estimates of biomass from egg surveys were not used as it was found that the available estimates were from surveys where the assumptions of the survey design were not met and/or there were major difficulties in analysing the survey data. Finally, acoustic-survey estimates of biomass were only used when mainly single-species aggregations were surveyed with suitable equipment. Estimates of spawning orange roughy biomass were accepted for plumes on the flat surveyed using hull-mounted transducers or towed systems. On underwater features estimates were accepted when the shadow zone estimate was no more than about 10% of the total estimate. For hull-mounted transducers, this requires that the plumes are high in the water column or near the top of the feature (and not on the side of the feature where shadow zone corrections are often large).

The model structure assumed was similar across the assessments. In each case, the base models were single-sex, single-area models with separate categories for age and maturity. Maturity was estimated within the model from age-frequencies of spawning fish and, if available, from female proportion spawning at age data from pre-spawning wide-area trawl surveys (available for NWCR and MEC). All mature fish were assumed to spawn each year as this was consistent with the estimates of female proportion spawning at age (see the NWCR and MEC assessments). This is different to earlier assessments where acoustic and egg survey estimates of spawning biomass were scaled up using estimates of transition-zone mature biomass before being used in an assessment. In the recent assessments, acoustic estimates of *spawning* biomass were used directly without scaling.

The recent assessment models now include more reliable age data using the new ageing methodology (Tracey et al 2007, Horn et al 2016). Previously, the stock assessments were not thought to be reliable as the models were found to be insensitive to the recent abundance data; i.e., results did not change whether or not recent abundance indices were included because the model assumptions - particularly the assumption of deterministic recruitment - overwhelmed the data. The modelled biomass trajectories were estimated as a strong increasing trend as catches were scaled back, a pattern that was not supported by the fishery-independent abundance indices.

4.1.2 Acoustic *q* priors

The major sources of recent abundance information in the models are from acoustic surveys of spawning biomass. For each survey, the spawning biomass estimate was included in the appropriate assessment as an estimate of *relative* spawning biomass rather than *absolute* spawning biomass (the latter being used in previous assessments). The reason that the estimates are not used as absolute estimates of biomass is because there are two major potential sources of bias: (i) the estimates may be biased low or high because the estimate of orange roughy target strength is incorrect, and (ii) the survey is unlikely to have covered all of the spawning stock biomass. The unknown proportionality constant, or *q*, for each survey was estimated in the model using an informed prior for each *q*. Each prior was constructed from two components: orange roughy target strength and availability to the survey.

The target strength (TS) prior was derived from the estimates of Macaulay et al (2013) and Kloser et al (2013) who both obtained TS estimates (at 38 kHz) from visually verified orange roughy as they were herded by a trawl net (the "AOS" was mounted on the head of the net and acoustic echoes and stereo photos were obtained simultaneously). Macaulay et al (2013) estimated a TS (for 33.9 cm fish) of -52.0 dB with a 95% CI of -53.3 to -50.9 dB; Kloser et al (2013) gave a point estimate of -51.1 dB and gave a range, that allowed for the artificial tilt angles of the herded fish, from -52.2 to -50.7 dB. The prior was taken to be normal with a mean of -52.0 dB with 99% of the distribution covered by ± 1.5 dB (which covers both ranges). This results in a tight distribution for informed acoustic q priors, reflecting the high confidence in the target strength estimates.

For surveys that covered "most" of the spawning stock biomass (e.g., ESCR where in some years surveys covered the Old plume[1], the Rekohu plume, and the "Crack"), availability was modelled with a Beta(8,2) distribution (this has a mean of 0.8 – i.e., it is assumed *a priori* that 80% of the spawning stock biomass is being indexed). The acoustic *q* prior is the combination of the availability and TS priors (assuming they are independent). This was approximately normal with a mean of 0.8 and a CV

[1]For clarity, what was previously described as the 'Spawning plume' located in the Spawning Box has been renamed the 'Old-plume' so as to differentiate it from the Rekohu plume, which is also a spawning plume.

of 19%. For surveys that were considered to have covered less than “most” of the spawning biomass, a similar prior was used for the *q* except that a lower mean value was assumed for the “availability” component of the prior (see individual assessments for how the mean was derived in these cases). In the 2014 stock assessments, when a higher CV was applied, the median estimates of biomass and stock status were slightly higher, and the confidence intervals were wider with a much higher upper bound.

4.1.3 Year class strength estimation

The number of year class strengths (YCSs) estimated within each model depended on the timing and number of age frequency observations available. In general a YCS was estimated provided that it was observed in at least one age frequency when it was neither “too old” nor “too young”. “Old” YCSs were not estimated because it was considered that there was too little information about these cohorts as only a few of them remained. “Too young” YCSs were not estimated because the selectivity for these ages is low and consequently the YCS estimates would be unreliable.

The Haist parameterisation for estimating YCS was used for all models (Bull et al 2012). In the 2013 MEC assessment it was found that the alternative Francis parameterisation unduly restricted YCS estimates as evidenced by poor fits to the trawl survey biomass indices. In contrast, the Haist parameterisation, using uniform priors, resulted in a good fit to the abundance indices at the MPD stage and an adequate fit at the MCMC stage. The YCS estimates were primarily driven by the composition data (age and length frequencies), but if unduly penalised, the estimates are restricted to a space which does not allow the trawl biomass indices to be fitted well. In the recent assessments a “nearly uniform” prior was used with the Haist parameterisation (lognormal with mode = 1, and log-space s.d. = 4).

4.1.4 Model runs

For each assessment, a similar set of sensitivity runs was conducted. In addition to a base model, there were runs that estimated natural mortality (*M*); halved and doubled the recent acoustic biomass estimates (to show that the model was sensitive to recent biomass indices); assumed deterministic recruitment (to show the impact of estimating year class strengths); increased/decreased the mean of acoustic *q* priors; and two sensitivities that simultaneously increased/decreased *M* and decreased/increased the mean of the acoustic *q* priors by 20% (a lower stock status occurs when *M* is decreased and when the mean of the acoustic *q* priors is increased; similarly an increased stock status occurs for changes in the other direction). The runs estimating *M* (“EstM”) and those with the 20% changes in *M* and the mean of acoustic *q* priors (“LowM-Highq” and “HighM-Lowq”) were taken through to MCMC.

4.1.5 Fishing intensity

Fishing intensity for each year of the assessment was measured in units of 100 – ESD (Equilibrium Stock Depletion). This quantity was estimated by running the model to deterministic equilibrium, given the exploitation rate and fishing pattern associated with each year. The equilibrium level of the spawning biomass will be the ESD for that year (e.g., if the stock is fished at a very high fishing intensity, the equilibrium spawning stock biomass will be close to zero: ESD = 0% B_0; if the stock is being very lightly fished, then ESD = 100% B_0). The quantity (100 – ESD) ranges from 0–100 with 100 denoting any pattern and level of fishing that would eventually reduce the stock down to zero spawning biomass. In general, the fishing intensity associated with a deterministic equilibrium of x% B_0 is denoted as $U_{x\%B0}$. To aid with the interpretation of fishing intensity in both the fishing intensity and “snail trail” plots (which have fishing intensity on the right hand y-axis), the value $U_{x\%B0}$ has been replaced with an associated exploitation rate proxy on the left hand y-axis. Exploitation rate, expressed as a percentage, is the number of fish caught from every 100 available fish. The exploitation rate labels represent a median exploitation rate, as each $U_{x\%B0}$ maps to a range of exploitation rates, rather than to a single number.

In the most recent assessments conducted in 2019 and 2020, fishing intensity has been approximated using exploitation rates (total catch divided by catch-averaged vulnerable biomass) as this eliminates the 100 – ESD axis making interpretation more straightforward.

5. FUTURE RESEARCH CONSIDERATIONS

The research considerations below are generic to all or most of the orange roughy assessments.

- A large number of modifications have been made to orange roughy trawl and acoustic estimates due to refinements in analytical methods. These need to be compiled into a single document that outlines the history of, and rationale for, the changes.
- Further examine the potential for contamination by swim bladder species when using current AOS technology to estimate orange roughy acoustic biomass, and determine the potential magnitude of possible errors.
- Greater detail is needed on the performance of tows or transects from surveys, especially when there are issues with them. Such detail should be included in the comment field and will enable analysts to determine how or whether to include them in models.
- Provide a more detailed protocol for otolith collections in surveys to ensure sufficient otoliths are collected. For example, it may be useful to oversample the first few tows in case insufficient samples are collected subsequently.
- Re-examine the M=0.045 and h=0.75 assumptions for each orange roughy assessment, including estimation within and outside models and the determination of appropriate priors.
- Estimate von Bertalanffy growth parameters specifically for Puysegur orange roughy and ORH 7B, rather than using the estimates from the Chatham Rise.
- Review the appropriateness of assuming a 5% overrun for current and recent years.
- Adequate age information is needed for all stocks including from commercial fisheries.
- Locate data on Enterprise Allocation catches and limits for 1983–86 and include these in Plenary catch tables and graphs, as well as in stock assessments.
- Review the Management Strategy Evaluation and the resulting Harvest Control Rule, along with their application, in a technical Working Group to ensure that the approach still represents best practice.

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ORANGE ROUGHY NORTHERN NORTH ISLAND (ORH 1)

1. FISHERY SUMMARY

1.1 Commercial fisheries

The ORH 1 region extends northwards from west of Wellington around to Cape Runaway. Prior to 1993–94 there was no established fishery, and reported landings were generally small (Table 1). A new fishery developed in winter 1994, when aggregations were fished on two hill complexes in the western Bay of Plenty. In 1996 catches were also taken off the west coast of Northland. Figure 1 shows the historical landings and TACC values for ORH 1.

A TACC of 190 t was set from 1989–90. Prior to that there had been a 10 t TAC and various levels of exploratory quota. From 1995–96, ORH 1 became subject to a five year adaptive management programme, and the TACC was increased to 1190 t. A catch limit of 1000 t was applied to an area in the western Bay of Plenty (Mercury-Colville 'box'), with the former 190 t TACC applicable to the remainder of ORH 1. In 1994 and 1995, research fishing was also carried out under Special Permit (not included in the TACC). For the period June 1996–June 1997, a Special Permit was approved for exploratory fishing. This allowed an additional 800 t (not included in the TACC) to be taken in designated areas, although catches were limited from individual features (hills and seamounts etc).

Table 1: Reported landings (t) and TACCs (t) from 1982–83 to present. - no TACC. The reported landings do not include catches taken under an exploratory special permit of 699 t in 1998–99 and 704 t in 1999–2000. QMS data from 1986-present.

	Reported landings			
Fishing year	**West coast**	**North-east coast**	**Total**	**TACC**
1982–83*	< 0.1	0	< 0.1	-
1983–84*	0.1	0	0.1	-
1984–85*	< 0.1	96	96	-
1985–86*	< 1	2	2	-
1986–87*	0	< 0.1	< 0.1	10
1987–88	0	0	0	10
1988–89	0	19	19	10
1989–90	37	49	86	190
1990–91	0	200	200	190
1991–92	+	+	112	190
1992–93	+	+	49	190
1993–94	0	189	189	190
1994–95	0	244	244	190
1995–96	55	910	965	1 190
1996–97	+	+	1 021	1 190
1997–98	+	+	511	1 190
1998–99	+	+	845	1 190
1999–00	+	+	771	1 190
2000–01	+	+	858	800
2001–02	+	+	1 294	1 400
2002–03	+	+	1 123	1 400
2003–04	+	+	986	1 400
2004–05	+	+	1 151	1 400
2005–06	+	+	1 207	1 400
2006–07	+	+	1 036	1 400
2007–08	+	+	1 104	1 400
2008–09	+	+	905	1 400
2009–10	+	+	825	1 400
2010–11	+	+	772	1 400
2011–12	+	+	1 114	1 400
2012–13	+	+	1 171	1 400
2013–14	+	+	1 055	1 400
2014–15	+	+	1 181	1 400
2015–16	+	+	1 004	1 400
2016–17	+	+	775	1 400
2017–18	+	+	881	1 400
2018–19	+	+	592	1 400

* FSU data.
\+ Unknown distribution of catch.

Reported landings have varied considerably between years, and the location of the catch in the late 1980s/early 1990s is uncertain, as some may have been taken from outside the EEZ, as well as misreported from other areas. Research fishing carried out under Special Permit in 1994 and 1995 resulted in catches of 45.2 t and 200.7 t, respectively (not included in Table 1).

Based on an evaluation of the results of an Adaptive Management Programme (AMP) for the Mercury-Colville box initiated in 1995, the AMP was concluded and the TACC was reduced to 800 t for the 2000–01 fishing year. Catch limits of 200 t were established in each of four areas in ORH 1, with an individual seamount feature limit of 100 t. From 1 October 2001, ORH 1 was reintroduced into the AMP with different design parameters for the five years, and the TACC was increased from 800 to 1400 t and allocated an allowance of 70 t for other mortality caused by fishing. The AMP was discontinued in 2007, with the TACC remaining at 1400 t.

In recent years the fishery has also developed off the west coast and sizeable catches have been taken off the Tauroa Knoll and West Norfolk Ridge. However overall landings have declined, remaining well below the current TACC since its introduction in 2001–02. In 2018–19 landings dropped to levels last recorded in 1997–98 (592 t).

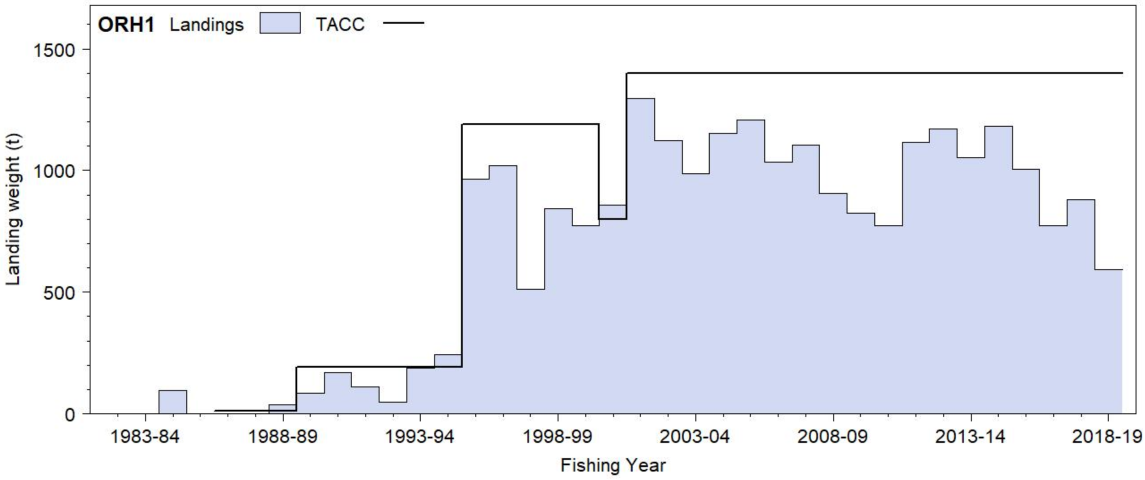

Figure 1: Reported commercial landings and TACC for ORH 1 (Auckland).

1.2 Recreational fisheries
There is no known non-commercial fishery for orange roughy in this area.

1.3 Customary non-commercial fisheries
No customary non-commercial fishing for orange roughy is known in this area.

1.4 Illegal catch
No quantitative information is available on the level of illegal catch in this area.

1.5 Other sources mortality
There may be some overrun of reported catch because of fish loss with trawl gear damage and ripped nets. In other orange roughy fisheries, a level of 5% has been estimated.

2. STOCKS AND AREAS

Orange roughy are distributed throughout the area. Spawning is known from several hills in the western Bay of Plenty as well as from features in the western regions of ORH 1. Stock status/affinities within the QMA are unknown. The Mercury-Colville grounds in the Bay of Plenty are about 120 n. miles from fishing grounds at East Cape (ORH 2A North), and spawning occurs at a similar time. Hence, it is likely that these are separate stocks. The Mercury and Colville Knolls in the

Bay of Plenty are about 25 miles apart and may form a single stock. Stock affinities with other fishing hills in the southern and central Bay of Plenty are unknown. The Tauroa Knoll and outer Colville Ridge seamounts are distant from other commercial grounds, and these fish may also represent separate stocks.

3. STOCK ASSESSMENT

An assessment for the Mercury-Colville box was carried out in 2001 and is repeated here. A deterministic stock reduction technique (*after* Francis 1990) was used to estimate virgin biomass (B_0) and current biomass ($B_{current}$) for the Mercury-Colville orange roughy stock. The model was fitted to the biomass indices using maximum likelihood and assuming normal errors. In common with other orange roughy assessments, the maximum exploitation rate was set at 0.67. The model treats sexes separately, and assumes a Beverton-Holt stock-recruit relationship. Confidence intervals of the biomasss estimates were derived from bootstrap analysis (Cordue & Francis 1994).

3.1 Estimates of fishery parameters and abundance

A series of trawl surveys of the Mercury-Colville box to estimate relative abundance were agreed under an Adaptive Management Programme. The first survey was carried out in June 1995 with a second survey in winter 1998 (Table 2). The biomass index of the latter survey was much lower than 1995, and because of warmer water temperatures it was uncertain whether the 1998 results were directly comparable to the 1995 results. They were not incorporated in the decision rule for the adaptive management programme. A third survey was carried out in June 2000, with the results suggesting that the abundance of orange roughy in the box had decreased considerably and was at low levels. However, these estimates are uncertain because of the suggestion that environmental factors may have influenced the distribution of orange roughy. The abundance indices from trawl survey and commercial catch-effort data used in the assessment are given in Table 2. The trawl survey indices had CVs of 0.27, 0.39 and 0.29 for 1995, 1998, and 2000 respectively.

Table 2: Biomass indices and reported catch used in estimation of B_0. Values in square brackets are included for completeness; they are not used in the assessment.

Year	1993–94	1994–95	1995–96	1996–97	1997–98	1998–99	1999–00
Trawl survey	-	76 200	-	-	[2 500]	-	3 800
CPUE	8.3	9.1	5.4	4.2	[0.5]	1.5	(2.0)
Catch (t)	230	440	915	895	295	140	250

The CPUE series is mean catch per tow (sum of catches divided by number of tows, target ORH) from Mercury Knoll in the month of June. This is the only month when adequate data exist from the fishery to compare over time. A CV of 0.30 was assigned to the CPUE data.

Catch history information is derived from TCEPR records, scaled to the reported total catch for ORH 1. Overrun of reported catch (e.g., burst bags, inappropriate conversion factors) was assumed to be zero, as even if there was some, it is likely that it was similar between years. The catch in 1999–00 was assumed to be 250 t.

Assessments were carried out for three alternative sets of biomass indices (Table 3).

Table 3: Three alternative sets of biomass indices used in the stock assessment.

Alternative	Trawl survey indices	CPUE indices
1	1995, 2000	All except 1998
2	1995, 2000	None
3	1995, 2000	All except 1998 and 2000

Biological parameters used are those for the Chatham Rise stock, except for specific Bay of Plenty values for the maturity and recruitment ogives (Annala et al 2000).

3.2 Biomass estimates

The estimated virgin biomass (B_0) is very similar for all three alternative assessments (Table 4). With alternative 1 the estimated B_0 is 3200 t, with a current biomass of 15% B_0. For both alternatives 2 and 3, the estimated B_0 is 3000 t, which is B_{min}, the minimum stock size which enables the catch history to be taken given a maximum exploitation rate of 0.67.

Table 4: Biomass estimates (with 95% confidence intervals in parentheses) for stock assessments with the three alternatives of Table 3. B_0 is virgin biomass; B_{MSY} is interpreted as B_{MAY}, which is 30%B_0; $B_{current}$ is mid-season 1999–00; and B_{beg} is the biomass at the beginning of the 2000–01 fishing year. Estimates are rounded to the nearest 100 t (for B_0), 10 t (for other biomasses), or 1%.

Biomass	Alternative 1		Alternative 2		Alternative 3	
B_0 (t)	3 200	(3 000, 3 600)	3 000	(3 000, 3 500)	3 000	(3 000, 3 300)
B_{MSY} (t)	960	(900, 1080)	900	(900, 1050)	900	(900, 990)
$B_{current}$ (t)	490	(290, 890)	290	(290, 790)	290	(290, 590)
$B_{current}$ (%B_0)	15	(10, 25)	10	(10, 23)	10	(10, 18)
B_{beg} (t)	480	(270, 900)	270	(270, 800)	270	(270, 590)

The model fits the CPUE data reasonably well but estimates a smaller decline than is implied by the two trawl survey indices.

3.3 Yield estimates and projections

Yield estimates were determined using the simulation method described by Francis (1992) and the relative estimates of *MCY*, E_{CAY} and *MAY*, as given by Annala et al (2000).

Yield estimates are all much lower than recent catches (Table 5). Estimates of current yields ($MCY_{current}$ and *CAY*) lie between 16 t and 35 t; long-term yields ($MCY_{long\text{-}term}$ and *MAY*) lie between 44 t and 67 t.

Table 5: Yield estimates (t) for stock assessments with the three alternatives of Table 3.

Yield	Alternative 1		Alternative 2		Alternative 3	
MCY_{curren}	35	(22, 53)	22	(22, 51)	22	(22, 44)
$MCY_{long\text{-}term}$	47	(44, 53)	44	(44, 51)	44	(44, 49)
CAY	29	(16, 54)	16	(16, 48)	16	(16, 36)
MAY	67	(58, 70)	58	(58, 68)	58	(58, 64)

CSP for this stock is just under 100 t for any B_0 between 3000 t and 3600 t.

4. ANALYSIS OF ADAPTIVE MANAGEMENT PROGRAMME

The ORH 1 TACC was increased from 800 to 1400 t in October 2001/02 under the Adaptive Management Programme. The objectives of this AMP were to determine stock size, geographical extent, and long-term sustainable yield of the ORH 1 stock. This is a complex AMP, with ORH 1 divided into four sub-areas (see Figure 2), each with total catch and "feature" catch limits (Table 6) (a "feature" was defined as being within a 10 n. mile radius of the shallowest point).

Table 6: Description of control rules implemented in the ORH 1 AMP.

ORH 1 Subarea	Proposed Catch Limit	Feature Limit (t/fishing year)
Area A	200 t	100 t
Area B	500 t	150 t
Area C	500 t	150 t
Area D	200 t	75 t

Feature limits also serve as limits to the total catch in any area due to the limited number of available productive features. The Mercury-Colville "Box" (located within Area D) has been given a specific limit of 30 t per year to allow for the bycatch of orange roughy when fishing for black cardinalfish. The catch of orange roughy in the Mercury-Colville "Box" is included in the overall limit for Area D.

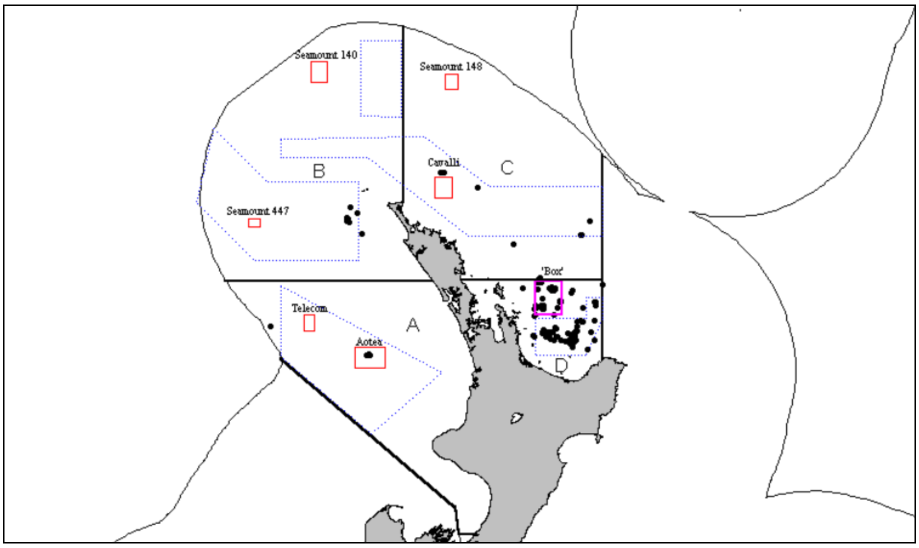

Figure 2: Four sub-management areas for the ORH 1 AMP (labelled A-D). Dotted lines enclose the exploratory fishing areas defined in the special permit issued on 6 July 1998. Solid lines enclose seamount closures and the Mercury-Colville Ohena 'box' (labelled at their top). Trawls (dots) where orange roughy were reported as the target species and caught during 1997–98 and 1998–99 are shown. Note that the lines separating Areas A and D from Areas B and C are incorrectly drawn at 36° S latitude rather than 35°30' S latitude.

From 1 October 2007 the stock is no longer part of the Adaptive Management Programme but stakeholders have agreed to continue with the sub-area and feature limits within the overall ORH 1 TACC.

Review of ORH 1 AMP in 2007

In 2007 the AMP FAWG reviewed the performance of the AMP after the full 5-year term.

Fishery Characterisation

- In most years, the total catch has been less than the TACC (Table 7).
- The area splits into A, B, C and D only occurred in 2001.
- Main fishery is in area B; the fishery in area A only began in 2002.
- Two main goals of the AMP:
  - Reduce fishing in area D, in particular the Mercury-Colville "box".
  - Look for new fishing areas, distributing effort across the QMA, with feature limits to reduce the possibility of localised overfishing.

Table 7: Estimated target catches by sub-area, scaled to landings, reported landings, and TACC for ORH 1. The scaling factor is calculated as reported catch/estimated (all target) catch (source: Anderson 2007b)

	Sub-area target catch (t)				Total target	Reported	TACC	Scaling
	A	B	C	D	catch(t)	landings (t)	(t)	factor
1998	0.5	5.6	0.0	491.0	497	511	1 190	0.99
1999	5.2	575.2	165.0	724.5	1 470	1 543	1 190	0.99
2000	0.8	644.6	164.8	597.5	1 408	1 476	1 190	1.03
2001	8.5	166.3	99.4	164.6	439	858	800	1.11
2002	122.7	440.5	265.8	227.1	1 056	1 294	1 400	1.06
2003	196.7	508.1	237.9	72.2	1 015	1 123	1 400	0.98
2004	223.2	421.7	117.0	110.1	872	986	1 400	1.01
2005	277.0	389.8	173.4	174.1	1 014	1 151	1 400	1.13
2006	151.0	473.2	372.6	186.0	1 183	1 201	1 400	1.13

CPUE Analysis

- Unstandardised CPUE is in kg/tow. The short time series, the nature of the fishery (fishing aggregations spread over a wide area in different seasons) and the impact of catch limits on features and sub-areas prevent any useful relative abundance indices from being developed at this point for ORH 1.

- Where features are less than 10 n. mile apart, catch is apportioned according to the distance to the feature. Industry in-season reporting is based on the feature closest to the start of the tow.
- Possible problems with the area A observations in 2005–06, as there seem to be more reported tows than expected given the number of vessels operating in the area.

Observer Programme

- 50% observer coverage prior to 1 October 2006 (a high level relative to that for other deepwater stocks, with a large number of samples taken relative to the size of the fishery). From 1 October 2006, 100% coverage was requested by the Minister, but this has not been fully achieved, as some ORH 1 is taken as bycatch on trips that do not predominantly target ORH.
- The size frequency data show high levels of stock variability between fisheries on features or feature groups. Size variation does not seem to be linked to exploitation rate.

Environmental Effects

- Observer data from 2000 to 2003 indicated that incidental captures of seabirds did not occur in the ORH 1 target fishery (Baird 2005). Marine mammal interactions are also not .a problem.
- Only three non-fish bycatch records have been reported from observed trips (in 1994 and 1995). All were shearwaters that landed on deck and were released alive. It was verified that observers were briefed in the same way as for other MFish trips including recording non-fish bycatch i.e. seabirds and marine mammals. Note that this does not include benthic organisms.
- The overall impact of bottom trawling on seamounts in ORH 1 is not known. A number of seamounts have been closed to fishing and the Norfolk Deep BPA is included in the industry accord relating to benthic protection areas within New Zealand's EEZ.

Sub-area D Directed Adaptive Exploratory Fishing Programme

- The purpose of this exercise was to establish whether fish populations shift between features in different years in sub-area D.
- Based on the results from the exploratory fishing from 2002 to 2005 it is evident that catches from all features contained a high proportion of ripe or ripe running females and that synchronised spawning occurs on a range of hills during winter.
- In 2006 the AMP Working Group recommended some changes to the design of the exploratory survey; however, this was not achieved during the 2006 survey.

The abbreviated checklist questions for full- and mid-term reviews are:

1. Is stock abundance adequately monitored?

   The working group concluded that CPUE does not seem to be a proportional measure of abundance for this stock. However, CPUE is used in ORH 1 as a management tool. When CPUE drops on a feature, fishers are meant to move to another feature.
2. Is logbook coverage sufficient?

   As there are Ministry fisheries observers on these vessels, fishers are not required to complete detailed logbooks for the AMP. This is the highest level of monitoring of any ORH fishery in New Zealand.
3. Are additional analyses of current data necessary?

   No. The Working Group concluded that no other information can currently be extracted from the existing data that will provide insight into the status of the ORH 1 stocks. However, a potential problem with the 2005–06 catch records from Area A still needs to be checked.
4. Based on the biomass index, is current harvest sustainable?

   Unknown. The purpose of the AMP was to spread effort in an attempt to reduce fishing pressure on any one sub-area or feature (and Area D in particular). ORH 1 is a large area, with orange roughy aggregations spread across a number of areas and features. The amount of fishing in some areas appears to be low, but without any indication of current abundance, there is no way to determine if this level of fishing is in fact sustainable, or if current feature limits will avoid overexploitation of localised areas.
5. Where is stock, based on weight of evidence, in relation to B_{MSY}?

Unknown. In 2001, when the AMP was initiated, the Working Group stated that the stock was likely to be above B_{MSY}; while the information collected since that time has not improved the understanding about the status of the stock, the intent of the AMP design for ORH 1 was to spread effort to reduce the likelihood of the biomass declining below B_{MSY}.

ORH 1 is unlikely to be a single biological stock, and probably includes a number of constituent stocks. The Working Group concluded that it is not possible to estimate B_{MSY} for any of the individual stocks, let alone aggregate up to an estimate for ORH 1 as a whole. Moreover, a better understanding is not possible in the near future. B_{MSY} is difficult to estimate in situations involving an unknown number of constituent stocks.

6. Are the effects of fishing adequately monitored?

   Yes, there is good observer coverage. The Working Group noted that one consequence of deliberately spreading effort was to increase the possible benthic impact.

7. Are rates of non-fish bycatch acceptable?

   Yes.

8. Should the AMP be reviewed by the Plenary?

   This AMP does not need to be reviewed by the Plenary.

5. STATUS OF THE STOCKS

From 1 October 2001, the TACC for ORH 1 was increased to 1400 t within the AMP, with sub-area and feature limits. From 1 October 2007 the stock is no longer part of the Adaptive Management Programme but stakeholders have agreed to continue with the sub-area and feature limits within the overall ORH 1 TACC.

In most years the total catch has been less than the TACC. However, it is not known if recent catch levels or current TACCs are sustainable in the long term. Except for the small area of the Mercury-Colville box no assessment of stock status is currently available.

An assessment of the Mercury-Colville box in 2001 indicated that biomass had been reduced to 10–15% B_0 (compared to an assumed B_{MSY} of 30% B_0). As the stock was considered to be well below B_{MSY}, a catch limit of 30 t was set for the box. The assessment indicated that a catch level of about 100 t would probably maintain the stock at the 2000 stock size (assuming deterministic recruitment) and catch levels from 16 to 35 t (consistent with *CAY* or *MCY* strategies) might allow the stock to rebuild slowly.

In other areas of ORH 1 the status of the constituent stocks is unknown. The amount of fishing in some areas appears to be low, but without any indication of current abundance, there is no way to determine if this level of fishing is in fact sustainable or if current feature limits will avoid overexploitation of localised areas.

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ORANGE ROUGHY, CAPE RUNAWAY TO BANKS PENINSULA (ORH 2A, 2B, 3A)

1. FISHERY SUMMARY

1.1 Commercial fisheries

The first reported landings of orange roughy between Cape Runaway and Banks Peninsula were in 1981–82 occurring with the development of the Wairarapa fishery. Total reported landings and TACCs grouped into the three orange roughy Fishstocks from 1981–82 to 2018–19 are shown in Table 1. The historical landings and TACCs for these stocks are shown in Figure 1.

Table 1: Reported landings (t) and TACCs (t) from 1981–82 to 2018–19. QMS data from 1986–present.

Fishing Year	QMA 2A (Ritchie + E.Cape)		QMA 2B (Wairarapa)		QMA 3A (Kaikoura)		All areas combined	
(1 Oct–30 Sep)	Landings	TACC	Landings	TACC	Landings	TACC	Landings	TACC or catch limit
1981–82*	-	-	554	-	-	-	554	-
1982–83*	-	-	3 510	-	253	-	3 763	-
1983–84†	162	-	6 685	-	554	-	7 401	-
1984–85†	1 862	-	3 310	3 500	3 266	§	8 438	-
1985–86†	2 819	4 576	867	1 053	4 326	2 689	8 012	8 318
1986–87	5 187	5 500	963	1 053	2 555	2 689	8 705	9 242
1987–88	6 239	5 500	982	1 053	2 510	2 689	9 731	9 242
1988–89	5 853	6 060	1 236	1 367	2 431	2 839	9 520	10 266
1989–90	6 259	6 106	1 400	1 367	2 878	2 879	10 537	10 352
1990–91	6 064	6 106	1 384	1 367	2 553	2 879	10 001	10 352
1991–92	6 347	6 286	1 327	1 367	2 443	2 879	10 117	10 532
1992–93	5 837	6 386	1 080	1 367	2 135	2 879	9 052	10 632
1993–94	6 610	6 666	1 259	1 367	2 131	2 300	10 000	10 333
1994–95	6 202	7 000	754	820	1 686	1 840	8 642	9 660
1995–96	4 268	4 261	245	259	612	580	5 125	5 100
1996–97	3 761	4 261	272	259	580	580	4 613	5 100
1997–98	3 827	4 261	254	259	570	580	4 651	5 100
1998–99	3 335	3 761	257	259	582	580	4 174	4 600
1999–00	3 120	3 761	234	259	617	580	3 971	4 600
2000–01	1 385	1 100	190	185	479	415	2 054	1 700
2001–02	1 087	1 100	180	185	400	415	1 667	1 700
2002–03	782	680	105	99	235	221	1 122	1 000
2003–04	703	680	103	99	250	221	1 056	1 000
2004–05	1 120	1 100	206	185	416	415	1 742	1 700
2005–06	1 076	1 100	172	185	415	415	1 663	1 700
2006–07	1 131	1 100	203	185	401	415	1 736	1 700
2007–08	1 068	1 100	209	185	432	415	1 709	1 700
2008–09	1 114	1 100	173	185	414	415	1 701	1 700
2009–10	1 117	1 100	213	185	390	415	1 720	1 700
2010–11	1 113	1 100	158	185	420	415	1 690	1 700
2011–12	876	875	140	140	428	415	1 445	1 430
2012–13	727	#875	102	#140	296	#415	1 124	#1 430
2013–14	732	875	108	140	331	415	1 171	1 430
2014–15	483	488	54	60	156	177	693	725
2015–16	474	488	59	60	178	177	710	725
2016–17	505	488	57	60	174	177	736	725
2017–18	485	488	46	60	117	177	647	725
2018–19	491	488	61	60	129	177	680	725

* Ministry data † FSU data. § Included in QMA 3B TAC.

\# In 201213, shelving (an agreement that transfers ACE to a third party to effectively reduce the catch without adjusting the TACC) occurred (ORH 2A 165 t, ORH 2B 34 t and ORH 3A 101 t)

There was a major change in the ORH 2A fishery in 1993–94 with a shift of effort from the main spawning hill on Ritchie Bank to hills off East Cape. Although these hills had apparently only been lightly fished in the past, during 1993–94 52% of the total catch from ORH 2A was taken from the East Cape area (Table 2). This led to an agreement between industry and the Minister responsible for fisheries that, from 1994–95, the traditionally fished areas within ORH 2A (south of 38°23', hereafter referred to as "2A South") would be managed separately from the new East Cape fishery (north of 38°23', "2A North"). ORH 2A South was combined with ORH 2B and ORH 3A to form the Mid-East Coast (MEC) stock for management purposes.

The catch limits for these two areas changed several times in the following years, including a subdivision of 2A North (Table 3). Catches in the exploratory sub-area of 2A North never approached the catch limit, with only 37 t being caught in 1996–97 and less in subsequent years.

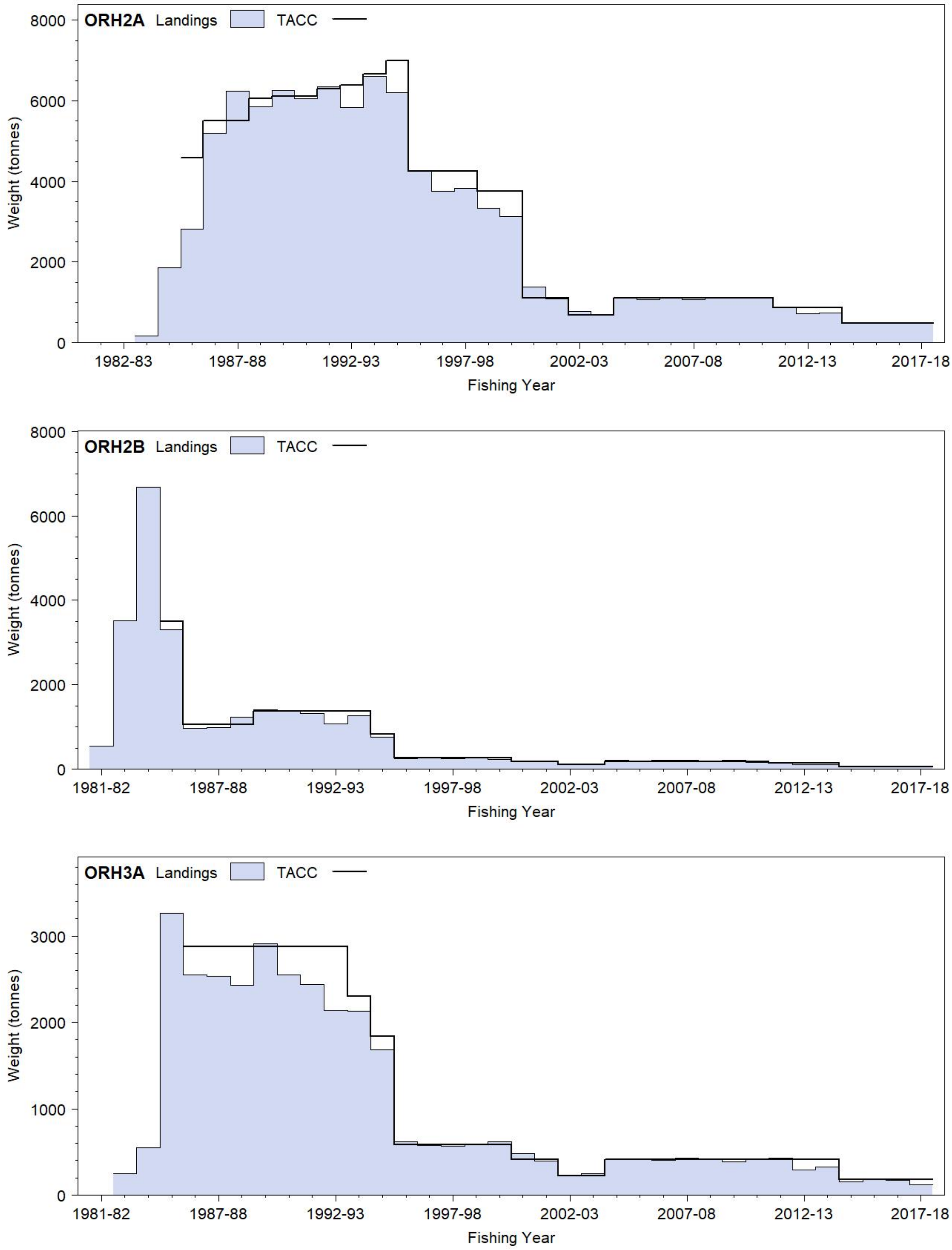


Figure 1: Reported commercial landings and TACCs for ORH 2A (Central (Gisborne)), ORH 2B (Central (Wairarapa)), and ORH 3A (Central/Challenger/South-East (Cook Strait/Kaikoura)).

For the 2000–01 fishing year, the TACC for ORH 2A was reduced to 1100 t, that for ORH 2B to 185 t, and that for ORH 3A to 415 t. Within the TACC for ORH 2A, the catch limit for all of 2A North was reduced to 200 t, without specifying separate catch limits for the East Cape Hills and the exploratory area, while the catch limit for 2A South was reduced to 900 t. This gave a catch limit for the MEC stock of 1500 t. The catch limit for MEC was reduced to 800 t (and ORH 2A South to 480 t) for the 2002–03 and 2003–04 fishing years. From 1 October 2004 there was an increase in the TACC to 1100 t, 185 t, and 415 t in 2A, 2B, and 3A respectively. Furthermore, an allowance of 58 t, 9 t, and 21 t, for other mortality was allocated to 2A, 2B, and 3A in 2004 as well.

In 2012–13 the fishing industry voluntarily shelved (an agreement that transfers ACE to a third party to effectively reduce the catch without adjusting the TACC) approximately 25% of the MEC quota, resulting in effective catch limits of 510 t, 106 t, and 314 t for 2A South, 2B, and 3A respectively. In 2014–15 TACCs were lowered further, to 488 t, 60 t, and 177 t in 2A, 2B, and 3A respectively. Reported commercial landings have closely followed the decreasing TACCs in all three orange roughy stocks and totalled just 608 t in 2018–19.

Table 2: North Mid-East Coast + East Cape (ORH 2A) catches by area, in tonnes and by percentage of the total ORH 2A catch. (Percentages up to 1993–94 and from 2007–08 calculated from Ministry data; 1994–95 to 1996–97 from NZFIB data, and 1997–98 to 2016–17 from Orange Roughy Management Co.) Mid-East Coast (MEC) stock (ORH 2A South, ORH 2B, and ORH 3A combined) catches in tonnes.

Fishing year	2A North		2A South		MEC (t)
	t	%	t	%	
1983–84	0	0	162	100	7 401
1984–85	4	< 1	1 858	99	8 434
1985–86	41	1	2 778	99	7 971
1986–87	253	5	4 934	95	8 452
1987–88	36	< 1	6 203	99	9 695
1988–89	143	2	5 710	98	9 377
1989–90	20	< 1	6 239	99	10 517
1990–91	13	< 1	6 051	99	9 988
1991–92	18	< 1	6 329	99	10 099
1992–93	30	< 1	5 807	99	9 022
1993–94	3 437	52	3 173	48	6 563
1994–95	2 921	47	3 281	53	5 721
1995–96	3 235	76	1 033	24	1 890
1996–97	2 491	66	1 270	34	2 122
1997–98	2 411	63	1 416	37	2 240
1998–99	1 901	57	1 434	43	2 273
1999–00	1 456	47	1 666	53	2 517
2000–01	302	22	1 083	78	1 752
2001–02	186	17	901	83	1 480
2002–03	173	24	546	76	886
2003–04	170	24	533	76	886
2004–05	271	24	849	76	1 471
2005–06	216	20	859	80	1 445
2006–07	229	20	902	80	1 506
2007–08	200	24	868	76	1 509
2008–09	230	21	884	79	1 471
2009–10	267	24	850	76	1 453
2010–11	207	19	906	81	1 484
2011–12	184	21	692	79	1 260
2012–13	190	26	537	74	935
2013–14	176	25	530	75	5 315
2014–15	179	42	248	58	458
2015–16	186	40	280	60	466
2016–17	188	37	317	63	626
2017-18	196	41	280	59	444
2018-19	197	39	304	61	493

Table 3: Catch limits (t) by sub-area within ORH 2A, as agreed between the industry and the Minister responsible for fisheries since 1994–95 and the catch limit for the Mid-East Coast (MEC) stock (ORH 2A South, ORH 2B, ORH 3A combined). (Note that 2A North was split, for the years 1996–97 to 1999–2000, into the area round the East Cape Hills and the remaining area, which is called the exploratory area). [Continued on next page]

Fishing year	2A North	2A South	MEC
1994–95	3 000	4 000	6 660
1995–96	3 000	1 261	2 100
1996–97	3 000*	1 261	2 100
1997–98	3 000*	1 261	2 100
1998–99	2 500*	1 261	2 100
1999–00	2 500*	1 261	2 100
2000–01	200	900	1 500

Table 3 [Continued]

Fishing year	2A North	2A South	MEC
2001–02	200	900	1 500
2002–03	200	480	800
2003–04	200	480	800
2004–05	200	900	1 500
2005–06	200	900	1 500
2006–07	200	900	1 500
2007–08	200	900	1 500
2008–09	200	900	1 500
2009–10	200	900	1 500
2010–11	200	900	1 500
2011–12	200	675	1 230
2012–13	200	510	930
2013–14	200	510	930
2014–15	200	288	525
2015–16	200	288	525
2016–17	200	288	525

*Catch limit for East Cape Hills including 500 t for the exploratory area.

1.2 Recreational fisheries
Recreational fishing for orange roughy is not known in this area.

1.3 Customary non-commercial fisheries
No information on customary non-commercial fishing for orange roughy is available for this area.

1.4 Illegal catch
No information is available about illegal catch in this area.

1.5 Other sources of mortality
There has been a history of catch overruns in this area because of lost fish and discards, particularly in the early years of the fishery. In the assessments presented here total removals were assumed to exceed reported catches by the overrun percentages in Table 4.

All yield estimates and forward projections presented make an allowance for the current estimated level of overrun of 5%.

Table 4: Catch overruns (%) by QMA and year. -, no catches reported.

Year	2A (North and South)	2B	3A
1981–82	-	30	-
1982–83	-	30	30
1983–84	50	30	30
1984–85	50	30	30
1985–86	50	30	30
1986–87	40	30	30
1987–88	30	30	30
1988–89	25	25	25
1989–90	20	20	20
1990–91	15	15	15
1991–92	10	10	10
1992–93	10	10	10
1993–94	10	10	10
1994–95 and subsequent years	5	5	5

2. BIOLOGY

Biological parameters used in this assessment are presented in the Biology section at the beginning of the Orange Roughy Introduction section.

3. STOCKS AND AREAS

Two major spawning locations have been identified in ORH 2A, one at the East Cape Hills in "2A North" and the other on the Ritchie Bank in "2A South". Spawning orange roughy were located in Wairarapa (ORH 2B) in winter 2001, but no large concentrations were found, and the significance of this spawning event is not known. Spawning orange roughy have not been located in Kaikoura (ORH 3A). The major spawning area in ORH 2A South, ORH 2B, and ORH 3A is still believed to be the Ritchie Bank, although spawning aggregations were not seen here in the 2013 AOS survey.

Results from allozyme studies showed that orange roughy from the three areas, "2A South", Wairarapa, and Kaikoura could not be separated, but were distinct from fish on the eastern Chatham Rise. Earlier analyses that suggested there was a genetic stock boundary between East Cape and Ritchie Bank were not supported by a more recent replicate sample from East Cape. For these reasons, orange roughy in this region are currently treated as two stocks: the Mid-East Coast (MEC) stock (2A South, Wairarapa, and Kaikoura) and the East Cape (EC) stock (2A North). The relationship between these areas and the location of the main fishing grounds is shown in Figure 2.

4. STOCK ASSESSMENT

Stock assessments are reported below for East Cape from 2003 and for Mid-East Coast (MEC) from 2014. In 2018 there was a preliminary update of the MEC stock assessment (Cordue 2017). The stock status and biomass trajectories from the preliminary stock assessment did not change or revise those reported for the 2014 assessment (Cordue 2014b). Because of the similarity in results, rather than report the preliminary results from the 2018 assessment, the 2014 assessment was retained in this report.

4.1 East Cape stock (2A North)

The stock assessment for the East Cape was last updated in 2003 and is summarised here (Anderson 2003b). An attempt to update the assessment with a new set of CPUE indices was made in 2006, but was rejected by the Working Group because of changes in the fishery which invalidated the utility of the CPUE series as an index of abundance. With no other abundance estimates available, an updated stock assessment was not possible.

4.1.1 Assessment Inputs

A CPUE analysis was performed in 2006, but was considered unreliable because of a change in fishing patterns and fleet size corresponding to the reduction of the catch limit to 200 t in 2000–01. The CPUE analysis was updated in 2011 and was considered more reliable by the Working Group due to the increase in the number of trawls per year since 2006. The 2011 analysis showed that standardised CPUE decreased after a peak in 2003–04, and has subsequently remained at a level similar to that in the late 1990s to early 2000s (Table 5).

Previous concerns by the Working Group that the fishery was dominated by a single vessel were alleviated somewhat by the return or entry of three other vessels to the fishery since 2003–04, but the utility of CPUE analyses in fisheries where substantial catch limit reductions have caused major changes in fishing patterns remains an issue for this stock.

The model inputs for the 2003 stock assessment were catches, an egg survey, and CPUE indices (Table 5). The biological parameters used are presented in the Biology section at the beginning of the Orange Roughy section.

4.1.2 Stock assessment

A stock assessment analysis for the East Cape stock was performed in 2003 using the stock assessment program, CASAL (Bull et al 2002) to estimate virgin and current biomass.

- The model was fitted using Bayesian estimation and partitioned the EC stock population by sex, maturity (the fishery was assumed to act on mature fish only) and age (age-groups used were 1–

70, with a plus group).

- The model estimated virgin biomass, B_0, and the process error for the CPUE indices. Catchability, *q*, was treated as a nuisance parameter by the model.
- The stock was considered to reside in a single area, and to have a single maturation episode modelled by a logistic-producing ogive where 50% of fish of both sexes were mature at age 26 and 95% at age 29.
- The catch equation used was the instantaneous mortality equation from Bull et al (2002) whereby half the natural mortality was applied, followed by the fishing mortality, then the remaining natural mortality.
- The size at age model used was the von Bertalanffy.
- No stock recruitment relationship was assumed.
- A Bayesian estimation procedure was used with a penalty function included to discourage the model from allowing the stock biomass to drop below a level at which the historical catch could not have been taken.
- Lognormal errors, with known (sampling error) CVs were assumed for the CPUE and egg survey indices. Additionally, process error variance was estimated by the model and added to the CVs from the CPUE indices.
- Confidence intervals were calculated from the posterior profile distribution of B_0 estimates, where the process error parameter was fixed at the value previously estimated.

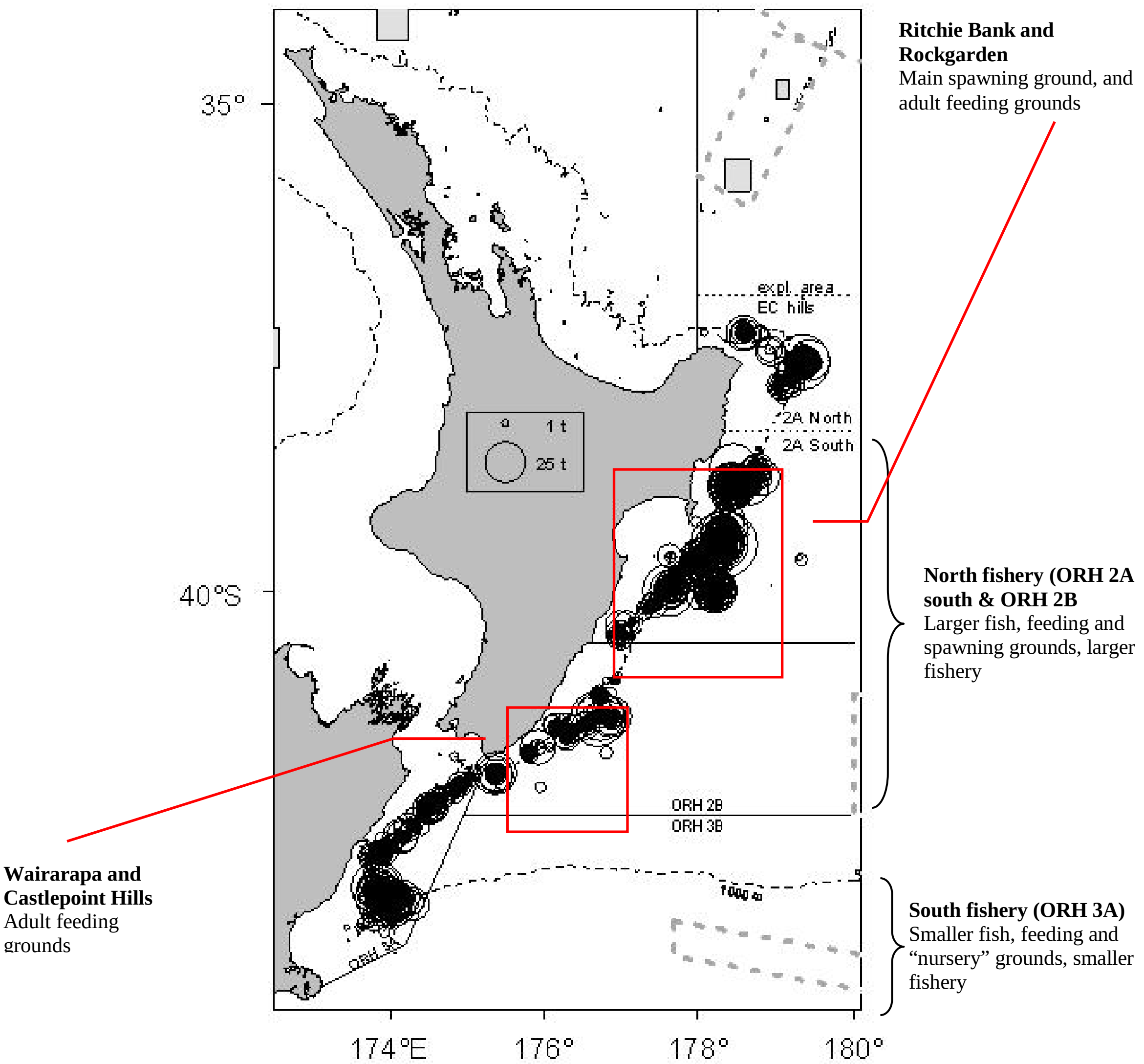


Figure 2: Catch (t) per tow of orange roughy in ORH 2A, ORH 2B, and ORH 3A for the five fishing years from 2006–07 to 2010–11 (circles, with area proportional to catch size), location of the fisheries assumed during stock assessment, and the location of the main spawning, feeding, and nursery grounds. Perimeters of Benthic Protection Areas (BPAs) closed to bottom trawling are marked with dashed grey lines, and seamounts closed to trawling are marked as shaded rectangles.

Table 5: Standardised CPUE and egg survey indices, and CVs for the East Cape stock, as used in the 2003 assessment, and an updated standardised CPUE index derived in 2011. -, no data.

	CPUE index 2003	CV(%)	Egg survey	CV(%)	CPUE index 2011	CV(%)
1993–94	1.00	12	-	-	0.95	23
1994–95	0.69	8	29 000	69	0.76	22
1995–96	0.60	8	-	-	0.61	23
1996–97	0.41	8	-	-	0.47	22
1997–98	0.25	7	-	-	0.27	23
1998–99	0.25	7	-	-	0.28	23
1999–00	0.22	9	-	-	0.23	23
2000–01	0.21	15	-	-	0.28	26
2001–02	0.22	16	-	-	0.23	27
2002–03	-	-	-	-	0.51	32
2003–04	-	-	-	-	0.50	30
2004–05	-	-	-	-	0.29	27
2005–06	-	-	-	-	0.37	28
2006–07	-	-	-	-	0.36	29
2007–08	-	-	-	-	0.27	28
2008–09	-	-	-	-	0.24	28
2009–10	-	-	-	-	0.20	27

4.1.3 Biomass estimates

Biomass estimates for this stock are given in Table 6 and the biomass trajectories, plotted against the scaled indices, are shown in Figure 3. The base case assessment of the EC stock included only the CPUE indices. An alternative assessment was carried out including the point estimate of biomass from the 1995 egg survey along with the CPUE indices. The CPUE indices agree well with the biomass estimates, with only the 1993–94 and 1997–98 indices departing from the biomass 95% confidence intervals. The egg survey biomass estimate, with the large associated CV, has little effect on the biomass trajectory.

Table 6: Estimates of virgin biomass (B_0), B_{MSY} (calculated as B_{MAY}, the mean biomass under a *CAY* policy), and B_{2003}, for the EC stock (with 95% confidence intervals in parentheses).

					B_{2003}	
Assessment	**Index**	**B_0 (t)**	**B_{MSY} (t)**	**(t)**	**% B_0**	
Base case	CPUE	21 100 (19 650–23 350)	6 300	5 100	24	(20–32)
Alternative	CPUE + Egg survey	21 200 (19 700–23 550)	6 380	5 200	25	(20–33)

The base case estimate of $B_{CURRENT}$ (the mid-year biomass in 2002–03) is 5100 t (24% B_0) with a 95% confidence interval of 3800 to 7550 t. This is almost twice the value of B_{2003} estimated for mid-year 1999–2000 in the previous assessment (Anderson 2000). The alternative assessment gives a very similar estimate of B_{2003}.

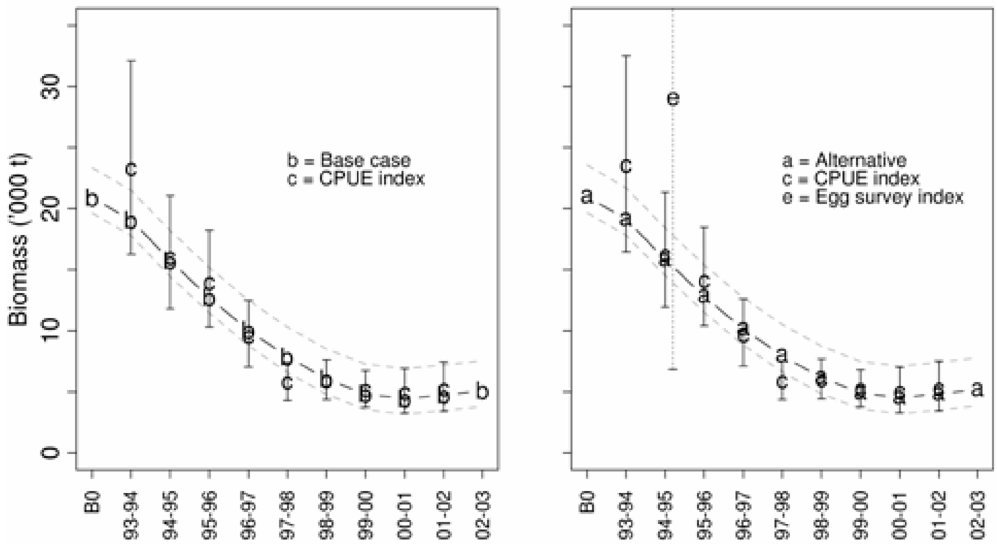


Figure 3: Estimated biomass trajectories for the base case and alternative model runs for the EC stock. Annual biomass estimates are mean posterior density (MPD) values and 95% confidence intervals (grey dashed lines) are calculated from the posterior profile distribution of B_0 estimates. The CPUE index CVs (sampling error plus process error) are shown, as is the CV calculated for the egg survey biomass estimate.

4.1.4 Yield estimates and projections
Estimates of *MCY* and *CAY* for the *EC* stock were calculated from large numbers of simulation runs using posterior profile sampling of B_0 and a series of trial harvest levels. These estimates, together with *MAY* (the mean catch with a *CAY* harvesting strategy) and *CSP* (current surplus production) are given in Table 7. *CSP* is driven by recruitment of fish spawned before the fishery began.

Table 7: Estimates of *MCY*, *CAY*, *MAY*, and *CSP* for the *EC* stock, with 95% confidence intervals in parentheses (all corrected for an assumed overrun of 5%).

Assessment	*MCY* (t)	*CAY* (t)	*MAY* (t)	*CSP* (t)
Base case	350	370	410	550
Alternative	350	370	410	550

4.2 Mid-East Coast stock (2A South, 2B, 3A)
There was no new information available that would change the accepted stock definition of the MEC orange roughy stock i.e. comprising ORH 2A South, ORH 2B, and ORH 3A.

The Mid-East Coast (MEC) stock assessment was updated in 2014 using the methods common to the four assessments performed in 2014 (see Orange Roughy Introduction). The previous model based assessment was in 2013 but that assessment used data which did not meet the quality threshold applied in 2014 (i.e., CPUE indices, wide-area acoustic survey and egg-survey estimates). In 2014, an age-structured population model was fitted to the data described in Section 4.2.2 below.

4.2.1 Model structure
The model was single-sex and age-structured (1–120 years with a plus group) with maturity in the partition (i.e., fish were classified by age and as mature or immature). A single area and a single time step were used with two year-round fisheries defined by different selectivities (a “southern” fishery catching young fish (double-normal selectivity) and a “northern” fishery catching older fish (logistic selectivity). The spawning season was assumed to occur after 75% of the mortality and 100% of mature fish were assumed to spawn each year.

The catch history was constructed from the catches in Tables 1 and 2, adding the catch over-run percentages in Table 4. The northern fishery combined catches from ORH 2A South and ORH 2B, and the southern fishery used ORH 3A. Natural mortality was assumed to be fixed at 0.045 and the stock-recruitment relationship was assumed to follow a Beverton-Holt function with steepness of 0.75. The remaining fixed biological parameters are given in the Orange Roughy Introduction.

4.2.2 Input data and statistical assumptions
There were three main data sources for observations fitted in the assessment: a spawning biomass estimate from an acoustic survey (2013); a trawl-survey time series of relative biomass indices (1992–1994, 2010) with associated length frequencies (1992, 1994), and age frequencies and estimates of proportion spawning at age (1993, 2010); and length and age frequencies collected from the commercial fisheries, including four spawning-season age frequencies (1989–1991, 2010).

Research surveys
The MEC area has been surveyed using acoustic and trawl methods, and egg surveys have also been conducted. Not all survey data have been used in the 2014 assessment. The egg survey estimates have some quality issues associated with them; the 1993 survey data were post-stratified and “corrected” for turn-over of fish (Zeldis et al 1997). The 1993 egg-survey estimate was used in the 2013 assessment but was not considered to be reliable enough for the 2014 assessment (which had a higher “quality threshold”). Similarly, the wide-area acoustic survey estimates from 2001 and 2003 (Doonan et al 2003, 2004a) were rejected in 2014 as being not sufficiently reliable (in particular, the biomass estimates primarily came from mixed species marks and “orange roughy” marks identified subjectively; rather than being from easily identified spawning plumes).

Trawl survey data

A time series of pre-spawning season, random, stratified, trawl surveys were conducted in March–April on *RV Tangaroa* in 1992–94 and 2010 (Grimes et al 1994, 1996a, 1996b; Doonan & Dunn 2011). The 2010 survey was specifically designed to be comparable with the earlier surveys and to produce an abundance index for the MEC home grounds (Doonan & Dunn 2011). In addition to the relative biomass indices (Table 8), the survey data were analysed to produce length frequencies from all years and age frequencies from 1993 and 2010 (Doonan et al 2011). Also, estimates of female proportion spawning at age were produced for the 1993 and 2010 surveys (Ian Doonan, pers. comm.).

Table 8: Biomass indices and CVs used in the stock assessment.

Year	Trawl index (t)	CV (%)	Acoustic index (t)	CV (%)
1992	20 838	29		
1993	15 102	27		
1994	12 780	14		
2010	7 074	19		
2011				
2012				
2013			4 225	20

The biomass indices were fitted as relative biomass with a double-normal selectivity (it is apparent that the trawl survey did not fully select the largest/oldest fish) and an uninformed prior on the proportionality constant (q). The length frequencies from 1992 and 1994 were fitted as multinomial, as were the age frequencies from 1993 and 2010 (length frequencies from 1993 and 2010 had been used in the production of the age frequencies). The proportion spawning at age was assumed binomial at each age. Effective sample sizes were all taken from the 2013 assessment (Cordue 2014).

Acoustic survey estimate

The only reliable acoustic estimate of spawning biomass for MEC came in 2013 when a multi-frequency "AOS" survey was conducted (acoustic and optical gear mounted on the trawl headline, e.g., see Kloser et al 2011). Four areas were visited in 2013 but the only substantial spawning plume was seen in the "Valley" (a known spawning site near Ritchie Bank). Four snapshots were taken and the estimates from 38 kHz were averaged to produce a biomass index (Table 8).

The "standard" assumption in the 2014 stock assessments, for acoustic estimates from spawning plumes, is that they collectively cover "most" of the spawning biomass where "most" is taken to be 80%. However, for MEC, only one spawning plume was found and it was in a very small area. There are many potential sites in the MEC for spawning plumes. For these reasons, "most" was taken to be 60% in the base model (and sensitivities were done at 40% and 80%). That is, the acoustic estimate was fitted as relative biomass with an informed prior: lognormal (mean = 0.6, CV = 19%) for the base model.

Commercial age and length frequencies

As in 2011 and 2013, composition data were also used: length frequency samples from the northern commercial fishery (ORH 2A South and ORH 2B) for 16 years between 1988–89 and 2009–10, and from the southern commercial fishery (ORH 3A) for nine years between 1989–90 and 2008–09, and age frequency samples from commercial landings of the spawning fishery in ORH 2A south in 1989, 1990, 1991. The otoliths from the 1989–91 samples were re-aged for the 2013 assessment using the new ageing protocol (Tracey et al 2007). In addition, age samples taken from a single vessel in the 2010 spawning season were also used. These had been aged with the new protocol but because they were from a single vessel and a fishery 20 years later than in 1990 the age frequency was fitted with its own selectivity. The age frequencies from 1989–91 were assumed to be from spawning fish (i.e., no selectivity fitted). The composition data were all assumed to be multinomial and effective sample sizes from the 2013 assessment were used (except that the southern fishery length frequencies were down-weighted following the iterative reweighting procedure of Francis (2011)).

4.2.3 Model runs and results

In the base model, natural mortality (*M*) was fixed at 0.045. There were numerous MPD sensitivity runs and six main sensitivities are presented in this report: estimate *M*; down-weight the trawl indices; separate selectivity for spawning age frequencies; mean acoustics *q* prior = 0.4; and the *LowM-Highq* and *HighM-Lowq* "standard" runs (see Orange Roughy Introduction).

In the base model, the main parameters estimated were: virgin biomass (B_0), the maturity ogive, the two fishery selectivities, the trawl survey selectivity, the 2010 age frequency selectivity, and year class strengths (YCS) from 1881 to 1996 (with the Haist parameterisation and "nearly uniform" priors on the free parameters). Additional estimated parameters included the CV of the length-at-age parameters and the proportionality constants (*q*s)for the trawl survey time series and the 2013 acoustics estimate.

Model diagnostics

The MPD fits to the biomass indices were excellent (Figure 4), although the MCMC fit was only just adequate for the trawl survey indices, particularly to the 2010 index (Figure 5). The poorer MCMC fit to the 2010 trawl index when compared to the MPD fit occurred because the MPD pattern of YCS did not match the posterior distribution of the same quantities, showing much greater year-to-year variation than seen in the MCMC posterior (Figure 6). This result highlights the difference between MPD estimates and MCMC estimates: the MPD finds the single vector of parameters which give the best fit to the data, while the MCMC procedure finds the parameter space that best explains the data. There is no reason why the MPD has to be in the "middle" of the posterior distribution, here we have an example where the MPD estimates are in the tail of the posterior distribution.

The MCMC fit to the acoustics index had also degraded when compared to the MPD fit (see Figures 4 and 5), as well as estimating a lower acoustics *q* (Figure 7). The cause of this is the same as for the 2010 trawl index; the MPD spawning biomass trajectory almost exactly matched the 2013 acoustic estimate but, given the less variable MCMC YCS trajectory, the resulting MCMC biomass trajectory was shifted higher (and the acoustic *q* shifted lower to compensate).

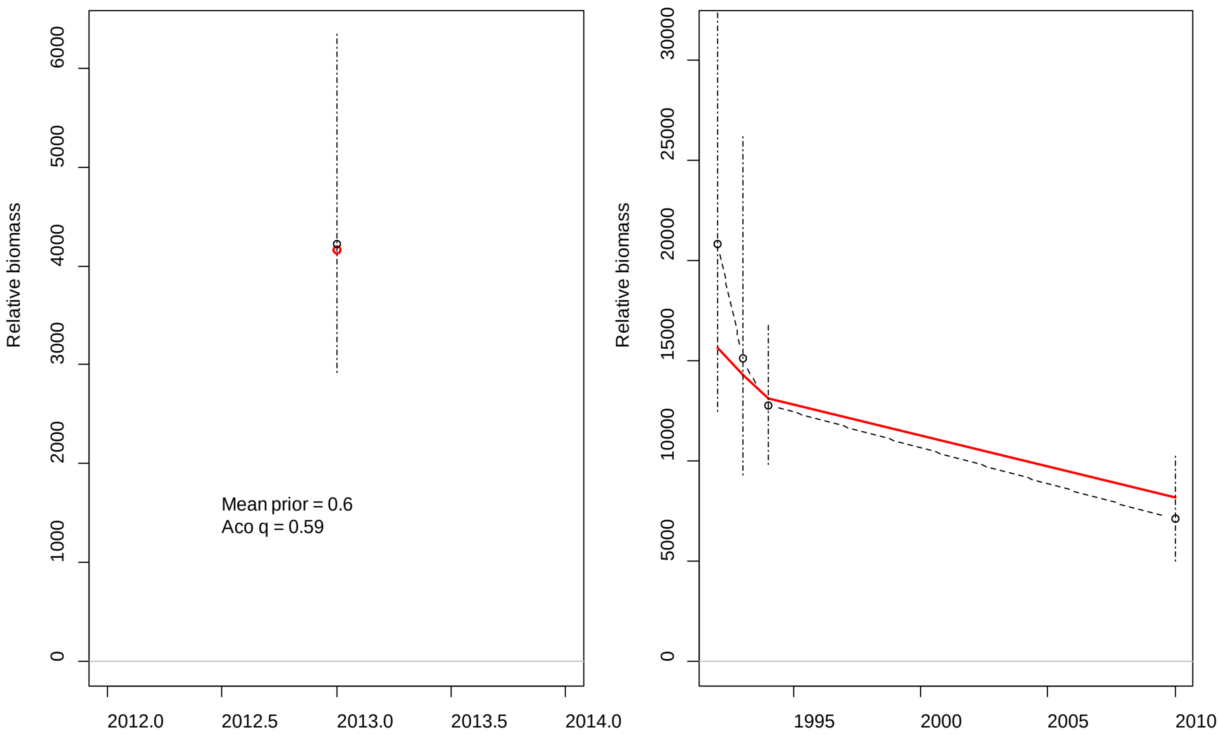


Figure 4: MPD fit to biomass indices: left: acoustic-survey spawning biomass index (fitted with an informed *q* prior, mean = 0.6; MPD estimated *q* = 0.59); right: *Tangaroa* trawl-survey indices. Vertical lines are 95% CIs.

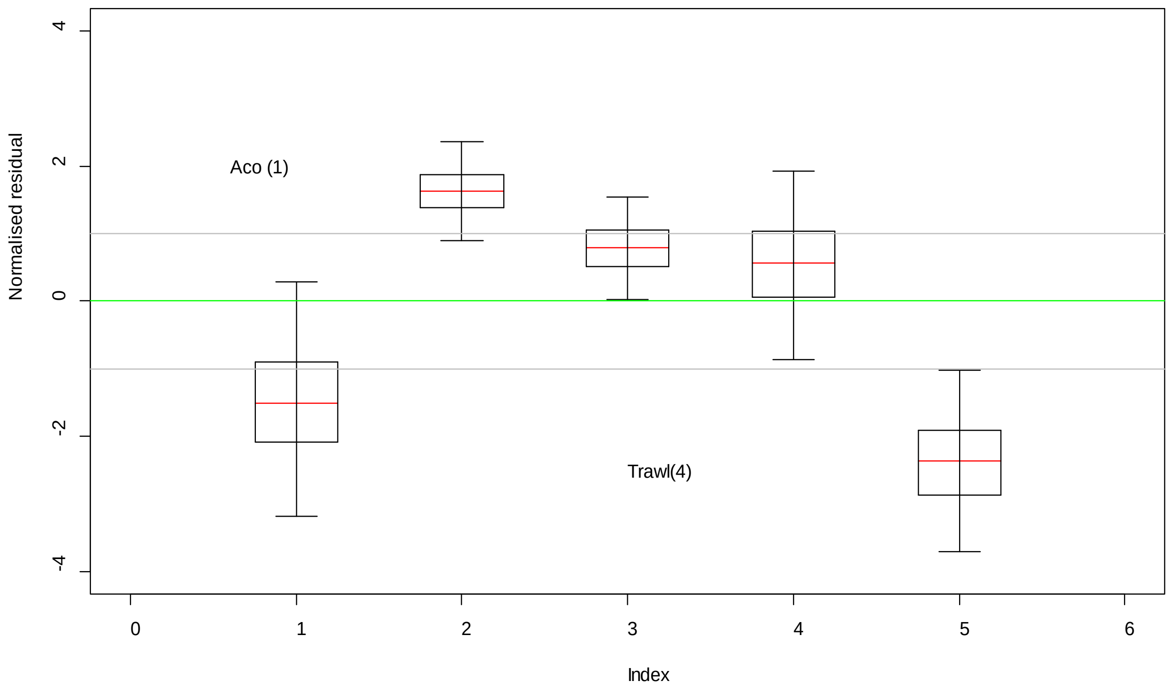


Figure 5: MCMC base: normalised residuals for the biomass indices. The box covers 50% of the distribution for each index and the whiskers extend to 95% of the distribution. "Aco" denotes the acoustic estimate (2013). "Trawl" denotes the *Tangaroa* trawl-survey time series (1992–94, 2010).

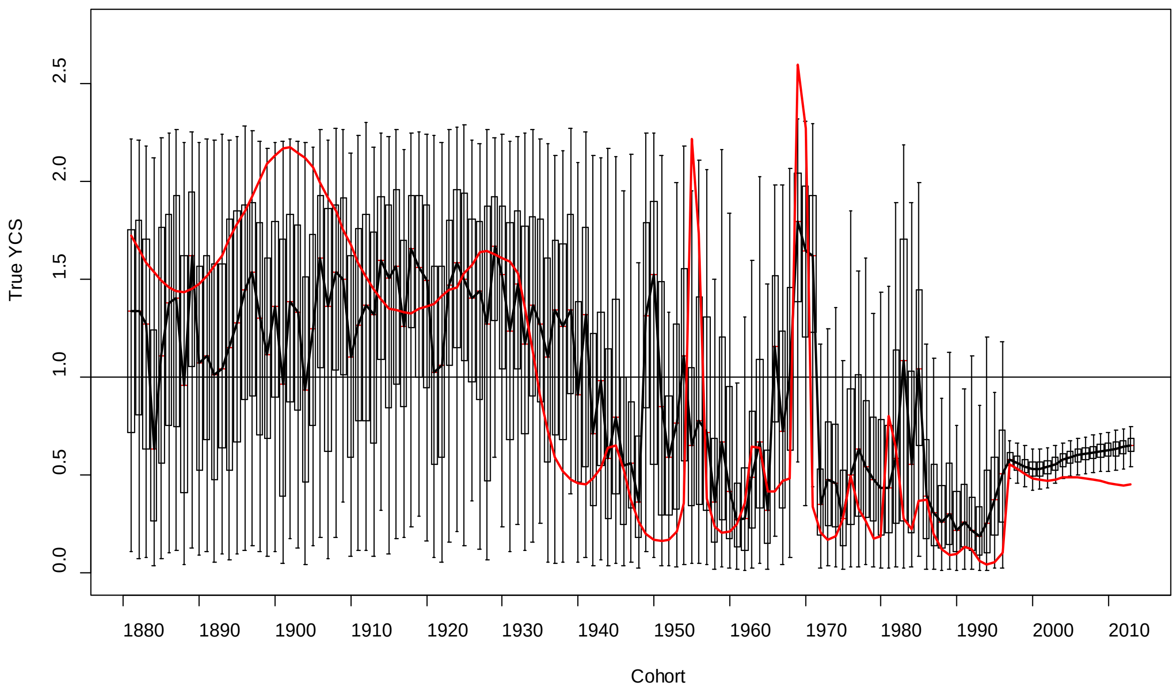


Figure 6: Base model: MCMC estimated "true" YCS (R_y/R_0) (in black). The box in each year covers 50% of the distribution and the whiskers extend to 95% of the distribution. The MPD estimates are shown in red.

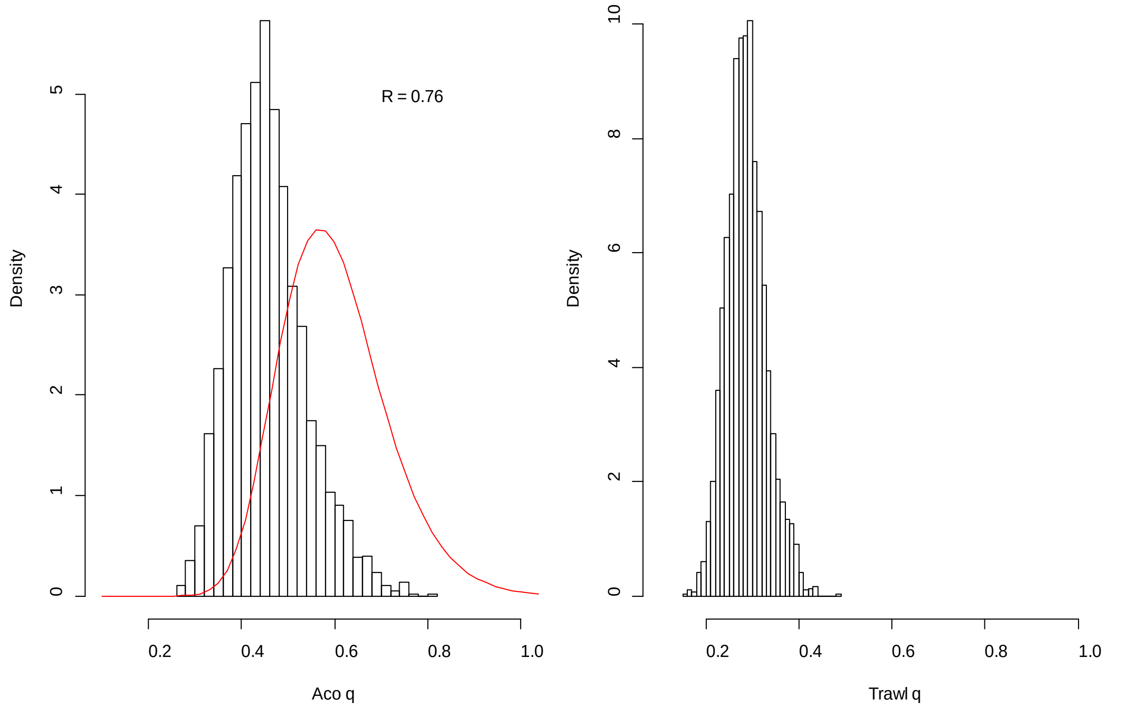


Figure 7: Base model MCMC diagnostics: prior and posterior distributions for the acoustic *q* (prior in red, posterior black histogram) (left); posterior distribution for the trawl-survey *q* (the prior was uninformed) (right). R = 0.76 is the ratio of the mean of the acoustic *q* posterior to the mean of the prior.

The MPD fits to the commercial length frequencies were adequate (Figures 8 and 9). They could never be very good because the length frequencies show a great deal of year-to-year variability, as evidenced by the annual mean lengths (Figure 10). The model predictions of annual mean length are necessarily fairly smooth from year-to-year; as they are only able to track the main trend but not the annual jumps (Figure 10).

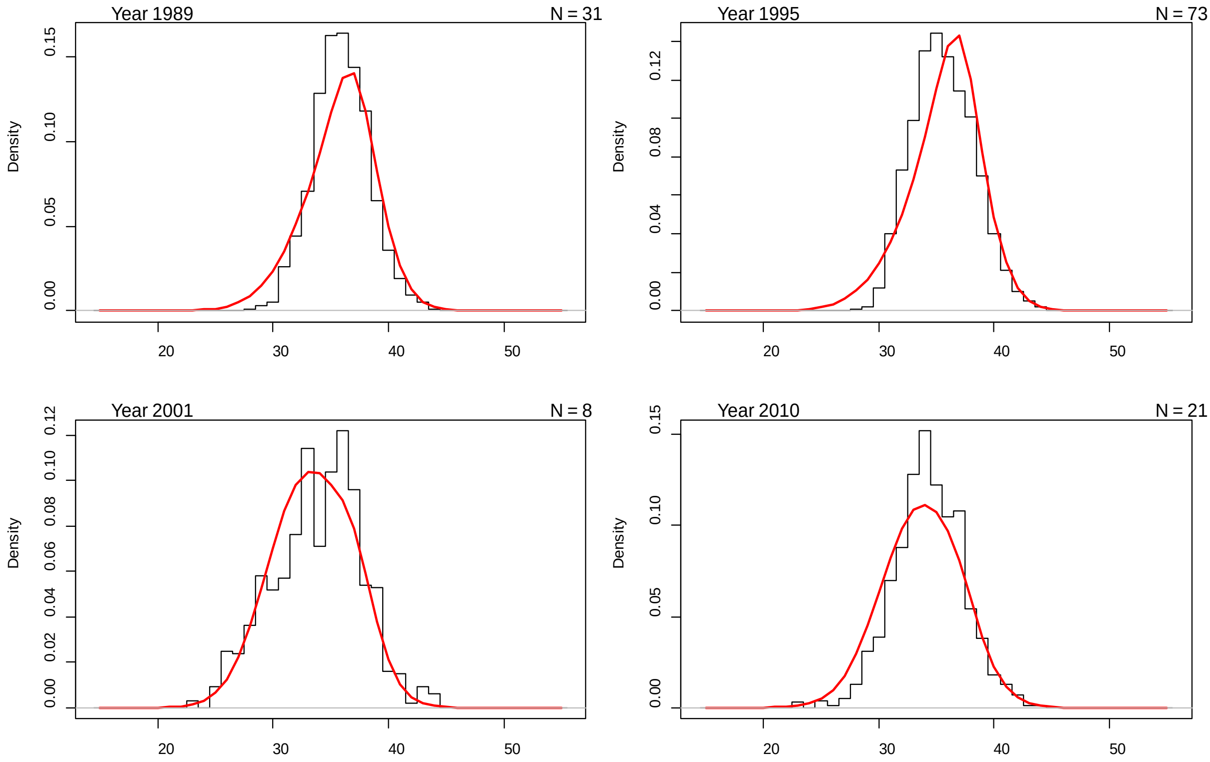


Figure 8: Example MPD fits to northern fishery length frequencies (N is the assumed effective sample size in the given year; x-axis is fish length (cm)). Observations are black lines; model predictions are the red lines.

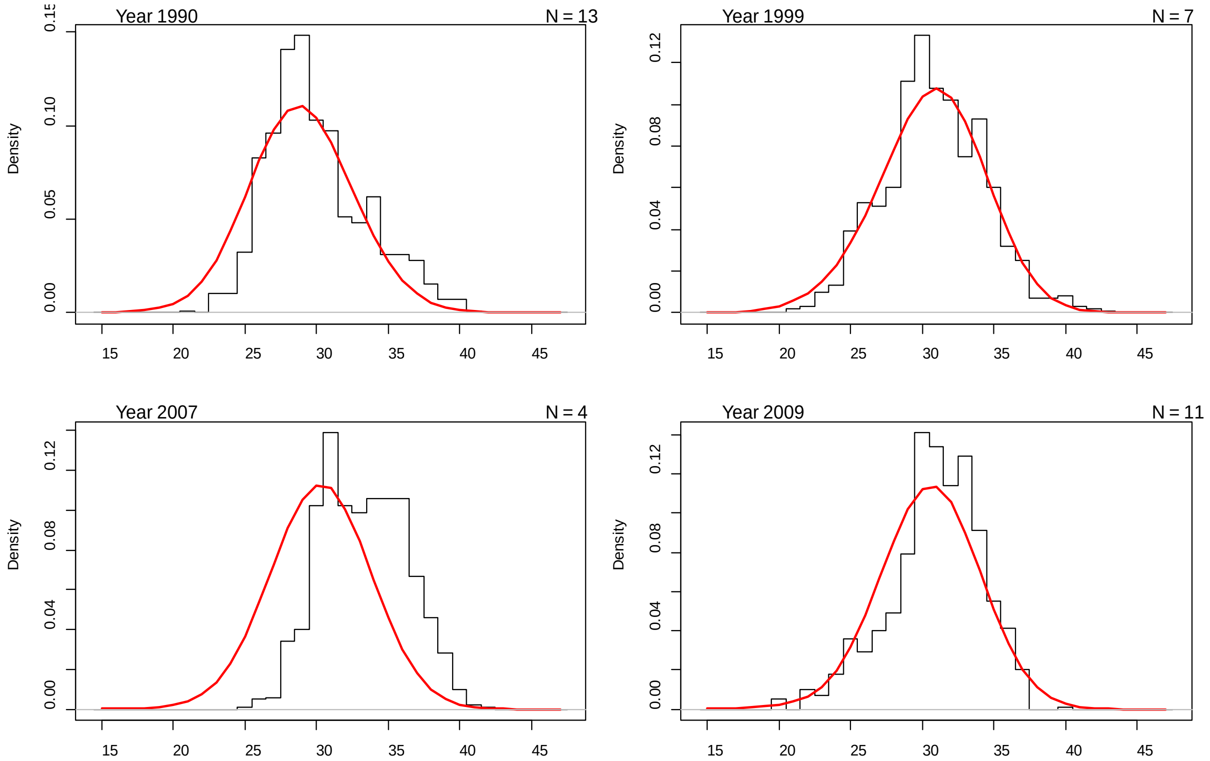


Figure 9: Example MPD fits to southern fishery length frequencies (N is the assumed effective sample size in the given year; x axis is fish length (cm)). Observations are black lines; model predictions are the red lines.

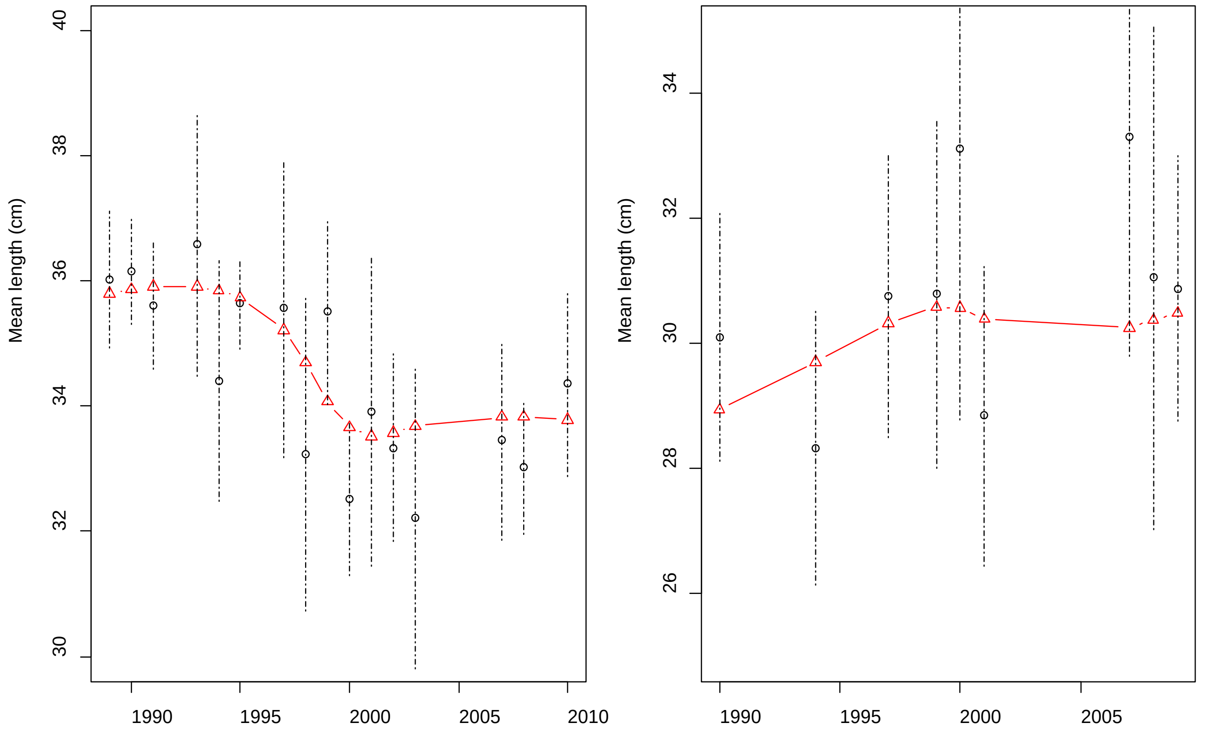


Figure 10: Annual mean lengths from the commercial length frequencies (northern fishery on the left, southern on the right) with 95% CIs (black, circles, dashed vertical lines) and the base model predictions (red, triangles, solid lines).

The MPD fits to the trawl-survey length frequencies and estimates of proportion spawning at age are good (Figure 11). It is notable that the model fits the different shape of the proportion spawning estimates in 1993 and 2010 (Figure 11). The spawning-season age frequencies are only adequately fitted (Figure 12). There is a misfit for the young ages (except for 2010 which had its own selectivity) as these data compete with the proportion spawning-at-age data to define the maturity ogive (see Figure 11 – young fish are spawning according to the proportion spawning data). In response to the misfit in Figure 12, a sensitivity run was done where the 1989–91 spawning age frequencies were allowed to have a logistic selectivity. This improved the fit substantially and raised the model estimate of the 2014 stock status from 14 to 17% B_0. However the base model was preferred, to be consistent across the four orange roughy stocks assessed in 2014, with the maturity ogive used to define the spawning-season selectivity and age frequencies.

The fit to the trawl-survey age frequencies is excellent, which should be expected given the large effective sample size of N = 200 (Figure 13). A number of sensitivity runs were done with alternative data weighting, including down-weighting the trawl-survey age frequencies, which demonstrated that the model was robust to a wide range of assumptions. For example, the only runs that made a substantial difference to the MPD estimates of stock status were doubling the acoustic index (10.2% B_0 compared to the base estimate of 6.5% B_0) and assuming deterministic recruitment (25.8% B_0); the other 16 runs had MPD estimates in the range 4–9% B_0.

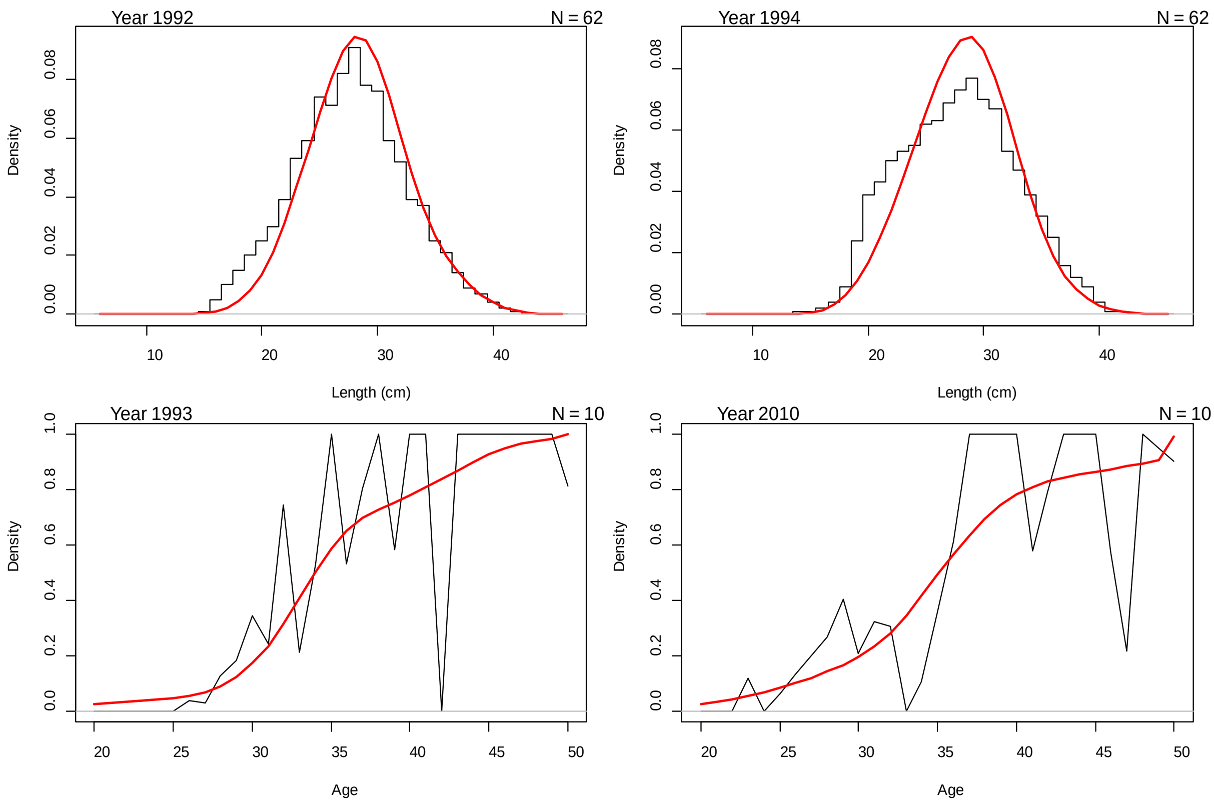


Figure 11: Base, MPD fits to trawl-survey length frequencies (N is the assumed effective sample size in the given year) and proportion spawning-at-age (N =10 is the binomial sample size assumed for each age). Observations are black lines; model predictions are the red lines.

MCMC results

MCMC convergence diagnostics were very good for the base model and sensitivities. Virgin biomass (B_0) was estimated to be about 100 000 t for all runs (Table 9). Current stock status was similar for the base and the estimate-*M* run (Table 9). The slightly lower stock status when *M* was estimated reflects the lower estimate of *M* (0.032 rather than 0.045). Down-weighting the trawl indices (by adding process error CV of 20%) reduced the magnitude of the normalised residuals and raised the median estimate of 2014 stock status from 14 to 16% B_0 (Table 9). Giving the 1989–91 spawning age frequencies a selectivity improved the fit to younger age fish, decreased the estimate of B_0 from 95 000 t to 91 000 t and increased estimated stock status from 14 to 17% B_0 (Table 9). The reduction in the mean of the acoustic *q* from 0.6 to 0.4 increased the median estimate of stock status to 19% B_0, but the median estimate was still below the soft limit (Table 9). The two "bounding runs" where *M* and the mean of the acoustic *q* were shifted by 20%, still had median estimates under the soft limit, with the "*LowM-Highq*" run at the hard limit (Table 9). Other sensitivities not reported here included several where the effective sample size on age frequencies was appreciably increased or decreased; in all cases, this had little impact on the estimates of stock status.

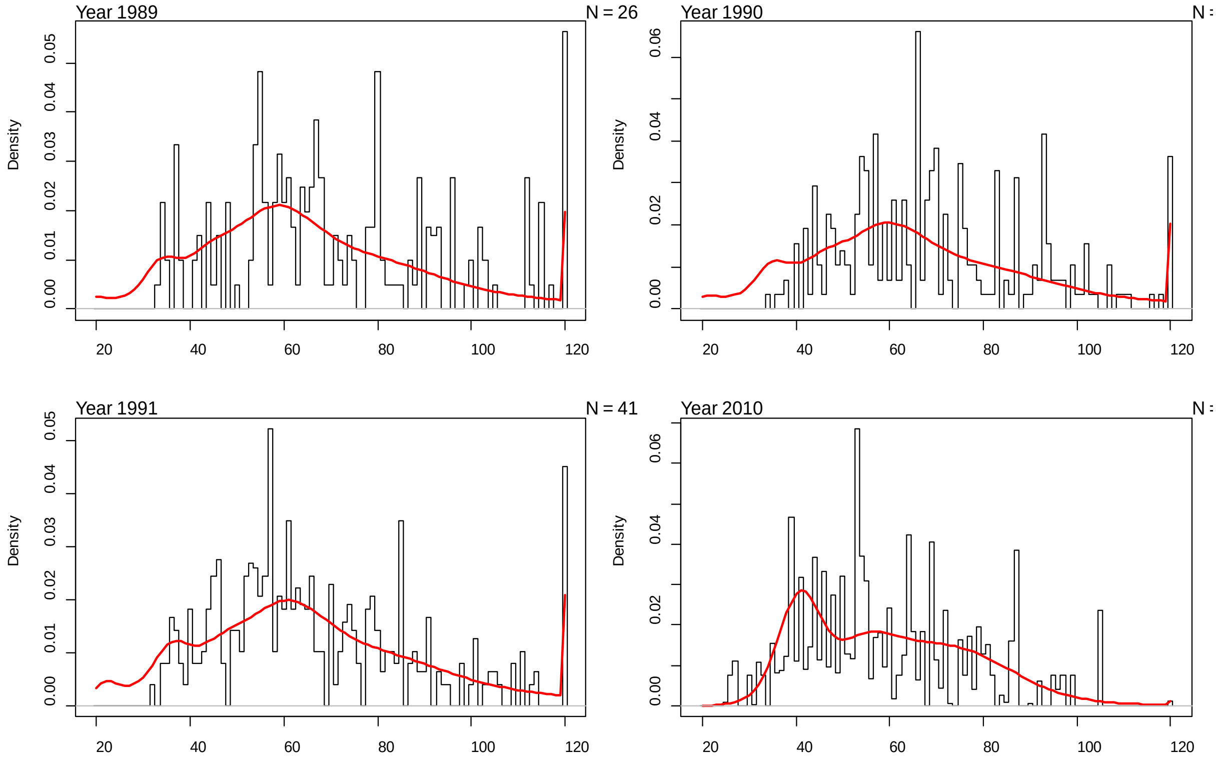


Figure 12: Base, MPD fit to spawning-season age frequencies (N is the assumed effective sample size in the given year). Observations are black lines; model predictions are the red lines.

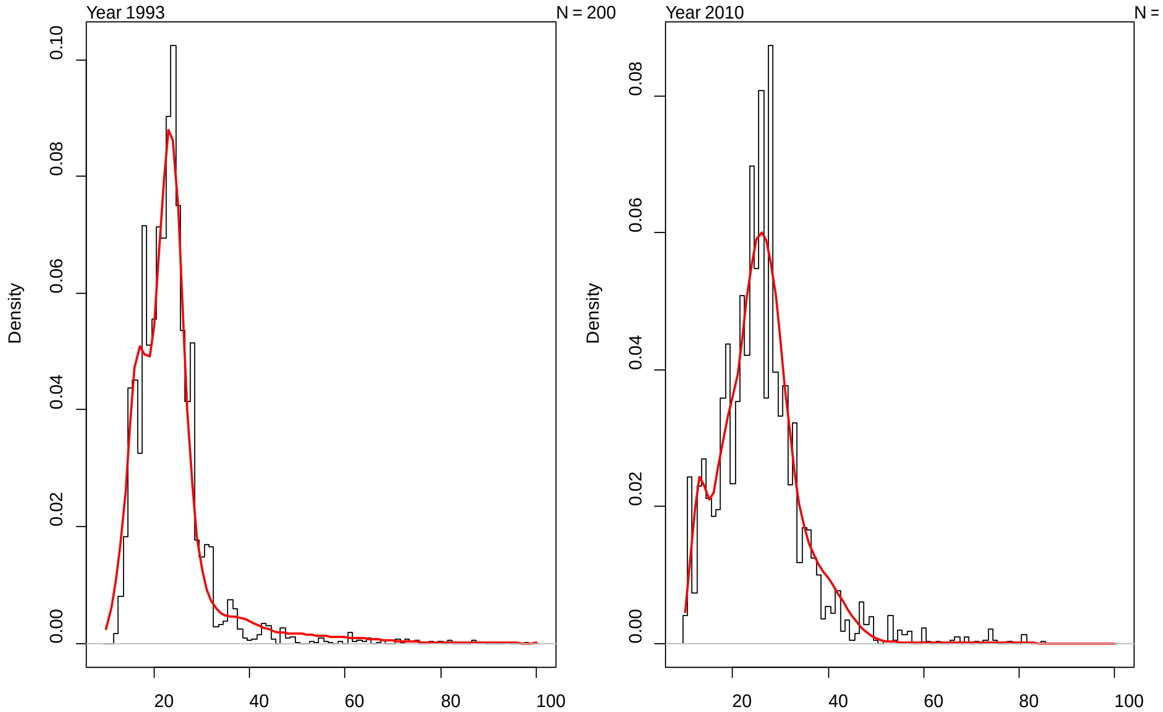


Figure 13: Base, MPD fit to trawl-survey age frequencies (N = 200 is the assumed effective sample size). Observations are black lines; model predictions are the red lines.

Table 9: MCMC estimates of virgin biomass (B0) and stock status (B2014 as %B0) for the base model, and the six following sensitivity runs: a) estimating natural mortality; b) down-weighting the trawl indices by adding 20% process error to the CV; c) adding a selectivity to spawning age frequencies for 1989–91; d) reducing the mean acoustic catchability coefficient, q, from 0.6 to 0.4; e) decreasing M and increasing acoustic q by 20%; and f) increasing M and decreasing acoustic q by 20%.

Assessment	*M*	B0 (000 t)	95% CI	B2014 (%B0)	95% CI
Base model	0.045	95	87–104	14	9–21
a) Estimate M	0.032	104	96–112	11	7–16
b) Down-weight trawl	0.045	97	88–108	16	11–22
c) Spawn AF selectivity	0.045	91	83–102	17	12–24
d) Mean aco. q = 0.4	0.045	100	92–112	19	13–26
e) LowM-Highq	0.036	96	90–103	10	7–15
f) HighM-Lowq	0.054	99	89–114	19	13–27

The estimated fishery selectivities showed the northern fishery taking fish over 30 years with the southern fishery primarily taking fish from 20–40 years (Figure 14). The trawl-survey selectivity primarily sampled fish from 10–70 years with peak selection from 20–30 years (Figure 14). The 2010 age frequency appears to have been a subset of spawning fish focussed on those from about 50–90 years (Figure 14).

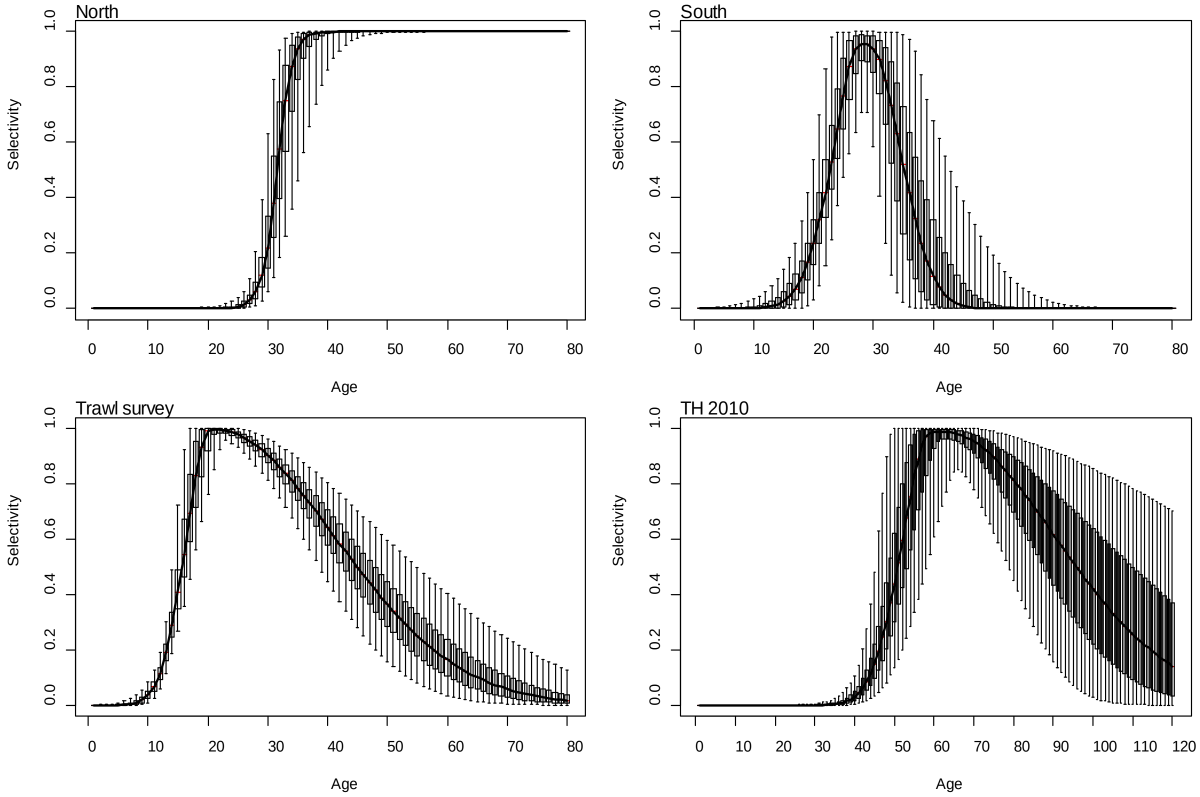


Figure 14: Base, MCMC estimated selectivities (northern and southern fisheries, the trawl survey, and the 2010 age frequency). The box at each age covers 50% of the distribution and the whiskers extend to 95% of the distribution.

The estimated YCS show strong variation across cohorts and exhibit a long-term trend, with recruitment well below average since the early 1970s (Figure 15). The most recent 10 years of estimates, 1986–1995 (those resampled for short-term projections) are well below average.

The stock status trajectory shows an increasing trend before the start of fishery as the above average recruitment estimated by the model feeds into the spawning biomass (Figure 16). Then there is a steep decline from the start of fishery until the year 2000 when the biomass reached 10% B_0, after which there was a slow increase (Figure 16).

Fishing intensity was estimated in each year for each MCMC sample to produce a posterior distribution for fishing intensity in each year. Fishing intensity is represented in terms of the median exploitation rate and the Equilibrium Stock Depletion (ESD). For the latter, a fishing intensity of $U_{x\%B0}$ means that fishing (forever) at that intensity will cause the SSB to reach deterministic equilibrium at x% B_0 (e.g., fishing at $U_{30\%B0}$ drives the SSB to a deterministic equilibrium of 30%

B_0). Fishing intensity in these units is plotted as 100–ESD so that fishing intensity ranges from 0 ($U_{100\%B0}$) up to 100 ($U_{0\%B0}$).

Estimated fishing intensity was above the target range ($U_{30\%B0}$–$U_{40\%B0}$) from 1984 to 2012 (Figure 17). In the last two years, fishing intensity has decreased to within the target range.

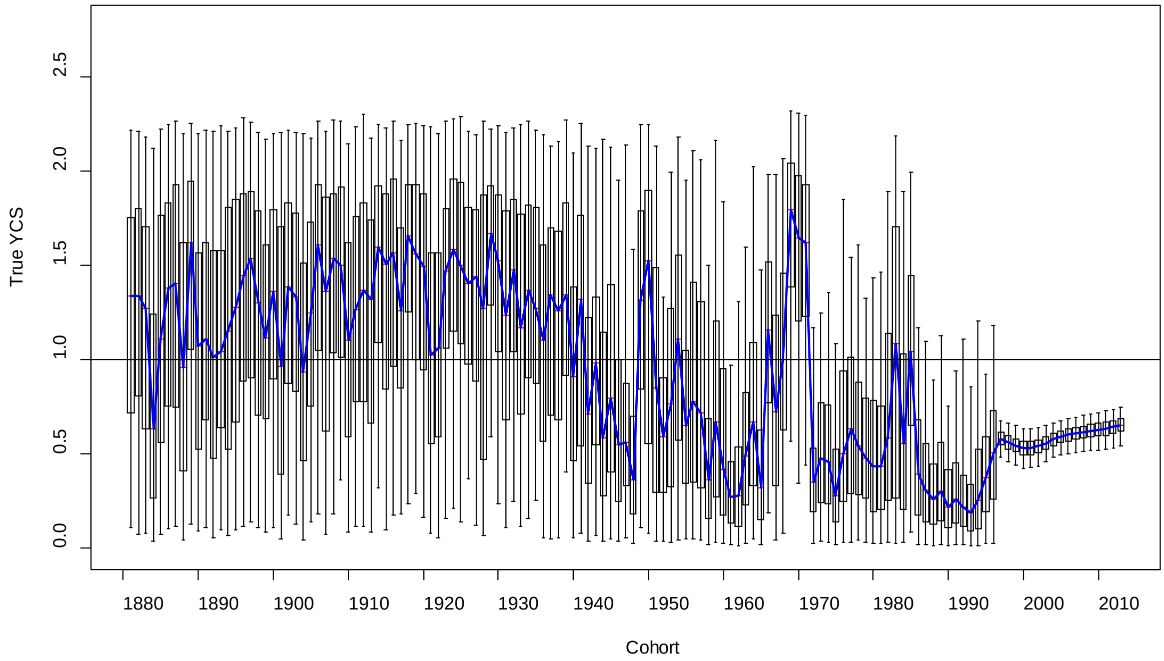


Figure 15: Base, MCMC estimated "true" YCS (R_y/R_0). The box in each year covers 50% of the distribution and the whiskers extend to 95% of the distribution.

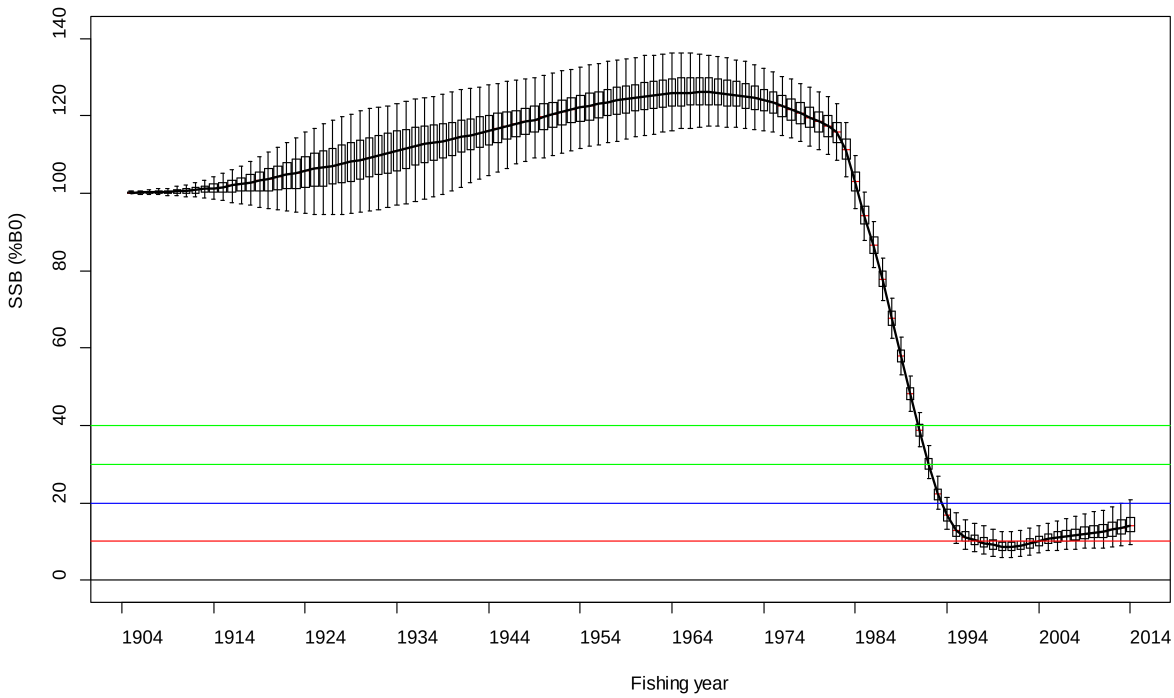


Figure 16: Base, MCMC estimated spawning-stock biomass trajectory. The box in each year covers 50% of the distribution and the whiskers extend to 95% of the distribution. The hard limit, 10% B_0 (red), soft limit, 20% B_0 (blue), and biomass target range, 30–40% B_0 (green) are marked by horizontal lines.

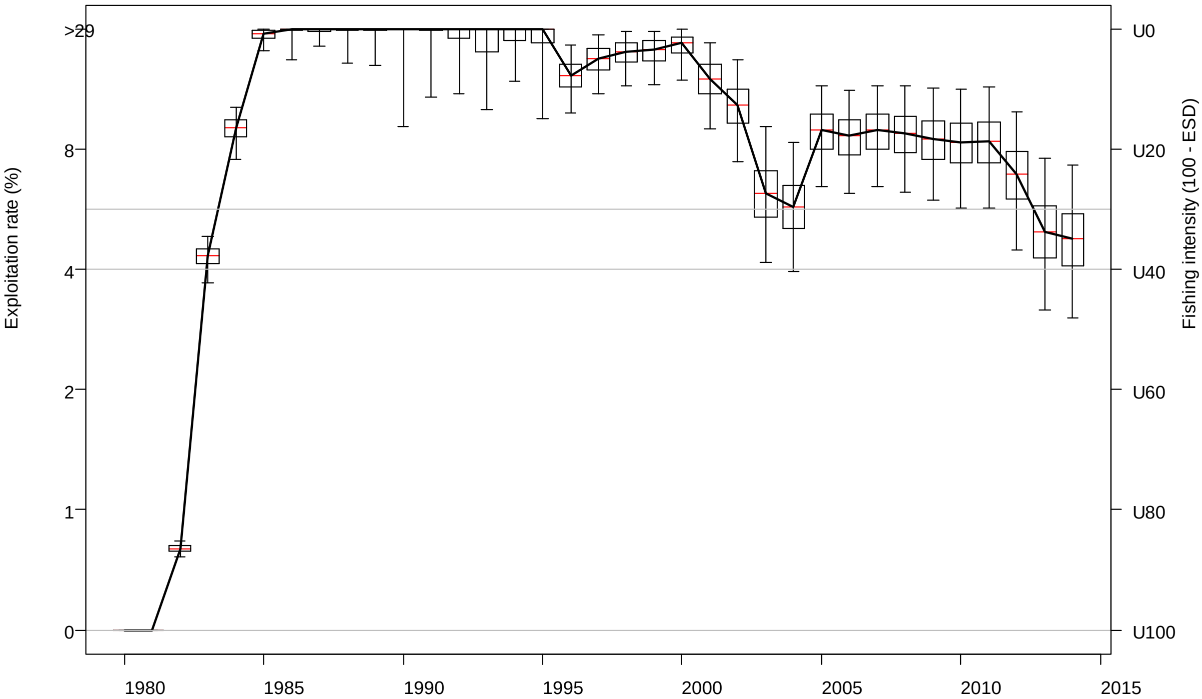


Figure 17: Base, MCMC estimated fishing-intensity trajectory. The box in each year covers 50% of the distribution and the whiskers extend to 95% of the distribution. The fishing-intensity range associated with the biomass target of 30–40% B_0 is marked by horizontal lines.

Biological reference points, management targets and yield

MCMC estimates of deterministic B_{MSY} and associated values were produced for the base model. The yield at 35% B_0 (the mid-point of the target range) was also estimated. There is little variation in the reference points and associated values across the MCMC samples (Table 10).

There are several reasons why deterministic B_{MSY} is not a suitable target for use in fisheries management. 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 often poorly known. Third, 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.

Table 10: Base, MCMC estimates of deterministic equilibrium spawning stock biomass (SSB) and long-term yield (% B_0 and tonnes) for U_{MSY} and $U_{35\%B0}$. The equilibrium SSB at U_{MSY} is deterministic B_{MSY} and the yield is deterministic MSY.

Fishing intensity		SSB (% B_0)	Yield (% B_0)	Yield (t)
U_{MSY}	Median	22.5	2.3	2214
	95% CI	21.8–23.0	2.3–2.4	2048–2415
$U_{35\%B0}$	Median	35.0	2.2	2075
	95% CI	35.0–35.0	2.2–2.2	1916–2264

Projections

Five year projections were conducted (with resampling from the last 10 estimated YCS) for catch at the current catch limit of 930 t (with a 5% catch over-run assumed). Projections were done just for the base model. At the current catch limit (930 t), SSB is predicted to increase slowly over the next five years but still be well below the soft limit in 2019 (Figure 18). The estimated minimum time to rebuild (assuming zero catch and requiring a 70% probability of being above the lower bound of the 30–40% B_0 target range), is 21 years (T_{min}) (Figure 19).

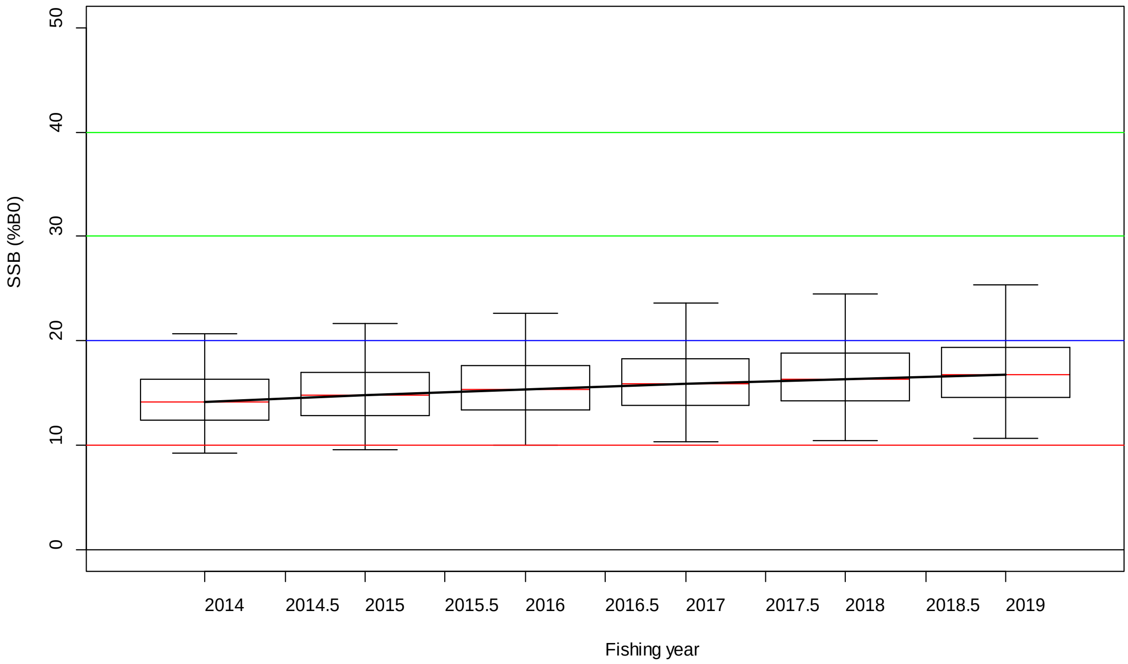


Figure 18: Base, MCMC projections. The box in each year covers 50% of the distribution and the whiskers extend to 95% of the distribution. An annual catch at the current catch limit of 930 t was assumed (with a 5% catch over-run in each year). The target range (30–40% B_0) is indicated by horizontal green lines, with the soft limit (20% B_0) in blue and the hard limit (10% B_0) in red.

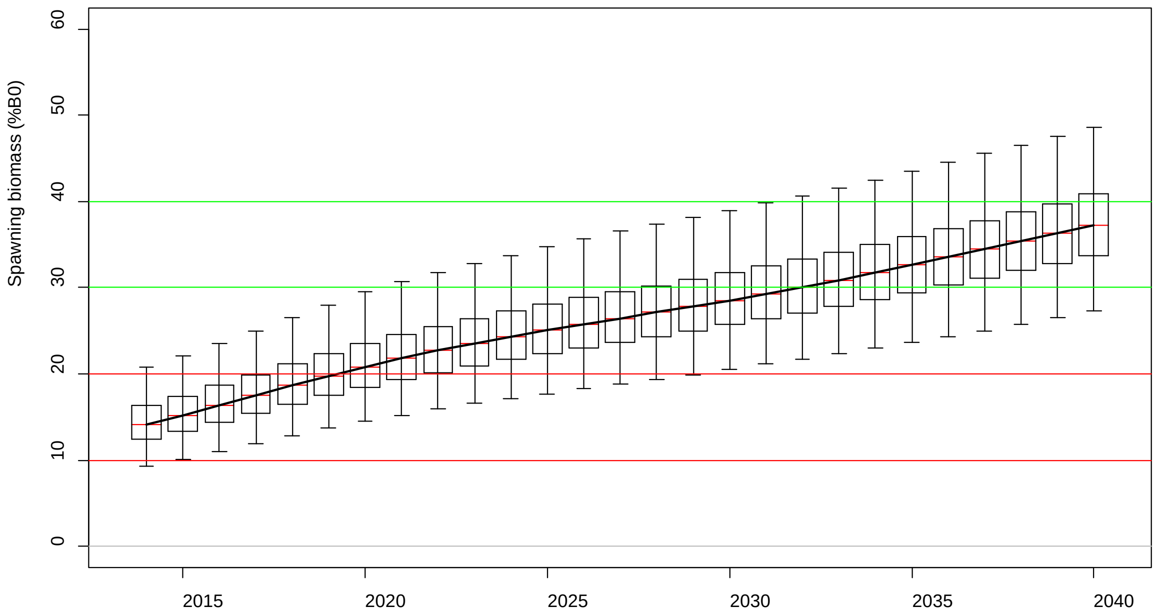


Figure 19: Base, MCMC projections. The box in each year covers 50% of the distribution and the whiskers extend to 95% of the distribution. The annual catch used in these projections is zero tonnes. The target range (30–40% B_0) is indicated by horizontal green lines, with the soft limit (20% B_0) in blue and the hard limit (10% B_0) in red.

5. STATUS OF THE STOCKS

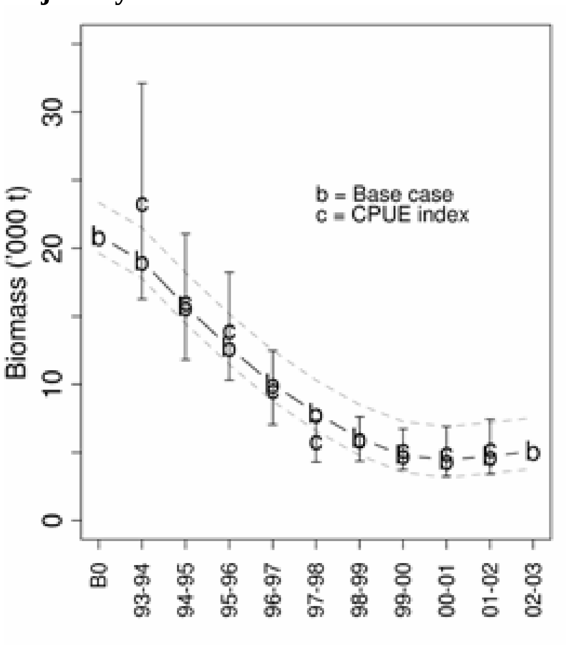
Stock Structure Assumptions
Orange roughy in ORH 2A, 2B and 3A are treated as two biological stocks based on the location of spawning grounds. These stocks are managed and assessed separately however some mixing has been shown to occur. The 2A North stock spawns around the East Cape hills off of the North Island. The 2A South, 2B and 3A stock is assumed to spawn on the Ritchie Bank.

For orange roughy stocks, the current management target is a biomass range from 30–40% B_0.

- **ORH East Cape Stock (2A North)**

Stock Status	
Year of Most Recent Assessment	2003
Assessment Runs Presented	A base case with one alternative
Reference Points	Management Target: 30–50% B_0 Soft Limit: 20% B_0 Hard Limit: 10% B_0 Overfishing threshold:-
Status in relation to Target	B_{2003} was 24% B_0, which was Unlikely (< 40%) to be at or above the target.
Status in relation to Limits	B_{2003} was Unlikely (< 40%) to be below the Soft Limit, and Very Unlikely (< 10%) to be below the Hard Limit

Historical Stock Status Trajectory and Current Status



Estimated biomass trajectory for the base model run for the EC stock. Annual biomass estimates are mean posterior density (MPD) values and 95% confidence intervals (grey dashed lines) are calculated from the posterior profile distribution of B_0 estimates. The CPUE index CVs (sampling error plus process error) are shown.

Fishery and Stock Trends	
Recent Trend in Biomass or Proxy	Biomass declined in the early 1990s but appeared to stabilise at around 5000 t.
Recent Trend in Fishing Mortality or Proxy	*F* has declined along with the agreed catch limit and remains stable at the current catch level of 200 t.
Other Abundance Indices	-
Trends in Other Relevant Indicators or Variables	-

Projections and Prognosis (2003)		
Stock Projections or Prognosis	The estimated *CAY* (370 t) and *MAY* (410 t) were both greater than the catch limit of 200 t, and this suggested the stock would start to rebuild.	
Probability of Current Catch or TACC causing Biomass to remain below or to decline below Limits	Soft Limit: Unlikely (< 40%) Hard Limit: Very Unlikely (< 10%)	
Probability of Current Catch or TACC causing Overfishing to continue or to commence	-	
Assessment Methodology and Evaluation		
Assessment Type	Level 1 – Full Quantitative Stock Assessment	
Assessment Method	Statistical catch-at-age model implemented in CASAL with Bayesian estimation of posterior distributions	
Assessment Dates	Latest assessment: 2003	Next assessment: Unknown
Overall assessment quality rank	-	
Main data inputs	- Catch data - Standardised CPUE data - 1994–95 ORH egg survey	
Data not used (rank)	-	
Changes to Model Structure and Assumptions	-	
Major Sources of Uncertainty	-	

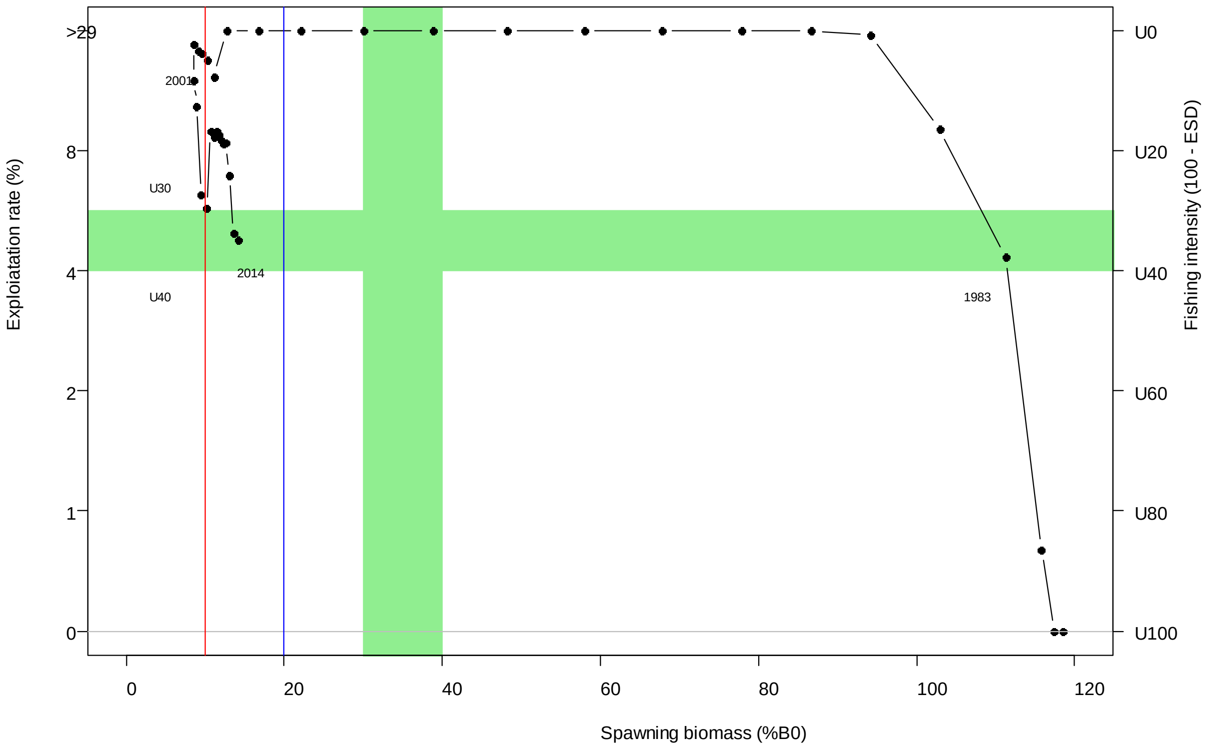
Qualifying Comments
The most recent assessment (2003) is now 11 years out-of-date. In recent years, the ability of stock assessment models that assume deterministic recruitment for orange roughy stocks to reflect current or projected stock status has been called into question.

Fishery Interactions
The main bycatch species are cardinalfish and alfonsino. Low productivity bycatch species include deepwater sharks, deepsea skates and corals. Protected species bycatch includes seabirds and corals.

- **ORH Mid-East Coast Stock (2A South, 2B, 3A)**

Stock Status	
Year of Most Recent Assessment	2014
Assessment Runs Presented	Base model
Reference Points	Management Target: Biomass range 30–40% B_0 Soft Limit: 20% B_0 Hard Limit: 10% B_0 Overfishing threshold: Fishing intensity range $U_{30\%B0}$–$U_{40\%B0}$
Status in relation to Target	B_{2014} was estimated to be 14% B_0 Very Unlikely (< 10%) to be at or above the lower end of the management target range
Status in relation to Limits	B_{2014} is Likely (> 60%) to be below the Soft Limit B_{2014} is Unlikely (< 40%) to be below the Hard Limit
Status in relation to Overfishing	Fishing intensity in 2014 was estimated at $U_{35\%B0}$ Overfishing is About as Likely as Not (40–60%) to be occurring

Historical Stock Status Trajectory and Current Status



Historical trajectory of spawning biomass (%B_0), median exploitation rate (%) and fishing intensity (100-ESD) (base model, medians of the marginal posteriors). The biomass target range of 30–40% B_0 and the corresponding exploitation rate (fishing intensity) range are marked in green. The soft limit (20% B_0) is marked in blue and the hard limit (10% B_0) in red. Note that the Y-axis is non-linear.

Fishery and Stock Trends	
Recent Trend in Biomass or Proxy	Estimated spawning biomass has been slowly increasing since about 2000.
Recent Trend in Fishing Intensity or Proxy	Estimated fishing intensity has been declining in recent years.
Other Abundance Indices	-
Trends in Other Relevant Indicators or Variables	-
Trends in Other Relevant Indicators or Variables	-

Projections and Prognosis	
Stock Projections or Prognosis	At the current catch limit, the stock is projected to increase slowly over the next 5 years but still be below the soft limit in 2019. The minimum rebuild period to reach 30% B_0 with 70% probability is estimated to be 21 years with no catch.
Probability of Current Catch or TACC causing Biomass to remain below or to decline below Limits	For the current catch and catch limit (in the short term): Soft Limit: Very Likely (> 90%) Hard Limit: Unlikely (< 40%)
Probability of Current Catch or TACC causing Overfishing to continue or to commence	For the current catch and catch limit: As Likely as Not (40–60%)

Assessment Methodology and Evaluation		
Assessment Type	Level 1 - Full Quantitative Stock Assessment	
Assessment Method	Age-structured CASAL model with Bayesian estimation of posterior distributions	
Assessment Dates	Latest assessment: 2014	Next assessment: 2022
Overall assessment quality rank	1 – High Quality	
Main data inputs (rank)	- Acoustic biomass estimate (2013)	1 – High Quality
	- Trawl-survey biomass indices (1992–94, 2010), age frequencies (1993, 2010), length frequencies (1992, 1994), proportion spawning at age (1993, 2010)	1 – High Quality
	- Spawning-season age frequencies (1989–91, 2010)	1 – High Quality
	- Commercial length-frequencies (1989–90 to 2009–10)	1 – High Quality
Data not used (rank)	- CPUE indices	3 – Low Quality: unlikely to be indexing stock-wide abundance
	- 2002 spawning-season age frequency	2 – Medium or Mixed Quality: needs to be re-aged
	- Wide-area acoustic estimates	2 – Medium or Mixed Quality: too much potential bias due to target identification and mixed species issues
	- Egg survey estimates	2 – Medium or Mixed Quality: too much potential bias due to survey design assumptions not being meet
Changes to Model Structure and Assumptions	A more stringent data quality threshold was imposed on data inputs (e.g., wide-area acoustics, egg survey, and CPUE indices not used).	
Major Sources of Uncertainty	- The proportion of the spawning stock biomass that was indexed by the 2013 acoustic survey (little survey effort has been expended in this area relative to other orange roughy grounds). - Patterns in year class strengths are based on only 5 years of age composition data.	

Qualifying Comments
Estimates of stock biomass are sensitive to the means of the *q* priors. In addition, when higher CVs were used for the informed acoustic *q* priors, the median estimates of biomass and stock status were slightly higher and the confidence intervals were wider with a much higher upper bound.

Fishery Interactions
Fish bycatch is estimated to make up about 20% of the total catch in this fishery. The main bycatch species are alfonsino, smooth oreo and hoki. Low productivity bycatch species include deepwater sharks, deepsea skates and corals. Observed incidental captures of protected species include corals, low numbers of seabirds and a New Zealand fur seal. Orange roughy are caught using bottom trawl gear. Bottom trawling interacts with benthic habitats.

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ORANGE ROUGHY, CHATHAM RISE AND SOUTHERN NEW ZEALAND (ORH 3B)

1. FISHERY SUMMARY

1.1 Commercial fisheries

Orange roughy are found in waters deeper than 750 m throughout Quota Management Area 3B. Historically, the main fishery has been concentrated on the Chatham Rise. Annual reported orange roughy catches in ORH 3B ranged between 24 000–33 000 t in the 1980s, progressively decreased from 1989–90 to 1995–96 because of a series of TACC reductions, were stable over the mid-1990s–mid-2000s and decreased further from 2005–2006 as TACCs were further reduced (Table 1 and Figure 1).

Table 1: Annual reported catches and TACCs of orange roughy from ORH 3B. (Catches from 1978–79 to 1985–86 are from Robertson & Mace 1988) and from 1986–87 to 2018–19 from Fisheries Statistics Unit and Quota Monitoring System data). ‡

Fishing year	Reported catch (t)	TACC (t)	Agreed catch limit (t) β
1979–80†	11 800	-	-
1980–81†	31 100	-	-
1981–82†	28 200	23 000	-
1982–83*	32 605	23 000	-
1983–84*	32 535	30 000	-
1984–85	29 340	30 000	-
1985–86	30 075	29 865	-
1986–87	30 689	38 065	-
1987–88	24 214	38 065	-
1988–89	32 785	38 300	-
1989–90	31 669	32 787	-
1990–91	21 521	23 787	-
1991–92	23 269	23 787	-
1992–93	20 048	21 300	-
1993–94	16 960	21 300	-
1994–95	11 891	14 000	-
1995–96	12 501	12 700	-
1996–97	9 278	12 700	-
1997–98	9 638	12 700	-
1998–99	9 372	12 700	-
1999–00	8 663	12 700	-
2000–01	9 274	12 700	-
2001–02	11 325	12 700	-
2002–03	12 333	12 700	-
2003–04	11 254	12 700	-
2004–05	12 370	12 700	-
2005–06	12 554	12 700	-
2006–07	11 271	11 500	-
2007–08	10 291	10 500	-
2008–09	8 758	9 420	-
2009–10	6 662	7 950	-
2010–11	3 486	4 610	3 860
2011–12	2 765	3 600	2 850
2012–13	2 515	3 600	2 850
2013–14	4 492	4 500	-
2014–15	4 747	5 000	-
2015–16	4 529	5 000	-
2016–17	4 486	5 197	-
2017–18	4 942	5 197	-
2018–19	5 157	6 091	-

† Catches for 1979–80 to 1981–82 are for an April–March fishing year.
* Catches for 1982–83 and 1983–84 are 15 month totals to accommodate the change over from an April–March fishing year to an October–September fishing year. The TACC for the interim season, March to September 1983, was 16 125 t.
‡ Catches from 1984–85 onwards are for a 1 October–30 September fishing year.
β Agreed, non-regulatory catch limits between industry and MPI, which includes 'shelving' (an agreement that transfers ACE to a third party to effectively reduce the catch without adjusting the TACC).

There have been major changes in the distribution of catch and effort over the history of this fishery (Table 2). Initially, it was confined to the Chatham Rise and, until 1982, most of the catch was taken from areas of relatively flat bottom on the northern slopes of the Rise (in the Spawning Box), between mid-June and mid-August, when the fish form large aggregations for spawning (Figure 2).

From 1983 to 1989 about one third of the catch was taken from the south and east Chatham Rise, where new fishing grounds developed on and around knolls and hill features. Much of the catch from these areas was taken outside the spawning season as the fishery extended to most months of the year.

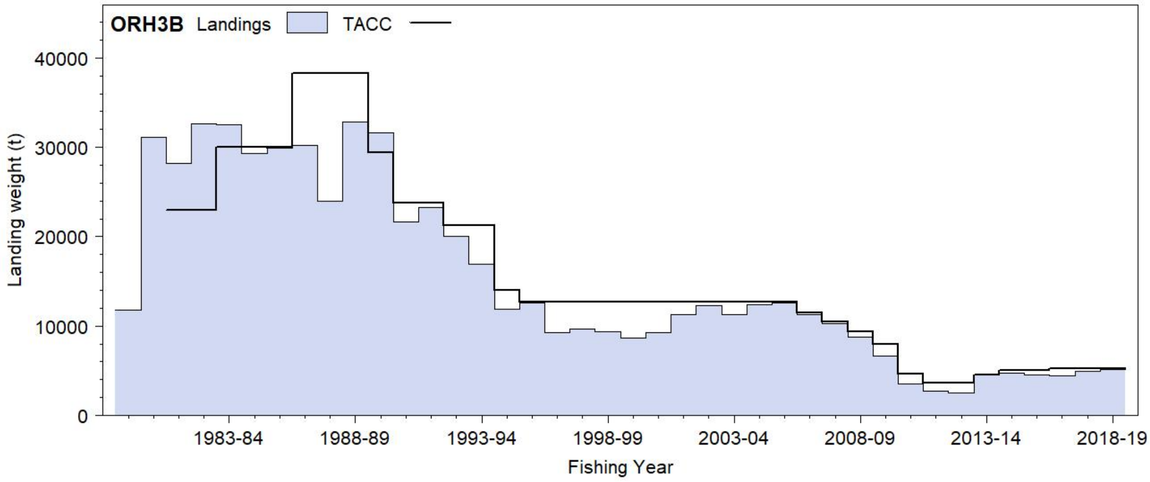


Figure 1: Reported commercial landings and TACCs for ORH 3B.

Table 2: ORH 3B catches by area, to the nearest 10 t or 100 t, and by percentage (to the nearest percent) of the total ORH 3B reported catch. Catches are equivalent to those shown in Table 1, but allocated to area using the ratio of estimated catches, and revised such that all years are from 1 October–30 September. Note that catches for the East Rise are given by the sum of Spawning Box and Rest of East Rise.

Year	Northwest Rise		South Rise		Spawning box		Rest of East Rise		Non-Chatham	
	t	%	t	%	t	%	t	%	t	%
1978–79	0	0	0	0	11 500	98	300	2	0	0
1979–80	1 200	4	800	3	27 900	90	1 200	4	0	0
1980–81	8 400	30	3 700	13	16 000	57	100	0	0	0
1981–82	7 000	28	500	2	16 600	67	800	3	0	0
1982–83	5 400	35	4 800	31	4 600	30	600	4	0	0
1983–84	3 300	13	5 100	21	15 000	61	1 500	6	0	0
1984–85	1 800	6	7 900	27	18 400	63	1 100	4	0	0
1985–86	3 700	12	5 300	18	17 000	56	4 100	13	0	0
1986–87	3 200	10	4 900	16	20 200	66	2 400	8	0	0
1987–88	1 600	7	6 800	28	13 500	56	2 300	10	0	0
1988–89	3 800	12	9 200	28	16 700	51	3 100	9	0	0
1989–90	3 300	10	11 000	35	16 200	51	1 100	3	200	1
1990–91	1 500	7	6 900	32	6 100	28	6 100	29	900	4
1991–92	300	1	2 200	9	1 000	4	12 000	51	7 800	34
1992–93	3 800	19	5 400	27	100	0	4 700	23	6 100	30
1993–94	3 500	21	5 100	30	0	0	4 900	29	3 500	20
1994–95	2 400	20	1 600	13	500	5	3 500	30	3 800	32
1995–96	2 400	19	1 300	10	1 600	13	2 200	17	5 000	40
1996–97	2 200	24	1 400	15	1 700	19	1 900	21	1 900	21
1997–98	2 300	23	1 700	17	2 400	24	2 200	22	1 600	16
1998–99	2 700	28	1 200	13	1 100	11	2 500	27	1 900	21
1999–00	2 100	24	1 100	13	1 500	17	3 100	36	800	9
2000–01	2 600	27	1 700	18	1 200	13	2 300	24	1 500	17
2001–02	2 200	19	1 100	10	3 100	28	3 600	31	1 300	12
2002–03	2 200	19	1 500	13	3 200	27	3 900	33	1 500	7
2003–04	2 000	18	1 400	12	4 300	38	2 600	23	1 000	9
2004–05	1 600	13	1 700	14	4 100	33	3 000	24	2 000	16
2005–06	1 400	11	1 300	10	3 900	31	3 900	31	2 100	16
2006–07	700	7	1 200	11	4 200	37	3 700	32	1 500	16
2007–08	800	8	1 300	13	3 800	37	2 700	26	1 600	16
2008–09	750	8	1 170	14	3 400	39	2 150	25	1 290	15
2009–10	720	11	940	14	3 120	47	1 260	19	620	9
2010–11	40	1	460	13	1 860	53	740	21	380	11
2011–12	70	3	300	11	1 520	55	770	28	100	3
2012–13	110	4	290	12	1 450	58	590	24	70	3
2013–14	800	18	500	12	1 420	33	1 240	29	540	12
2014–15	800	17	370	8	1 990	43	700	15	630	14
2015–16	700	16	360	8	1 220	28	1 800	42	460	11
2016–17	730	16	530	12	1 310	29	1 150	26	590	13
2017–18	840	17	445	9	1 285	26	1 532	31	840	17
2018–19	304	7	455	10	2 556	55	651	14	684	15

In the early 1990s, effort within the Chatham Rise further shifted from the Spawning Box to eastern and northwestern parts of the Rise. The Spawning Box was closed to fishing from 1992–93 to 1994–95. Since it was reopened the majority of the annual catch is often taken in the Spawning Box with the highest or next highest contribution generally being from the rest of the east Rise (Table 2).

The early 1990s also saw the Puysegur fishery develop, followed by other fishing grounds near the Auckland Islands and on the Pukaki Rise, which was also a focus for the fishery south of the Chatham Rise.

Since 1992–93, the distribution of the catch within ORH 3B has been affected by a series of catch-limit agreements between the fishing industry and the Minister responsible for fisheries. Initially, the agreement was that at least 5000 t be caught south of 46° S. Subsequently, the catch limits, and the designated sub-areas to which they apply, have changed from year to year.

The TACC was reduced to 3600 t in 2011–12 but has since increased (Table 1). The agreed catch limit for the East and South Chatham Rise has increased in each year since 2017–18 (Table 3).

The catch limit for the Sub-Antarctic has been substantially undercaught since 2009–10. However, the combined East and South Rise sub-area catch limits were exceeded by 450 t in 2005–06 and by 350 t in 2006–07 (100 t were taken against the allowance for research surveys). Taking the research allowance into account, catch limits for the combined east and south Rise sub-area have not been exceeded in subsequent years. Since 2004–05, 250 t of the ORH 3B TACC has been set aside for industry research surveys (Table 3), although this has sometimes been used in areas outside the East and South Chatham Rise.

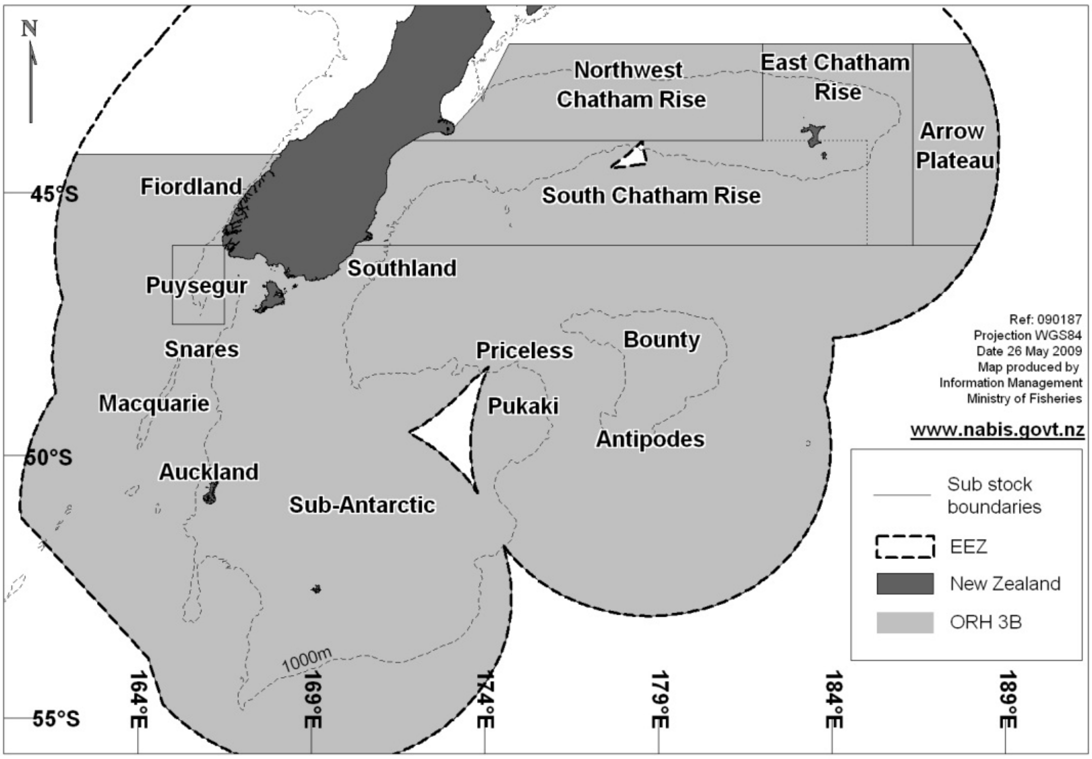


Figure 2: ORH 3B sub-areas and the approximate position of other named fisheries outside of the Chatham Rise. The Spawning Box is in the western part of the East Rise (to the west of the vertical broken line at 175°W). The East and South Rise are currently managed as a single unit. The Arrow Plateau has been designated a Benthic Protected Area. The Sub-Antarctic is all areas below 46°S on the east coast, and 44°16'S on the west coast, except Puysegur.

Outside the Spawning Box, catches increased in the 1990s and catch rates have been highly variable, sustained largely by the discovery of new fishing areas. Flat areas on the Northwest Rise and several major hills on the South Rise were important in the late 1980s, but currently do not support their previous levels of catch, now accounting for less than 5% of the estimated catch (Table 4). High catch rates can still occur, but these are less frequent than observed in the early years of the fishery. Catches from the Northwest Rise fell to near zero in 2010–11 as a result of an agreement among quota owners to avoid fishing in this area (Table 2). This agreement was extended to the 2011–12 and 2012–13 fishing years. Quota owners then agreed to shelve 207 tonnes of Northwest Chatham Rise ACE for 2014–15 to 2017–18. The catch limit was set at 1150 t from 1 October 2018.

Table 3: Catch limits (t) by designated sub-area within ORH 3B, as agreed between the industry and the Ministers responsible for fisheries since 1992–93. Note that East Rise includes the Spawning Box, closed between 1992–93 and 1994–95. Sub-area boundaries have varied somewhat between years. * South Rise included in East Rise catch limit. ** Arrow Plateau included in Sub-Antarctic.

Year	Northwest Chatham Rise	East Chatham Rise	South Chatham Rise	Puysegur	Arrow Plateau	Sub-Antarctic
1992–93	3 500	4 500	6 300	5 000	-	2 000
1993–94	3 500	4 500	6 300	5 000	-	2 000
1994–95	2 500	3 500	2 000	2 000	3 000	1 000
1995–96	2 250	4 950	*	1 000	**	4 500
1996–97	2 250	4 950	*	500	**	5 000
1997–98	2 250	4 950	*	0	1 500	4 000
1998–99	2 250	4 950	*	0	1 500	4 000
1999–00	2 250	4 950	*	0	1 500	4 000
2000–01	2 250	4 950	*	0	1 500	4 000
2001–02	2 000	7 000	1 400	0	1 000	1 300
2002–03	2 000	7 000	1 400	0	1 000	1 300
2003–04	2 000	7 000	1 400	0	1 000	1 300
2004–05†	1 500	7 250	1 400	0	1 000	1 300
2005–06†	1 500	7 250	1 400	0†	1 000	1 300
2006–07	750	8 650‡	*	0	0	1 850
2007–08†	750	7 650#	*	0	0	1 850
2008–09†	750	6 570§	*	0	0	1 850
2009–10†	750	5 100	*	0	0	1 850
2010–11	750β	2 960†	*	150	0	500
2011–12	750β	1 950†	*	150	0	500
2012–13	750 β	1 950†	*	150	0	500
2013–14	750	3 100	*	150	0	500
2014–15	1 250 δ	3 100	*	150	0	500
2015–16	1 250 δ	3 100	*	150	0	500
2016–17	1 250 δ	3 100	*	347	0	500
2017–18	1 250 δ	3 100	*	347	0	500
2018–19	1 150	4 095	*	347	0	500
2019–20	1 150	4 775	*	347	0	500

† an additional 250 t set aside for industry research surveys.
‡ 8650 t allocated to the East and South Chatham Rise combined, with no more than 2000 t from the South Rise, and no more than 7250 t from the East Rise.
# Combined East and South Rise catch not to exceed 7650 t; East Rise not to exceed 6500 t; South Rise catch not to exceed 1750 t.
§ In 2008–09, the catch from the spawning plume was not to exceed 3285 t.
β From 2010–11 to 2012–13, quota owners agreed to avoid fishing the Northwest Rise.
δ Quota owners agreed to shelve 207 tonnes of Northwest Chatham Rise ACE for 2014–15 to 2017–18. This left 1043 tonnes available to catch.

Between 1991–92 and 2000–01, more than half of the Chatham Rise catch came from four hill complexes: the Andes, Smith City and neighbours, Graveyard, and Big Chief and neighbours (Table 4). All of these have shown a decline in unstandardised catch rate since the early years of the fishery, and in recent years, catch rates in these hill complexes have remained relatively low. After 2000–01, the proportion of the catch from these hill complexes decreased, as a greater proportion of the catch came from the Spawning Box (about 39% in 2008–09). In addition, large catches have been made in recent years outside of the spawning season, in recently developed areas of the southeast Rise. Catches from the Spawning Box taken during the spawning season (which peaks in July) have been relatively high since 2001–02, although unstandardised catch rates have been variable (Table 4).

Table 4: Orange roughy estimated catches (to nearest 10 t) and unstandardised median catch rates (to nearest 0.1 t/tow) for four important hill complexes and the Spawning Box In season (spawning plume area, May-August) and Out season (September-April) on the Chatham Rise (letters indicating subareas, as in Table 3, in parentheses), using catch and effort data held by NIWA. Only tows targeted at orange roughy are included. (Approximate positions are: Big Chief, 44.7 S, 175.2 W; Smiths City and near-neighbours, 43.1 S, 174.2 W; Andes, 44.2 S, 174.6 W; Graveyard, 42.8 S, 180 W). -, catch < 10 t. - means catch < 10 t. NA means catch >10 t but there were fewer than 3 vessels in the fishery. [Continued on next page]

	Andes (E)			Smith's City NE Hills (E)			Spawning Box In (E)			Spawning Box Out (E)		
Year	**Catch**	**Tows**	**t/tow**	**Catch**	**Tows**	**t/tow**	**Catch**	**Tows**	**t/tow**	**Catch**	**Tows**	**t/tow**
1979–80	-	-	-	110	36	3.1	9 800	968	10.7	7 400	795	6.1
1980–81	-	-	-	-	2	-	11 100	890	11.5	6 240	462	11.5
1981–82	-	-	-	40	11	3.6	4 750	470	4.5	4 450	604	4.9
1982–83	-	-	-	40	2	17.8	3 980	227	13.4	3 840	386	8.1
1983–84	-	-	-	60	7	6.3	6 590	378	13.4	8 630	836	7.7
1984–85	-	-	-	10	3	3.2	9 320	676	10.4	7 460	537	10.0
1985–86	-	-	-	670	52	11.4	8 521	659	10.0	7 650	859	6.1
1986–87	-	-	-	210	34	3.9	8 090	597	8.9	12 010	1 036	6.2
1987–88	-	-	-	160	33	4.5	7 870	622	8.0	5 820	701	5.1
1988–89	30	18	0.3	310	48	3.9	7 070	598	9.6	6 500	811	5.0
1989–90	90	13	1.5	40	9	4.0	6 830	403	12.5	4 960	602	5.3
1990–91	80	12	3.2	4 890	633	3.5	2 820	238	8.0	2 810	206	8.0
1991–92	7 080	724	5.0	1 270	222	2.0	650	85	6.0	300	54	5.7
1992–93	2 940	345	5.0	600	84	2.0	50	2	27.0	-	-	-
1993–94	3 320	605	1.8	560	109	2.8	-	-	-	-	-	-
1994–95	1 650	573	1.0	1 140	345	1.0	490	86	0.3	10	25	0.1
1995–96	1 120	418	0.5	410	145	1.0	1 360	127	5.0	140	27	0.8
1996–97	730	260	1.0	720	164	1.0	930	101	3.0	620	130	2.3
1997–98	1 140	476	0.5	400	146	0.4	1 580	118	6.0	630	148	1.1.65
1998–99	1 260	448	1.0	810	272	1.0	510	73	2.7	490	139	2.0
1999–00	1 990	529	1.0	680	210	0.8	910	34	25.0	510	111	2.0
2000–01	980	354	1.1	650	191	1.0	810	59	5.5	430	123	2.0
2001–02	2 040	546	1.5	490	167	0.9	2 120	159	4.0	980	222	1.8
2002–03	2 230	872	1.0	400	124	0.5	2 150	166	8.0	1 000	216	2.3
2003–04	1 170	677	0.5	360	160	0.8	1 880	163	6.0	1 050	278	2.5
2004–05	1 090	518	0.6	310	127	0.9	1 910	214	4.4	850	230	3.8
2005–06	1 340	727	0.5	370	119	0.7	1 630	117	9.0	1 740	257	2.6
2006–07	1 160	583	0.5	570	201	0.7	1 980	121	11.2	1720	356	2.5
2007–08	N/A	N/A	N/A	N/A	N/A	N/A	2 550	200	5.0	750	192	3.0
2008–09	N/A	N/A	N/A	N/A	N/A	N/A	2 020	121	18.0	1 010	209	2.4
2009–10	440	243	0.5	160	84	0.5	1 980	136	8.5	850	248	1.7
2010–11	460	151	1.2	90	27	0.4	1 230	75	15.0	70	28	2.0
2011–12	450	164	1.0	130	26	0.5	660	39	22.5	80	24	3.8
2012–13	N/A	N/A	N/A	-	-	-	N/A	N/A	N/A	N/A	N/A	N/A
2013–14	790	218	1.0	140	39	0.9	390	40	4.9	30	18	2.0
2014–15	460	162	1.0	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
2015–16	1 180	437	0.4	130	75	0.2	N/A	N/A	N/A	390	96	3.0
2016–17	700	407	0.3	68	36	0.4	0	0	0	320	104	1.7
2017–18	761	483	0.3	202	73	1.0	0	0	0	396	111	2.0

	Rest of East (E)			Graveyard (NW)			Rest of Northwest (NW)			Hegerville (S)		
Year	**Catc**	**Tow**	**t/to**	**Catch**	**Tows**	**t/tow**	**Catch**	**Tows**	**t/tow**	**Catch**	**Tows**	**t/tow**
1979–80	560	206	2.2	-	-	-	840	81	7.7	20	2	8.1
1980–81	30	10	3.5	50	7	4.0	7 960	2 074	2.3	980	235	3.3
1981–82	360	77	4.0	90	12	6.4	3 830	616	4.4	40	9	4.3
1982–83	1 030	63	8.5	90	11	5.0	8 500	1 484	3.6	7 440	856	7.1
1983–84	1 190	139	6.4	-	-	-	2 780	657	2.9	3 370	493	4.5
1984–85	990	80	9.5	-	-	-	1 640	314	3.3	5 660	824	4.5
1985–86	3 030	306	8.1	30	11	2.5	3 400	564	2.8	3 660	840	1.8
1986–87	1 950	296	4.6	30	11	2.0	2 920	660	2.3	2 470	601	1.6
1987–88	2 100	324	5.3	130	19	4.7	1 360	386	2.4	2 020	673	0.8
1988–89	2 080	299	4.5	130	25	3.2	2 780	782	1.8	1 170	568	0.6
1989–90	360	86	3.0	160	28	5.5	2 100	602	2.0	470	237	0.6
1990–91	480	87	1.0	10	2	4.2	1 230	261	2.6	170	75	0.3
1991–92	3 050	366	5.0	70	25	1.3	180	60	2.0	30	52	< 0.1
1992–93	570	75	2.0	3 300	297	5.1	170	69	1.4	290	83	1.5
1993–94	510	122	1.9	2 180	363	1.9	1 120	213	1.0	220	129	0.5
1994–95	440	195	1.0	1 510	363	1.0	720	268	1.0	100	95	< 0.1
1995–96	450	120	0.5	1 790	355	1.0	430	212	0.8	80	104	< 0.1
1996–97	370	117	1.0	870	243	0.5	1 210	400	2.0	170	75	0.2
1997–98	450	259	0.3	830	305	0.4	1 290	487	1.0	60	52	0.1
1998–99	350	214	0.3	930	186	0.8	1 510	550	1.0	50	1	0.5
1999–00	390	162	0.3	630	239	0.5	1 280	353	1.0	50	10	0.3
2000–01	580	155	1.0	1 010	301	0.5	1 310	613	1.0	100	21	3.0
2001–02	900	240	1.1	730	206	0.9	1 260	645	0.8	30	18	0.6
2002–03	1 280	397	0.8	1 080	253	0.8	1 050	593	0.8	150	42	1.4
2003–04	840	394	0.6	740	126	0.7	1 030	586	1.0	100	48	0.4
2004–05	1 330	405	0.9	920	170	1.1	560	331	0.7	100	23	2.2
2005–06	1 810	533	0.8	960	188	0.6	380	238	0.7	90	53	0.5
2006–07	1 540	573	0.9	590	78	1.8	80	29	0.2	160	38	0.6
2007–08	N/A	N/A	N/A	390	176	0.6	320	109	0.8	280	107	0.6
2008–09	1 170	443	1.0	390	75	1.3	280	110	0.5	500	182	0.5

Table 4 [Continued]

	Rest of East (E)			Graveyard (NW)			Rest of Northwest (NW)			Hegerville (S)		
Year	**Catc**	**Tow**	**t/to**	**Catch**	**Tows**	**t/tow**	**Catch**	**Tows**	**t/tow**	**Catch**	**Tows**	**t/tow**
2009–10	560	217	1.2	290	90	0.8	360	193	1.2	470	120	1.0
2010–11	130	43	0.6	N/A	N/A	N/A	30	5	1.0	150	32	2.0
2011–12	120	61	0.7	-	-	-	30	4	1.5	N/A	N/A	N/A
2012–13	N/A	N/A	N/A	-	-	-	30	7	1.6	N/A	N/A	N/A
2013–14	260	82	1.0	570	102	1.1	110	67	0.7	N/A	N/A	N/A
2014–15	200	52	1.4	550	164	0.5	180	106	0.7	-	-	-
2015–16	360	263	0.3	400	165	0.5	180	215	0.5	-	-	-
2016–17	269	154	0.4	187	137	0.5	473	329	0.7	21	34	0.1
2017–18	450	166	0.8	400	177	0.5	351	214	0.6	N/A	N/A	N/A

	Big Chief (S)			Rest of South (S)			Rekohu		
Year	**Catc**	**Tow**	**t/to**	**Catc**	**Tow**	**t/to**	**Catch**	**Tow**	**t/to**
1979–80	-	-	-	20	12	< 0.1	30	8	3.1
1980–81	-	-	-	110	25	3.4	60	4	14.1
1981–82	-	-	-	30	28	1.1	-	-	-
1982–83	-	-	-	180	31	< 0.1	30	4	3.9
1983–84	-	-	-	120	86	0.1	-	-	-
1984–85	-	-	-	870	289	0.6	-	-	-
1985–86	-	-	-	530	198	0.6	40	2	2.3
1986–87	-	-	-	1 440	433	1.1	N\A	N/A	N/A
1987–88	-	-	-	3 180	924	0.7	40	5	0.4
1988–89	1 010	199	1.7	4 650	1	0.3	60	5	0.6
1989–90	2 830	529	1.5	4 090	1	1.0	N/A	N/A	N/A
1990–91	3 150	453	2.1	1 620	500	0.3	N/A	N/A	N/A
1991–92	820	138	2.5	780	308	0.3	-	-	-
1992–93	3 310	703	2.0	1 190	462	< 0.1	-	-	-
1993–94	2 350	698	0.6	2 060	1	0.1	-	-	-
1994–95	510	242	0.8	880	937	< 0.1	-	-	-
1995–96	580	151	1.0	460	553	< 0.1	-	-	-
1996–97	560	195	0.5	440	304	< 0.1	-	-	-
1997–98	950	285	0.4	410	503	0.1	-	-	-
1998–99	560	215	0.5	390	258	0.3	-	-	-
1999–00	380	123	0.5	430	173	0.5	-	-	-
2000–01	1 020	213	0.8	400	203	0.5	-	-	-
2001–02	660	234	0.9	280	186	0.5	-	-	-
2002–03	660	276	0.5	480	204	0.5	-	-	-
2003–04	570	300	0.5	460	266	0.4	1 030	151	4.0
2004–05	790	308	0.5	490	231	0.6	1 030	200	2.9
2005–06	500	303	0.4	400	281	0.4	160	65	1.1
2006–07	510	282	0.4	200	187	0.3	80	43	0.7
2007–08	690	335	0.5	170	189	0.3	N/A	N/A	N/A
2008–09	330	307	0.2	120	158	0.1	N/A	N/A	N/A
2009–10	180	121	0.3	40	68	0.2	60	28	1.3
2010–11	210	60	0.5	30	34	< 0.1	400	31	6.5
2011–12	180	72	0.5	10	20	0.5	670	36	19.5
2012–13	N\A	N\A	N\A	50	19	0.3	710	39	25.0
2013–14	350	77	1.0	90	40	0.9	950	40	24.2
2014–15	250	56	0.9	40	11	0.5	1 780	89	21.7
2015–16	190	159	0.1	110	61	0.1	700	54	10.8
2016–17	393	139	0.2	69	74	0.1	868	115	5.0
2017–18	340	172	0.2	20	30	0.4	801	83	5.5

Table 5: Estimated ORH 3B catches (to the nearest 10 t) and unstandardised median catch rates (to nearest 0.1 t/tow) for areas outside the Chatham Rise, using estimated catch and effort data held by NIWA. Only tows targeted at orange roughy are included. For this table the areas were defined by the following rectangles: Arrow - 42.17-46°S, 173.67°W; Auckland - 49-52 °S, 165-167 °E; Bounty - 46-47.5°S, 177.5-180°E; Priceless - 48-48.44°S, 174.7-175.2°E; Other Pukaki - 47-50.4°S, 174-176.4°E (and not in Priceless); Puysegur - 46-47.5 °S, 165-166.5 °E. The area described as Antipodes in previous reports is now included in Other Pukaki. All years are from 1 October-30 September (2016–17 data are provisional and catch totals may be incomplete). - means catch < 10 t. N/A means catch greater than 10 t, but there were fewer than 3 vessels in the fishery. [Continued on next page]

	Arrow		Auckland		Bounty		Priceless		Other Pukaki		Puysegur		Other	
Year	**Catch**	**t/tow**	**Catch**	**t/tow**	**Catch**	**t/tow**	**Catch**	**t/tow**	**Catch**	**t/tow**	**Catch**	**t/tow**	**Catch**	**t/tow**
1985–86	120	18.5	-	-	-	-	-	-	-	-	-	-	-	-
1986–87	110	10.6	-	-	-	-	-	-	-	-	-	-	-	-
1987–88	-	-	-	-	-	-	-	-	-	-	-	-	-	-
1988–89	-	-	-	-	-	-	-	-	-	-	-	-	30	<0.1
1989–90	-	-	-	-	-	-	-	-	-	-	100	1.4	50	6.0
1990–91	150	4.5	-	-	-	-	-	-	-	-	600	4.6	20	<0.1
1991–92	100	10.0	-	-	-	-	-	-	-	-	6 320	10.6	170	0.6
1992–93	10	6.5	30	< 0.1	-	-	-	-	-	-	4 280	6.7	330	< 0.1
1993–94	470	1.0	180	< 0.1	-	-	-	-	-	-	2 410	1.9	80	< 0.1
1994–95	750	0.3	880	0.2	-	-	-	-	-	-	1 260	7.9	20	< 0.1
1995–96	170	0.1	370	0.1	-	-	-	-	3 060	5.0	730	2.4	520	< 0.1

Table 5 [Continued]

Year	Catch	t/tow	Catch	t/tow	Catch	t/tow	Catch	t/tow	Catch	t/tow	Catch	t/tow	Catch	t/tow
1996–97	280	0.1	120	< 0.1	20	< 0.1	-	-	670	< 0.1	490	2.6	400	< 0.1
1997–98	330	0.1	360	0.1	240	< 0.1	10	< 0.1	130	< 0.1	-	-	1 050	< 0.1
1998–99	730	0.3	440	0.1	130	0.1	-	-	120	< 0.1	-	-	1 820	0.5
1999–00	280	0.1	150	< 0.1	170	< 0.1	-	-	-	-	-	-	60	< 0.1
2000–01	190	0.1	60	< 0.1	150	0.3	-	-	20	< 0.1	-	-	1 030	0.3
2001–02	70	0.2	130	0.1	40	0.1	550	22.3	-	-	-	-	460	0.4
2002–03	220	0.2	-	-	220	1.5	480	7.0	-	-	-	-	400	0.4
2003–04	140	0.1	-	-	90	0.2	450	0.3	-	-	-	-	440	< 0.1
2004–05	60	0.1	-	-	100	0.4	540	0.3	520	9.8	N/A	N/A	550	< 0.1
2005–06	100	0.1	-	-	40	0.2	540	0.9	740	4.0	N/A	N/A	250	< 0.1
2006–07	-	-	-	-	-	-	470	0.5	N/A	N/A	-	-	-	-
2007–08	-	-	N/A	N/A	-	-	N/A	N/A	N/A	N/A	-	-	-	-
2008–09	-	-	N/A	N/A	-	-	N/A	N/A	N/A	N/A	-	-	150	0.5
2009–10	-	-	N/A	N/A	N/A	N/A	210	< 0.1	320	0.3	-	-	60	< 0.1
2010–11	-	-	N/A	N/A	N/A	N/A	-	-	N/A	N/A	-	-	20	0.4
2011–12	-	-	N/A	N/A	-	-	-	-	-	-	-	-	-	-
2012–13	-	-	N/A	N/A	-	-	-	-	N/A	N/A	-	-	-	-
2013–14	-	-	N/A	N/A	-	-	-	-	-	-	-	-	-	-
2014–15	-	-	350	< 0.1	-	-	-	-	-	-	-	-	38	0.6
2015–16	-	-	380	0.6	-	-	-	-	-	-	N/A	N/A	-	-
2016–17	-	-	184	0.3	N/A	N/A	-	-	N/A	N/A	N/A	N/A	49	0.8
2017–18	-	-	105	0.1	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A

The first fishery to be developed south of the Chatham Rise was on Puysegur Bank, where spawning aggregations of orange roughy were found during a joint Industry-Ministry exploratory fishing survey in 1990–91. The fishery developed rapidly, but from 1993–94 catch limits were substantially under-caught. Catch limits were subsequently reduced from the initial level of 5000 t, and the industry implemented a catch limit of 0 t beginning in the 1997–98 fishing year (reported catches in 2004–05 and 2005–06 were taken during industry surveys). A catch limit of 150 t was provided for research purposes in Puysegur from 2010–11 (Table 3). Following a stock assessment of Puysegur in 2017, a commercial catch limit was set at 347 t from 1 October 2017.

Exploratory fishing on the Macquarie Ridge south of Puysegur in 1993 led to the development of a fishery off the Auckland Islands. Total catch rose to around 900 t in 1994–95, but then dropped to less than 200 t by 1999–00, and catches remained low until an increase in 2013–14. In 1993–94, catches were taken on the ‘Arrow Plateau’, and became the first major fishery to develop on the easternmost section of the Chatham Rise. A catch limit of 3000 t was put in place for 1994–95, with an additional limit of 500 t for each hill. Only a few hills in this area have been fished successfully, and the catch has never reached the catch limit, which was reduced to 1000 t by the early 2000s (Table 3). The Arrow Plateau was closed to orange roughy fishing when it was designated a Benthic Protected Area in 2007 Table 5).

In 1995–96, large catches were reported on the southeast Pukaki Rise, with a catch total of over 3000 t. However, the catches dropped rapidly and the fishery effectively ceased within a few years. From 2001–02, a fishery developed on the northeast Pukaki Rise, including the area known as Priceless, where catches were mostly taken at the start of the fishing year. Catches at Priceless reached the feature limit of 500 t for each of the six years up to 2006–07, but catches and catch rates declined substantially from 2007–08, and have remained low since. Areas of the northeast Pukaki Rise outside of Priceless were developed in 2004–05 and also showed a rapid decline in catches and catch rates. By 2007–08, the fishery in the sub-Antarctic was limited to the Auckland Islands and northeast Pukaki Rise areas. From 2008–09 the fishery extended over a relatively wide area, but catches and catch rates were low, and the fishery effectively ceased from 2010–11 (Table 5).

Catches of orange roughy have also been taken off the Bounty Islands (around 100–200 t per year from 1997–98 to 2004–05, but infrequently since then, and none since 2011–12) (Table 5), off the Snares Islands (up to around 500 t per year, but infrequently in recent years), areas of the Macquarie Ridge (100–500 t per year from 2000–01 to 2004–05, and in 2008–09), and off Fiordland (around 500 t in 2000–01, but subsequent catches rapidly decreased).

1.2 Recreational fisheries
No recreational fishing for orange roughy is known in this quota management area.

1.3 Customary non-commercial fisheries
No customary non-commercial fishing for orange roughy is known in this quota management area.

1.4 Illegal catch
No information is available on illegal catch in this quota management area.

1.5 Other sources of mortality
There has been a history of catch overruns on the Chatham Rise because of lost fish and discards, and discrepancies in tray weights and conversion factors. In assessments, total removals from each part of the Chatham Rise were assumed to exceed reported catches by the overrun percentages in Table 6. For Puysegur and other southern fisheries there is no reason to believe that, if there was an overrun in catches, this shows any trend over time. For this reason, it was assumed that there was no overrun for this area.

Table 6: Chatham Rise catch overruns (%) by year.

Year	**1978–79**	**1979–80**	**1980–81**	**1981–82**	**1982–83**	**1983–84**	**1984–85**	**1985–86**	**1986–87**	**1987–88**
Overrun	30	30	30	30	30	30	30	28	26	24

Year	**1988–89**	**1989–90**	**1990–91**	**1991–92**	**1992–93**	**1993–94**	**1994–95 and subsequently**
Overrun	22	20	15	10	10	10	5

Within the TAC an allowance of 5% of the TACC is allocated for other sources of mortality (currently 225 t).

2. BIOLOGY

Biological parameters used in this assessment are presented in the Biology section at the beginning of the Orange Roughy section.

3. STOCKS AND AREAS

For the purposes of this report the term “stock” refers to a biological unit with a single major spawning ground, in contrast to a “Fishstock” which refers to a management unit.

Genetically two main stocks are recognised within ORH 3B (Chatham Rise and Puysegur; Smith & Benson 1997) and these are considered to be distinct from stocks in adjacent areas (Cook Canyon and Ritchie Bank). However, it is likely, because of their geographical separation and discontinuities in the distribution of orange roughy, that concentrations of spawning fish on the Arrow Plateau, near the Auckland Islands, and west of the Antipodes Islands also form separate stocks.

Genetic data have been applied to define stock boundaries, both within ORH 3B, and between it and adjacent areas. Mitochondrial DNA shows that there are considerable differences between Puysegur fish and fish from the geographically adjacent areas Cook Canyon and Chatham Rise. Allozyme frequency studies suggest that Chatham Rise fish are distinct from those on the Ritchie Bank (ORH 2A). These data also suggest multiple stocks within the Chatham Rise, but do not indicate clear stock boundaries. Although there is significant heterogeneity amongst allozyme frequencies from different areas of the Rise, these frequencies varied as much in time (samples from the same location at different times) as in space (samples from different locations at the same time).

Chatham Rise
The stock structure of orange roughy on the Chatham Rise was comprehensively reviewed in 2008 (Dunn & Devine 2010). This review evaluated all available data as no single dataset seemed to provide definitive information about likely stock boundaries. The data analysed included: catch distribution and

CPUE patterns; location of spawning and nursery grounds; inferred migrations; size, maturity and condition data; genetic studies, and habitat and natural boundaries.

There is evidence that a separate stock exists on the Northwest Rise. The Northwest Rise contains a large spawning ground on the Graveyard Hills, and also nursery grounds around, and primarily to the west of, the Graveyard Hills. There is a gap in the distribution of early juveniles (under 15 cm SL) between the Graveyard area and the Spawning Box at approximately 178°W. A research trawl survey found post-spawning adult fish to the west, but not to the east, of the Graveyard Hills, and a westerly post-spawning migration was inferred. Analyses of median length from commercial and research trawls found that orange roughy on the Northwest Chatham Rise and Graveyard Hills were smaller than those on the East Rise. A substantial decline in the size of 50% maturity after 1992 was found for both the Graveyard Hills and the Northwest Rise, but not for other areas. The only information that does not support the Northwest Rise being a separate stock is an indication from patterns in commercial catch rates that some fish arriving to spawn in the Spawning Box may come from the west (Coburn & Doonan 1994, 1997). Catch data and genetic studies do not shed any further light on stock structure. Oceanographic models suggest that a gyre to the east of the Graveyard may provide a mechanism for a separation between the Northwest Chatham Rise and the East Rise. Based on the available data, the Northwest Chatham Rise is considered to be a separate stock.

The separation of the Northeast Hills and Andes as separate stocks from the Spawning Box and Eastern Flats was based on observations of simultaneous spawning aggregations occurring on these hills, and because stock assessment models indicated a mismatch between the standardised CPUE trends. On the other hand, the occurrence of a continuous nursery ground throughout the area; similar trends in size of 50% maturity in each area; the essentially continuous habitat with similar environmental conditions and inferred post-spawning migrations from the Spawning Box towards the east Rise all suggest that all of these areas are a single stock. Analyses of median lengths from commercial catches showed no obvious differences between areas. In addition, the spawning aggregations found on the Northeast Hills and Andes appear to have been minor compared to that in the Spawning Box. The spawning aggregation on the Northeast Hills is also associated with an increase in mean length and catch rates, suggesting that fish spawning on these hills are not resident, and thus are not separate from the surrounding area. Based on the available data the Northeast Hills and Andes are therefore considered to be from the same stock as the Spawning Box and Eastern Flats.

The only evidence to separate the eastern area of the South Rise (Big Chief and surrounds) from the East Rise is the lack of spawning migrations inferred from an absence of a seasonal effect in standardised CPUE analyses. The evidence that the Big Chief area is the same stock as the East Rise includes the fact that the nursery grounds and habitat are continuous; there were no splits between the areas identified from analyses of median length; and the fisheries are similar. The reports of spawning fish around Big Chief have been infrequent, and so are considered equivocal on stock structure. The Big Chief area is therefore considered part of the East Rise stock.

There is weak evidence that the area of the South Rise west of and including Hegerville is a separate stock. The evidence includes median length analyses which indicated a split in this area, and an oceanographic front at 177°W. However, very few catches of spawning orange roughy have been reported in this area, and there appears to be no substantial nursery ground. Both of these factors support the idea that this area does not have a separate stock. In the area to the west of the suggested split the fish are relatively small during spawning, and relatively large during non-spawning. Combined with a standardised CPUE which shows a decline in abundance around July (peak spawning), and a somatic condition factor which declines during September–November (post-spawning), this supports a hypothesis of adult fish leaving the area to spawn elsewhere.

The South Rise could provide feeding habitat for the stock, which is estimated to have had an initial biomass of over 300 000 t, an amount that was probably too large to inhabit only the East Rise. There is more evidence to support the idea of orange roughy in this area being part of the East Rise stock than there is to the contrary. The current hypothesis is that the area to the west of the current convergence may be relatively marginal habitat, where larger juvenile, maturing and adult orange roughy were once predominant, and there is little spawning and few juveniles because the water is relatively cold.

Based on these analyses, the Chatham Rise has been divided into two areas: the Northwest, and the East and South Rise combined (Figure 2). The centre of the Northwest stock is the Graveyard Hills. The centre of the East and South Rise stock is the Spawning Box during spawning, and the southeast corner of the Rise during non-spawning.

4. STOCK ASSESSMENT

No model-based stock assessments were conducted for ORH 3B stocks from 2007 to 2013 inclusive. This was primarily because the 2006 stock assessment, which assumed deterministic recruitment, showed an increasing trend in biomass which was not supported by recent biomass indices. Deterministic recruitment was assumed because ageing data were considered to be unreliable. With the successful assessment of the MEC stock in 2013, which used age data from the new ageing methodology (Tracey et al 2007; Horn et al 2016), there was a return to model-based assessment in 2014. Recruitment in all of these assessments has been derived from limited age data.

4.1 Northwest Chatham Rise

A Bayesian stock assessment was conducted for the Northwest Chatham Rise (NWCR) stock in 2018, using data up to 2016–17. This used an age-structured population model fitted to acoustic-survey estimates of spawning biomass, proportion-at-age from a trawl survey and targeted trawling on a spawning aggregation, proportion-spawning-at-age from a trawl survey, and length frequencies from the commercial fishery.

4.1.1 Model structure

The model was single-sex and age-structured (1–100 years with a plus group), with maturity estimated separately (i.e., fish were classified by age and as mature or immature). A single-time step was used and the single fishery was assumed to be year-round on mature fish. Spawning was taken to occur after 75% of the mortality and 100% of mature fish were assumed to spawn each year. The catch history was constructed from the Northwest catches in Table 2 using the catch over-run percentages in Table 6. Natural mortality was assumed to be fixed at 0.045 and the stock-recruitment relationship was assumed to follow a Beverton-Holt function with steepness of 0.75. The remaining fixed biological parameters are given in table 2 of the Orange Roughy Introduction section.

4.1.2 Input data and statistical assumptions

There were three main data sources for observations fitted in the assessment: acoustic-survey spawning biomass estimates from the main spawning hills (Graveyard and Morgue); an age frequency and an estimate of proportion-spawning-at-age taken from a 1994 wide-area trawl survey; an age-frequency taken from targeted trawls above Morgue, and length frequencies collected from the commercial fishery covering 1989–2005.

Acoustic estimates

Three types of acoustic-survey estimates were available for use in the assessment: AOS estimates (from a multi-frequency towed system, e.g., see Kloser et al 2011); 38 kHz estimates from a towed-body system; and 38 kHz estimates from a hull-mounted system. The reliability of the data from the different systems in each year was considered and estimates from the AOS and towed-body systems were used in the base model (Table 7). An alternative treatment of the available acoustic data was to include additional survey estimates from 2002 and 2004 (Table 7). All of the data in Table 7 were used in the sensitivity run labelled “Extra acoustics”.

The acoustic estimates in 1999, 2012 (total = 14 637 t, CV 17%), and 2016, were assumed to represent “most” of the spawning biomass in each year. This was modelled by treating the acoustic estimates as relative biomass and estimating the proportionality constant (q) with an informed prior. The prior was normally distributed with a mean of 0.8 (i.e., “most” = 80%) and a CV of 19% (see Orange Roughy Introduction). The 2013 Graveyard estimate was modelled as relative biomass with an informed prior on the q with a mean of 0.3 (derived from the relative proportions of the Graveyard and Morgue estimates in 2012 with the 80% assumption).

Table 7: Acoustic survey estimates of spawning biomass used in the base model (excludes 2002 and 2004) and the sensitivity run "Extra acoustics" (uses all data). "GY" = Graveyard, "M" = Morgue, "O" = other hills. The CVs are those used in the model and do not include any process error.

Year	System	Frequency	Areas	Snapshots	Estimate (t)	CV (%)
1999	Towed-body	38 kHz	GY+M+O	1	8 126	22
2002	Towed-body	38 kHz	GY+O	2	9 414	20
2004	Hill-mounted	38 kHz	GY	6	2 717	16
2012	AOS	38 kHz	GY	3	5 550	17
	AOS	38 kHz	M	4	9 087	11
2013	AOS	120 kHz	GY	1	6 656	31
2016	AOS	38 kHz	GY	1	0	N/A
	AOS	38 kHz	M	3	14 051	13

Trawl survey data

A wide-area trawl survey of the northwest flats was conducted in late May and early June of 1994 (72 stations; Tracey & Fenaughty 1997). An age-frequency for the trawl-selected biomass was estimated using 300 otoliths selected using the method of Doonan et al (2014). The female proportion spawning-at-age was also estimated. These data were fitted in the model: age frequency (multinomial with an effective sample size of 60); proportion-spawning-at-age (binomial with effective sample size at each age equal to the number of female otoliths at age).

Length frequencies

The length frequencies from the previous assessment in 2006 were used: nine years of length-frequency data from the period 1989–97 were combined into a single length-frequency that was centred on the 1993 fishing year. Eight years of length-frequency data from the period 1998–2005 were combined into a single length-frequency that was centred on the 2002 fishing year. The effective sample size was set at one sixth of the number of tows for each period: 19 for the "1993" period and 35 for the "2002" period (A. Hicks pers. comm.). The data were assumed to be multinomial.

Age frequencies

In addition to the age frequencies from the 1994 trawl survey, an age frequency was developed from samples taken above Morgue during the spawning season in 2016. Approximately 300 otoliths were randomly selected from three tows. The age frequency was fitted as multinomial with effective sample sizes of 60. The 2016 age frequency from Morgue was derived from the use of a demersal trawl fished a few metres off the bottom, and this in part led to concerns about the representativeness of this sampling.

4.1.3 Model runs and results

In the base model, the acoustic estimates from 1999, 2012, 2013, and 2016 were used, and the age-frequency from 2016 was excluded. There were four main sensitivity runs: add the extra acoustic data; the *LowM-Highq* and *HighM-Lowq* "standard" runs (see Orange Roughy Introduction); and including the 2016 age-frequency with its own (logistic) selectivity.

In the base model, the main parameters estimated were: virgin (unfished, equilibrium) biomass (B_0), maturity ogive, trawl-survey (logistic) selectivity, CV of length-at-mean-length-at-age for ages 1 and 100 years (linear interpolation assumed for intermediate ages), and year class strengths (YCS) from 1940 to 1979 (with the Haist parameterisation and "nearly uniform" priors on the free parameters). In the sensitivity run including the 2016 age-frequency the YCS were estimated from 1940 to 1992.

Model diagnostics

The model provided good MPD fits to the data (Figures 3 and 4). The acoustic indices, free to "move" somewhat as they are relative, were fitted well (Figure 3). The posterior estimates for the acoustic *q*s were not very different from the priors, but there was some movement in the Graveyard and Morgue *q*, with the posterior slightly lower (and therefore SSB slightly higher) than expected (Figure 5).

Numerous MPD sensitivity runs were performed. These showed that the main drivers of the estimated stock status were natural mortality (*M*) and the means of the acoustic *q* priors (lower *M* and higher mean *q* give lower stock status; higher *M* and lower mean *q* give higher stock status).

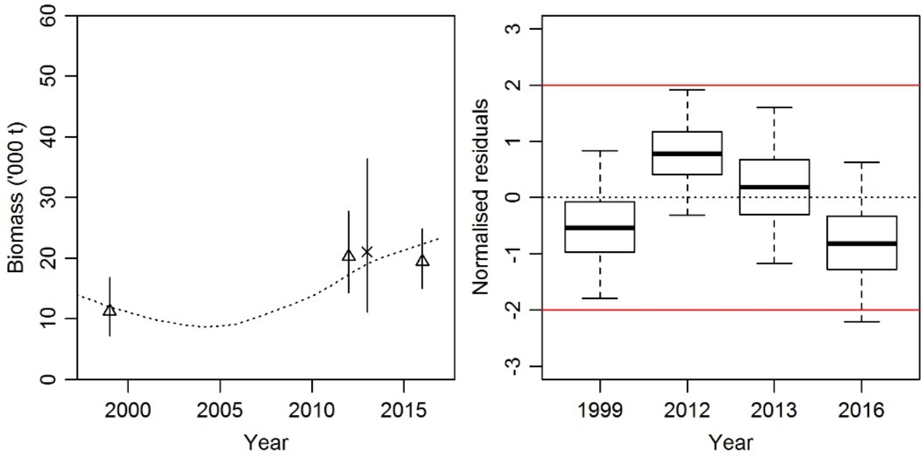


Figure 3: NWCR, base, (left) MPD fits to the acoustic biomass indices; broken line, spawning biomass trajectory; scaled acoustic indices for x, Graveyard survey, and Δ, Graveyard and Morgue surveys; (right) MCMC normalised residuals for the acoustic biomass indices. The box in each year covers 50% of the distribution and the whiskers extend to 95% of the distribution.

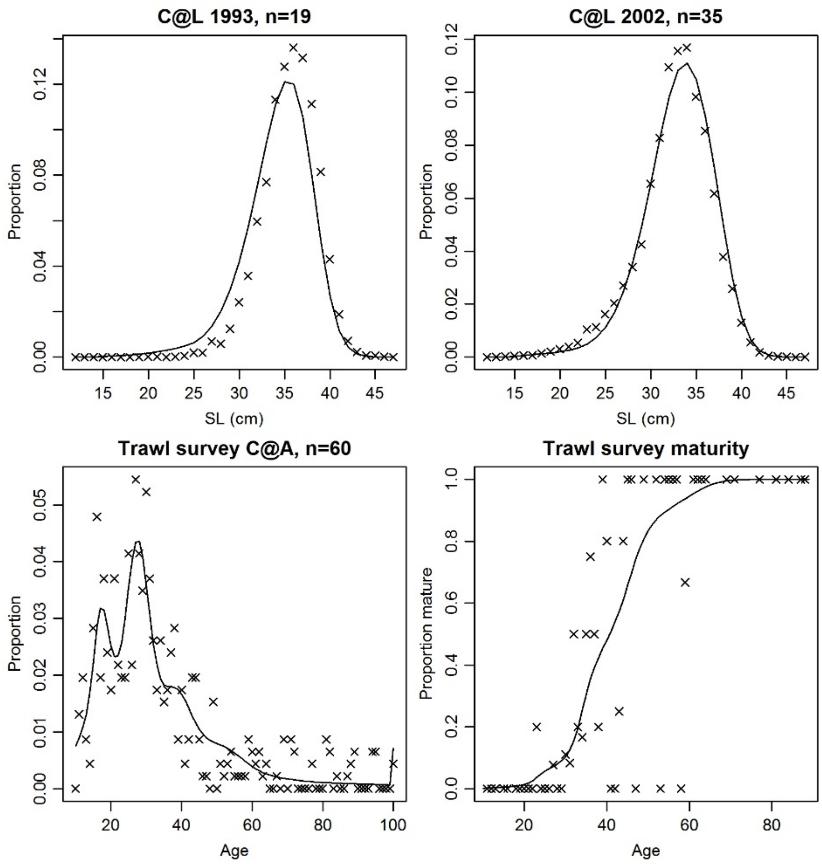


Figure 4: NWCR, base, MPD fits: (x, observations; lines, predictions): (top) commercial catch-at-length samples (n is the effective sample size); (bottom) trawl survey catch-at-age and proportion mature at age.

When the Morgue age-frequency was fitted assuming that the selectivity on Morgue was equal to maturity the fit was poor, particularly to the left-hand side of the age frequency distribution. When the Morgue age frequency was fitted assuming a separate logistic selectivity ogive the fit was acceptable (Figure 6). The Morgue age frequency had an unexpectedly high proportion of older fish, and the sampling methodology was also unusual. As a result, it was agreed to exclude the Morgue age frequency data from the base model.

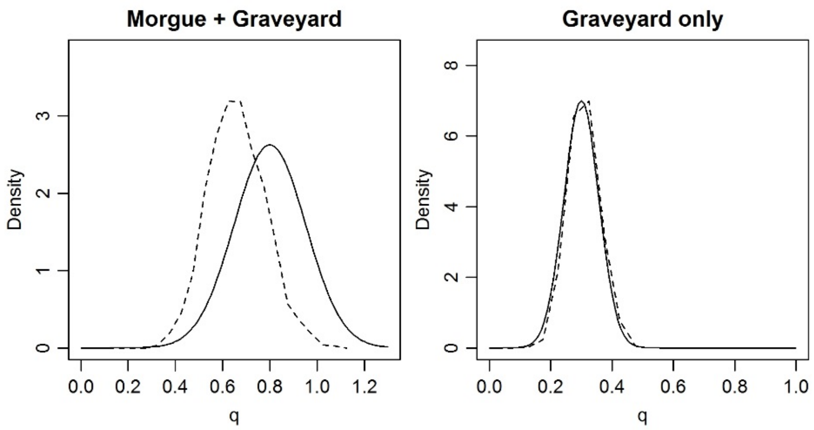


Figure 5: NWCR base, MCMC diagnostics: prior (solid line) and posterior (broken line) distributions for the two acoustic *q*s (left, mean *q*-prior = 0.8; right, mean q-prior = 0.3).

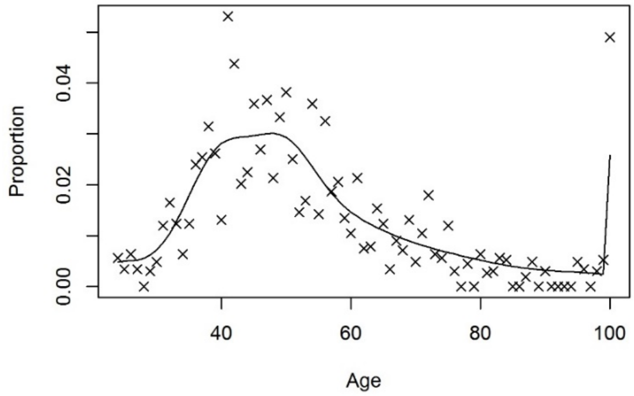


Figure 6: NWCR, base, MPD fits: (x, observations; lines, predictions) to the Morgue age frequency (effective sample size n = 60).

MCMC Results

For the base model, and the sensitivity runs, MCMC convergence diagnostics indicated no lack of convergence. Virgin biomass, B_0, was estimated to be between 64 000–67 300 t for all runs (Table 8). Current stock status was similar across the base and the first two sensitivity runs (Table 8). For the two "bounding" runs, where *M* and the mean of the acoustic *q* priors were shifted by 20%, median current stock status was estimated to be close to the lower bound, or upper bound, of the target range of 30–50% B_0 (Table 8).

Table 8: NWCR, MCMC estimates of virgin biomass (B_0) and stock status (B_{2017} as %B_0) for the base model and four sensitivity runs.

	M	B_0 (000 t)	95% CI	B_{2017} (%B_0)	95% CI
Base	0.045	65.2	59.9–75.0	38	31–48
Extra acoustics	0.045	64.0	60.0–76.7	36	31–43
Include Morgue AF	0.045	65.1	58.6–76.5	38	30–48
Low *M*-High q	0.036	67.3	63.0–73.9	29	23–36
High *M*-Low q	0.054	65.5	58.2–77.7	48	40–58

For the base model, there was a 98% probability that the stock was above 30% B_0 in 2017. For the sensitivity runs, the probability of being above 30% B_0 in 2017 was 98% (Extra acoustics), 97% (Include Morgue AF), 36% (Low *M*-High *q*), and 100% (High *M*-low *q*).

The estimated YCS showed little variation across cohorts, but recruitment was relatively high in 1940–52, 1965–68, and 1975–79 (Figure 7).

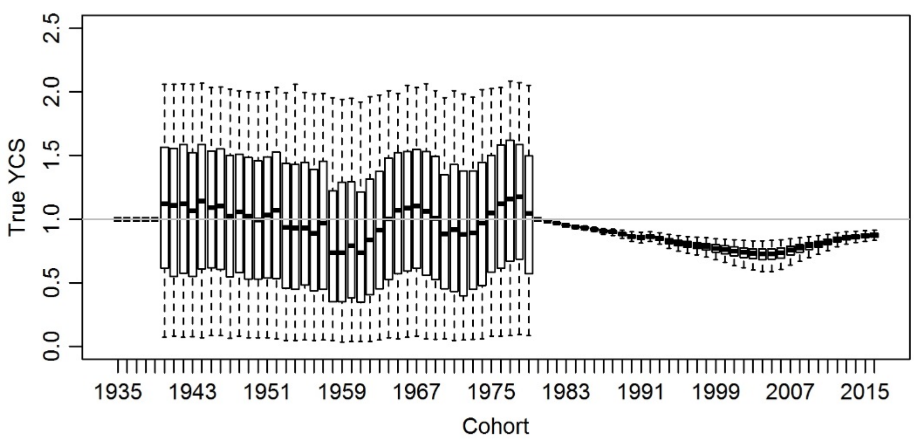


Figure 7: NWCR base, MCMC estimated "true" YCS (R_y/R_0). The box in each year covers 50% of the distribution and the whiskers extend to 95% of the distribution.

The estimated spawning-stock biomass (SSB) trajectory showed a declining trend from 1980 (when the fishery started) through to 2004 when the biomass was About as Likely as Not (40–60%) to be below the soft limit (Figure 8). Since 2005 the estimated biomass has increased steadily.

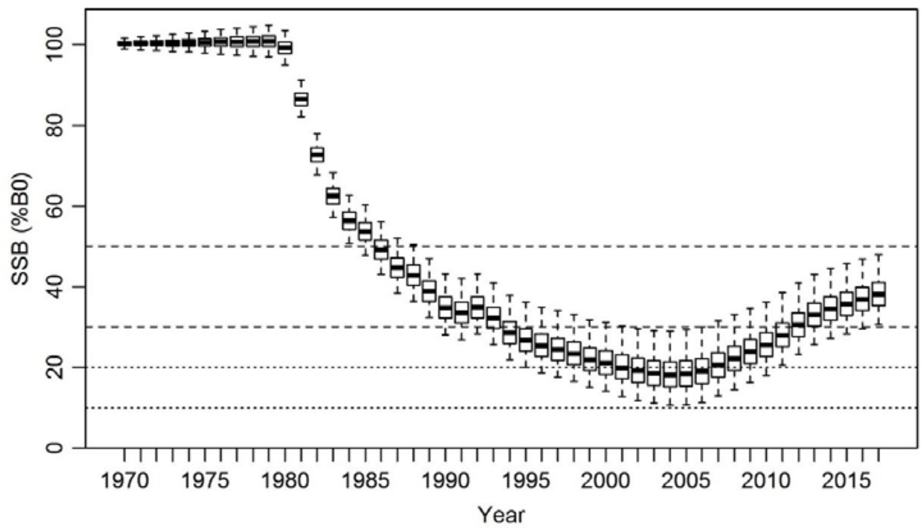


Figure 8: NWCR base, MCMC estimated spawning-stock biomass trajectory. The box in each year covers 50% of the distribution and the whiskers extend to 95% of the distribution. Dotted lines indicate the hard limit (10% B_0) and soft limit (20% B_0), dashed lines the management target range (30–50% B_0).

Fishing intensity was estimated in each year for each MCMC sample to produce a posterior distribution for fishing intensity by year. Fishing intensity is represented in term of the median exploitation rate and the Equilibrium Stock Depletion (ESD). For the latter, a fishing intensity of $U_{x\%B0}$ means that fishing (forever) at that intensity (at that rate, not tonnage) will cause the SSB to reach deterministic equilibrium at x% B_0 (e.g., fishing at $U_{30\%B0}$ forces the SSB to a deterministic equilibrium of 30% B_0). Fishing intensity in these units is plotted as 100–ESD so that fishing intensity ranges from 0 ($U_{100\%B0}$) up to 100 ($U_{0\%B0}$).

Estimated fishing intensity was above $U_{20\%B0}$ for most of the history of the fishery; it was briefly in the target range ($U_{30\%B0}$–$U_{40\%B0}$) from 2009–2010 before dropping substantially when the industry agreed to curtail fishing the NWCR in 2011, and has been in or just below the target range since 2014 (Figure 9). There was less than a 1% probability that the exploitation rate in 2017 was below $U_{30\%B0}$.

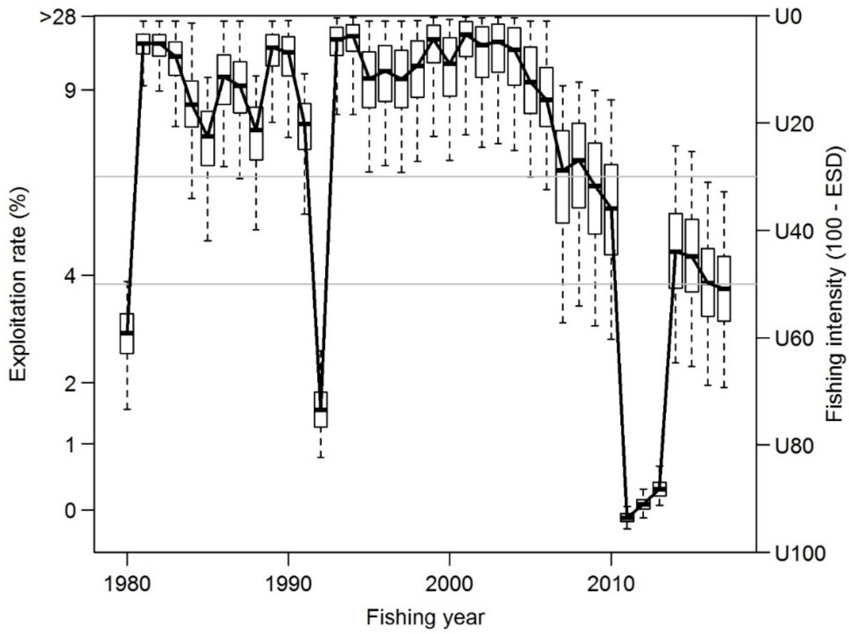


Figure 9: NWCR base, MCMC estimated fishing-intensity trajectory. The box in each year covers 50% of the distribution and the whiskers extend to 95% of the distribution. The fishing-intensity range associated with the biomass target of 30–50% B_0 is marked by horizontal lines.

Projections

Five-year biomass projections were made for the Base model run assuming future catches to be the TACC (1250 t), or the current agreed catch limit (1043 t; 207 t has been shelved). For each projection scenario, future recruitment variability was sampled from actual estimates between 1940 and 1979.

At the TACC (1250 t) and the current agreed catch limit (1043 t), SSB is predicted to remain stable or slowly increase over the next five years, and the probability of the SSB going below the soft or hard limits is zero (Table 9).

Table 9: ORH 3B NWCR Bayesian median and 95% credible intervals (in parentheses) of projected B_{2022}, B_{2022} as a percentage of B_0, and B_{2022}/B_{2017} (%) for the model runs.

Model run	Catch	B_{2022}	B_{2022} (% B_0)	B_{2022}/B_{2017} (%)	p(B_{2022} < 0.2 B_0)	p(B_{2022} < 0.1 B_0)
Base	1 043	26 500 (20 000–38 100)	41 (33–51)	107 (104–111)	0	0
	1 250	25 600 (19 100–37 200)	39 (31–50)	104 (101–107)	0	0

Biological reference points, management targets and yield

Orange roughy stocks with model based stock assessments are managed according to the Harvest Control Rule (HCR) that was developed in 2014 using a Management Strategy Evaluation (MSE) (Cordue 2014b). The HCR has a target management range of 30–50% B_0.

Yield estimates are not reported for this stock.

4.2 East and South Chatham Rise

The East and South Chatham Rise (ESCR) stock was assessed in 2014 (Cordue 2014a). The assessment was updated in 2018 using data up to 2016–17 (Dunn & Doonan 2018). That assessment was then updated to the end of 2017–18 to allow application of the orange roughy Harvest Control Rule (HCR) (Cordue 2014b, 2018). The assessment has been updated in 2020 to apply the HCR to calculate a catch recommendation for 2020–21. In each assessment the model was an age-structured population model fitted to acoustic-survey estimates of spawning biomass, trawl-survey biomass indices, age frequencies from spawning aggregations, and length frequencies from trawl surveys and commercial fisheries.

4.2.1 Model structure

The model was single-sex and age-structured (1–100 years with a plus group), with maturity estimated separately (i.e., fish were classified by age and as mature or immature). A single-time step was used and, in the updated base model, four year-round fisheries, with logistic selectivities, were modelled: Box & flats, Eastern hills, Andes, and South Rise. These fisheries were chosen following Dunn (2007) who assessed the Box & flats, Eastern hills, and Andes as separate stocks and hence had already prepared length frequency data for those fisheries. No length frequencies were available from the South Rise fishery and its selectivity was assumed to be the same as the Andes (so effectively there were three fisheries in the model). Spawning was taken to occur after 75% of the mortality and 100% of mature fish were assumed to spawn each year.

The catch history was constructed by apportioning the total ORH 3B reported catch across areas using catch proportions from estimated catch on TCEPR forms (Table 2). The over-run percentages in Table 6 were applied. Natural mortality was assumed fixed at 0.045 and the stock-recruitment relationship was assumed to follow a Beverton-Holt function with steepness of 0.75. The remaining fixed biological parameters are given in table 2 of the Orange Roughy Introduction section.

4.2.2 Input data and statistical assumptions

There were four main data sources for observations fitted in the assessment: acoustic-survey spawning biomass estimates from the Old-plume (2002–2014, 2016), Rekohu (2011–2014, 2016) and the Crack (2011, 2013, 2016); age frequencies from the spawning areas (2012, 2013, and 2016); trawl survey biomass indices and length frequencies; and length frequencies collected from the commercial fisheries.

Acoustic estimates

The Old plume was acoustically surveyed as early as 1996, but the survey estimates are only considered to represent a consistent time series from 2002–2012 (see Cordue 2008; Hampton et al 2008, 2009, 2010; Doonan et al 2012). Like the Rekohu plume, which was first noted in 2010 and first surveyed in 2011, the Old plume occurs on an area of flat bottom and can be adequately surveyed using a hull-mounted transducer. In 2011, 2013 and 2016, an additional (but known historically) spawning area was surveyed; known as the Crack (also known as Mt. Muck), it is an area of rough terrain which requires a towed-body or trawl-mounted system to be used to reduce the height of the shadow or dead zone (i.e., with the transducer at a depth of about 500–700 m).

The estimates selected by the DWFAWG for use in the stock assessment are shown in Table 10. In order to make the estimates as comparable as possible across years, only biomass estimates from 38 kHz transducers were used and those from the hull-mounted system were weather-adjusted in the same way as earlier estimates (see presentations from Kloser and Ryan to the DWFAWG meetings in 2013 and 2014).

A key question evaluated in the 2014 assessment was how long the Rekohu plume has been in existence (Cordue, 2014a). If the Rekohu plume had always existed (and was not discovered until 2010) then it would be one of three major spawning sites and could be modelled as such along with the Old plume and the Crack. This would imply that the Old-plume time series was tracking a consistent part of the spawning biomass (and its decline over time was therefore an important indicator of stock status). If, on the other hand, the Rekohu plume had very recently formed, this would imply that the Old-plume time series was a biomass index only up until the year before the Rekohu plume came into existence.

Following Cordue (2014a), it is assumed that the Old-plume time series cannot be relied on to provide a consistent index for any part of the spawning biomass. In 2011, 2013 and 2016, the estimates of average spawning biomass across the three areas were summed to form comparable indices for each year. The 2012 and 2014 estimates from Rekohu and the Old-plume were summed to provide a 2012 and 2014 index with a different proportionality constant q. The Old-plume indices from 2002–2010 were used, but each point in the time series was given its own q. Informed priors were used for all of the qs in the Old-plume series, for the 2012 and 2014 biomass indices, and the indices comprising 2011, 2013, and 2016 observations.

For 2011, 2013, and 2016, it was assumed that "most" of the biomass was being indexed so the "standard" acoustic *q* prior was used for this proportionality constant (q_1): lognormal (mean = 0.8, CV = 19%) (see Orange Roughy Introduction). The mean of the *q* prior for 2012 and 2014 was derived from the observed biomass proportions across the three areas and the assumption that 80% of the spawning biomass was indexed in 2011, 2013 and 2016. This gave a mean of 0.7 for the proportionality constant (q_2) of the 2012 and 2014 indices, a reflection that this index did not include an estimate for the Crack. For 2002 to 2010 the means of the *q* priors were assumed to decrease linearly from 0.7 (2002) down to 0.30 (2010), reflecting the gradual increase in the relative importance of the Rekohu plume. The linear sequence was derived by assuming 0.7 in 2002 (i.e., assuming that the Rekohu plume did not exist and only the Crack was missing from the survey estimate) and using the observed biomass proportions in 2011 with the 80% assumption (which gave the Old-plume being about 25% of the total spawning biomass). To reflect the increased uncertainty in the acoustic *q*s in years other than 2011 and 2013, the priors were given an increased CV of 30%.

Table 10: Acoustic estimates of average pluming spawning biomass in the three main spawning areas as used in the assessment. All estimates were obtained from surveys on *FV San Waitaki* from 38 kHz transducers. Each estimate is the average of a number of snapshots as reflected by the estimated CVs. Some estimates have been revised since the 2014 assessment (Dunn & Doonan 2018).

	Old plume		Rekohu		Crack	
	Estimate (t)	CV (%)	Estimate (t)	CV (%)	Estimate (t)	CV (%)
2002	63 950	6	–	–	–	–
2003	44 316	6	–	–	–	–
2004	44 968	8	–	–	–	–
2005	43 923	4	–	–	–	–
2006	47 450	10	–	–	–	–
2007	34 427	5	–	–	–	–
2008	31 668	8	–	–	–	–
2009	28 199	5	–	–	–	–
2010	21 205	7	–	–	–	–
2011	16 422	8	28 113	18	6 794	21
2012	19 392	7	27 121	10	–	–
2013	15 554	14	33 348	10	5 471	16
2014	19 360	18	44 421	25	–	–
2015	–	–	–	–	–	–
2016	11 192	13	27 027	13	5 341	10

As well as updating the base model, two additional runs were made which had different assumptions with regard to the acoustic *q*s. In the standard LowMhighq sensitivity run the means of the acoustic *q* priors were all increased by 20% (and the value of *M* was decreased by 20%). In the "q-ratio model" a prior was placed on the ratio q_1/q_2. The standard lognormal prior was used for q_1 and a uniform prior for q_2. A lognormal prior was used for the ratio with the mean equal to 1.14 (0.8/0.7) and a CV of 7.5% which strongly encouraged the ratio to be greater than 1 (reflecting that three areas had been surveyed for the first time series but only two of those areas for the second time series).

There was no agreement in the DWFAWG as to whether the updated base model or the q-ratio model was to be preferred. The LowMhighq model was run relative to the updated base model as that had the lowest estimated stock status and therefore the LowMhighq model would be a "worst case" scenario as intended. The updated base model is denoted as the "current model" rather than the base model.

Trawl survey data

Research trawl surveys of the Spawning Box during July were completed from 1984 to 1994, using three different vessels: FV *Otago Buccaneer*, FV *Cordella*, and RV *Tangaroa* (Figure 10). A consistent area was surveyed using fixed station positions (with some random second phase stations each year).

The biomass indices were fitted as relative indices with a separate time series for each vessel (with uninformed priors on the *q*s). The second point in the *Tangaroa* time series, although very large (driven by a single high catch), has a large CV and so is unlikely to have had much effect on the assessment results.

Data from two wide-area surveys by *Tangaroa* in 2004 and 2007 were also used. These surveys covered the area which extends from the western edge of the Spawning Box around to the northern edge of the Andes. The area surveyed did not include the Old-plume, the Northeast Hills, or the Andes. The survey used a random design over sixteen strata grouped into five sub-areas. The trawl net used was the full-wing and relatively fine mesh 'ratcatcher' net. The surveys covered the same survey area as the Spawning Box trawl surveys from 1984 to 1994 as well as additional strata to the east. In 2007, the survey ran from 4–27 July and 62 trawl tows were completed. In 2004, the survey ran from 7–29 July and 57 trawl tows were completed.

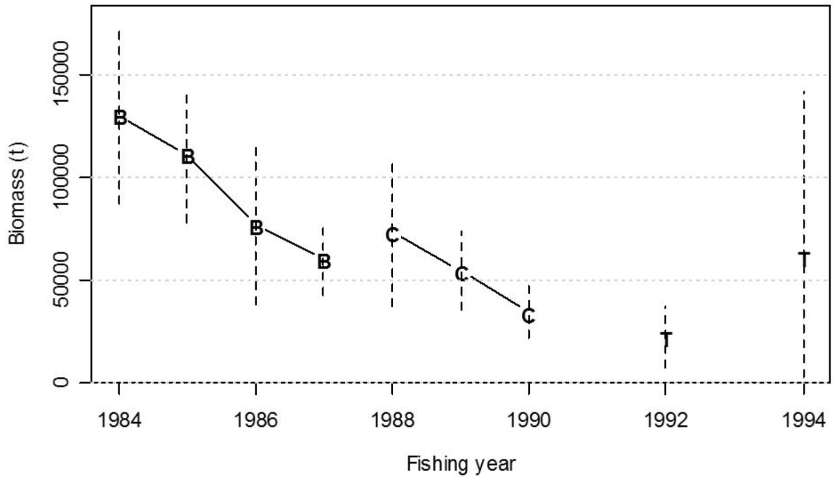


Figure 10: The Spawning Box trawl survey biomass indices (assuming a catchability of 1 for each vessel), with 95% confidence intervals shown as vertical lines. Vessels indicated as B, FV *Otago Buccaneer*; C, FV *Cordella*; T, RV *Tangaroa*.

The surveys had almost identical estimates of total biomass in each year (17 000 t) with low CVs (10% and 13% respectively). They were fitted as relative biomass with an uninformed prior on the *q*.

Length frequencies

The length frequencies from all of the trawl surveys were fitted in the model as multinomial random variables. Effective sample sizes (N) were taken from Dunn (2007) for the Spawning Box surveys and were assumed equal to the number of tows for the wide-area surveys (across all surveys the effective Ns ranged from about 20–80). Trawl survey length frequencies were fitted assuming that all mature fish were selected, but immature fish were selected assuming capped-logistic ogives. One selectivity ogive for immature fish was shared by the *Buccaneer*, *Cordella*, and *Tangaroa* Spawning Box surveys, with a second ogive for the immature fish caught in the *Tangaroa* wide-area survey.

Length frequencies from the commercial fisheries were developed by Hicks (2006) and also fitted in the model. For the Spawning Box and associated flat ground fishery, three years of length-frequency data from the period 1989–91 were combined into a single length-frequency that was centred on 1990, and four years 2002–05 were combined and centred on 2004. In a similar way, for Andes four years 1992–95 were combined and centred on 1993, three years 1997–99 combined and centred on 1998, and five years combined 2001–05 and centred on 2003. For the eastern hills, seven years 1991–97 were combined and centred on 1995, and five years 2001–05 combined and centred on 2003. These were fitted as multinomial with effective sample sizes ranging from 8–38.

Age frequencies

Age frequencies were developed for the Old-plume and Rekohu plume in 2012, and for the Old-plume, Rekohu, and the Crack in 2013 and 2016 (Doonan et al 2014a, b; 2018). Approximately 300 otoliths were randomly selected from each area in 2012 and 2016, and 250 from each area in 2013. The fish in the Old-plume were noted to be generally older than those in the Rekohu plume. The fish from the Crack, showed a mixture of ages from new spawners (20–30 years) through to much older fish (80–100 years). In the base model, the age frequencies were combined across areas and fitted as multinomial with effective sample sizes of 50 (2012) and 60 (2013 and 2016) respectively, reflecting the low number of trawls from which samples were taken.

4.2.3 Model runs and results

As well the updated base model (denoted as the “current model”) there were two additional models: the q-ratio model which assumed a single fishery on mature fish, had a prior on q_1/q_2, and added 20% process error to the associated acoustic biomass indices; and the standard LowMhighq model (see Orange roughy Introduction)

In all three models, the main parameters estimated were: virgin (unfished, equilibrium) biomass (B_0), the maturity ogive, trawl-survey selectivities, fisheries selectivities, CV of length-at-mean-length-at-age for ages 1 and 100 years (linear relationship assumed for intermediate ages), and year class strengths (YCS) from 1930 to 1990 (with the Haist parameterisation and “nearly uniform” priors on the free parameters). There were also the numerous acoustic and trawl-survey *q*s.

MCMC chain diagnostics

For each model, three chains of fifteen million iterations were run. One sample in each one thousand iterations were stored and the first one thousand samples were discarded as a “burn-in” (the chains start near the MPD estimate and early samples may be unrepresentative of the posterior distribution). The traces of the main free parameters were checked to make sure that they did not exhibit any long term trends and the estimates of B_0 and current stock status ($ss_{2020} = B_{2020}/B_0$) from each chain were checked to see that they were the same to two significant figures. Point estimates (median) and 95% credibility intervals (95% CIs) were constructed using all three chains combined after the burn-in (a total of 42 000 samples).

Model diagnostics

MPD fits and MCMC fits and residuals and marginal posterior distributions for the *q*s were examined for the current model and the q-ratio model. In general, the fits were excellent and the *q* posterior distributions and standardised residuals were acceptable (see Figures 11–13). The main exception was for the current model where the normalised residuals for the 2016 acoustic estimate are well outside the expected range (Figure 14). In the q-ratio model the residuals are much improved because of the addition of 20% process error (the CV is only 10% in the current model which is just a measure of observation error).

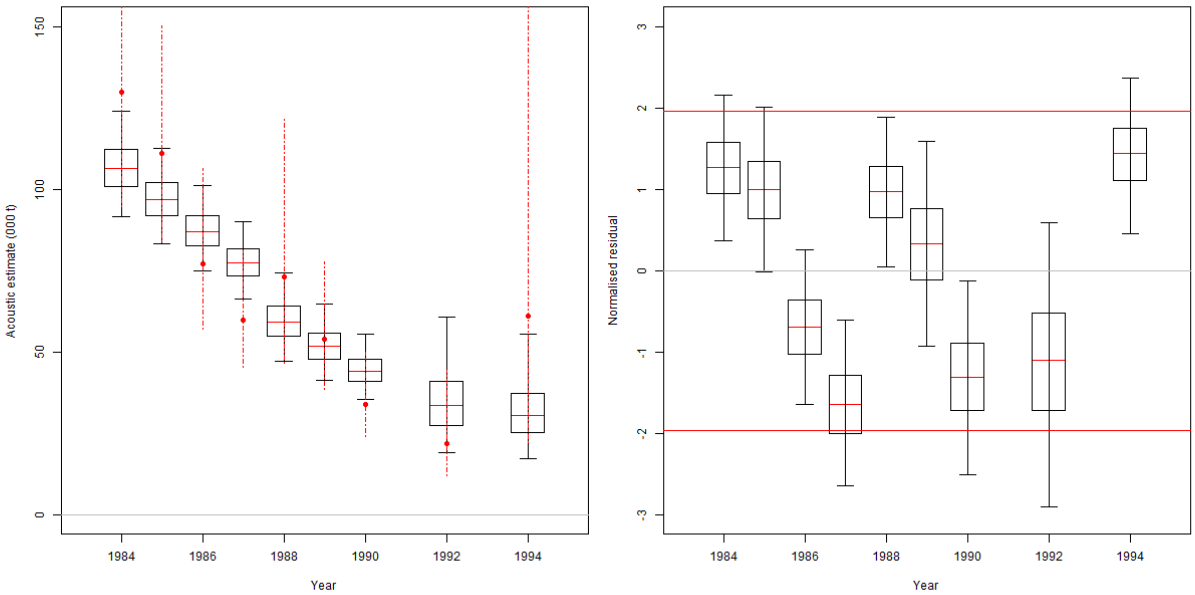


Figure 11: Current model: the MCMC fits and normalised residuals for the trawl survey biomass estimates in the spawning box. The observations are plotted with 95% confidence intervals (left plot, red vertical lines). The MCMC predictions (left plot) and normalised residuals (right plot) are plotted as a “box and whiskers”. The middle 50% of the distribution is in the box with the whiskers extending to a 95% C.I.

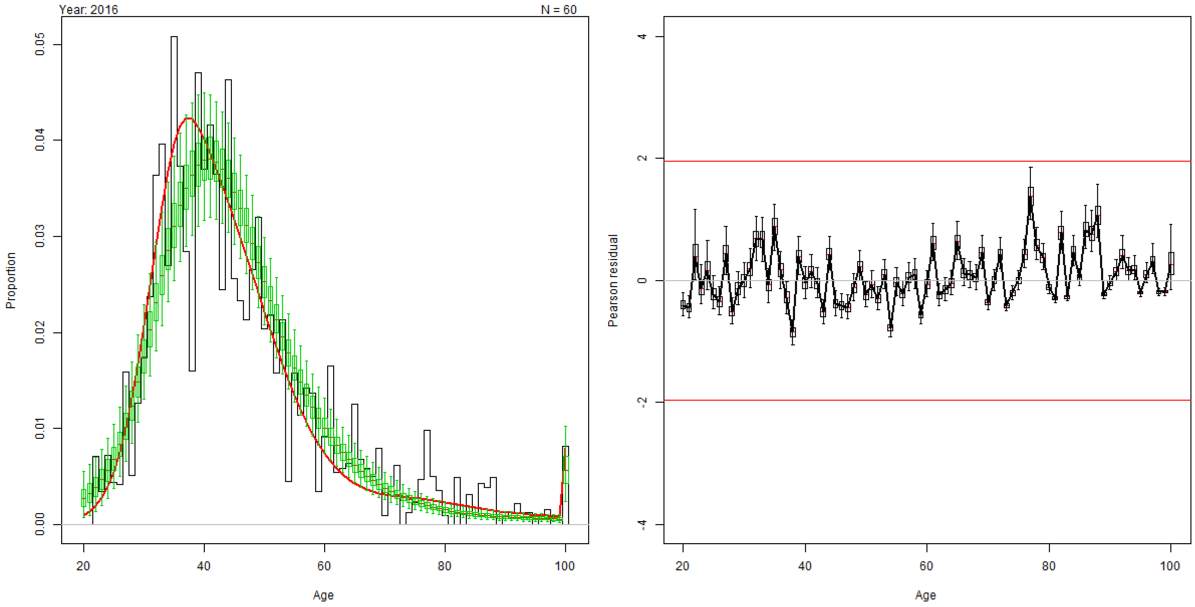


Figure 12: Current model: the MCMC fits and normalised residuals for the 2016 spawning population age frequency (left plot, histogram in black). The MPD fit is shown as the red line in the left plot. The MCMC predictions (left plot) and Pearson residuals (right plot) are plotted as a "box and whiskers". The middle 50% of the distribution is in the box with the whiskers extending to a 95% C.I.

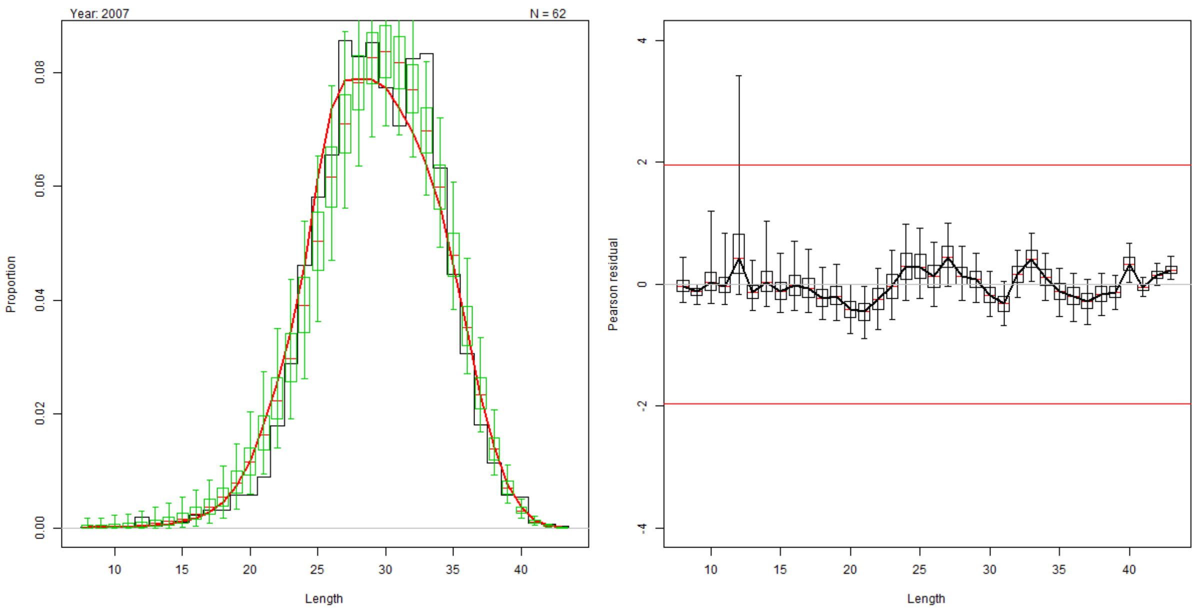


Figure 13: Current model: the MCMC fits and normalised residuals for the 2007 wide-area trawl survey length frequency (left plot, histogram in black). The MPD fit is shown as the red line in the left plot. The MCMC predictions (left plot) and Pearson residuals (right plot) are plotted as a "box and whiskers". The middle 50% of the distribution is in the box with the whiskers extending to a 95% C.I.

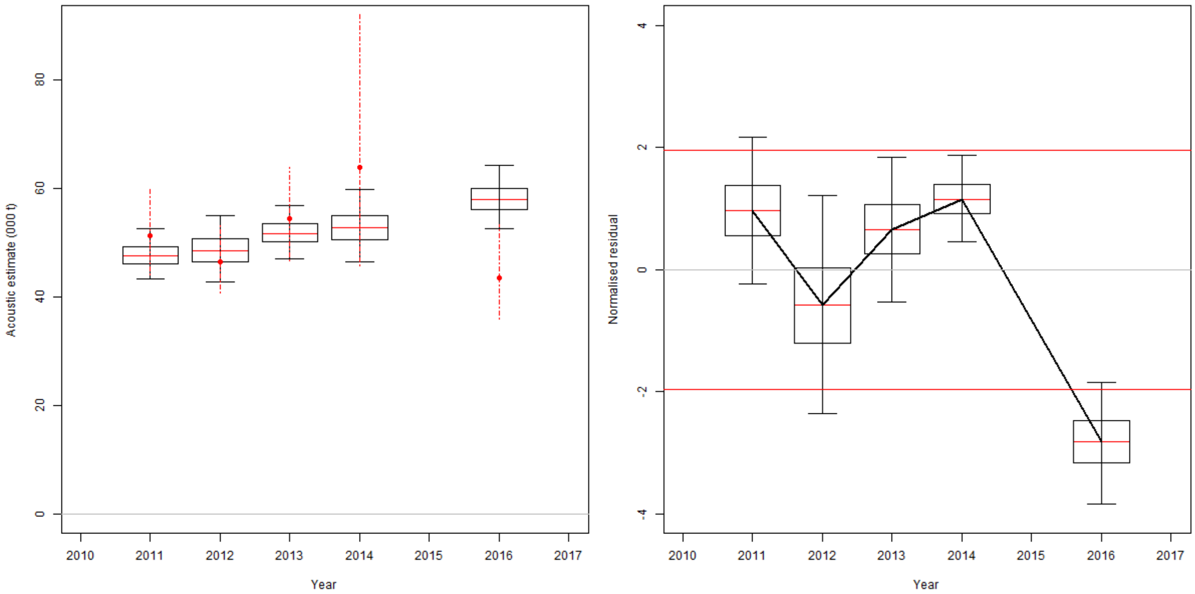


Figure 14: Current model: the MCMC fits and normalised residuals for the acoustic survey biomass estimates since 2011. The observations are plotted with 95% confidence intervals (left plot, red vertical lines). The MCMC predictions (left plot) and normalised residuals (right plot) are plotted as a “box and whiskers”. The middle 50% of the distribution is in the box with the whiskers extending to a 95% C.I.

The marginal posterior distributions for the two main acoustic *q*s are well within their prior distributions (Figure 15). However, in the current model the ratio of the two *q*s has a probability of being less than 1 of 39%. A value less than 1 must be considered very unlikely as an extra area is surveyed for the q_1 time series. This is the main reason for the q-ratio model which corrects this diagnostic through the informed prior (and has a marginal posterior distribution with only a 5% probability of being less than 1).

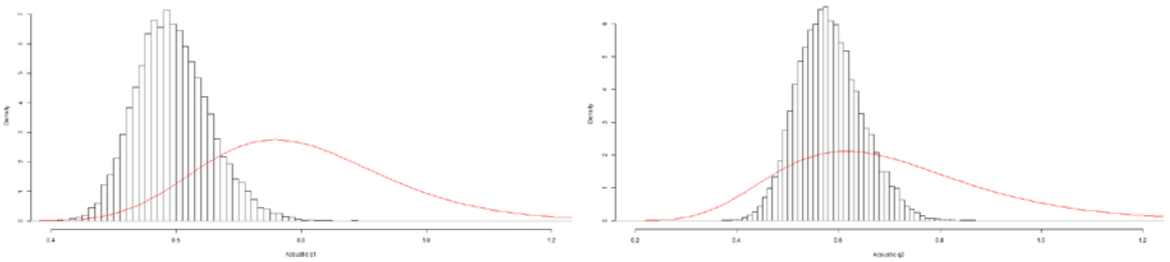


Figure 15: Current model: the prior distributions (red lines) and marginal posterior distributions (histograms) for the two main acoustic *q*s.

MCMC results

Virgin biomass, B_0, was estimated to be about 300 000–350 000 t for the three models (Table 11). Current stock status was similar for the current and q-ratio models, both having the 95% CIs above 30% B_0 (Table 11). The pessimistic LowMhighq run has stock status estimated just below 30% B_0 (Table 11).

Table 11: ESCR, MCMC estimates of virgin biomass (B_0), current biomass (B_{2020}), and stock status (B_{2020} as $\%B_0$) for the three models..

	B_0 (000 t)		B_{2020} (000 t)		Stock status ($\%B_0$)	
	Median	95% CI	Median	95% CI	Median	95% CI
Current model	312	281–346	111	91–135	36	30–41
q-ratio model	354	331–380	135	109–164	38	32–44
LowMhighq	337	308–363	90	71–111	27	22–32

The estimated YCS show little variation across cohorts but do exhibit a long-term trend (Figure 16). The stock status trajectory shows a steady decline from the start of fishery until the mid-1990s, where it remained in the 20–30% range until an upturn in about 2010 (Figure 17).

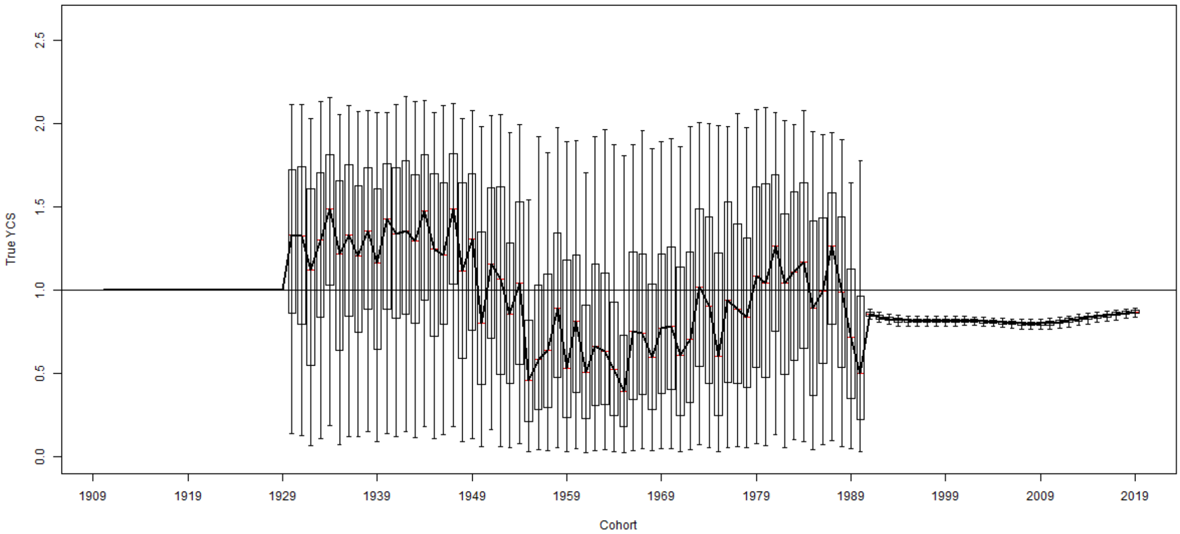


Figure 16: ESCR current model, MCMC estimated "true" YCS (R_y/R_0). The box in each year covers 50% of the distribution and the whiskers extend to 95% of the distribution. Year classes between 1930 and 1990 were estimated.

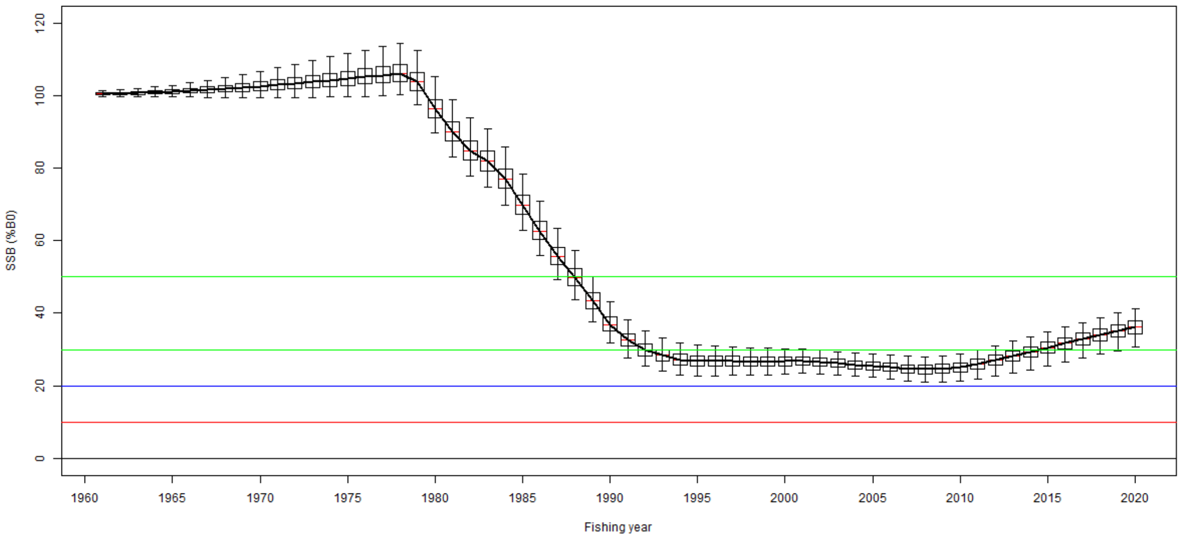


Figure 17: ESCR current model, MCMC estimated spawning-stock biomass trajectory. The box in each year covers 50% of the distribution and the whiskers extend to 95% of the distribution. Horizontal lines are plotted at the hard limit (10% B_0), the soft limit (20% B_0), and the biomass target range (30–50% B_0).

Fishing intensity was approximated using an average exploitation rate (total catch divided by catch-weighted beginning-of-year vulnerable biomass). Estimated exploitation rates were within or above the target range ($U_{30\%B0}$–$U_{50\%B0}$) up to 2009–10. Since 2010–11 they have generally been below the target range (Figure 18).

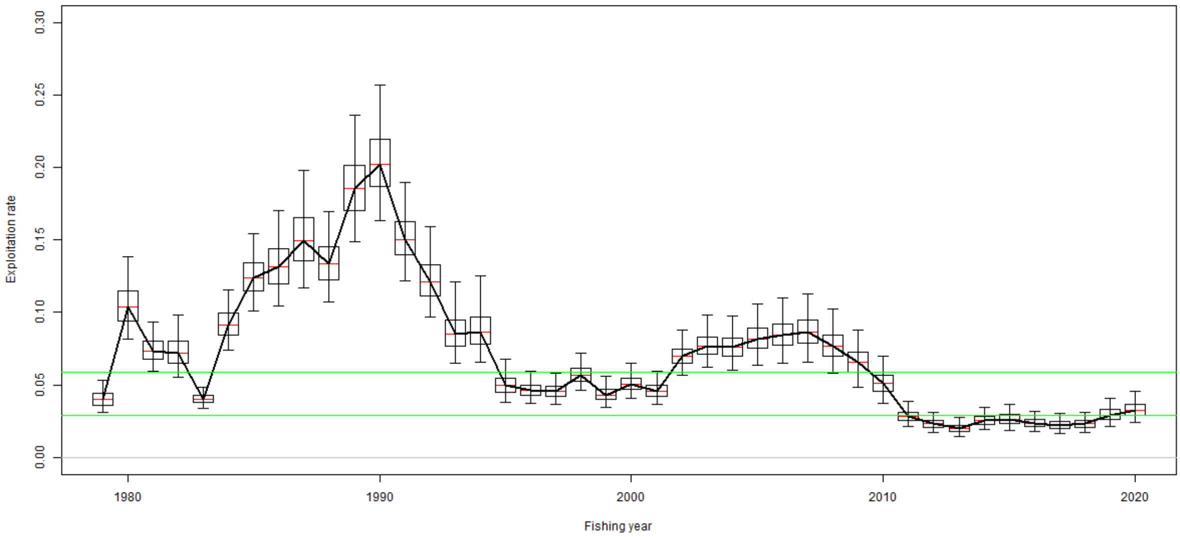


Figure 18: ESCR current model, MCMC estimated exploitation rates. The box in each year covers 50% of the distribution and the whiskers extend to 95% of the distribution. The exploitation rates associated with the biomass target of 30–50% B_0 are marked by horizontal lines at $U_{30\%B0}$ and $U_{50\%B0}$.

Biological reference points, management targets and yield

Catch limits for the ESCR stock are recommended from the Harvest Control Rule (HCR) that was developed in 2014 using a Management Strategy Evaluation (MSE) (Cordue 2014b). The HCR has a target management range of 30–50% B_0. Within that range there is a linear relationship between current estimated stock status and the instantaneous fishing mortality (exploitation rate) that is applied to next year's beginning-of-year vulnerable biomass to obtain the recommended catch limit (Figure 19).

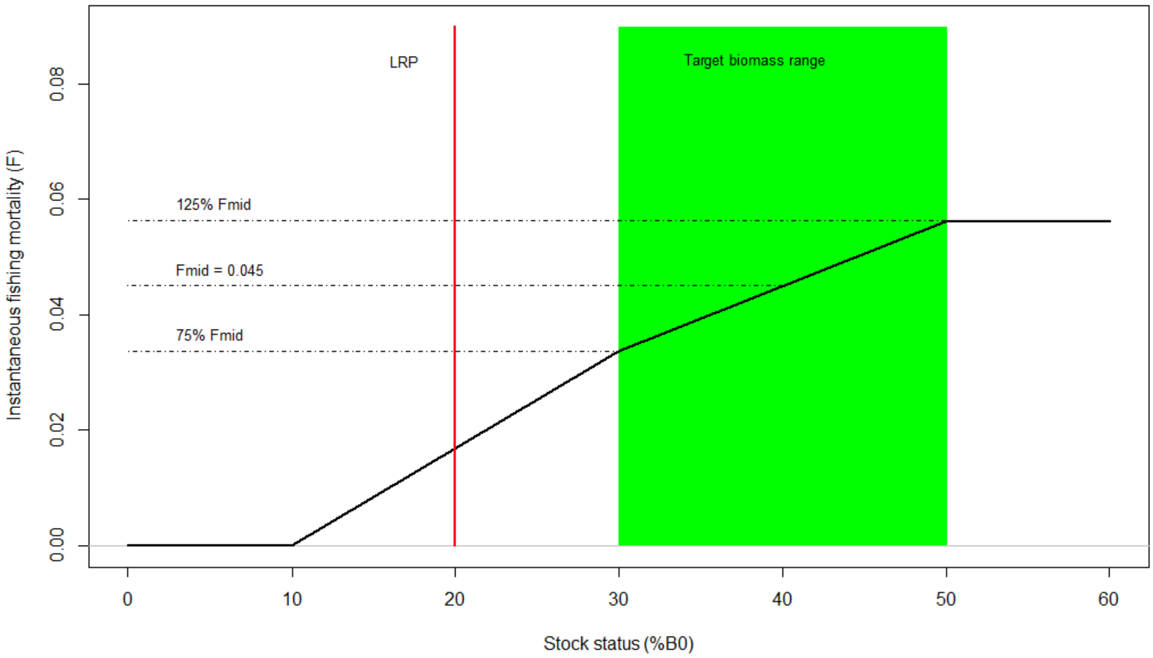


Figure 19: The orange roughy HCR showing the relationship between current estimated stock status and the instantaneous fishing mortality rate (or exploitation rate) applied to next year's beginning-of-year vulnerable biomass to derive the recommended catch limit. The target biomass range is 30–50% B_0 and the limit reference point (LRP) is 20% B_0 (see Cordue 2014b).

The HCR was applied to the current model and the q-ratio model. The medians of the marginal posterior distributions are used in the calculation. As estimated stock status is less than 40% B_0 in both runs the exploitation rates are less than F_{mid} = 0.045 (Figure 19, Table 12). The slightly higher stock status for the q-ratio model gives a higher exploitation rate than the current model but because of the lower vulnerable biomass the recommended catch limit from both models is similar (Table 12).

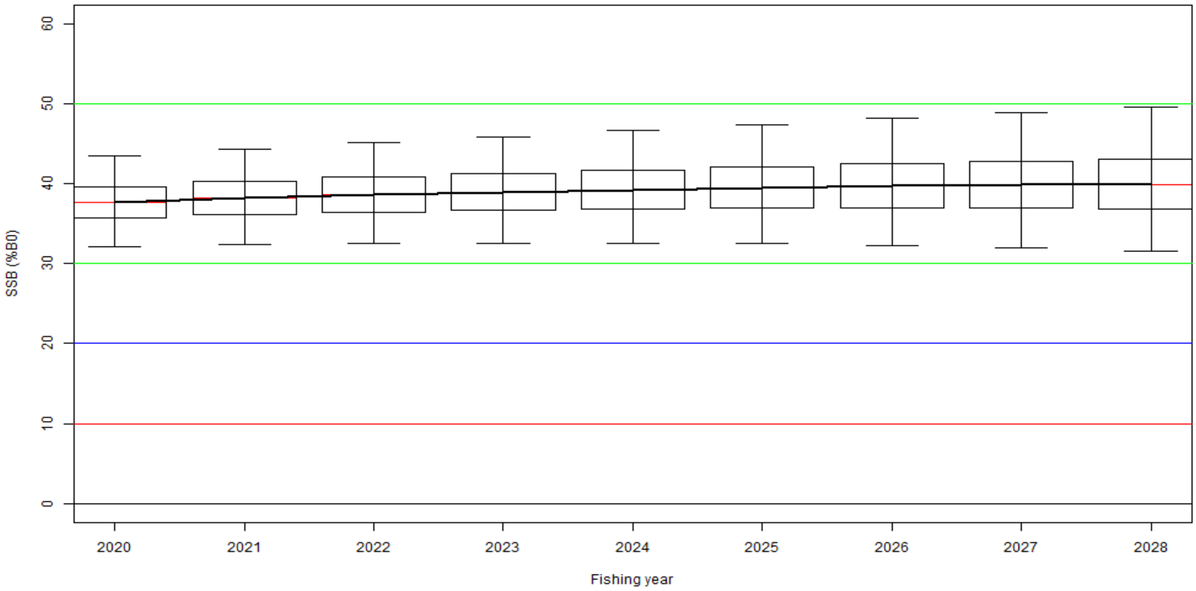
Table 12: The estimated stock status in 2019–20, the catch-weighted vulnerable biomass at the beginning of 2020–21, and the associated exploitation rate and recommended catch limit from the HCR for the current model and the q-ratio model.

Model	Stock status (%B_0)	Exploitation rate	Vulnerable biomass (t)	Catch limit (t)
Current model	36	0.04050	156 735	6 348
q-ratio model	38	0.04275	146 977	6 283

Projections

Projections at the recommended catch limits (plus 5% to allow for incidental mortality) were performed for the current model and the q-ratio model. The highest of the two catch limits was used in a projection for the LowMhighq model. This was to check that the highest HCR recommended catch limit was still safe even if the pessimistic scenario represented by the LowMhighq model was true. Projections were done over 8 years as the HCR is meant to be applied every four years. Random recruitment was brought in from 1991 by resampling from the last ten years of estimated YCS (1981–1990).

In each case, stock status was projected to rise slowly from the current estimated stock status and there was close to zero probability of the stock status being below 20% B_0 over the next 8 years (Figure 20).



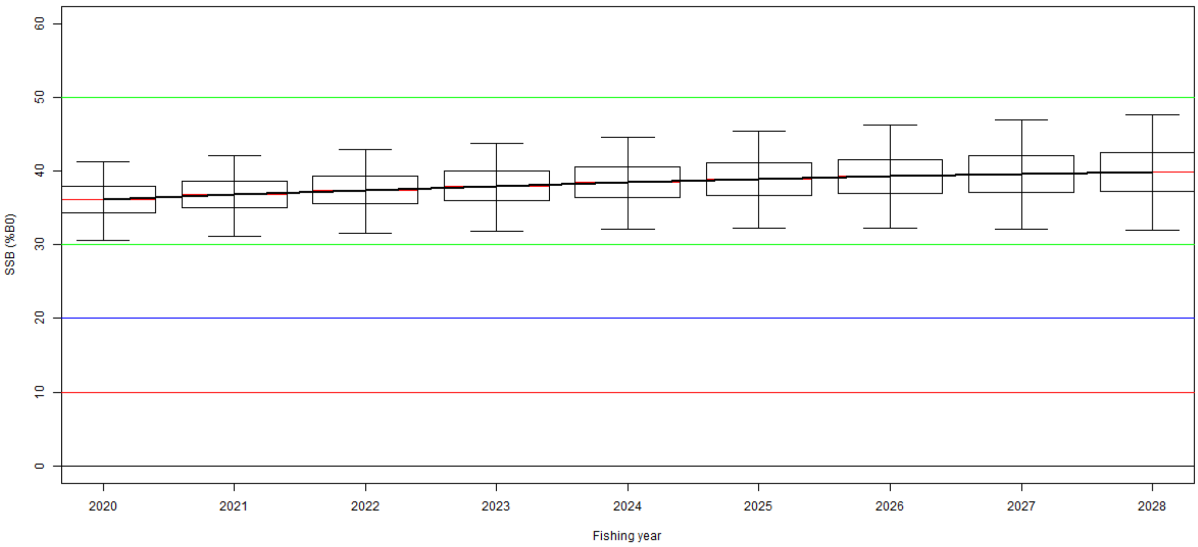


Figure 20: Projected stock status for catches at the HCR recommended catch limits plus 5% to allow for incidental mortality. Top left: q-ratio model projected at 6283 t (plus 5%). Top right: current model projected at 6348 t (plus 5%). Bottom left: LowMhighq model projected at 6348 t (plus 5%). Each box covers the middle 50% of the distribution and the whiskers extend to 95% CIs. [Continued on next page]

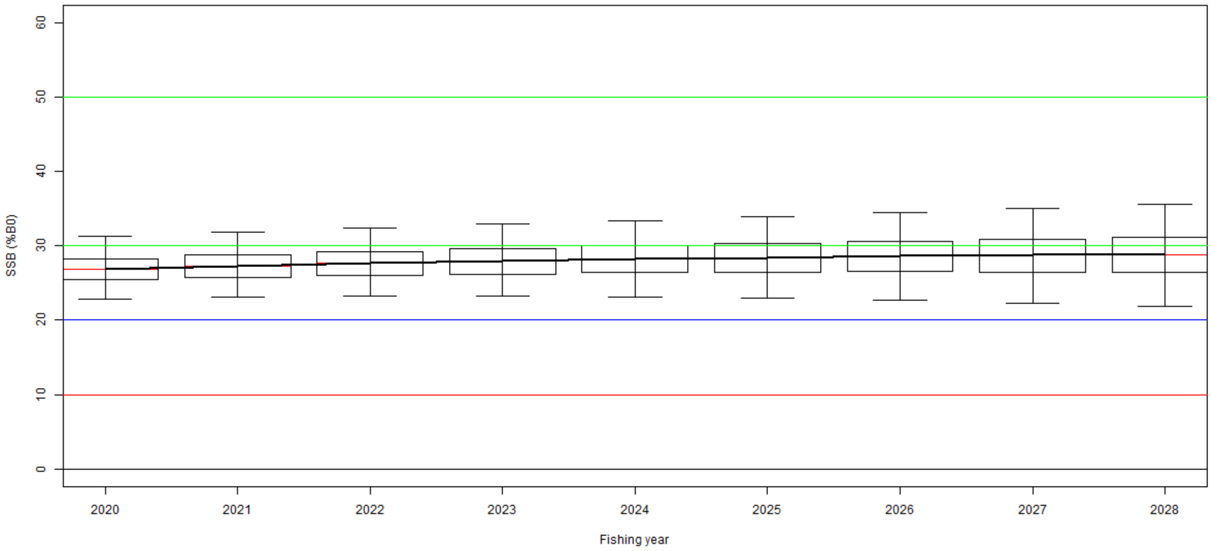


Figure 20 [Continued]: Projected stock status for catches at the HCR recommended catch limits plus 5% to allow for incidental mortality. Top left: q-ratio model projected at 6283 t (plus 5%). Top right: current model projected at 6348 t (plus 5%). Bottom left: LowMhighq model projected at 6348 t (plus 5%). Each box covers the middle 50% of the distribution and the whiskers extend to 95% CIs.

4.3 Puysegur

A Bayesian stock assessment was conducted for the Puysegur stock in 2017 using very similar methods to those used in the 2014 orange roughy stock assessments of ESCR, NWCR, MEC, and ORH 7A (Cordue 2014a). An age-structured population model was fitted to an acoustic-survey estimate of spawning biomass, two trawl-survey indices and associated length frequencies, two spawning-season age frequencies, and a small number of length frequencies from the commercial fishery.

4.3.1 Model structure

The model was single-sex and age-structured (1–120 years with a plus group), with maturity estimated separately (i.e., fish were classified by age and as mature or immature). Two time steps were used to model a non-spawning season fishery and a spawning season fishery. Spawning was taken to occur after 50% of the spawning-season mortality and 100% of mature fish were assumed to spawn each year.

The catch history as reported in Table 5 (see above) was split into a spawning (June-August) and a non-spawning season (October-May and September) using the ratio of estimated catches, with the addition of catches during 2005, 2006, and 2015 when fish were caught during acoustic surveys. The catch for 2016–17 was assumed to be zero. Natural mortality was fixed at 0.045 and the stock-recruitment relationship was assumed to follow a Beverton-Holt function with steepness of 0.75. The remaining fixed biological parameters are given in table 2 of the Orange Roughy Introduction section (ESCR growth parameters were assumed).

4.3.2 Input data and statistical assumptions

There were four main data sources used in the assessment: an acoustic-survey spawning biomass estimate in 2015 from the main spawning hill (Goomzy); two age frequencies during the spawning seasons in 1992 and 2015; biomass indices and length frequencies from trawl surveys in 1992 and 1994; and scaled length frequencies developed from Scientific Observer data collected from the commercial fishery in 1994 and 1997.

Acoustic estimate

Two types of acoustic-survey estimates were available for use in the assessment: an estimate from a 38 kHz hull-mounted system during an AOS survey (AOS is a multi-frequency towed system, see for example Kloser et al 2011) and 38 kHz estimates from a hull-mounted system. The reliability of the data from the different surveys and the two main hills was considered and only the estimate from the 2015 survey on Goomzy was used in the base model (Table 13). The estimates from Godiva were unreliable because the surveyed marks contained a mix of species (Hampton et al 2005, 2006). In 2005 and 2006 it was not clear that the marks on Goomzy were exclusively orange roughy but in 2015 there was strong evidence from both trawling and the multi-frequency system that the surveyed marks were almost exclusively orange roughy (Ryan & Tilney 2016).

Table 13: Acoustic survey estimates of spawning biomass available to the stock assessment. Only the 2015 estimate from Goomzy was used in the base model.

Year	Area	Snapshots	Estimate (t)	CV (%)
2005	Godiva	3	2 600	23
	Goomzy	4	4 000	22
2006	Godiva	4	900	51
	Goomzy	3	3 200	50
2015	Godiva	2	180	Not calculated
	Goomzy	2	4 200	26

The acoustic estimate in 2015 from Goomzy was assumed to represent "most" of the spawning biomass in that year. This was modelled by treating the acoustic estimate as relative biomass and estimating the proportionality constant (*q*) with an informed prior. The prior was lognormally distributed with a mean of 0.8 (i.e., "most" = 80%) and a CV of 19% (see Orange Roughy Introduction section).

Age frequencies

Age frequencies were developed for the *Giljanes* spawning-season trawl survey in 1992 (Clark & Tracey 1993) and the targeted trawling on spawning marks during the 2015 acoustic survey (Ryan & Tilney 2016)(Ian Doonan, NIWA, pers. comm.). Approximately 400 otoliths were used for each age frequency and CVs were calculated for each proportion at age from bootstrapping. In 2015, the mode (for the smoothed distribution) is at about 40 years whereas in 1992 the mode is closer to 60 years (Figure 21). It is notable that in both years the ages extend out to at least 130 years (Figure 21). In the base model, the age frequencies were fitted as multinomial with effective sample sizes of 80 and 60 respectively. The sample size of 80 is the approximate number of trawl stations during the survey in 1992 and the value of 60 was derived from the between year ratio of equivalent multinomial sample sizes derived from the bootstrap CVs.

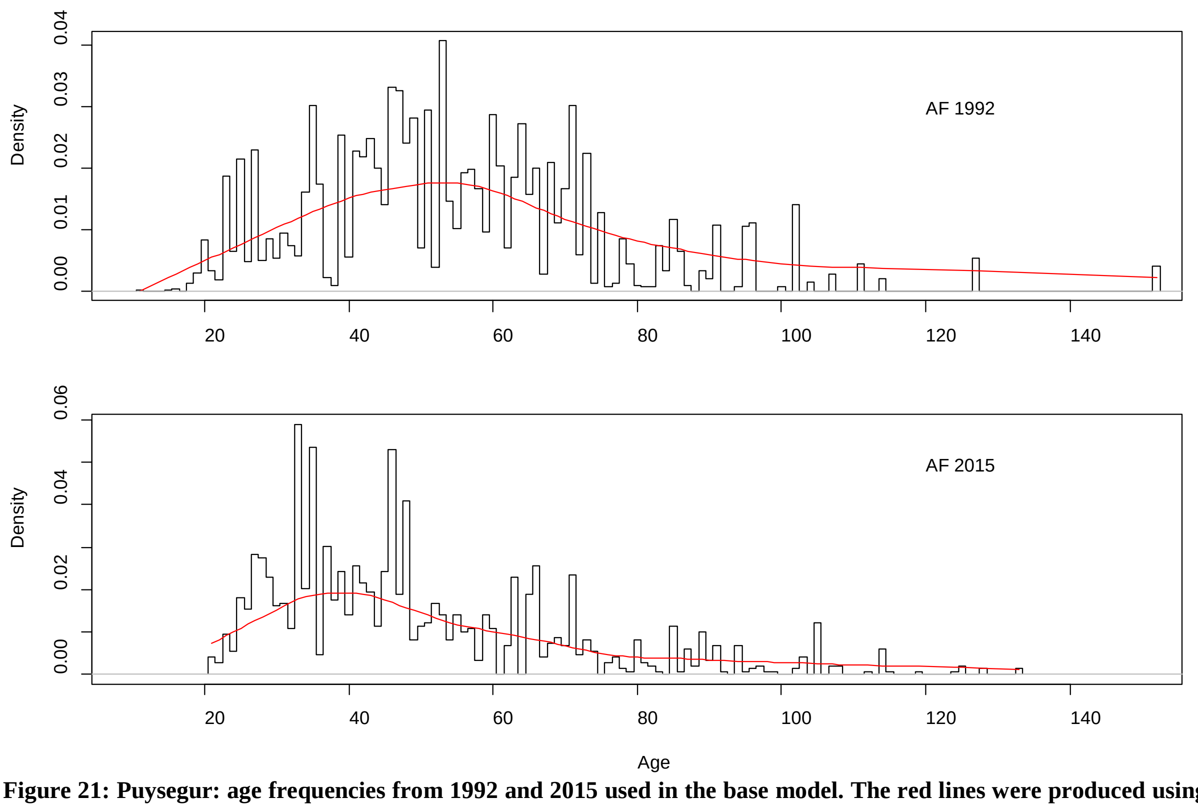


Figure 21: Puysegur: age frequencies from 1992 and 2015 used in the base model. The red lines were produced using the lowess smoother in R.

Trawl survey data

Trawl surveys of the Puysegur area were undertaken on *Tangaroa* in 1992 and 1994 (Clark & Tracey 1994, Clark et al 1996). However, the timing of the surveys was not ideal with the second survey being more than a month later than the first (Puysegur strata occupied in 1992: 8 August–11 September, and in 1994: 24 September–23 October). An analysis of seasonal CPUE suggested that catch rates in the later period could be expected to be 50% of those in the earlier period. Also, an analysis of fish length data suggested that larger fish were caught in the June-August period – the period taken to be the "spawning season" in the model (although spawning occurs in July). It appears that during the June-August period larger fish are more available to the fishing fleet and could have been more available to the trawl survey. There was a very large reduction in the biomass indices for such a short period (Table 14).

To allow for a possible reduction in availability between the 1992 and 1994 surveys, due to the change in timing, the selectivity for the trawl survey was modelled separately for mature and immature fish and an availability parameter for mature fish was estimated for the 1994 survey. The length frequencies from the trawl surveys are bimodal which could be partly explained by two groups of fish distinguished by maturity (Figure 22).

Table 14: Trawl survey biomass indices for all fish from the *Tangaroa* trawl surveys of the Puysegur area in 1992 and 1994. The CVs given are those used in the modelling and include no process error.

	Biomass index (t)	CV (%)
1992	6 630	28
1994	1 160	24

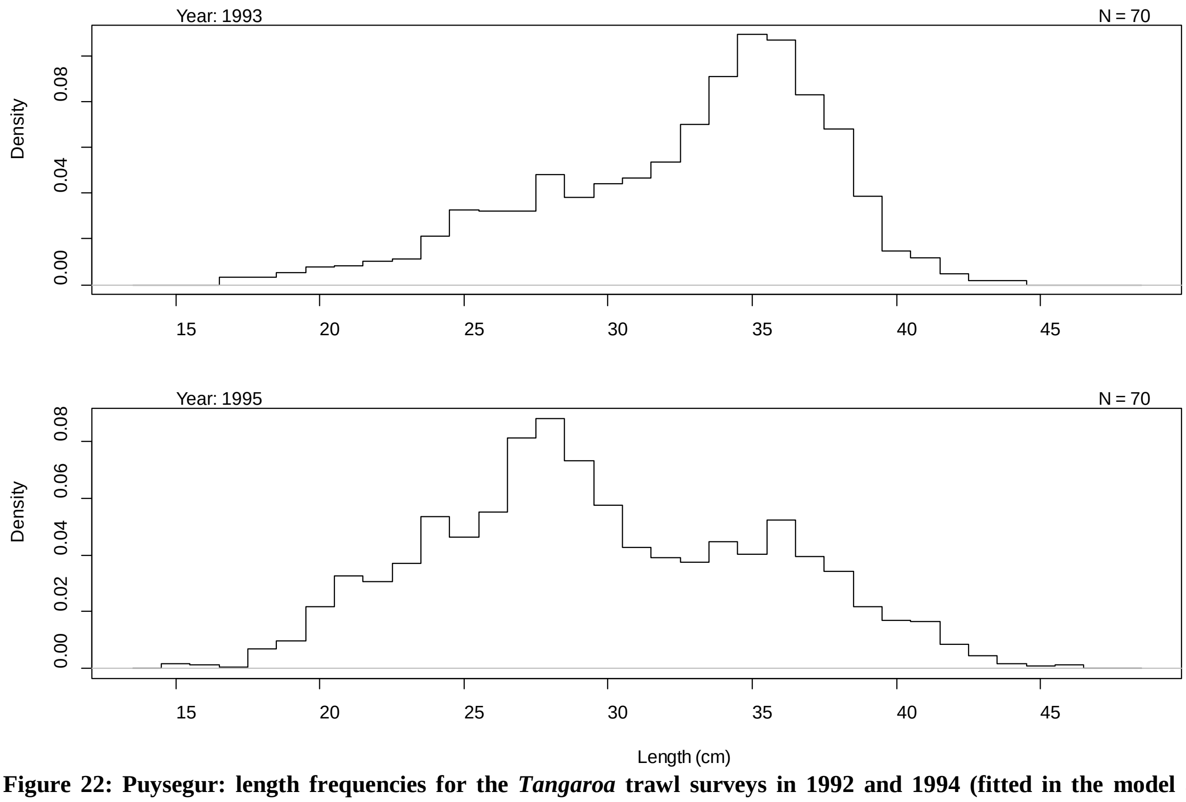


Figure 22: Puysegur: length frequencies for the *Tangaroa* trawl surveys in 1992 and 1994 (fitted in the model as beginning of year in 1993 and 1995). The effective samples sizes of N = 70 were the approximate number of stations in each survey.

Length frequencies (commercial fishery)

Scientific observer coverage of the Puysegur fishery was very patchy over the small number of years when the fishery operated. The best coverage was in the 1993–94 fishing year when there were 15 samples in the non-spawning season and 44 samples in the spawning season. The next best year, when more than one month was sampled in the non-spawning season, was 1996–97 when there were 6 non-spawning season samples and 3 spawning season samples. Scaled length frequencies were produced in those two years for the spawning and non-spawning seasons. The data were assumed to be multinomial with effective sample sizes equal to the number of samples.

4.3.3 Model runs and results

In the base model, the acoustic estimate from Goomzy in 2015 was used, with the *Tangaroa* trawl survey data, and natural mortality (*M*) was fixed at 0.045. There were six main sensitivity runs: exclude the *Tangaroa* trawl survey data; low weight on the age frequencies; high weight on the age frequencies; estimate *M*; and the *LowM-Highq* and *HighM-Lowq* "standard" runs (see Orange Roughy Introduction section). There were additional sensitivities: treating the trawl surveys as strictly comparable; using lognormal priors on the free year class strength parameters; alternative fixed non-spawning season fishing selectivities; adding a 5% overrun to the catch history; and using a higher CV on the acoustic *q* prior.

In the base model, the main parameters estimated were: virgin (unfished, equilibrium) spawning biomass (B_0), maturity ogive, trawl-survey selectivity, CV of length-at-mean-length-at-age for ages 1 and 120 years (linear relationship assumed for intermediate ages), and year class strengths (YCS) from 1917 to 1990 (with the Haist parameterisation and "nearly uniform" priors on the free parameters).

Model diagnostics

The model provided good MPD fits to the data. Residuals were examined mainly at the MCMC level and these were all acceptable suggesting that the data weightings (CVs and effective sample sizes) were reasonable.

The marginal posterior distribution of the acoustic *q* shifted somewhat to the left of the prior but remains well within the distribution of the prior (Figure 23).

The MPD sensitivity runs where the trawl surveys were assumed strictly comparable, despite the difference in timing, were unable to fit the decline in the trawl indices and showed poorer fits to the trawl survey length frequencies than the base model. The objective function decreased by 7 likelihood units when the availability parameter for 1994 was estimated (which supports the inclusion of the single additional parameter).

When lognormal priors were used for the free YCS parameters the trawl survey indices were fitted adequately (as the availability parameter was estimated) but the fits to the composition data (length and age frequencies) were degraded compared to the base model (which used nearly uniform priors on the free YCS parameters). The worst example of the poor fits was for the *Tangaroa* trawl survey length frequency in 1994. The reason for the poorer fits to the composition data was because the use of a lognormal prior severely constrained the estimated YCS. The near uniform prior allows much more freedom in the pattern of estimated YCS. Behaviour in the MCMC runs is much improved for the lognormal priors but there is the issue that the choice of sigmaR is arbitrary (see the Orange Roughy Introduction section).

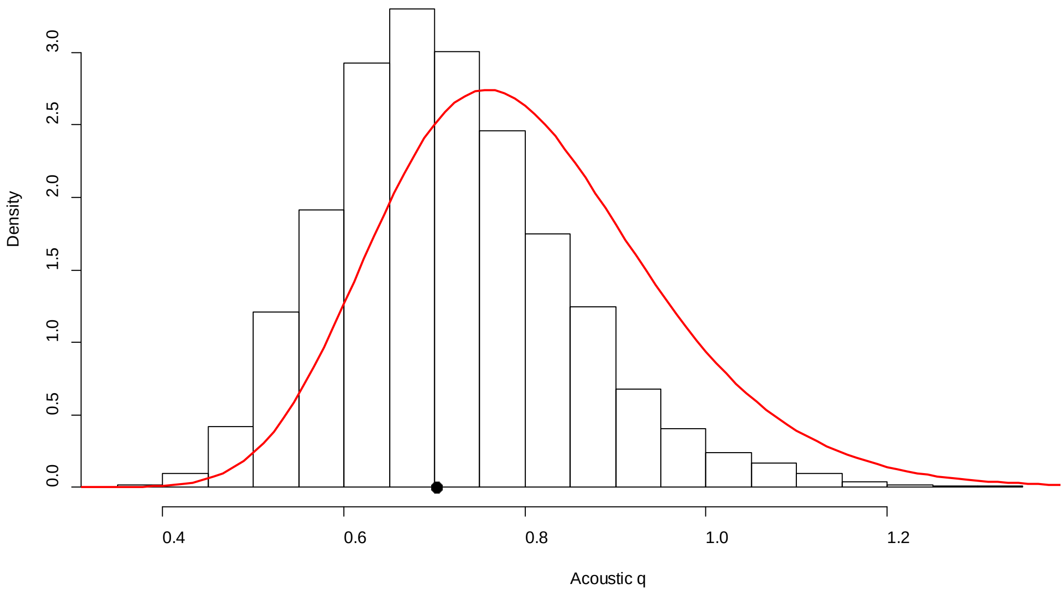


Figure 23: Puysegur: the marginal posterior distribution of the acoustic *q* (histogram) compared to its prior (red line). The black dot marks the median of the marginal posterior.

MCMC Results

For the base model, and the sensitivity runs, MCMC convergence diagnostics for virgin biomass (B_0) and stock status were very good. B_0 was estimated to be between 12 000–26 000 t for all runs (Table 15). Current stock status was similar across the base and the first four sensitivity runs (Table 15). The slightly lower stock status when *M* was estimated reflects the lower estimates of *M* (0.040 rather than 0.045). For the two “bounding” runs, where *M* and the mean of the acoustic *q* prior were shifted by 20%, median current stock status was within or above the biomass target range of 30–50% B_0 for both runs (Table 15). The sensitivity with a higher CV on the acoustic *q* prior gave similar results to the base model with a slighter higher B_0 and stock status. The 5% overrun model gave almost identical results to the base model. All other sensitivity runs gave stock status estimates within the range covered by the *LowM-Highq* and *HighM-Lowq* models.

Table 15: Puysegur: MCMC estimates of virgin biomass (B_0) and stock status (B_{2017} as %B_0) for the base model and six sensitivity runs.

	M	B_0 (000 t)	95% CI	B_{2017} (%B_0)	95% CI
Base	0.045	17	13–23	49	36–62
No trawl	0.045	17	13–24	51	39–64
Low AF	0.045	15	12–21	46	34–61
High AF	0.045	18	14–26	51	39–63
Estimate M	0.040	18	13–25	47	34–61
LowM-Highq	0.036	18	14–23	42	30–55
HighM-Lowq	0.054	17	12–25	57	44–69

For the base model, (and all sensitivities) the stock is considered to be fully rebuilt according to the Harvest Strategy Standard (at least a 70% probability that the lower end of the management target range of 30–50% B_0 has been achieved).

The estimated YCS show a trend across cohorts with above average recruitment prior to 1950 with below average recruitment up until about 1980 (Figure 24). The variation in the more recent (true) YCS is due to variation in depletion levels across the MCMC samples (and hence different levels of recruitment were generated from the stock-recruitment relationship).

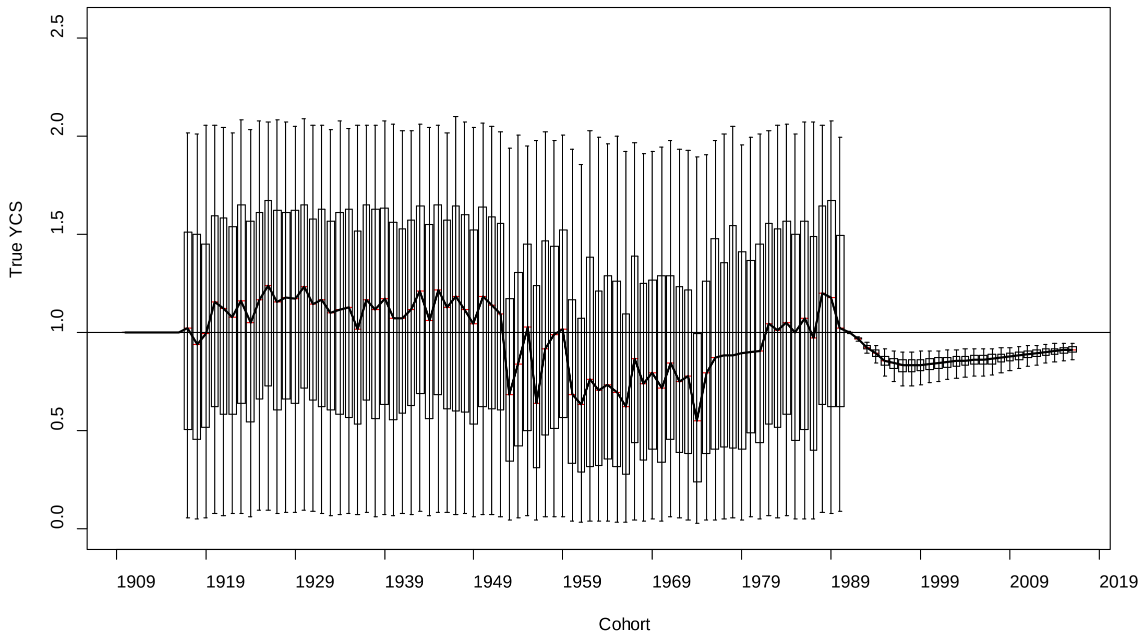


Figure 24: Puysegur base, MCMC estimated “true” YCS (R_y/R_0). The box in each year covers 50% of the distribution and the whiskers extend to 95% of the distribution.

The estimated spawning-stock biomass (SSB) trajectory showed a declining trend from 1990 (when the fishery started) through to 1998 when the fishery was closed (Figure 25). Since 1998 the estimated biomass has increased steadily and has been well within the target range for the last decade (Figure 25).

Fishing intensity was estimated in each year for each MCMC sample to produce a posterior distribution for fishing intensity by year. Fishing intensity is represented in terms of the median exploitation rate and the Equilibrium Stock Depletion (ESD). For the latter, a fishing intensity of $U_{x\%B0}$ means that fishing (forever) at that intensity will cause the SSB to reach deterministic equilibrium at x% B_0 (e.g., fishing at $U_{30\%B0}$ forces the SSB to a deterministic equilibrium of 30% B_0). Fishing intensity in these units is plotted as 100–ESD so that fishing intensity ranges from 0 ($U_{100\%B0}$) up to 100 ($U_{0\%B0}$).

Estimated fishing intensity was above $U_{20\%B0}$ for most of the history of the fishery before it was closed in 1998; it was briefly in the target range ($U_{30\%B0}$–$U_{50\%B0}$) in 2006 when there was a combined acoustic and trawl survey (Figure 26).

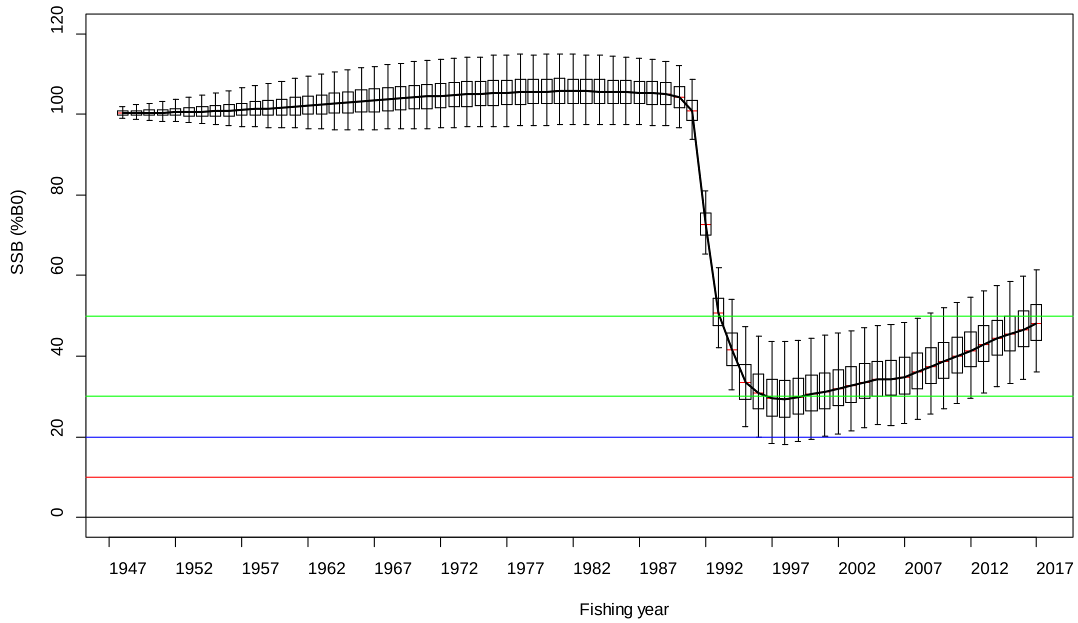


Figure 25: Puysegur base, MCMC estimated spawning-stock biomass trajectory. The box in each year covers 50% of the distribution and the whiskers extend to 95% of the distribution. The hard limit (red), soft limit (blue), and biomass target range (green) are marked by horizontal lines.

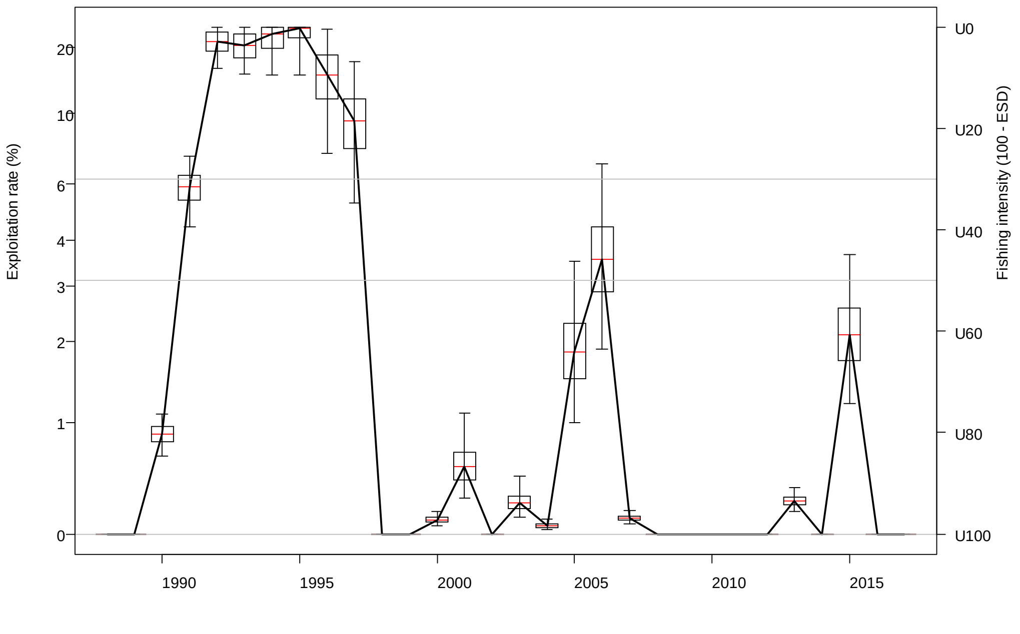


Figure 26: Puysegur base, MCMC estimated fishing-intensity trajectory. The box in each year covers 50% of the distribution and the whiskers extend to 95% of the distribution. The fishing-intensity range associated with the biomass target of 30–50% B_0 is marked by horizontal lines.

Biological reference points, management targets and yield

Orange roughy stocks with model based stock assessments are managed according to the Harvest Control Rule (HCR) that was developed in 2014 using a Management Strategy Evaluation (MSE) (Cordue 2014b). The HCR has a target biomass range of 30–50% B_0.

Yield estimates are not reported for this stock.

5. STATUS OF THE STOCKS

5.1 Chatham Rise

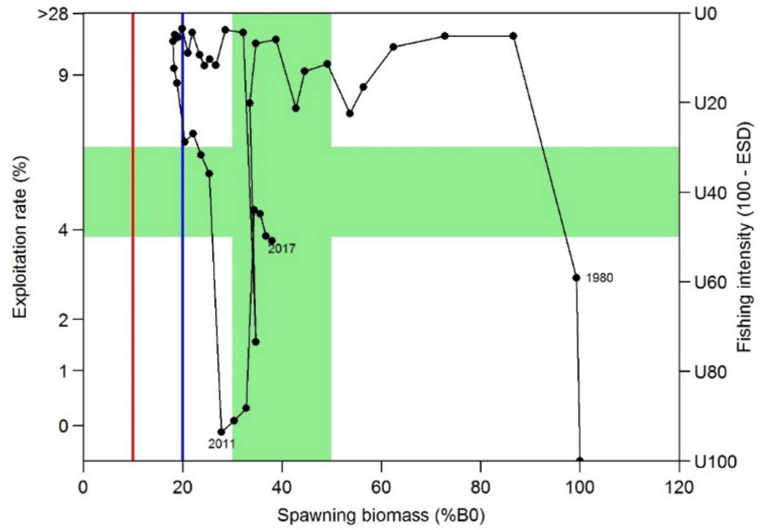
Stock Structure Assumptions

Chatham Rise orange roughy are believed to comprise two biological stocks; these are assessed and managed separately: one on the Northwest of the Chatham Rise and the other ranging throughout the East and South Rise. This assumed stock structure is based on the presence of two main areas where spawning takes place simultaneously, and observed and inferred migration patterns of adults and juveniles. These two biological stocks form the bulk of the ORH 3B Fishstock. They are geographically separated from all other ORH 3B biological stocks.

- **Northwest Chatham Rise**

Stock Status	
Year of Most Recent Assessment	2018
Assessment Runs Presented	Base model only
Reference Points	Management Target: Biomass range 30–50% B_0 Soft Limit: 20% B_0 Hard Limit: 10% B_0 Overfishing threshold: Fishing intensity range $U_{30\%B0}$–$U_{50\%B0}$
Status in relation to Target	B_{2017} was estimated at 38% B_0. Very Likely (> 90%) to be at or above the lower end of the management target range
Status in relation to Limits	B_{2017} is Exceptionally Unlikely (< 1%) to be below the Soft Limit. B_{2017} is Exceptionally Unlikely (< 1%) to be below the Hard Limit
Status in relation to Overfishing	Overfishing is Exceptionally Unlikely (< 1%) to be occurring

Historical Stock Status Trajectory and Current Status



Historical trajectory of spawning biomass (%B_0), median exploitation rate (%) and fishing intensity (100-ESD) (base model, medians of the marginal posteriors). The biomass target range of 30–50 % B_0 and the corresponding exploitation rate range are marked in green. The soft limit (20% B_0) is marked in blue and the hard limit (10% B_0) in red. Note that the Y-axis is non-linear.

Fishery and Stock Trends	
Recent Trend in Biomass or Proxy	Biomass reached its lowest point in 2004 and has increased consistently since then. According to the Harvest Strategy Standard, the stock is considered to be fully rebuilt (at least a 70% probability that the lower end of the management target range of 30–50% B_0 has been achieved).
Recent Trend in Fishing Intensity or Proxy	Fishing intensity decreased sharply from 2010 to 2011 and has remained below the overfishing threshold since then.
Other Abundance Indices	-
Trends in Other Relevant Indicators or Variables	-

Projections and Prognosis	
Stock Projections or Prognosis	At both the TACC (1 250 t) and current agreed catch (1 043 t), the biomass is expected to stay steady or increase over the next 5 years.
Probability of Current Catch or TACC causing Biomass to remain below or to decline below Limits	At both TACC and current agreed catch limit: Soft Limit: Exceptionally Unlikely (< 1%) Hard Limit: Exceptionally Unlikely (< 1%)
Probability of Current Catch or TACC causing Overfishing to continue or to commence	Exceptionally Unlikely (< 1%) at both TACC and current agreed catch limit.

Assessment Methodology and Evaluation		
Assessment Type	Level 1 - Full Quantitative Stock Assessment	
Assessment Method	Age-structured CASAL model with Bayesian estimation of posterior distributions	
Assessment Dates	Latest assessment: 2018	Next assessment: 2021
Overall assessment quality rank	1 – High Quality	
Main data inputs (rank)	- Acoustic estimates of spawning biomass on Graveyard (1999, 2012–13) and Morgue (1999, 2012, 2016).	1 – High Quality
	- Trawl survey age frequency and proportion-spawning-at-age (1994).	1 – High Quality
	- 17 years of length frequency data.	1 – High Quality
	- Morgue age frequency (2016); only as a sensitivity	2 – Medium or Mixed Quality: potential non-representative sampling
Data not used (rank)	- CPUE	3 – Low Quality: unlikely to be indexing stock-wide abundance
	- Trawl surveys of hills (1990–2002)	3 – Low Quality: unlikely to be indexing stock-wide abundance
	- Wide-area acoustic survey estimates	2 – Medium or Mixed Quality: large potential bias due to mixed-species
	- Chatham Rise trawl survey deepwater stations (2010–2016)	2 – Medium or Mixed Quality: variable indices
	- Egg survey estimate	3 – Low Quality: survey design assumptions not met

Changes to Model Structure and Assumptions	-
Major Sources of Uncertainty	- The largest source of uncertainty is the proportion of the NWCR spawning stock that is indexed by the acoustic survey in each year. - In the base case, patterns in year class strengths are based on only one year of age composition data. - The time series of abundance indices is short and restricted to the period of lower stock status.

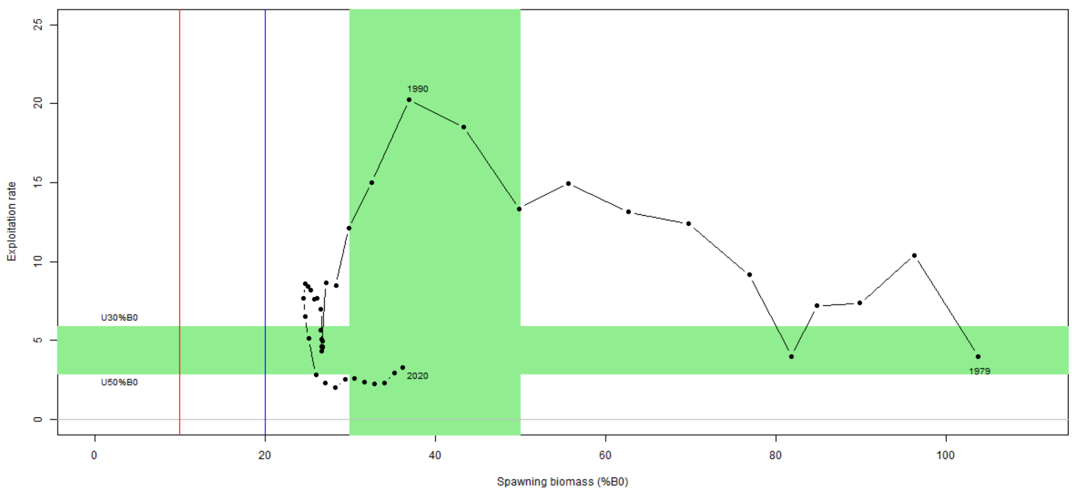
Qualifying Comments
Estimates of stock biomass are sensitive to the means of the *q* priors.

Fishery Interactions
Main bycatch species are smooth oreo, black oreo, rattails, deepwater dogfish and hoki, with lesser bycatches of Johnson's cod and ribaldo. Low productivity bycatch species include deepwater sharks, skates and corals. Observed incidental captures of protected species include corals, low numbers of seabirds and occasional New Zealand fur seals. Orange roughy are caught using bottom trawl gear. Bottom trawling interacts with benthic habitats.

- **East and South Chatham Rise**

Stock Status	
Year of Most Recent Assessment	2020
Assessment Runs Presented	Updated 2018 base model
Reference Points	Management Target: Biomass range 30–50% B_0 Soft Limit: 20% B_0 Hard Limit: 10% B_0 Overfishing threshold: Fishing intensity range $U_{30\%B0}$–$U_{50\%B0}$
Status in relation to Target	B_{2020} was estimated to be 36% B_0 Likely (> 60%) to be at or above the lower end of the management target range
Status in relation to Limits	B_{2020} is Very Unlikely (< 10%) to be below the Soft Limit B_{2020} is Exceptionally Unlikely (< 1%) to be below the Hard Limit
Status in relation to Overfishing	Overfishing is Exceptionally Unlikely (< 1%) to be occurring

Historical Stock Status Trajectory and Current Status



Historical trajectory of spawning biomass (%B_0) and exploitation rate (%) (current model, medians of the marginal posteriors). The biomass target range of 30–50 % B_0 and the corresponding exploitation rate range are marked in green. The soft limit (20% B_0) is marked in blue and the hard limit (10% B_0) in red.

Fishery and Stock Trends	
Recent Trend in Biomass or Proxy	The spawning biomass is estimated to have been slowly increasing since 2009-10.
Recent Trend in Fishing Intensity or Proxy	Fishing intensity (exploitation rate) is estimated to have been near or below the lower end of the target range since 2010-11.
Other Abundance Indices	-
Trends in Other Relevant Indicators or Variables	-

Projections and Prognosis	
Stock Projections or Prognosis	Biomass is expected to increase slowly at catches equal to the current catch limit (4 775 t) or the HCR recommended catch limit (6 348 t).
Probability of Current Catch or TACC causing Biomass to remain below or to decline below Limits	At the current catch limit (4 775 t) or the HCR recommended catch limit (6 348 t): Soft Limit: Very Unlikely (< 10%) Hard Limit: Exceptionally Unlikely (< 1%)

Assessment Methodology and Evaluation		
Assessment Type	Level 1 – Full Quantitative Stock Assessment	
Assessment Method	Age-structured CASAL model with Bayesian estimation of posterior distributions	
Assessment Dates	Latest assessment: 2020	Next assessment: 2021
Overall assessment quality rank	1 – High Quality	
Main data inputs (rank)	- Four short time series of biomass indices from research trawl surveys	1 – High Quality
	- Acoustic indices from research surveys of spawning plumes (Old-plume, Rekohu plume, Crack)	1 – High Quality
	- Age frequencies from the spawning plumes in 2012, 2013, and 2016	1 – High Quality
	- Length frequencies from commercial fisheries	1 – High Quality
Data not used (rank)	- CPUE	3 – Low Quality: unlikely to be indexing stock-wide abundance
	- Acoustic surveys of hills (hull-mounted transducers)	3 – Low Quality: major species identification and dead zone issues
	- Wide-area acoustic survey estimates	2 – Medium or Mixed Quality: large potential bias due to mixed-species
	- Chatham Rise deepwater trawl survey stations (2010–2020)	2 – Medium or Mixed Quality: variable indices
Changes to Model Structure and Assumptions	None	
Major Sources of Uncertainty	- The largest source of uncertainty is the proportion of the ESCR spawning stock that is indexed by the acoustic survey in each year. - Stock status is dependent on the timing of the appearance of the Rekohu spawning plume, which is unknown. - Patterns in year class strengths are based on only 3 years of age composition data.	

Qualifying Comments
Estimates of stock biomass are sensitive to the means of the *q* priors. Lack of fit to the 2016 acoustic biomass estimate.
Fishery Interactions
Main bycatch species are smooth oreo, black oreo, deepwater dogfish, hoki and rattails, with lesser bycatches of slickhead, Johnson's cod and morids. Low productivity bycatch species include deepwater sharks and dogfish and also corals. Observed incidental captures of protected species include corals, low numbers of seabirds and occasional New Zealand fur seals. Orange roughy are caught using bottom trawl gear. Bottom trawling interacts with benthic habitats.

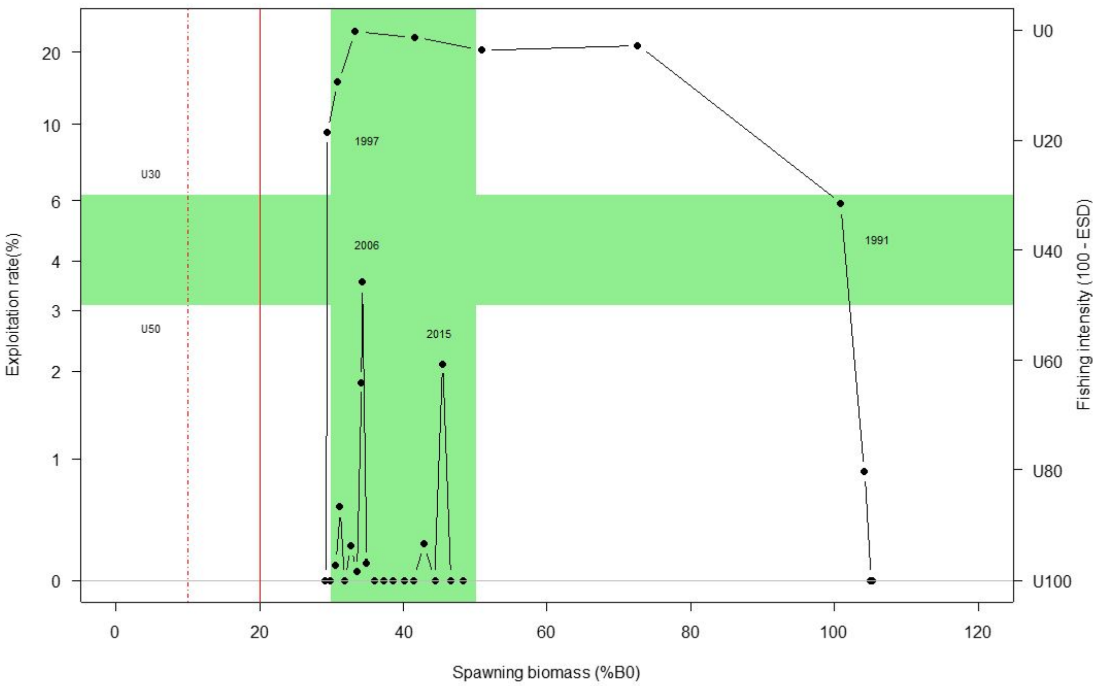
- **5.2 Southern ORH 3B fisheries**

There are several other small fisheries in ORH 3B in the southern waters of which Puysegur appears to be the largest stock.

Puysegur

Stock Status	
Year of Most Recent Assessment	2017
Assessment Runs Presented	Base model only
Reference Points	Management Target: Biomass range 30–50% B_0 Soft Limit: 20% B_0 Hard Limit: 10% B_0 Overfishing threshold: Fishing intensity range $U_{30\%B0}$
Status in relation to Target	B_{2017} was estimated at 49% B_0. Very Likely (> 90%) to be at or above the lower end of the management target range
Status in relation to Limits	B_{2017} is Exceptionally Unlikely (< 1%) to be below the Soft or Hard Limits
Status in relation to Overfishing	An agreed closure of the fishery was in place until 2017. Overfishing in 2017 is Exceptionally Unlikely (< 1%) to be occurring

Historical Stock Status Trajectory and Current Status



Historical trajectory of spawning biomass (%B_0), median exploitation rate (%) and fishing intensity (100-ESD) (base model, medians of the marginal posteriors). The biomass target range of 30–50% B_0 and the corresponding exploitation rate range are marked in green. The soft limit (20% B_0) and the hard limit (10% B_0) are marked in red. Note that the left-hand Y-axis is non-linear.

Fishery and Stock Trends	
Recent Trend in Biomass or Proxy	Biomass reached its lowest point in 1998 and has increased steadily since then. According to the Harvest Strategy Standard, the stock is now considered to be fully rebuilt (at least a 70% probability that the lower end of the management target range of 30–50% B_0 has been achieved).
Recent Trend in Fishing Intensity or Proxy	Fishing intensity has been close to zero since the fishery was closed in 1997-98 with the exception of 2005, 2006, and 2015 when surveys were conducted.
Other Abundance Indices	-
Trends in Other Relevant Indicators or Variables	-

Projections and Prognosis	
Stock Projections or Prognosis	No projections were conducted
Probability of Current Catch or TACC causing Biomass to remain below or to decline below Limits	Current catch is zero
Probability of Current Catch or TACC causing Overfishing to continue or to commence	Current catch is zero

Assessment Methodology and Evaluation		
Assessment Type	Level 1 - Full Quantitative Stock Assessment	
Assessment Method	Age-structured CASAL model with Bayesian estimation of posterior distributions	
Assessment Dates	Latest assessment: 2017	Next assessment: 2020
Overall assessment quality rank	1 – High Quality	
Main data inputs (rank)	- Acoustic estimate of spawning biomass on Goomzy (2015) - Trawl survey indices and length frequencies (1992, 1994) - Age frequencies (1992, 2015) - 2 years of length frequency data	1 – High Quality 1 – High Quality 1 – High Quality 1 – High Quality
Data not used (rank)	- CPUE - Winter trawl surveys (1991, 1992, 2006) - Acoustic survey estimates (2005, 2006) - Additional commercial length frequencies	3 – Low Quality: unlikely to be indexing stock-wide abundance 2 – Medium or Mixed Quality: unlikely to be indexing stock-wide abundance 2 – Medium or Mixed Quality: large potential bias due to mixed species 2 – Medium or Mixed Quality: not enough months sampled within each year
Changes to Model Structure and Assumptions	- The previous assessment was in 1998. - Model now based on spawning biomass rather than transition-zone mature biomass. - Age data included to enable estimation of year class strengths rather than assuming deterministic recruitment. - Trawl survey indices better modelled to allow for difference in timing	

	- A more stringent data quality threshold was imposed on data inputs (e.g., CPUE indices not used)
Major Sources of Uncertainty	-The largest source of uncertainty is the proportion of the Puysegur spawning stock that is indexed by the acoustic survey in 2015. - The single acoustic estimate is the only recent biomass index. - Patterns in year class strengths are based on only two years of age frequencies.
Qualifying Comments	
-	
Fishery Interactions	
Historically the Puysegur orange roughy fishery included black and smooth oreos, deepwater dogfish, black cardinal fish, slickheads and rattails as significant bycatch. Interactions with other species are currently being characterised. Orange roughy are caught using bottom trawl gear. Bottom trawling interacts with benthic habitats.	

- **Auckland Islands (Pukaki South)**

The Deepwater Working Group examined the data on orange roughy catch and effort from the Auckland Islands area in 2006, and found that there had been relatively little fishing activity in this area in the previous few years. There were insufficient data to conduct a standardised CPUE analysis, and it was believed that unstandardised CPUE did not provide a suitable index of relative abundance. Therefore, a stock assessment could not be carried out.

- **Other fisheries**

In 2006 the Deepwater Working Group examined the data on orange roughy catch and effort from other parts of ORH 3B – the Bounty Islands, Pukaki Rise, Snares Island and the Arrow Plateau – and agreed that there were insufficient data to carry out standardised CPUE analyses for any of these areas.

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ORANGE ROUGHY CHALLENGER PLATEAU (ORH 7A)

1. FISHERY SUMMARY

1.1 Commercial fisheries

Historically, the fishery mainly occurred in the south-western region of the Challenger Plateau, both inside and outside the EEZ. Fish were caught throughout the year, with most effort in winter when the orange roughy form aggregations for spawning. Domestic vessels caught most of the quota. Total landings peaked at 10 000–12 000 t annually from 1986–87 to 1988–89 (Table 1). Total landings and ORH 7A landings were less than 2100 t annually from 1990–91 until the closure in 2000–01 (Table 1, Figure 1), when the TACC for this stock was reduced to 1 t.

Recent surveys have shown an increase in biomass in the area. On 1 October 2010 the TACC was increased from 1 t to 500 t, with a 25 t allowance for other mortality, raising the TAC to a total of 525 t. This was to allow research surveys to be conducted using commercial fishing vessels. The TACC was further increased to 1600 t following a stock assessment in 2014. Total landings have closely followed the TACCs in recent years, averaging 1595 t in 2014–15 to 2018–19.

Table 1: Reported landings (t) and TACCs (t) from 1980–81 to present. QMS data from 1986-present. The last two columns are for research surveys on commercial vessels and give the research catch that was not recorded against ACE (WP = Westpac Bank).

Fishing year	EEZ	Outside	Total landings	TACC	EEZ extra	WP extra
1980–81†	1	32	33	-	0	0
1981–82†	3 539	709	4 248	-	0	0
1982–83†	4 535	7 304	11 839	-	0	0
1983–84†	6 332	3 195	9 527	-	0	0
1984–85†	5 043	74	5 117	-	0	0
1985–86†	7 711	42	7 753	-	0	0
1986–87†	10 555	937	11 492	10 000	0	0
1987–88	10 086	2 095	12 181	12 000	0	0
1988–89	6 791	3 450	10 241	12 000	0	0
1989–90	3 709	600	*4 309	2 500	0	0
1990–91	1 340	17	1 357	1 900	0	0
1991–92	1 894	17	1 911	1 900	0	0
1992–93	1 412	675	2 087	1 900	0	0
1993–94	1 594	138	1 732	1 900	0	0
1994–95	1 554	82	1 636	1 900	0	0
1995–96	1 206	463	1 669	1 900	0	0
1996–97	1 055	253	1 308	1 900	0	0
1997–98	+	+	1 502	1 900	0	0
1998–99	+	+	1 249	1 425	0	0
1999–00	+	+	629	1 425	0	0
2000–01	+	+	0.2	1	0	0
2001–02	+	+	0.1	1	0	0
2002–03	+	+	4	1	0	0
2003–04	+	+	< 0.1	1	0	0
2004–05	+	+	< 1	1	141	17
2005–06	+	+	< 1	1	196	22
2006–07	+	+	< 0.1	1	0	0
2007–08	+	+	< 0.1	1	0	0
2008–09	+	+	0.12	1	218	22
2009–10	+	+	< 0.1	1	339	5
2010–11	476	0	476	500	0	5
2011–12	504	7	511	500	0	0
2012–13	513	0	513	500	259	4
2013–14	484	13	497	500	0	50
2014–15	1 594	0	1 594	1 600	0	0
2015–16	1 248	320	1 568	1 600	0	0
2016–17	1 595	28	1 623	1 600	0	0
2017–18	1 026	575	1 601	1 600	126	53
2018–19	+	+	1 589	1 600	0	0

†FSU data
*This is a minimum value, because of unreported catches by foreign vessels fishing outside the EEZ.
+Unknown distribution of catch between inside and outside the EEZ

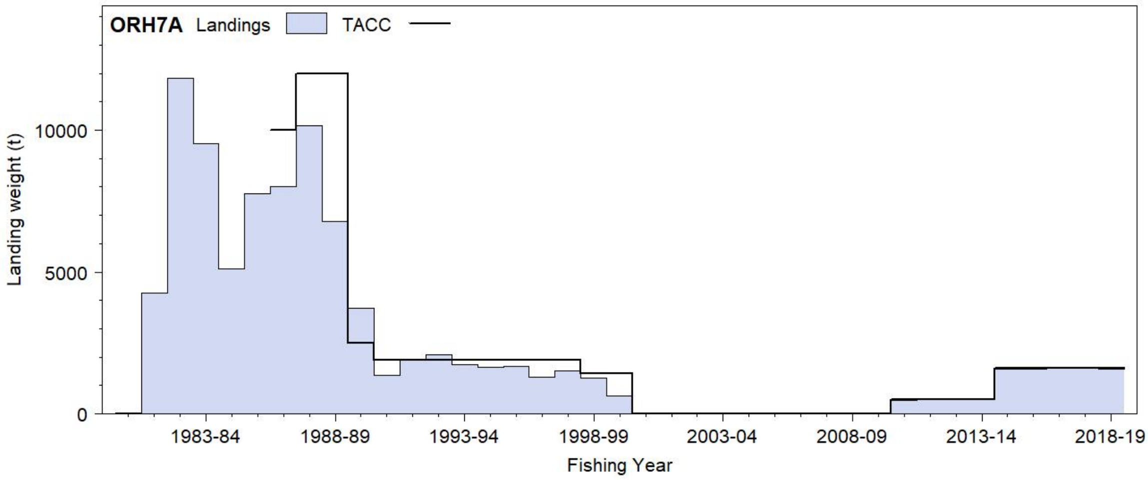


Figure 1: Reported commercial landings and TACC for ORH 7A.

1.2 Recreational fisheries
There is no known recreational fishing for orange roughy in this area.

1.3 Customary non-commercial fisheries
There is no known customary non-commercial fishing for orange roughy in this area.

1.4 Illegal catch
There is no quantitative information available on illegal catch which is likely to be negligible.

1.5 Other sources of mortality
Catch overruns from various sources (including lost and/or discarded fish, use of nominal tray weights and low conversion factors) have been estimated as: 1980–81 to 1987–88, 30%; 1988–89, 25%; 1989–90, 20%; 1990–91, 15%; 1991–92 to 1992–93, 10%; 1993–94 onwards, 5%. These estimates are used in the current stock assessment.

2. BIOLOGY

Biological parameters used in this assessment are presented in the Biology section at the beginning of the Orange Roughy Introduction section.

3. STOCKS AND AREAS

There is no new information on orange roughy stock structure beyond that presented in previous assessment documents.

Orange roughy on the southwest Challenger Plateau (Area 7A, including Westpac Bank) are regarded as a single stock. Size structure, parasite composition, flesh mercury levels, allozyme frequency and mitochondrial DNA studies show differences to other major fisheries. Spawning occurs at a similar time to fish on the Chatham Rise, Puysegur Bank, Ritchie Banks, Cook Canyon and Lord Howe Rise.

4. STOCK ASSESSMENT

From 2010 to 2013, assessments were conducted using an ad hoc approach which combined the virgin biomass estimate from the 2000 assessment (Annala et al 2000, Field & Francis 2001) and current biomass estimates from annual combined acoustic and trawl surveys (see Clark et al 2006, NIWA & FRS 2009, Doonan et al 2010, Hampton et al 2013, Hampton et al 2014, Cordue 2010a, 2012, 2013).

A model-based Bayesian stock assessment was carried out for this stock in 2019 following a similar assessment conducted in 2014 (Cordue 2014a).

The 2014 assessment for this stock was one of four orange roughy assessments carried out in 2014 which all used similar methods (see Orange Roughy Introduction). The same approach was continued in 2019 although there was a review of previous data inputs and a substantial amount of new data were available. An age-structured population model was fitted to acoustic and trawl-survey estimates of spawning biomass and six age frequencies.

4.1 Model structure

The model was single-sex and age-structured (1–100 years with a plus group), with maturity estimated separately (i.e., fish were classified by age and as mature or immature). Two time steps were used: a full year of natural mortality followed by an instantaneous spawning season and fishery on the spawning fish. Two fisheries were modelled, one within the EEZ and one on Westpac Bank (which is outside of the EEZ). The fishery selectivity for the EEZ was uniform across ages (for spawning fish) while a logistic selectivity (on spawning fish) was used for Westpac Bank where slightly older fish are caught. 100% of mature fish were assumed to spawn each year.

The catch history was constructed from the catches in Table 1 and the over-run percentages in Section 1.5. Natural mortality was assumed to be constant across ages at 0.045 and the stock-recruitment relationship was assumed to follow a Beverton-Holt function with steepness of 0.75. The remaining fixed biological parameters are given in the Orange Roughy Introduction.

4.2 Input data and statistical assumptions

There were three main data sources for observations fitted in the assessment: spawning biomass estimates from acoustic and trawl surveys (2005, 2006, 2009–2014, 2018); an early trawl survey time series of relative spawning biomass (1987–1989); four age frequencies from the trawl surveys (1987, 2006, 2009, and 2018); and two age frequencies from Volcano (a UTF on the Westpac Bank) (2014 and 2018).

4.2.1 Research surveys

Trawl surveys of orange roughy on the Challenger Plateau were conducted regularly from 1983 to 1990. However, a variety of vessels and survey strata were used which makes comparisons problematic (Dunn et al 2010). Wingtip biomass estimates in 1983–1986 ranged from 100 000–185 000 t but the 1989 and 1990 survey estimates were much lower at approximately 10 000 t. From these early trawl surveys a “comparable area” time series, defined by Clark & Tracey (1994) and covering the period 1987–89, was selected for use in the assessment to provide some information on the early rate of spawning biomass decline (see the *Amaltal Explorer* time series in Table 3).

In 2005, a new series of combined trawl and acoustic surveys was begun using the FV *Thomas Harrison* with a survey area comparable to that used from 1987–1990 (Clark et al 2005). The survey was repeated in 2006 (with an enlarged survey area) and was then conducted annually from 2009–2013 (Clark et al 2006, NIWA & FRS 2009, Doonan et al 2010, Hampton et al 2013, Hampton et al 2014) with another survey in 2018. It was apparent from the later surveys that the 2005 survey did not cover an appropriate area as the spawning biomass distribution had shifted somewhat in the intervening years. The surveys from 2006 onwards appear to have covered the bulk of the spawning biomass. Also, in 2014 an acoustic survey of Volcano was conducted using an Acoustic Optical System (AOS) (Ryan et al 2015) in addition to a hull-mounted transducer. The data from all of the surveys since 2005 have been analysed to produce acoustic and trawl survey indices of spawning biomass.

Acoustic survey indices

For the 2014 assessment, the method of Cordue (2010a, 2012) was used to produce combined acoustic and trawl survey indices for 2010 and 2013. This method used an estimate of orange roughy trawl vulnerability to allow the trawl survey estimates to be combined with the acoustic estimates (trawl estimates were essentially scaled down by a vulnerability distribution with a mean of 1.66). This assumed that the scalar (1.66) had been reliably estimated. To avoid this assumption in the 2019 assessment the acoustic data and trawl data were used separately.

The acoustic biomass estimates from 2005 to 2018 were reviewed and a number of adjustments were required to ensure that the time series of estimates were consistent.

Acoustic estimates of spawning aggregations on Volcano and in the west and east of the flats within the EEZ were used in three separate time series (Table 2). Estimates from the hull-mounted transducer were adjusted as necessary so that they all used the latest length to target strength relationship, the Doonan et al (2003) absorption coefficient, and a combined motion and bubble layer correction (1.33) borrowed from work done on the Chatham Rise (Cordue 2010b, Doonan et al 2012). The estimates from the AOS (2014 and 2018) were adjusted to use the Doonan et al (2003) absorption coefficient. In 2005, 2011, and 2013, the motion corrections applied to the snapshots were not documented and a factor of 1.06 (the mean for snapshots in 2006 and 2009) was used in the adjustment calculations. In those years the acoustic indices were assigned an additional 20% of process error to account for the approximate adjustment.

Table 2: Acoustic biomass estimates of spawning aggregations surveyed on Volcano, and the West and the East within the EEZ. The model CV is the observation error CV with an additional 20% of process error in the years when the vessel motion correction was unknown (2005, 2011, and 2013).

	West		East		Volcano	
Year	**Biomass (t)**	**Model CV (%)**	**Biomass (t)**	**Model CV (%)**	**Biomass (t)**	**Model CV (%)**
2005	4 210	53			2682	39
2006	4 383	59			6329	39
2009	13 555	22	8471	61		
2010	8 114	14	1707	34		
2011	13 340	33				
2013	10 183	22	5365	26	4559	34
2014					3954	29
2018	9 966	9				

The acoustic biomass estimate for each aggregation in each year is an average of a number of "snapshots" (individual surveys/estimates) of the aggregation in that year. Some of the snapshots in some years were not used in the average because they appeared to have been taken before the aggregation was fully formed (judged on the basis of female gonad stages from trawl catches at the time of the snapshot). Some snapshots in the eastern area (in 2010 and 2011) were not used as an examination of the distribution of backscatter on the transects showed that a genuine spawning aggregation was not surveyed (e.g., just a single transect on which positive backscatter was recorded).

In 2018 there were a number of snapshots of Volcano which showed substantial biomass (about 4000 t) but it was unclear from the gonad staging whether spawning was underway. These snapshots were not used in the assessment (and there is no estimate for Volcano in 2018). In 2009, there was a single snapshot on Volcano which satisfied the timing criteria but it was a very low estimate (671 t) compared to all of the other years. It was considered that this estimate was unlikely to be representative of the spawning biomass on Volcano in 2009. It was not used in the base model but was used in a sensitivity run.

Informed priors on the proportionality constants (q) were used for the acoustic time series. The means of the priors were derived from the 2013 proportions across aggregations and the assumption that all three aggregations combined represented "most" of the spawning biomass (80%). The prior used in this case for orange roughy assessments (since 2014) is LN(mean=0.8, CV=19%) (Cordue 2014a). Splitting this prior into three components gave priors for the West, East, and Volcano qs respectively: LN(0.41, 30%), LN(0.22, 30%), LN(0.18, 30%).

Trawl survey indices

The spawning biomass estimates from the *Thomas Harrison* trawl surveys (Table 3) were used as relative biomass with an informed prior. They excluded the rough terrain strata 9–11 and the mean of the informed prior was: $0.9 \times 0.85 \times 1.25 = 0.95$ (allowing for total-survey availability (0.9), exclusion of strata 9–11 (0.85) and trawl vulnerability – adjusted mean of estimated vulnerability distribution = 1.25). Given the problematic nature of these trawl surveys (fish pluming and moving within the area), a process error CV of 20% was added to the estimated CVs (Table 3).

Table 3: Biomass indices from trawl surveys used in the stock assessment. The model CV is the observation error CV with an additional 20% of process error.

Vessel	Year	Biomass (t)	Model CV (%)
Amaltal Explorer	1987	75 040	33
	1988	28 954	34
	1989	11 062	23
Thomas Harrison	2006	13 987	34
	2009	34 864	31
	2011	18 425	33
	2012	22 451	27
	2013	18 993	55
	2018	48 038	55

Age frequencies

Age frequencies were available from four of the trawl surveys for use in the assessment. A previous analysis produced age frequencies for the 1987 *Amaltal Explorer* survey and the 2009 *Thomas Harrison* survey (Doonan et al 2013), although that study was based on a relatively small number of otoliths, it showed that the 2009 age frequency had much younger fish than the 1987 age frequency. For the 2014 stock assessment, the existing age frequencies were augmented with an increased number of otoliths (for a total of about 300 for each survey) and a new age frequency (from about 300 otoliths) was produced for the 2006 *Thomas Harrison* survey. For the 2019 assessment the age data from the 2018 survey were used to produce an age frequency for the EEZ (750 otoliths) and Volcano (150 otoliths). An age frequency was also produced from the 2014 survey of Volcano (470 otoliths) (Doonan et al 2015).

The age frequencies were assumed to be multinomial and were mainly assigned effective sample sizes of 300/5 = 60 (with the sample size reflecting the number of trawl stations rather than the number of otoliths). However, the 2018 age frequency from Volcano was obtained from only one targeted trawl and this was given a much lower effective sample size of 30 (to reflect that it may not have been representative of the spawning plume). No reweighting was attempted because of the short time series.

There are no age frequencies from the commercial fishery.

4.3 Model runs and results

In the base model, natural mortality (M) was fixed at 0.045. There were numerous MPD and MCMC sensitivity runs but four main sensitivities are presented in this report: "All trend" (informed priors removed), estimate M, and the LowM-Highq and HighM-Lowq runs (see the Orange Roughy Introduction section for specifications).

In the base model the main parameters estimated were: virgin biomass (B_0), the maturity ogive, the selectivity for Westpac Bank and year class strengths (YCS) from 1925 to 1995 (with the Haist parameterisation and "nearly uniform" priors on the free parameters). There were also the five proportionality constants (q) for the two trawl and three acoustic survey time series.

4.3.1 Model diagnostics

The MCMC (and MPD) fits to the data in the base model were very good except in two cases.

The *Amaltal Explorer* time series shows a very steep decline over only three years in the late 1980s (Figure 2). The steep decline cannot be fitted by the model unless a very high weight is placed on the time series and all other data are down-weighted. In this case the estimate of the minimum stock status is reduced to about 5% B_0 (compared to 15% B_0 for the base) but the estimate of current stock status is unchanged from the base model. It is likely that the *Amaltal Explorer* indices do not reflect true stock abundance in those years.

There are good fits to the main biomass indices, the West aggregation (Figure 3) and the *Thomas Harrison* trawl indices (Figure 4). Both sets of indices and the fits show an increase from 2005/2006 through to 2018.

The second poor fit is for the 2018 Volcano age frequency (Figure 5). This age frequency was obtained from a single large catch on Volcano and only 150 otoliths. It has much older fish than the age frequency from Volcano in 2014 which was obtained from samples from six trawl catches on Volcano. It is possible that the 2018 age frequency is not representative of the age distribution of the spawning aggregation on Volcano in 2018. Compared to 2018, the fit and associated residuals for the 2014 age frequency are excellent (Figure 6).

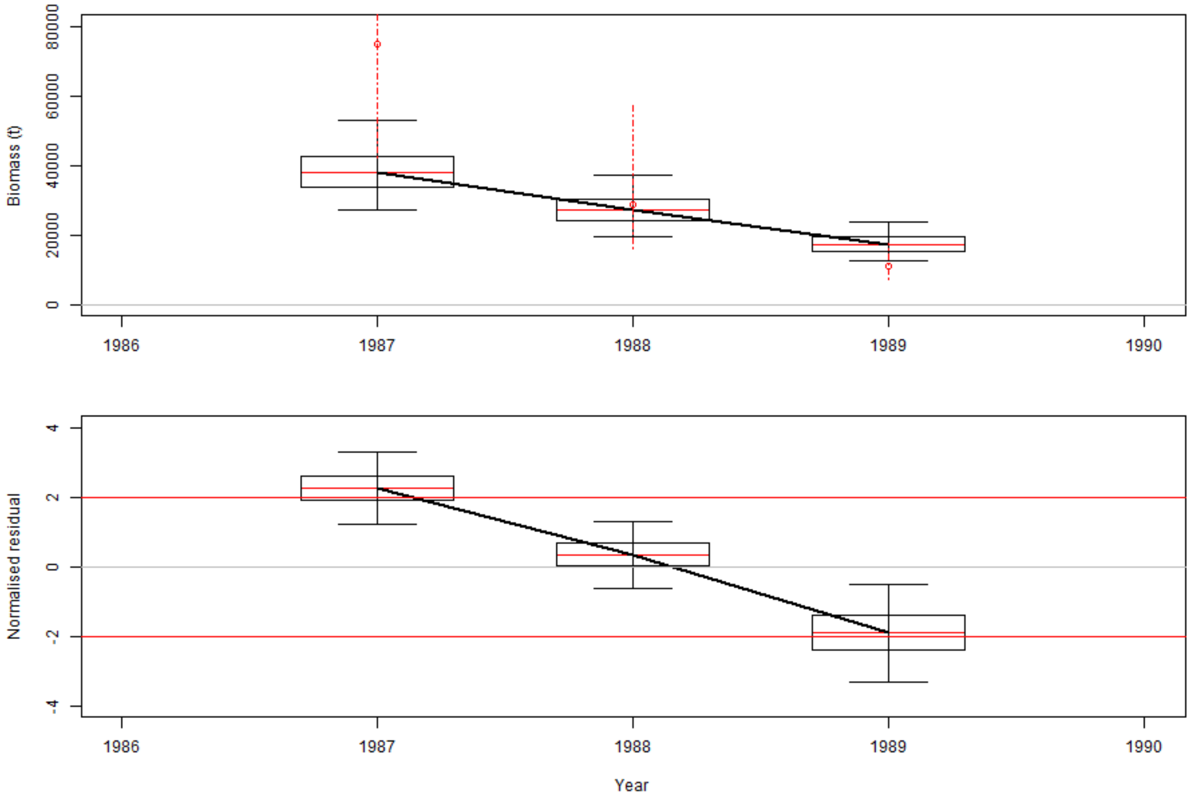


Figure 2: Base, MCMC: fit to the *Amaltal Explorer* trawl indices (top panel) and the associated normalised residuals (bottom panel). Each box covers the middle 50% of the distribution and the whiskers extend to 95% CIs. The indices are plotted in the top panel (open circles) with 95% CIs (dashed red lines).

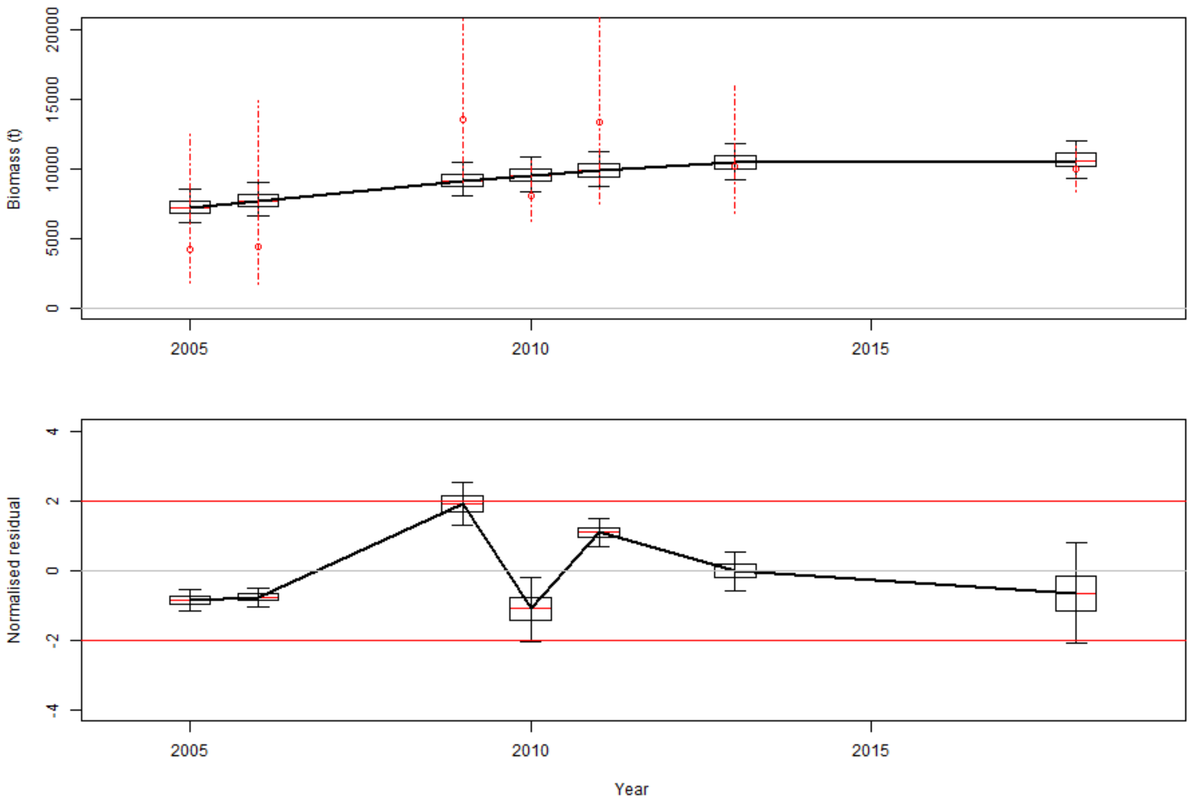


Figure 3: Base, MCMC: fit to the West spawning aggregation (top panel) and the associated normalised residuals (bottom panel). Each box covers the middle 50% of the distribution and the whiskers extend to 95% CIs. The indices are plotted in the top panel (open circles) with 95% CIs (dashed red lines).

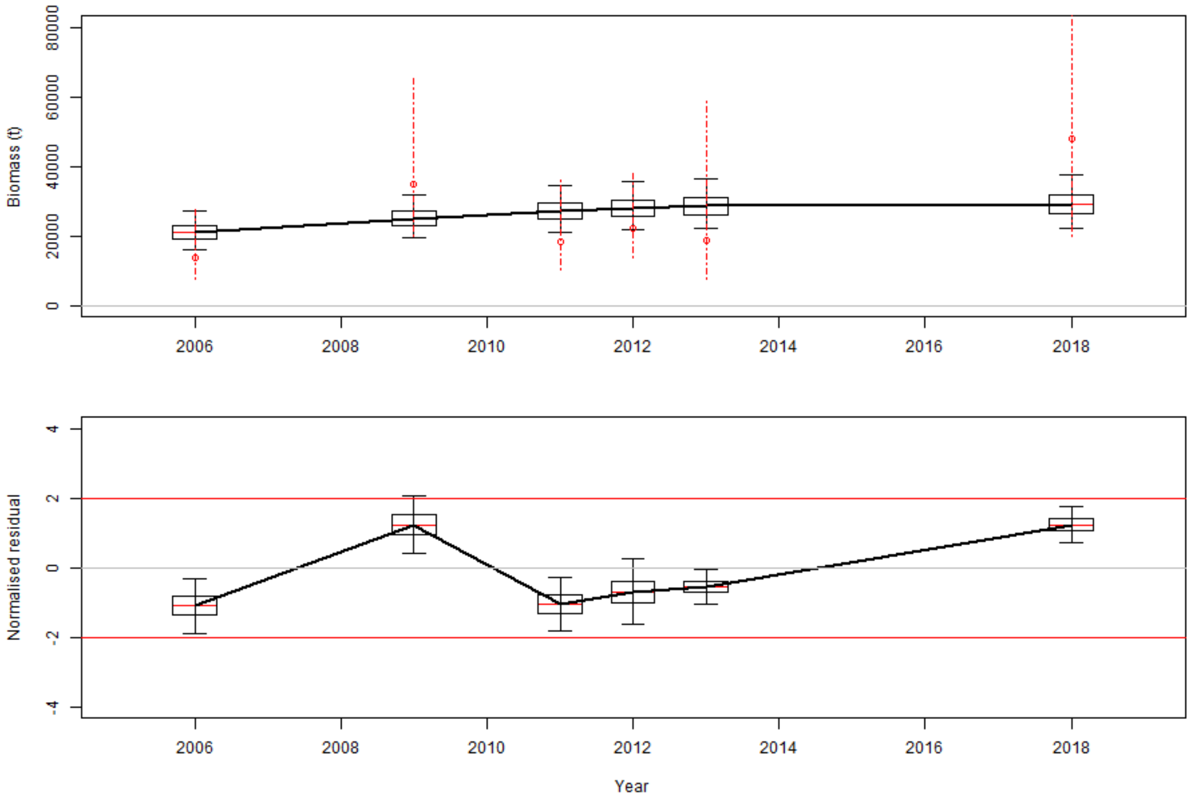


Figure 4: Base, MCMC: fit to the *Thomas Harrison* trawl indices (top panel) and the associated normalised residuals (bottom panel). Each box covers the middle 50% of the distribution and the whiskers extend to 95% CIs. The indices are plotted in the top panel (open circles) with 95% CIs (dashed red lines).

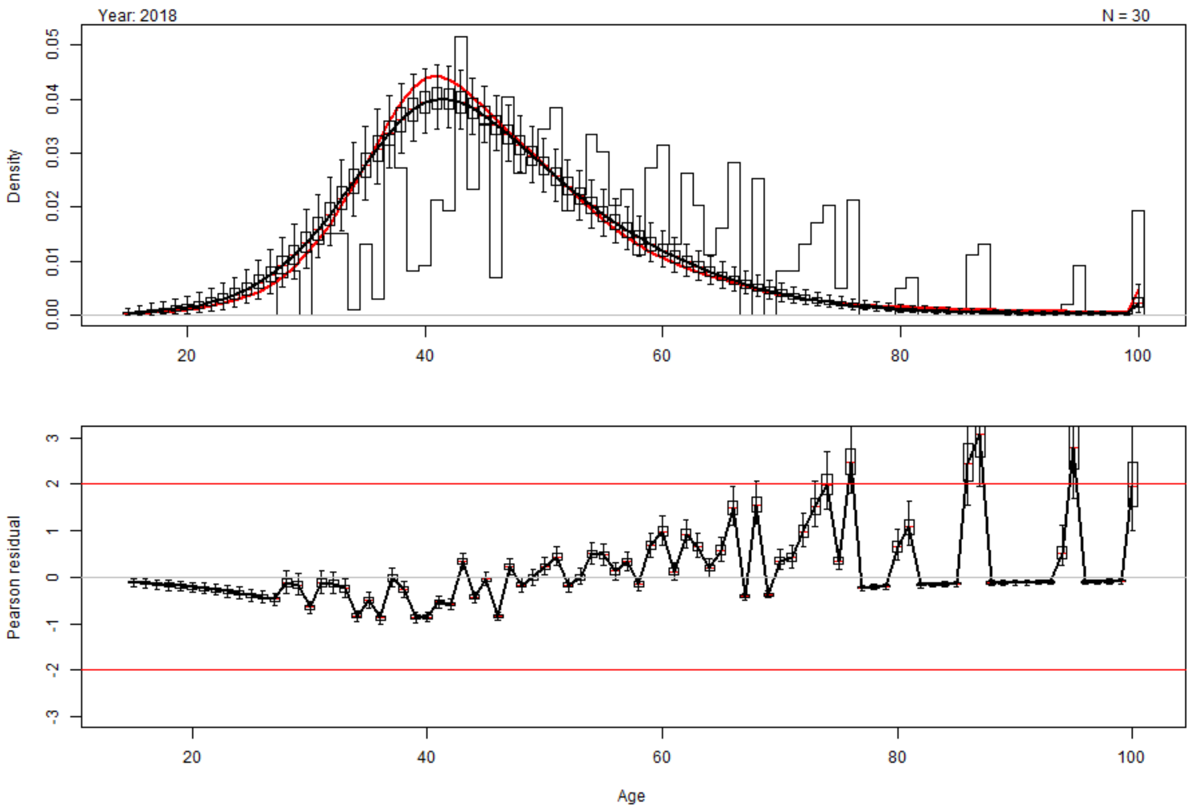


Figure 5: Base, MCMC: fit to the 2018 Volcano age frequency (top panel) and the associated Pearson residuals (bottom panel). Each box covers the middle 50% of the distribution and the whiskers extend to 95% CIs. The indices are plotted in the top panel (open circles) with 95% CIs (dashed red lines). The MPD fit is shown in red (top panel).

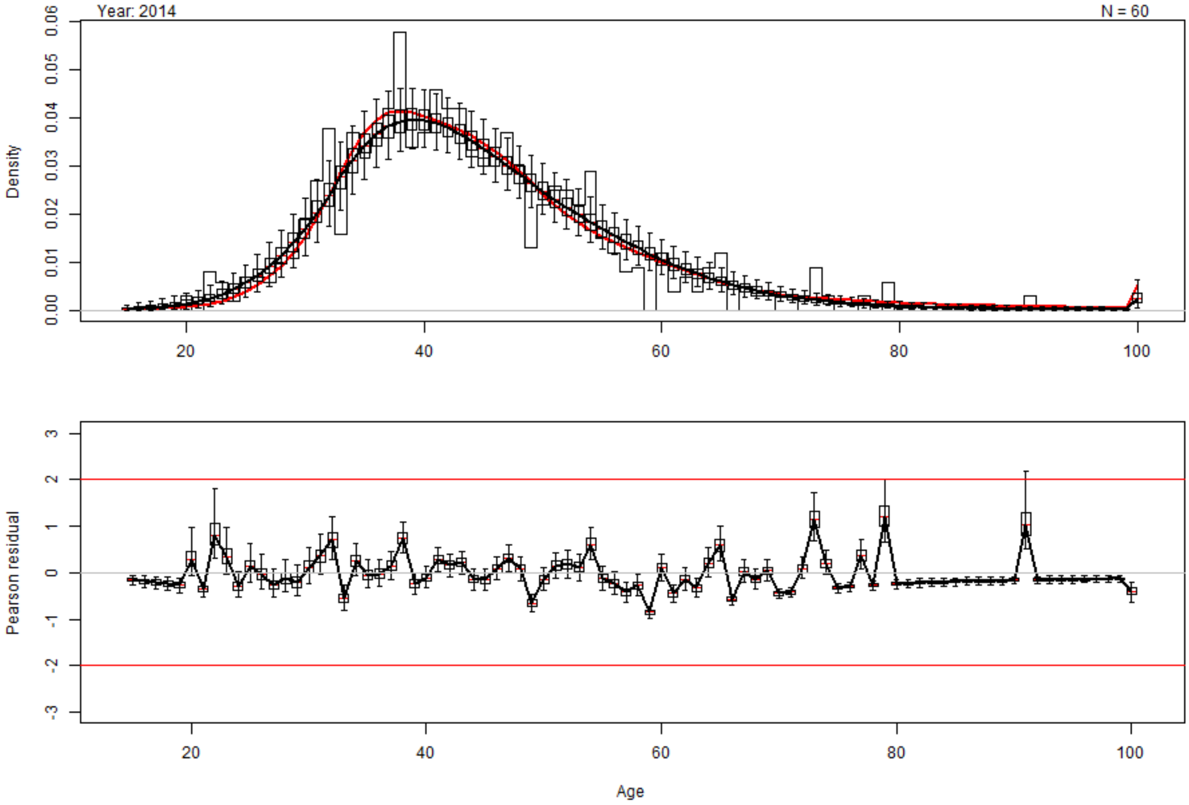


Figure 6: Base, MCMC: fit to the 2014 Volcano age frequency (top panel) and the associated Pearson residuals (bottom panel). Each box covers the middle 50% of the distribution and the whiskers extend to 95% CIs. The indices are plotted in the top panel (open circles) with 95% CIs (dashed red lines). The MPD fit is shown in red (top panel).

The posterior distributions of the *q*s, which had informed priors, show movement to lower values of *q* for *Thomas Harrison*, the West, and the East aggregations, with a shift to higher values for Volcano (Figure 7). Although there is a substantial move to the left (for West and East), the posterior distributions are still within the range of the prior distributions and so the estimates of *q* are credible. For Volcano, the move to higher values probably reflects the nature of the associated selectivity which is to the right of maturity (which is the selectivity for the West and East aggregations).

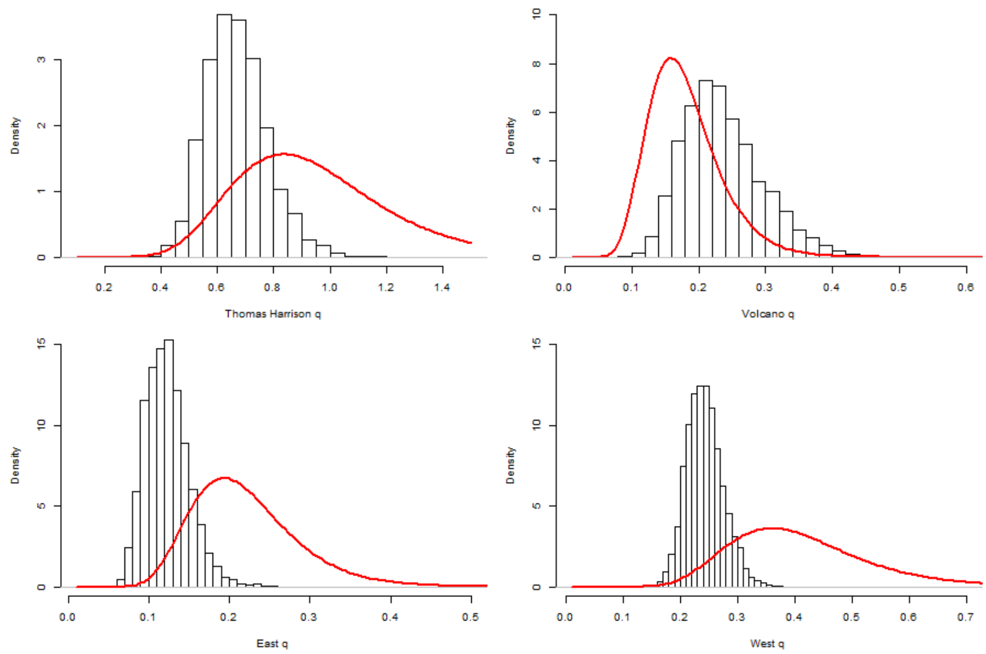


Figure 7: Base, MCMC: Prior distributions (solid red lines) and marginal posterior distributions (histograms) for the *Thomas Harrison* and acoustic *q*s.

MCMC results

For the base model, and the sensitivity runs, MCMC convergence diagnostics were excellent. Virgin biomass (B_0) was estimated to be about 95 000 t for all runs except when the informed priors on the *q*s were removed (Table 4). When the informed priors were removed, virgin biomass was estimated to be higher than in the base model (Table 4). This indicates that the trend in the biomass indices, and to some extent the age frequencies, support a higher virgin biomass than was implied by information on the scale of the stock from the informed priors. The base model estimates are to be preferred as the informed priors contain information on orange roughy target strength and spawning biomass areal availability that is not otherwise available to the model. For all runs, current stock status was estimated to be within or above the target biomass range of 30–50% B_0 (Table 4).

Table 4: MCMC estimates of virgin biomass (B_0) and stock status (B_{2019} as %B_0) for the base model and four sensitivity runs.

	M	B_0 (000 t)	95% CI	B_{2019} (%B_0)	95% CI
Base	0.045	94	86–104	47	39–55
All trend	0.045	107	94–126	57	46–67
Estimate M	0.037	97	89–106	40	31–51
LowM-Highq	0.036	95	88–103	37	30–45
HighM-Lowq	0.054	94	85–106	56	48–65

The estimated YCS show little variation across cohorts but exhibit a long-term trend (Figure 8). The cohorts from 1989–1995 were spawned when SSB was at about 20% B_0 (Figure 9). It is encouraging that the YCS estimates for these cohorts was about average (Figure 8). This suggests that steepness in the assumed Beverton-Holt stock recruitment relationship for this stock is not particularly low.

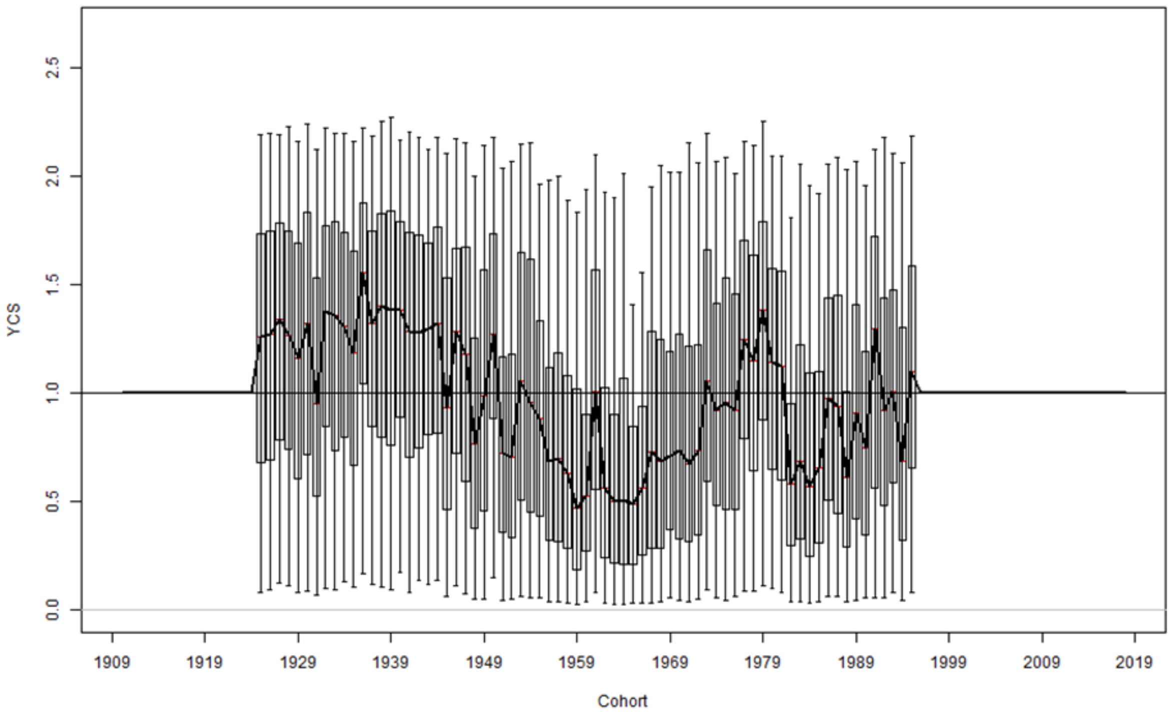


Figure 8: Base, MCMC estimated YCS. The box in each year covers 50% of the distribution and the whiskers extend to 95% of the distribution.

The stock status trajectory shows a steep decline to about 15% B_0 in 1990, reflecting the large removals during the initial fish-down phase of this stock (Figure 9). From 1990 stock status remains at about 15% B_0 until an upturn in the late 1990s (Figure 9). Biomass is estimated to have peaked in 2015, near the top of the target biomass range, before the increased catches (enabled by a TACC increase) caused a levelling out of the biomass trajectory (Figure 9).

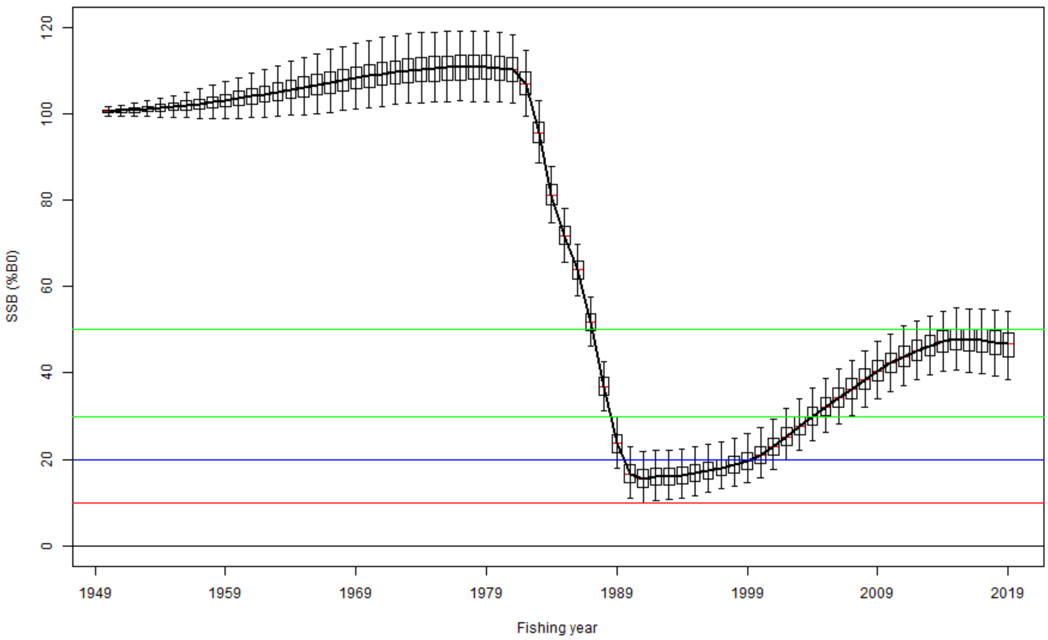


Figure 9: Base, MCMC estimated spawning-stock biomass trajectory. The box in each year covers 50% of the distribution and the whiskers extend to 95% of the distribution. The hard limit 10% B_0 (red), soft limit 20% B_0 (blue), and biomass target range 30–50% B_0 (green) are marked by horizontal lines.

Fishing intensity was estimated in each year as the total exploitation rate (total catch over beginning of fishing season spawning biomass) for each MCMC sample to produce a posterior distribution for fishing intensity by year. The fishing intensity reference points $U_{30\%B0}$ and $U_{50\%B0}$ were also calculated in terms of exploitation rate (for the assumed catch split in the 2018–19 fishing year).

Estimated fishing intensity was generally well above the target range ($U_{30\%B0}$–$U_{50\%B0}$) up until the closure of the fishery in 2001. Subsequently, it was well below the target range up until 2014, and from 2015 until now it is at the lower end of the range (Figure 10).

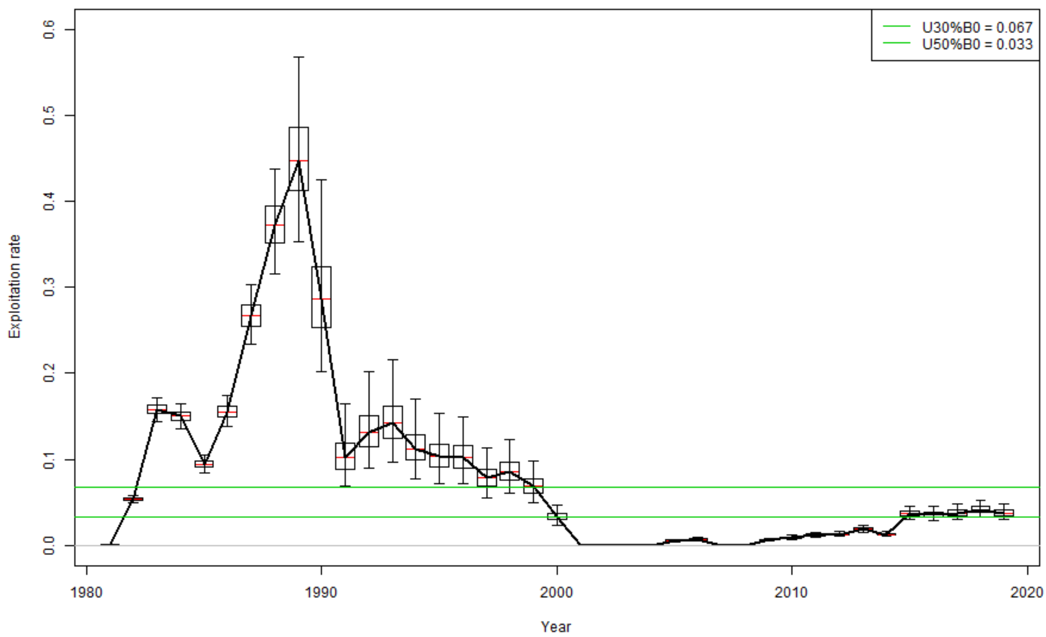


Figure 10: Base, MCMC estimated fishing-intensity trajectory. The box in each year covers 50% of the distribution and the whiskers extend to 95% of the distribution. The fishing-intensity range associated with the biomass target of 30–50% B_0 is marked by horizontal lines.

Projections

Five-year projections were conducted (with resampling from the last 10 estimated YCS, 1986–1995) for a constant catch of 1600 t (the current TACC). A 5% catch over-run was assumed. Projections were done for the base model and for the LowM-Highq sensitivity model (as a "worst case" scenario).

At the current TACC (1600 t), SSB is predicted to decrease slowly over the next five years for both models, while staying within the target biomass range (Figure 11). For both models the estimated probability of SSB going below either the soft limit (20% B_0) or the hard limit (10% B_0) is zero. For the base model projection, exploitation rates are predicted to slowly increase but still be at the lower end of the fishing intensity target range in 2024 (95% CI 0.030–0.054 compared to the target range of 0.033–0.067).

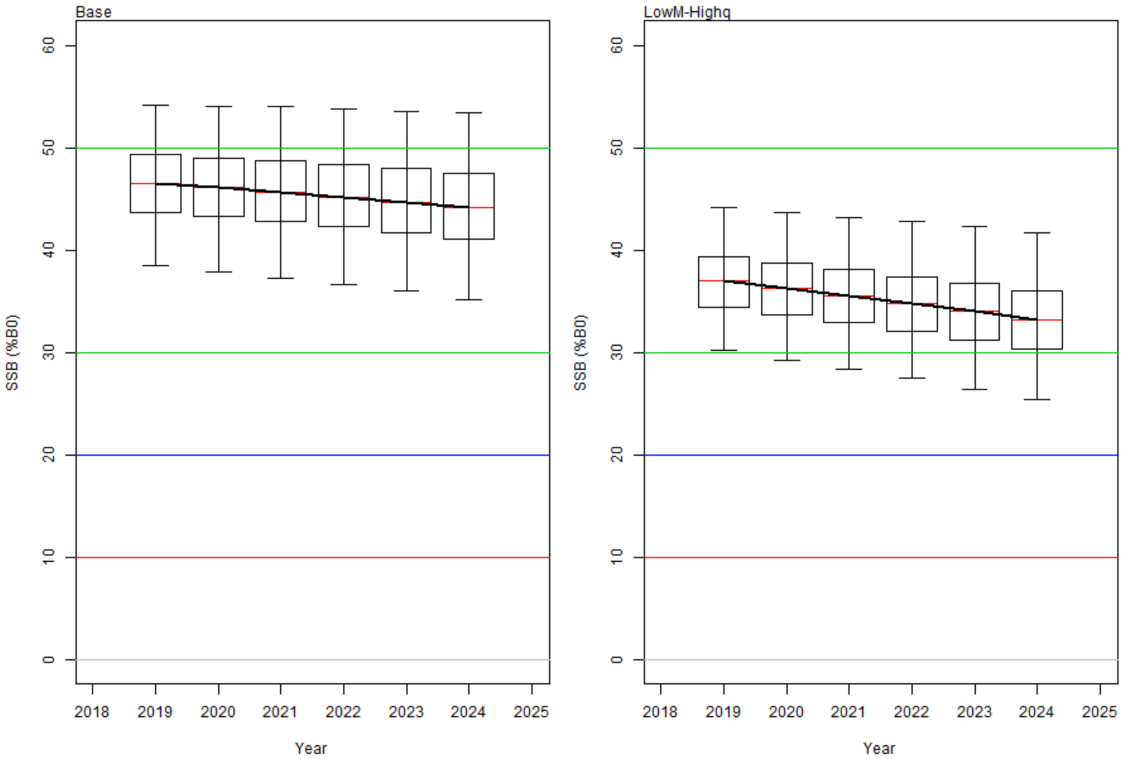


Figure 11: MCMC projections for a constant catch of 1600 t (plus a 5% allowance for incidental catch) for the base model and the LowM-Highq model. The box in each year covers 50% of the distribution and the whiskers extend to 95% of the distribution. The target biomass range (30–50% B_0) is indicated by horizontal green lines, the hard limit (10% B_0) by a red line and the soft limit (20% B_0) by a blue line.

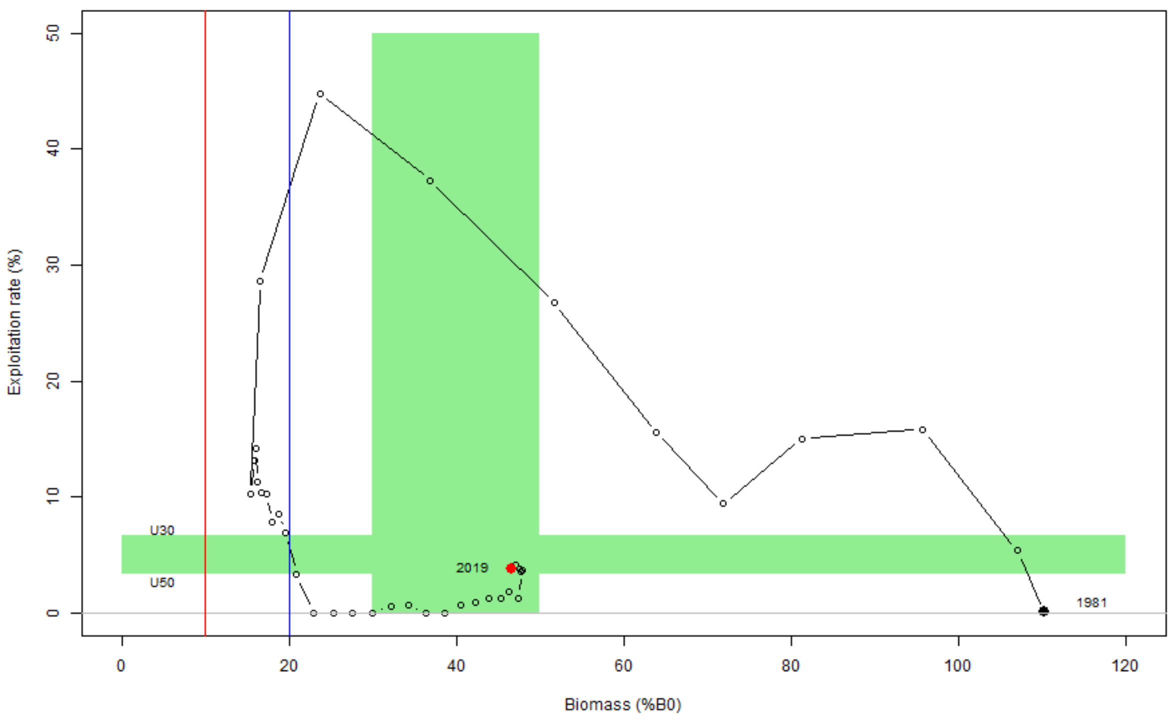
5. FUTURE RESEARCH CONSIDERATIONS

- Revise the acoustic survey design and implementation to ensure (i) improved estimation of the abundance in the 'East' aggregation and (ii) abundance estimates are obtained for all three aggregations ('East', 'West' and Volcano) in the same year.
- Reconsider the otolith sampling approach from acoustic surveys to ensure that adequate otoliths are obtained from each aggregation and that these are obtained from multiple tows to support the stock assessment.
- Review current arrangements for sampling commercial catches for age to ensure that adequate samples are being obtained from both spawning and non-spawning fisheries.

6. STATUS OF THE STOCK

Orange roughy on the southwest Challenger Plateau (Area 7A, including Westpac Bank) are regarded as a single stock.

Stock Status	
Year of Most Recent Assessment	2019
Assessment Runs Presented	Base model only
Reference Points	Management Target: Biomass range 30–50% B_0 Soft Limit: 20% B_0 Hard Limit: 10% B_0 Overfishing threshold: Fishing intensity range $U_{30\%B0}$–$U_{50\%B0}$
Status in relation to Target	B_{2014} was estimated to be 47% B_0 Very Likely (> 90%) to be at or above the lower end of the management target range and About as Likely as Not (40–60%) to be at or above the upper end of the management target range
Status in relation to Limits	B_{2019} is Exceptionally Unlikely (< 1%) to be below the Soft Limit B_{2019} is Exceptionally Unlikely (< 1%) to be below the Hard Limit
Status in relation to Overfishing	Fishing intensity in 2018–2019 was estimated to be below or within the fishing intensity range. Overfishing is Very Unlikely (< 10%) to be occurring.



Historical trajectory of spawning biomass (%B_0) and fishing intensity (exploitation rate) (base model, medians of the marginal posteriors). The biomass target range of 30–50% B_0 and the corresponding exploitation rate (fishing intensity) target range are marked in green. The soft limit (20% B_0) is marked in blue and the hard limit (10% B_0) in red.

Fishery and Stock Trends	
Recent Trend in Biomass or Proxy	Spawning biomass is estimated to have peaked in 2014–2015 near the top of the target biomass range and to have declined slightly since then.
Recent Trend in Fishing Intensity or Proxy	Fishing intensity has been near the bottom of the fishing intensity target range since 2014–15.
Other Abundance Indices	-
Trends in Other Relevant Indicators or Variables	-

Projections and Prognosis	
Stock Projections or Prognosis	Biomass is expected to slowly decrease at the current TACC (1600 t) over the next 5 years, but to remain within the target range.
Probability of Current Catch or TACC causing Biomass to remain below, or to decline below, Limits	Soft Limit: Exceptionally Unlikely (< 1%) within the next 5 years Hard Limit: Exceptionally Unlikely (< 1%) within the next five years
Probability of Current Catch or TACC causing Overfishing to continue or to commence	Very Unlikely (< 10%) within the next five years

Assessment Methodology and Evaluation		
Assessment Type	Level 1 - Full Quantitative Stock Assessment	
Assessment Method	Age-structured CASAL model with Bayesian estimation of posterior distributions	
Assessment Dates	Latest assessment: 2019	Next assessment: 2023
Overall assessment quality rank	1 – High Quality	
Main data inputs (rank)	- Acoustic survey indices for West, East, and Volcano aggregations	1 – High Quality
	- Two trawl survey time series: 1987–1989 and 2006, 2009–2012	1 – High Quality
	- Age frequencies from the trawl surveys in 1987, 2006, 2009, and 2018	1 – High Quality
	- Age frequencies from Volcano in 2014 and 2018	1 – High Quality
Data not used (rank)	- commercial CPUE	3 – Low Quality: unlikely to be indexing stock-wide abundance
	- Acoustic surveys of UTFs other than Volcano	2 – Medium or Mixed Quality: species identification and dead zone problems
	- Other acoustic estimates which did not meet the selection criteria	2 – Medium or Mixed Quality: not surveys of a spawning aggregation or timing too early
	- Early trawl surveys with different vessels covering different areas	2 – Medium or Mixed Quality: not a consistent time series
Changes to Model Structure and Assumptions	- Acoustic biomass estimates were adjusted using a combined correction for vessel motion and the bubble layer estimated for a different vessel on the Chatham Rise. In the 2014 assessment, estimates were not corrected for the bubble layer. - Two fisheries were modelled instead of a single fishery.	
Major Sources of Uncertainty	- The proportion of the stock that is indexed by the acoustic and trawl surveys.	

Qualifying Comments
-

Fishery Interactions
Since the fishery re-opened with a low level of catch and effort, bycatch levels have been relatively low at about 4 to 5%, with spiky oreo being 1.4% of the average catch for 2008-09 to 2013-14. The bycatch of low productivity species over this period includes a number of deepwater shark and coral species. There were no observed incidental captures of seabirds or marine mammals between 2002–03 and 2017–18. Orange roughy are caught using bottom trawl gear. Bottom trawling interacts with benthic habitats.

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ORANGE ROUGHY WEST COAST SOUTH ISLAND (ORH 7B)

1. FISHERY SUMMARY

1.1 Commercial fisheries

The orange roughy west coast South Island Fishstock was introduced into the Quota Management System with a TACC of 1558 t on 1 October 1986. The TACC was increased to 1708 t for the fishing year 1988–89. Landings ranged from 1139 t to 1763 t in the mid-1980s and early 1990s, before decreasing rapidly to just 290 t by 1994–95. The TACC was lowered to 430 t in 1995 and 110 t in 2001, before being reduced to just 1 t in 2007. Landings averaged just 0.68 t during the fishing years 2008–09 to 2018–19.

The fishery was initially centred on an area near the Cook Canyon in Statistical Areas 033, 034 and 705. Up until 1996–97 approximately 80% of the catch was taken in winter (June–July) when fish form aggregations for spawning. From 1997–98 onwards about 50% of the catch was taken in winter. Reported domestic landings and TACCs are shown in Table 1, while the historical landings and TACC for ORH 7B are depicted in Figure 1.

Table 1: Reported landings (t) of orange roughy and TACCs (t) for ORH 7B from 1983–84 to present. QMS data from 1986–present. Catches (t) taken under special permits during winter research surveys after 2013–14 are also noted.

Fishing year	Reported landings	TACC	Research catch
1983–84*	2	-	
1984–85*	282	-	
1985–86*	1 763	1 558	
1986–87*	1 446	1 558	
1987–88	1 413	1 558	
1988–89	1 750	1 708	
1989–90	1 711	1 708	
1990–91	1 683	1 708	
1991–92	1 604	1 708	
1992–93	1 139	1 708	
1993–94	701	1 708	
1994–95	290	1 708	
1995–96	446	430	
1996–97	425	430	
1997–98	330	430	
1998–99	405	430	
1999–00	284	430	
2000–01	161	430	
2001–02	95	110	
2002–03	90	110	
2003–04	119	110	
2004–05	106	110	
2005–06	77	110	
2006–07	125	110	
2007–08	5.95	1	
2008–09	1.44	1	
2009–10	0.04	1	
2010–11	0.14	1	
2011–12	0.06	1	
2012–13	0.25	1	
2013–14	0.62	1	
2014–15	1.67	1	21.7
2015–16	0.27	1	19.2
2016–17	0.58	1	11.0
2017–18	1.42	1	-
2018–19	1.00	1	57.0

*FSU data.

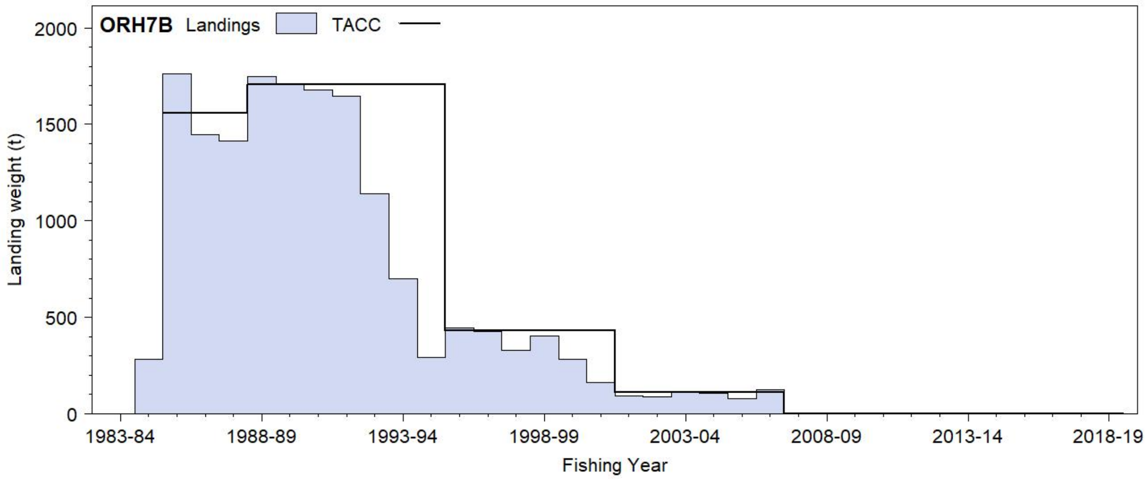

Figure 1: Reported commercial landings and TACC for ORH 7B (Challenger South).

1.2 Recreational fisheries
There is no known recreational fishery for orange roughy in this area.

1.3 Customary non-commercial fisheries
There is no known customary non-commercial fishing for orange roughy in this area.

1.4 Illegal catch
There is no quantitative information available on illegal catch.

1.5 Other sources of mortality
There is no quantitative information available on other sources of mortality in this fishery.

2. STOCKS AND AREAS

There is no new information which would alter the stock boundaries given in previous assessment documents.

Orange roughy in this fishery are thought to be a single stock. Genetic studies have shown that samples of Cook Canyon orange roughy are significantly different from Challenger Plateau and Puysegur Bank samples (Smith et al 1996). Moreover, the size structure and parasite composition differ from fish on the Challenger Plateau (Lester et al 1988). Spawning occurs at a similar time to fish on the Challenger Plateau and the Puysegur Bank.

3. STOCK ASSESSMENT

The previous assessment for this stock was carried out in 2004 and is summarised in the 2006 Plenary Report. Virgin biomass (B_0) was estimated to be approximately 12 000 t with 2004 stock status at 17% B_0 (95% confidence interval 14–23%) when CPUE was assumed to be directly proportional to abundance (McKenzie 2005).

An updated assessment was attempted in 2007 with the addition of catch data up to 2005–06 and new standardised CPUE indices (McKenzie 2008). The Working Group rejected the assessment because of the poor fit to the CPUE data. The results were similar to those from the 2004 assessment; namely a slow rebuild up to 2006, which was not supported by the CPUE data.

A preliminary stock assessment was carried out in 2020 and some results from that assessment are reported here. Results from this assessment were inconclusive.

Results from the 2007 CPUE analysis and the previous assessments are retained below as they are relevant to the decision to effectively close the fishery from 1 October 2007. The use of CPUE analysis for an orange roughy fishery, to provide indices of biomass for use in stock assessment, has not been considered appropriate for more than a decade. Also, the previous assessments assume deterministic recruitment which is also inappropriate for orange roughy stock assessments (Cordue 2014)

3.1 The 2007 analysis of catch and effort data

Commercial catch and effort data are available from 1985. In 2007, these data were examined using both an unstandardised and a standardised analysis. Unstandardised catch rates declined substantially over the course of the fishery but showed no clear trend in the latter years of the fishery to 2005–06 (Table 2).

The standardised CPUE analysis was divided into two series to address reporting form changes: (i) using TCEPR data from 1985–86 through to 1996–97, and (ii) using CELR data from 1990–91 through to 2005–06. In addition, in order to increase vessel linkage across years, it was decided to use all months of data not just that from the winter fishery (June–July) as had been done for previous standardisations.

The standardised analysis for the TCEPR data used catch per tow in a linear regression model. Indices from this model (Table 3, Figure 2) show a steep decline after the first two years, followed by a more gradual decline and a slight increase in catch rates in 1995–96 and 1996–97.

Table 2: Summary of groomed data from TCEPR and CELR forms.

Fishing year	Number of vessel days	Number of tows	Total estimated catch (t)	Mean daily catch rate (t/tow)	Mean daily catch rate (t/h)
1985–86	138	357	1 544	4.5	2.9
1986–87	132	405	1 250	4.0	2.7
1987–88	132	420	1 250	3.4	2.3
1988–89	133	368	827	2.5	1.6
1989–90	123	356	1 282	4.5	5.6
1990–91	208	632	1 657	2.8	3.3
1991–92	238	810	1 601	2.0	1.4
1992–93	258	784	1 128	1.5	2.3
1993–94	298	708	660	1.1	0.9
1994–95	162	361	320	0.9	1.6
1995–96	66	150	275	2.2	1.7
1996–97	90	182	244	1.3	7.5
1997–98	96	228	170	0.7	0.3
1998–99	188	566	359	0.6	0.2
1999–00	213	647	259	0.4	0.1
2000–01	149	442	162	0.4	0.1
2001–02	117	282	76	0.3	0.1
2002–03	97	292	112	0.4	0.2
2003–04	90	252	118	0.4	0.2
2004–05	121	393	102	0.3	0.1
2005–06	87	257	73	0.3	0.2

Table 3: Standardised CPUE indices (relative year effect) based on TCEPR data with number of vessel tows from 1985–86 to 1996–97.

Year	CPUE index	CV	Number of tows	Year	CPUE index	CV	Number of tows
1985–86	1.99	0.20	153	1991–92	0.48	0.23	231
1986–87	2.13	0.23	150	1992–93	0.29	0.23	230
1987–88	1.11	0.26	212	1993–94	0.14	0.25	341
1988–89	0.58	0.22	310	1994–95	0.13	0.27	172
1989–90	0.61	0.22	236	1995–96	0.51	0.33	37
1990–91	0.76	0.23	238	1996–97	0.41	0.26	104

The standardised analysis for the CELR data used daily catch in a linear regression model. Indices from this model (Table 4, Figure 2) show a steep decline for the first four years, followed by an increase to a peak in 1995–96, and subsequent low catch rates after then.

Table 4: Standardised CPUE indices (relative year effect) based on CELR data with number of days from 1990–91 to 2005–06.

Year	CPUE index	CV	Number of days	Year	CPUE index	CV	Number of days
1990–1991	2.17	0.27	110	1999–2000	0.34	0.27	131
1991–1992	1.11	0.27	108	2000–2001	0.34	0.28	88
1992–1993	0.74	0.27	126	2001–2002	0.33	0.28	73
1993–1994	0.28	0.28	81	2002–2003	0.61	0.26	67
1994–1995	0.53	0.30	46	2003–2004	0.59	0.25	75
1995–1996	1.16	0.33	29	2004–2005	0.35	0.24	114
1996–1997	0.53	0.38	19	2005–2006	0.36	0.26	80
1997–1998	0.36	0.30	52				
1998–1999	0.39	0.28	112				

3.2 Stock assessment estimates in 2004

Based on previous stock assessments using CPUE data the TACC was cut back severely from about 1700 t in 1994–95 to 110 t in 2000–01. By the late 1990s the stock was believed to be well below B_{MSY} where it continued until at least 2004 (17% B_0 in the 2004 assessment, Figure 3). Despite the large reduction in annual removals from the stock after 2001–02, catch rates did not increase over the subsequent 5 years.

An updated assessment was attempted in 2007 with the addition of catch data up to 2005–06 and new standardised CPUE indices (Figure 2) based on TCEPR data (1986 to 1997) and a separate CELR series (1991 to 2006). These data were incorporated in a Bayesian stock assessment with deterministic recruitment to estimate stock size. The Working Group rejected the assessment because of the poor fit to the recent CPUE data. The model was insensitive to the recent CPUE data and predicted a rebuild (driven by the recruitment assumptions) that was not supported by any observations in the fishery.

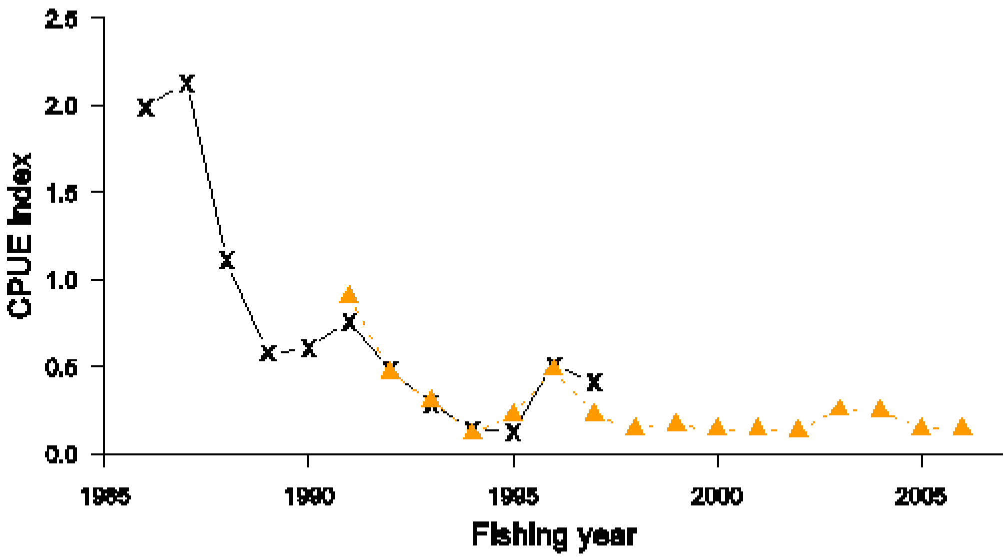

Figure 2: The CPUE indices based on: (i) TCEPR data (solid line and crosses) covering 1985–86 to 1996–97, and (ii) CELR data (triangles and dashed line) covering 1990–91 to 2005–06. The CELR index has been scaled so that it has the same mean value as the TCEPR index in the years that they overlap.

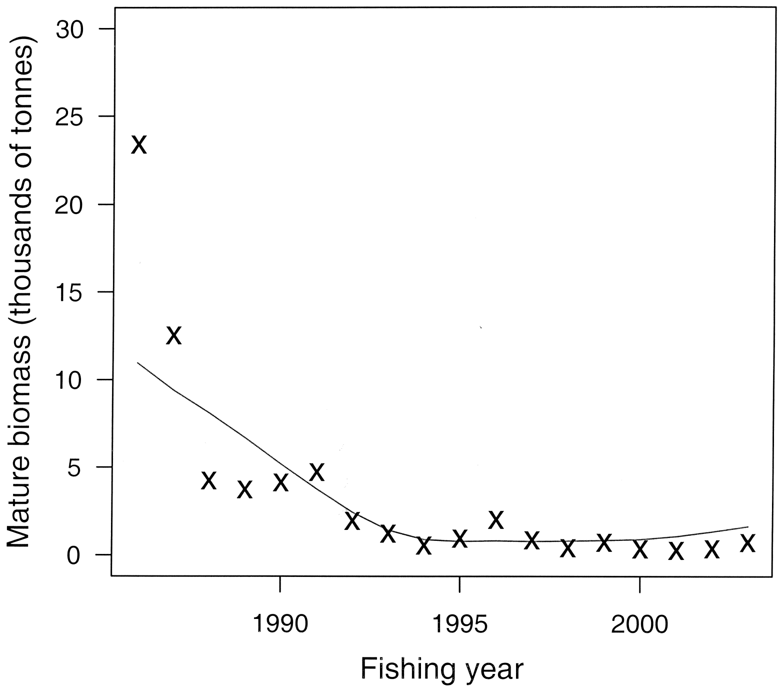

Figure 3: Biomass trajectory derived from Maximum Posterior Density (MPD) estimate of the model parameters (2004 stock assessment). The biomass trajectory is shown by the solid line; crosses denote the CPUE index scaled to biomass.

3.3 Survey biomass estimates

There were three random trawl surveys on the WCSI: two used the FV *Arrow* (October 1983, and in late July-early August 1986); and another by the RV *Tangaroa* in October 1991 (Tracey et al 1990, Armstrong & Tracey 1987, Clark 1991). All three used different stratification, but they broadly covered the same total area. Estimates from these trawl surveys are not used for assessment.

Since 2015, surveys have been regularly conducted in Cook Canyon aimed at locating and acoustically surveying spawning orange roughy plumes. In 2015 an orange roughy plume was seen in Cook Canyon during a search by FV *Amaltal Explorer* but it was transitory and could not be acoustically surveyed (Ryan & Tilney 2016). Another attempt was made from FV *Cook Canyon* from 8 to 11 July 2016 (Doonan et al 2016). There were two parts to the work in 2016: a search for spawning aggregations (plumes); and a random trawl survey in the area around the Cook Canyon, where most of the historical catch was caught. One main spawning plume was found on two consecutive nights, but it dispersed during daylight hours which is its historical behaviour. The plume was mapped using the vessel's echosounder (a fishing rather than a scientific echosounder), so it was not possible to perform acoustic integration and, hence, no acoustic abundance estimate was calculated. One short tow on the main plume produced about 18 t of spawning orange roughy with little bycatch. Most orange roughy catches in the random trawl survey (22 tows) were small (median 19 kg) with a wide size range (15 to 40 cm, mode at 22 cm), but there was one larger survey catch (600 kg) near the plume location which was composed of mainly spent (post-spawning) fish.

A successful acoustic survey was conducted on FV *Amaltal Explorer* in 2017 using a CSIRO acoustic-optical towed system (AOS) (Ryan & Tilney 2017). Three snapshots of a single spawning plume in Cook Canyon gave an average estimate of 824 t (Table 5). The timing of the snapshots was not ideal as they appeared to be late relative to the spawning cycle with 40–50% of sampled fish having spent gonads (Ryan & Tilney 2017). In 2019, on FV *Amaltal Mariner* a plume at the same location as in 2017 was surveyed with a hull mounted system (Ryan & Tilney 2019). The snapshots spanned the main spawning season and there was no trend in the estimates with the increasing percentage of spent fish, which reached 45–65% on 10–11 July (Table 6). The average estimate in 2019 of 877 t was very similar to that in 2017 (Table 6).

Table 5: Biomass estimates from CSIRO's AOS system (38 kHz) during the 2017 acoustic survey. For each snapshot the date, number of transects, the biomass estimate, and the CV are given. It is also noted that for each snapshot orange roughy marks were seen on more than two transects (indicating that a genuine spawning plume was surveyed).

Snapshot	Date	Transects	Biomass (t)	CV (%)	Transects with marks
1	4 July 17	5	627	53	> 2
2	5 July 17	7	930	32	> 2
3	6 July 17	7	915	50	> 2
Average			824	26	

Table 6: Biomass estimates from the *FV Amaltal Mariner* 38 kHz hull-mounted system during the 2019 acoustic survey. For each snapshot the date, number of transects, the biomass estimate, and the CV are given. The number of transects on which orange roughy marks were seen is also given (1 transect indicates a poor-quality snapshot; 2 transects may be adequate but more than 2 indicates that a genuine spawning plume was surveyed).

Snapshot	Date	Transects	Biomass (t)	CV (%)	Transects with marks
1	26 June 19	6	318	48	2
2	26 June 19	6	1393	35	2
3	3 July 19	9	927	21	> 2
4	4 July 19	9	746	31	> 2
5	9 July 19	6	511	64	1
6	9 July 19	5	473	38	2
7	10 July 19	10	958	33	> 2
8	16 July 19	4	198	58	1
Average (2 or >2)			803	14	
Average (>2)			877	17	

3.4 Age frequency data

Orange roughy otoliths have routinely been collected during research surveys of Cook Canyon but they have only been aged for the 2019 acoustic survey. There are some otoliths from early trawl surveys in 1983 and 1986 but the first survey "took place before the spawning distribution was well known" and the second survey was "carried out after spawning was finished" (O'Driscoll 2001). For the 2015 acoustic survey there are 360 otoliths available for Cook Canyon but there was probably only 1 trawl in the spawning plume (which caught 18 t of orange roughy) (Ryan & Tilney 2016). In 2016, there are 476 otoliths available, but 299 of these were from a single trawl catch of 18 t on the plume (Doonan et al. 2016). The otoliths collected in the 2017 acoustic survey are also likely to be unrepresentative of the spawning population that year as they were collected late in the spawning cycle and are heavily skewed towards females (452 female, 150 male) (Ryan & Tilney 2017). The age frequencies that could be created from these various collections of otoliths are likely not to be representative of the surveyed spawning fish population.

The 2019 age frequency was constructed using the method of Doonan et al (2013) from 500 otoliths collected over 6 trawls that targeted the plume. The trawls took place from 26 June to 16 July and caught from 2.5–18 t of orange roughy (Ryan & Tilney 2019). Males and females were almost equally represented and the age frequency across the 6 stations was similar. The scaled age frequency shows a large plus group at 100 years (Figure 4). The Working Group accepted that this sample was likely to be representative of the spawning plume.

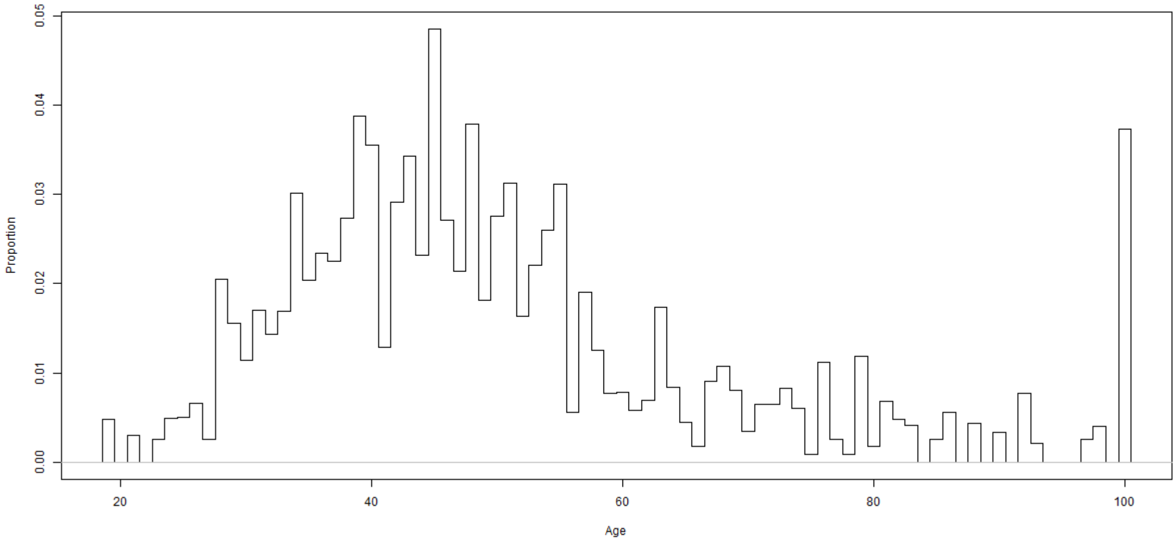

Figure 4: The proportion of orange roughy at age for the scaled age frequency from trawls targeting the spawning plume in the 2019 acoustic survey. There is a plus-group at 100 years.

3.5 The 2020 stock assessment

A preliminary stock assessment was performed in 2020 fitting to the acoustic biomass estimates in 2017 and 2019 and the 2019 age frequency. A single stock, single sex, single area, age-structured model was implemented in CASAL. There were three main model runs which used Bayesian estimation to estimate marginal posterior distributions for virgin biomass (B_0) and current stock status (SS_{2020}). Two of the models were constructed as "worst case" scenarios in an attempt to determine the lowest possible stock status consistent with the data and model assumptions. The other model used the standard approach for orange roughy stock assessments (e.g., Cordue 2014). The estimates of B_0 were consistent with previous estimates of virgin biomass. These estimates are driven by the total removals from the fishery.

The estimates of current biomass and stock status varied widely across the three preliminary models. The standard model adequately fitted the data. However, a low estimate of the acoustic *q* implied that the acoustic surveys had missed one or more spawning plumes. The other two models had lower stock status but were unable to fit the acoustic estimates and predicted much more spawning biomass in those years than had been observed (even allowing for the scaling effect of an acoustic *q* of about 0.6). Therefore, all three of the models implied that the acoustic surveys may have missed one or more spawning plumes.

It should be noted that since the ORH 7A stock has rebuilt spawning plumes have developed in areas where they were not previously seen (e.g., Cordue 2019). Also, for the ESCR orange roughy stock, there is an "old plume" which has been found in the same location for many years and a "new plume" which developed in a different location and consists of younger fish (Doonan et al 2017). The Working Group was unwilling to accept an assessment where current stock status depends on the existence of spawning biomass that has not been observed. The main alternative to an additional unobserved spawning plume is that there has been little recruitment to the spawning population since the closure of the fishery.

3.6 Future research considerations

The preliminary stock assessment results highlight the discrepancy between the expected increase in spawning stock biomass due to a lack of fishing and the observed acoustic survey spawning biomass estimates. Either there are spawning fish that have not been found or there has been an extended period of very low recruitment to the spawning population.

An acoustic survey of Cook Canyon is planned for 2020 using a hull-mounted system. This survey should include more time for searching than was previously planned, in order to:

- Obtain multiple snapshot estimates of the Cook Canyon spawning plume,
- Perform targeted trawling on the spawning plume to obtain a representative age frequency,
- Search for additional spawning plumes in new areas near but outside Cook Canyon (in orange roughy depths but not necessarily associated with a feature or previous fishing for orange roughy).

4. STATUS OF THE STOCK

Stock Structure Assumptions
The ORH 7B stock has been treated as a single spawning stock located around the Cook Canyon area. It is assessed and managed separately from other stocks and is assumed to be non-mixing with orange roughy stocks outside of the Cook Canyon area.

Stock Status	
Year of Most Recent Assessment	2020 (preliminary)
Assessment Runs Presented	N/A
Reference Points	Target: 30–50% B_0 Soft Limit: 20% B_0 Hard Limit: 10% B_0 Overfishing threshold: -
Status in relation to Target	Unknown
Status in relation to Limits	Unknown

Fishery and Stock Trends	
Recent Trend in Biomass or Proxy	Unknown, but biomass is likely to have increased since the closure of the fishery in 2007.
Recent Trend in Fishing Mortality or Proxy	Fishing mortality has been very low, limited to research catches, as the fishery has been closed since October 2007.
Other Abundance Indices	Acoustic surveys carried out in 2017 and 2019 showed no change in abundance
Trends in Other Relevant Indicators or Variables	-

Projections and Prognosis	
Stock Projections or Prognosis	Unknown but likely to be increasing at current catch levels
Probability of Current Catch or TACC causing Biomass to remain below or to decline below Limits	Soft Limit: Unknown Hard Limit: Unknown

Assessment Methodology and Evaluation		
Assessment Type	N/A	
Assessment Method	N/A	
Assessment Dates	Latest assessment: 2020 (preliminary)	Next assessment: 2021
Overall assessment quality rank	N/A	
Main data inputs (rank)	- Catch history - Acoustic biomass 2017, 2019 - Survey age frequency 2019	1 – High Quality 1 – High Quality 1 – High Quality
Data not used (rank)	- CPUE Trawl surveys 1983, 1986, 1991, 2016	3 – Low Quality: not considered to be an index of abundance 3 – Low Quality: not considered to be an index of abundance

Changes to Model Structure and Assumptions	N/A
Major Sources of Uncertainty	- The predicted spawning population, based on the estimated virgin biomass, catch history, and the expected increase with the lack of fishing since 2008, has not been detected by recent acoustic surveys

Qualifying Comments
-

Fishery Interactions
Historically, the main bycatch species were oreos and deepwater dogfish. Other bycatch species recorded include deepwater sharks, deepsea skates and corals. The fishery is currently closed.

5. FOR FURTHER INFORMATION

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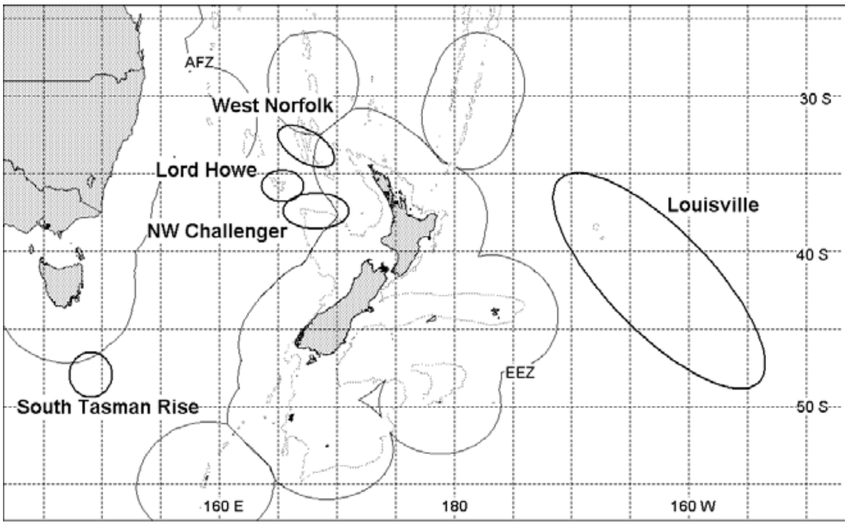
ORANGE ROUGHY OUTSIDE THE EEZ (ORH ET)



1. FISHERY SUMMARY

1.1 Commercial fisheries

Fisheries outside the EEZ in the New Zealand region occur on ridge systems and seamount chains in the Tasman Sea and southwest Pacific Ocean. There are five main fishing areas: Lord Howe Rise, Northwest Challenger Plateau, West Norfolk Ridge, South Tasman Rise, and Louisville Ridge (see figure above).

The first orange roughy fishery outside the EEZ developed on the "Westpac Bank" close to the main fishing grounds on the southwest Challenger Plateau in the early–mid 1980s. Catches were recorded as part of the straddling stock crossing into ORH 7A, and therefore excluded from this chapter, up until 2007. Further exploration in the region resulted in the development of commercial fisheries on the Lord Howe Rise in 1987–88, Northwest Challenger Plateau in 1988–89, Louisville Ridge in 1993–94, South Tasman Rise in 1997–98, and West Norfolk Ridge in 2001–02. Catches from all of these fisheries are tabulated by fishing year up to 2006–07, excluding Westpac catches (Table 1), and by calendar year from 2007 to present (Table 2), as required by the South Pacific Fisheries Management Organisation (SPRFMO).

Table 1: Estimated catches (t) of orange roughy for ORH ET fisheries from 1987–88 to 2006–07. (Data from New Zealand (FSU, QMS), Australia (AFMA), and various sources for other countries. Note that the fishing year for South Tasman Rise is March to February, all others are October to September). See Table 2 for catches from 2007 onwards.

Fishing year	Lord Howe	NW Challenger	Louisville	West Norfolk	South Tasman	Total ET
1987–88	4 000	5	0	0	0	4 005
1988–89	2 430	297	0	0	0	2 727
1989–90	927	425	0	0	0	1 352
1990–01	282	123	0	0	0	405
1991–02	859	620	0	0	0	1 479
1992–03	2 300	2 463	0	0	0	4 763
1993–04	840	1 731	689	0	0	3 260
1994–05	761	1 138	13 252	0	0	15 151
1995–06	5	500	8 816	0	0	9 321
1996–07	139	332	3 209	0	5	3 685
1997–08	26	397	1 404	0	3930	5 757
1998–09	440	961	3 164	0	705	5 270
1999–00	52	473	1 369	0	4 110	6 004
2000–01	428	1 228	1 598	10	830	4 094
2001–02	120	2 075	1 004	649	170	3 729
2002–03	272	1 010	1 296	94	110	2 782
2003–04	324	654	1 419	90	3	2 490
2004–05	430	464	1 510	277	55	2 736
2005–06	240	201	675	727	12	1 855
2006–07	40	96	323	552	0	1 011

Catch totals include data from New Zealand and Australian vessels available from tow by tow fishing records, with estimated catches added for vessels from Japan, USSR, Korea, Norway, South Africa and China. Catch statistics are likely to be incomplete.

These fisheries were historically unregulated, with the exception of the South Tasman Rise area, where catches by Australian and New Zealand vessels have at times been restricted by a TAC imposed under a Memorandum of Understanding between the two countries. The South Tasman Rise fishery is currently closed.

South Pacific Regional Fisheries Management Organisation (SPRFMO) Convention Area

Regulation of these fisheries was implemented following adoption of the SPRFMO interim measures in May 2007, and specific high sea fishing permits for the SPRFMO Area have been issued since 2007–08. Table 2 shows the number of New Zealand vessels that fished and their orange roughy catch by area. Since 2007, an orange roughy catch limit has been applied for New Zealand vessels, being the average annual catch between 2002 and 2006 (1852 t). Australia implements analogous limits for its vessels based on average catches between 2002 and 2006, and no other nations are currently fishing.

Table 2: Annual catch (t) and effort data for orange roughy from New Zealand vessels for the SPRFMO Area (calendar years). Westpac Bank is on the Challenger Plateau but is considered part of the straddling stock ORH 7A so landings from that area are tabulated separately. Australian catches over this period, mostly from the Tasman Sea, ranged from 0 to 148 t, mean 46 t per annum). No other nations fished.

Year	Number of Vessels	Number of tows	Lord Howe	NW Challenger	Westpac	Louisville	West Norfolk	Other	All areas
2007	8	415	34	36	-	280	515	-	866
2008	4	208	380	31	-	-	426	-	837
2009	6	545	403	238	23	-	233	31	928
2010	7	1 170	385	415	5	584	79	6	1 474
2011	7	1 158	1	675	5	285	113	-	1 079
2012	6	652	121	247	8	288	49	8	721
2013	5	760	344	230	3	565	19	3	1 164
2014	5	403	79	57	54	754	-	54	998
2015	5	959	157	530	118	462	20	-	1 287
2016	6	943	208	486	234	27	-	-	954
2017	5	1 423	215	307	129	420	22	-	1 093
2018	6	858	180	399	569	81	5	-	1 232

The SPRFMO Convention was closed for signature in January 2011 and formally entered into force in August 2012. Since that time, monitoring and assessment of catches and fisheries, including for orange roughy, has been overseen by the SPRFMO Scientific Committee.

South Tasman Rise

Exploratory fishing south of Tasmania located aggregations of orange roughy on the South Tasman Rise just outside the Australian Fishing Zone (AFZ) in late 1997. The fishery rapidly increased in the next four years (Table 3), with Australian and New Zealand vessels working several small hill features on the Rise. However, New Zealand vessels have not fished the South Tasman Rise since 2000–01. Effort dropped continuously from 2001–02, and mean catch per tow in 2004–05 was about 1 t/tow. Note that insufficient vessels have fished since 2005–06 to enable presentation of catch or effort summaries.

Table 3: Catch and effort data from the South Tasman Rise (combined Australian and New Zealand data).

Fishing year	Number of tows	Total recorded catch (t)	Mean tow length (h)	Mean catch rate (t/tow)	Mean catch rate (t/h)
1996–97	61	4	0.6	0.1	0.5
1997–98	1 132	3 930	0.7	3.5	17.4
1998–99	1 332	1 705	0.6	1.3	10.4
1999–00	1 086	3 360	0.5	3.1	21.1
2000–01	1 155	830	0.4	0.7	6.7
2001–02	201	170	0.8	1.0	3.5
2002–03	164	110	0.5	0.9	7.9
2003–04	67	2	0.3	0.1	0.4
2004–05	47	55	0.3	1.2	14.7

The fishery was formally regulated by a Memorandum of Understanding between Australia and New Zealand from December 1998. A precautionary TAC of 2100 t was applied, increased to 2400 t in 2000–01, and then progressively reduced to 600 t for 2004–05. The fishery was closed to all trawling in 2007.

1.2 Summary of trends in commercial fisheries

Information presented to the SPRFMO Scientific Committee shows that New Zealand catches of orange roughy have declined since the early 2000s and have been relatively stable at about 1000 t since about 2006 (Figure 1). This is well below the catch limit of 1 852 t. The distribution of catches between areas has varied substantially.

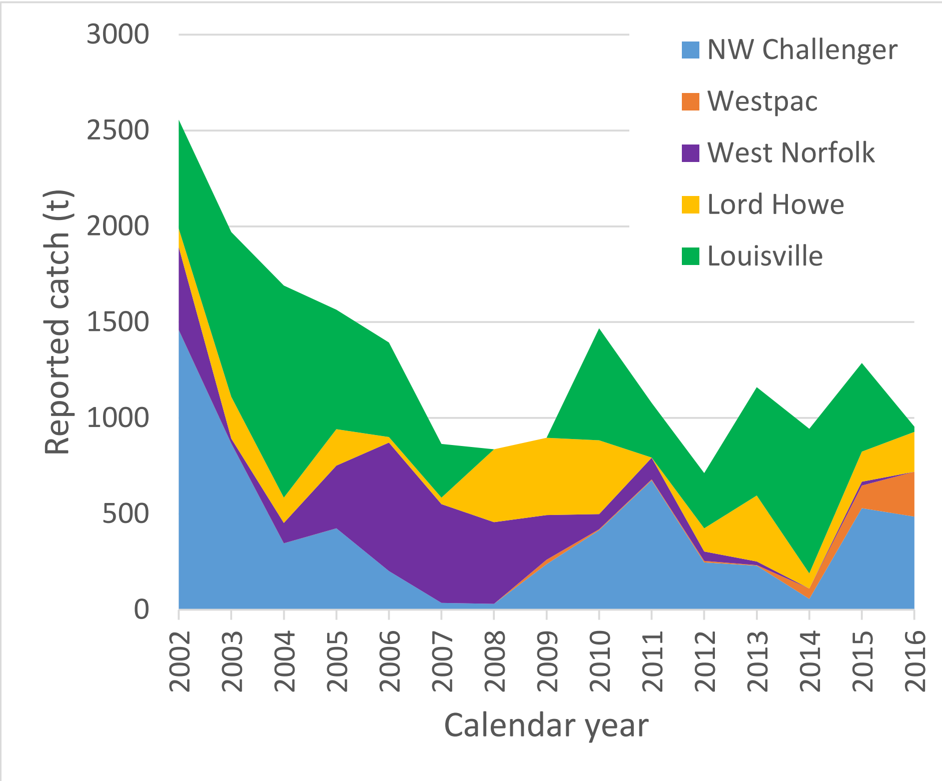


Figure 1: Reported catch by area by New Zealand vessels, 2002–2016.

Catch rates have varied considerably. Roux and Edwards (2017) developed a spatially-disaggregated CPUE index of stock abundance that corrects for some of the known issues with CPUE for orange roughy (Figure 2). This index shows less variability between years than unstandardized or standard GLM modelled-CPUE, but it is still not known whether it indexes biomass.

1.3 Recreational fisheries

There is no non-commercial fishery for orange roughy in these areas.

1.4 Customary non-commercial fisheries

There is no customary non-commercial fishing for orange roughy in these areas.

1.5 Illegal catch

In most of these areas, there were no regulations regarding limits on catch in international waters before 2007. The South Tasman Rise region has been subject to catch restrictions for Australian and New Zealand vessels under a Memorandum of Understanding between the two countries. In 1999–2000 vessels registered in South Africa and Belize fished the region. The estimated catch of at least 750 t has been included in the catch total for that year. No other information is available on any possible illegal catch on the South Tasman Rise, or the Westpac Bank part of ORH 7A.

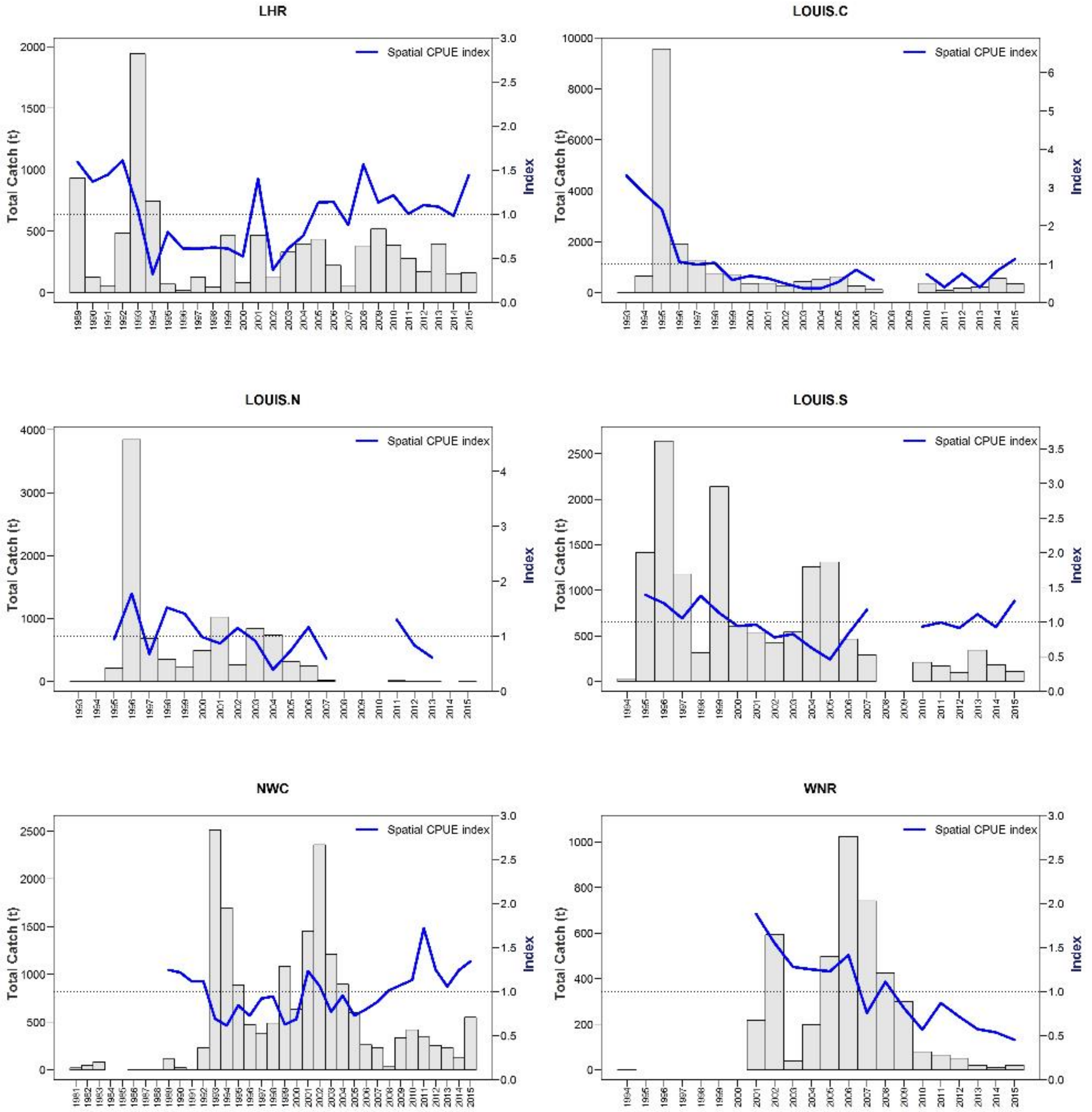


Figure 2: Spatial CPUE indices from Roux & Edwards (2017) for the six orange roughy management areas considered in stock assessments presented to the SPRFMO Scientific Committee in 2017, with annual catch series (histograms).

1.6 Other sources of mortality

There may be some overrun of reported catch because of fish loss with trawl gear damage, ripped nets, discards, and conversion factor inaccuracies. In a number of other orange roughy fisheries, a current level of 5% has been applied (higher in the past). No corrections are made here because of limited information on the sources which may differ with each fishery.

2. STOCKS AND AREAS

Stock structure is uncertain but Clark et al (2016) analysed multiple data sets and recommended that fishing grounds in the following areas be considered as separate units for the purpose of stock assessment: Lord Howe Rise; NW Challenger; SW Challenger; West Norfolk Ridge; South Tasman Rise, and North, Central, and South Louisville (Figure 3).

Orange roughy on the South Tasman Rise are regarded as a straddling stock with fish inside the AFZ. Those on the Westpac Bank on the SW Challenger Plateau are regarded as a straddling stock with fish inside New Zealand's EEZ and the ORH 7A stock.

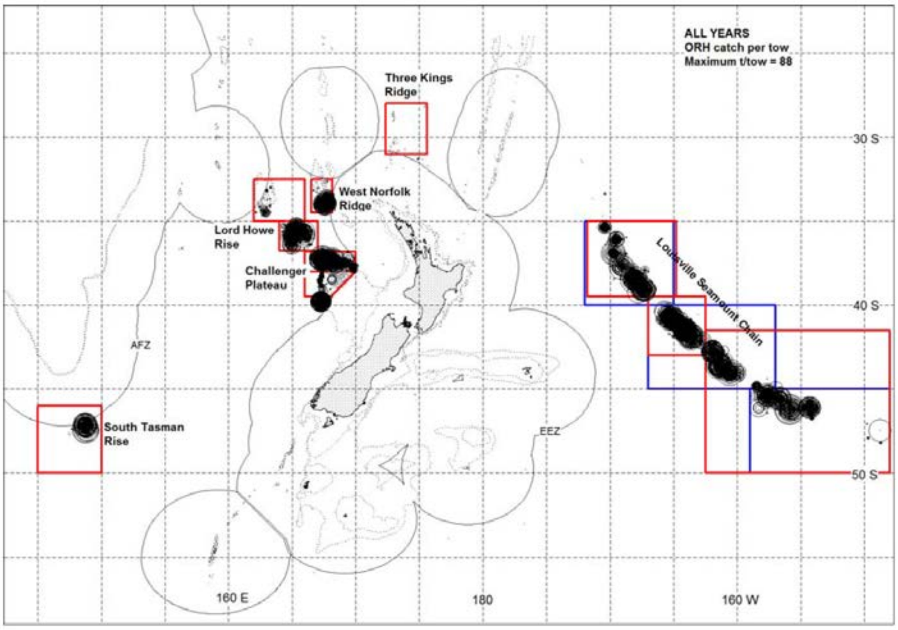


Figure 3: Comparison of new areas assumed for stock assessment purposes (in red) and previous areas (in blue) overlaid on the total distribution of catch rates for orange roughy. Where both areas are coincident, red boxes overlay blue boxes. See Clark et al 2016 for details.

3. STOCK ASSESSMENT

Several low-information stock assessments were presented to the SPRFMO Scientific Committee in 2015 and 2016 but these were not used by the committee to frame advice to the SPRFMO Commission until the 2017 meeting. The following is an extract from the report of the Scientific Committee's meeting in August 2017.

98. Noting the urgent need to collect information to support robust assessments of orange roughy in the SPRFMO Area for sound management advice, the Scientific Committee considered the three approaches to assess SPRFMO orange roughy stocks as detailed in SC5-DW11 to DW14, SC5-INF03, and the Report of the 2nd Deepwater Workshop of the Scientific Committee (Annex 5). Although none of the methods is ideal for the assessment of SPRFMO orange roughy stocks, the SC considered them to be collectively indicative of stock status and potential yields. The development of advice on catch limits for individual stocks was considered but, because of the level of uncertainty in estimates of status and yield by stock, it was considered better to group the stocks for the development of advice.

99. The SC used the lower 95% CIs of estimated stock status to inform the level of precaution that might be appropriate. The group of stocks to the west of New Zealand (in the Tasman Sea) have a greater potential for low stock status than those to the east (Louisville Ridge) and a more precautionary approach was considered appropriate there.

Papers adopted and cited by the Scientific Committee in framing this advice were as follows:

- Roux et al (2017), FAR 2017/01, tabled as paper SC5-DW11: Low information stock assessment of orange roughy in the SPRFMO Area. Available at: http://www.sprfmo.int/assets/SC5-2017/SC5-DW11-NZFAR-2017-01-Orange-roughy-SPRFMO-area.pdf
- Edwards & Roux (2017), tabled as paper SC5-DW12: A simple delay-difference model for assessment of data-poor orange roughy stocks. Available at: http://www.sprfmo.int/assets/SC5-2017/SC5-DW12-Edwards-Roux-Delay-difference-ORY-model.pdf

- Roux & Edwards (2017), tabled as paper SC5-DW13: A data limited approach for assessing small scale fisheries for orange roughy in the SPRFMO Area. Available at: http://www.sprfmo.int/assets/SC5-2017/SC5-DW13-rev1-Roux-Edwards-BDM-method-ORY.pdf
- Cordue (2017a), tabled as paper SC5-DW14: Catch-history based stock assessments of seven SPRFMO orange roughy stocks. Available at: http://www.sprfmo.int/assets/SC5-2017/SC5-DW14-Cordue-catch-history-method-ORY.pdf
- Cordue (2017b), tabled as paper SC5-INF03: A CPUE based stock assessment of the Louisville Central orange roughy stock. Available at: http://www.sprfmo.int/assets/SC5-2017/SC5-INF03-LouisCentralAssess.pdf
- Galvez et al (2017), tabled as paper SC5-Doc08: Report from the Deepwater Workshop in Hobart, May 2017. Available at: http://www.sprfmo.int/assets/SC5-2017/SC5-Doc08-rev1-DWG-Workshop-Report-Final27Sep17.pdf

4. STATUS OF THE STOCKS

The status of the stocks in the SPRFMO Convention Area is poorly known. The SPRFMO Scientific Committee based its precautionary advice to the Commission in 2017 on the papers cited in Section 3, using the lower limit of 95% confidence or credible intervals of the estimated status from a range of low-information methods. These were tabulated by Cryer et al (2017) (Table 4).

It is not known if recent catch levels are sustainable, or whether they will allow the stocks to move towards a size that will support the *MSY*.

Table 4: Summary results from biomass dynamic modelling using a spatially disaggregated CPUE index (BDM) and catch-history age-structured assessment (CAS) for seven putative stocks of orange roughy. The lower 95% credible limits of depletion are from Roux & Edwards 2017 (BDM) and Cordue 2017a (CAS) and potential yield is here estimated as B_{curr} x HR_{MSY} (BDM) and the lower limit of Cordue's illustrative range of percentiles from the posterior distribution of long-term yield (CAS).

Management unit	Lower 95% CI from BDM	Potential Yield from BDM (t)	Lower 95% CI from CAS	Potential Yield from CAS (t)
Louisville North	0.35	207	0.32	270
Louisville Central*	0.14	148	0.24	400
Louisville South	0.39	510	0.18	270
West Norfolk Ridge	0.26	60	0.19	110
Lord Howe Rise**	0.49	N/A	0.07	87
Northwest Challenger	N/A	N/A	0.13	170
South Tasman Rise	N/A	N/A	0.42	N/A

* An age-structured CPUE model for Louisville Central (Cordue 2017b) gave estimates of the lower 95% limits for depletion and yield intermediate between those of BDM and CAS models.

** The BDM fit for Lord Howe Rise included an implausibly high estimate of r_{max} for orange roughy and the model was not considered useful.

5. FOR FURTHER INFORMATION

Anderson, O F (2006) A summary of biological information on the New Zealand fisheries for orange roughy (*Hoplostethus atlanticus*) for the 2003–04 fishing year. *New Zealand Fisheries Assessment Report 2006/16*. 25 p.

Clark, M R (2003) Estimation of orange roughy biomass on the Louisville Ridge: application of "Seamount Meta-analysis" results. Final Research Report to the Ministry of Fisheries for ORH2002/03. (Unpublished report held by Fisheries New Zealand, Wellington.)

Clark, M R (2004) Descriptive analysis of orange roughy fisheries in the New Zealand region outside the EEZ: Lord Howe Rise, Northwest Challenger Plateau, West Norfolk Ridge, South Tasman Rise, and Louisville Ridge to the end of the 2002–03 fishing year. *New Zealand Fisheries Assessment Report 2004/51* 36 p.

Clark, M R (2006a) Descriptive analysis of orange roughy fisheries in the New Zealand region outside the EEZ: Lord Howe Rise, Northwest Challenger Plateau, West Norfolk Ridge, South Tasman Rise, and Louisville Ridge to the end of the 2003–04 fishing year. *New Zealand Fisheries Assessment Report 2006/25*. 37 p.

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Clark, M R (2008) Descriptive analysis of orange roughy fisheries in the New Zealand region outside the EEZ: Lord Howe Rise, Northwest Challenger Plateau, West Norfolk Ridge, South Tasman Rise, and Louisville Ridge to the end of the 2005–06 fishing year. *New Zealand Fisheries Assessment Report 2008/12*. 45 p.

Clark, M R; Anderson, O F (2001) The Louisville Ridge orange roughy fishery: an update of commercial catch-effort data and CPUE analysis of the fishery to the end of the 1999–2000 fishing year. *New Zealand Fisheries Assessment Report 2001/74*. 31 p.

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Clark, M R; O'Driscoll, R L (2002) Descriptive analysis of orange roughy fisheries in the Tasman Sea outside the New Zealand EEZ: Lord Howe Rise, Northwest Challenger Plateau, and South Tasman Rise from 1986–87 to the end of the 2000–01 fishing year. *New Zealand Fisheries Assessment Report 2002/59*. 26 p.

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Clark, M; Tilzey, R (1996) A summary of stock assessment information for orange roughy fisheries on the Lord Howe Rise: 1996. Bureau of Resource Sciences, Canberra. 23 p. (Available from BRS, P.O. Box E11, Canberra, Australia).

Clark, M; Tilzey, R (2001) A summary of commercial catch and effort information for the orange roughy (*Hoplostethus atlanticus*) fishery on the South Tasman Rise from 1987 to 1999. *New Zealand Fisheries Assessment Report 2001/3.* 16 p.

Cordue, P L (2017a) Catch-history based stock assessments of seven SPRFMO orange roughy stocks. Paper SC05-DW14 for the Scientific Committee of the South Pacific Regional Fisheries Management Organisation, Shanghai, 23–28 August 2017.

Cordue, P L (2017b) A CPUE based stock assessment of the Louisville Central orange roughy stock. Paper SC05-INF03 for the Scientific Committee of the South Pacific Regional Fisheries Management Organisation, Shanghai, 23–28 August 2017.

Cryer, M; Bock, T; Nicol, S (2017) Potential scientific advice for Orange roughy stocks / management units within the Western SPRFMO Area. Paper SC05-DW15 for the Scientific Committee of the South Pacific Regional Fisheries Management Organisation, Shanghai, 23–28 August 2017.

Edwards, C T T; Roux, M-J (2017) A simple delay-difference model for assessment of data-poor orange roughy stocks. Paper SC05-DW12 for the Scientific Committee of the South Pacific Regional Fisheries Management Organisation, Shanghai, 23–28 August 2017.

Galvez, M; Cryer, M; Nicol, S; Loveridge, C (2017) Report of the SPRFMO Deep Water Working Group Workshop. Paper SC05-Doc08 for the Scientific Committee of the South Pacific Regional Fisheries Management Organisation, Shanghai, 23-28 August 2017.

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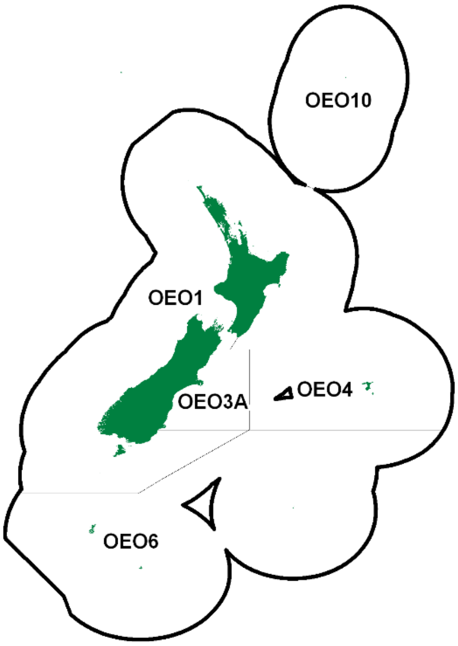
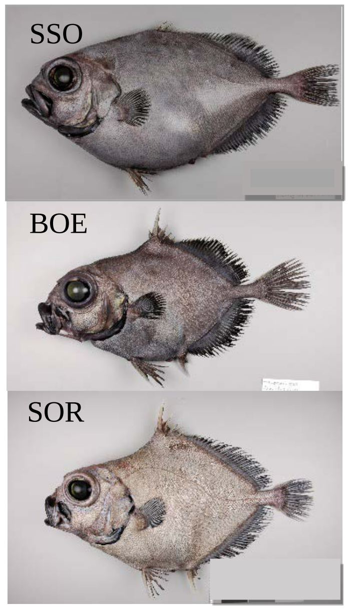
OREOS (OEO)

(*Pseudocyttus maculatus*, *Allocyttus niger*, *Neocyttus rhomboidalis* and *Allocyttus verucosus*)





1. INTRODUCTION

The oreo (OEO) complex consists of four species: smooth oreo (*Pseudocyttus maculatus*; SSO), black oreo (*Allocyttus niger*; BOE), spiky oreo (*Neocyttus rhomboidalis*; SOR) and warty oreo (*Allocyttus verucosus*; WOE). The species most commonly caught are smooth oreo and black oreo.

The main black oreo and smooth oreo fisheries have been assessed separately and individual reports produced for each as follows:

1. OEO 3A black oreo and smooth oreo
2. OEO 4 black oreo and smooth oreo
3. OEO 1 and OEO 6 black oreo and smooth oreo

2. BIOLOGY

2.1 Black oreo

Black oreo have been found within a 600 m to 1300 m depth range. The geographical distribution south of about 45° S is not well known. It is a southern species and is abundant on the south Chatham Rise, along the east coast of the South Island, the north and east slope of Pukaki Rise, the Bounty Platform, the Snares slope, Puysegur Bank and the northern end of the Macquarie Ridge. They most likely occur all around the slope of the Campbell Plateau.

Spawning occurs from late October to at least December and is widespread on the south Chatham Rise. Mean length at maturity for females, estimated from Chatham Rise trawl surveys (1986–87, 1990, 1991–93) using macroscopic gonad staging, is 34 cm TL.

They appear to have a pelagic juvenile phase, but little is known about this phase because only about 12 fish less than 21 cm TL have ever been caught. The pelagic phase may last for 4–5 years with lengths of up to 21–26 cm TL.

Unvalidated age estimates were obtained for Chatham Rise and Puysegur-Snares samples in 1995 and 1997 respectively using counts of the zones (assumed to be annual) observed in thin sections of otoliths.

These estimates indicate that black oreo is slow growing and long lived. The maximum estimated age was 153 years (45.5 cm TL fish). Australian workers used the same methods, i.e., sections of otoliths, and reported similar results A von Bertalanffy growth curve was fitted to the Puysegur samples only (Table 1). Estimated age at maturity for females was 27 years.

Table 1: Biological parameters for black oreo and smooth oreo stock assessments. Values not estimated are indicated by (-). Some parameters may be estimated in specific stock assessments.

Fishstock			Estimate
1. Natural Mortality - *M* (yr^{-1})			
	Females	Males	Unsexed
Black oreo (McMillan et al 1997)	0.044 (0.028–0.075)	0.044 (0.028–0.075)	0.044
Smooth oreo (Doonan et al 1997)	0.063 (0.042–0.099)	0.063 (0.042–0.099	
2. Age at recruitment - A_r (yr)			
Black oreo	-	-	-
Smooth oreo	21	21	
3. Age at maturity A_M (yr)			
Black oreo	27	-	-
Smooth oreo	31	-	

4. von Bertalanffy parameters

	Females			Males			Unsexed		
	L_{∞}(cm, TL)	k(yr^{1})	t_0 (yr)	L_{∞}(cm, TL)	k(yr^{1})	t_0 (yr)	L_{∞}(cm, TL)	k(yr^{1})	t_0 (yr)
Black oreo	39.9	0.043	-17.6	37.2	0.056	-16.4	38.2	0.05	-17.0
Smooth oreo	50.8	0.047	-2.9	43.6	0.067	-1.6			

5. Length-weight parameters (Weight = a(length)^b (Weight in g, length in cm fork length))

	Females		Males		Unsexed	
	a	b	a	b	a	b
Black oreo	0.008	3.28	0.016	3.06	0.0078	3.27
Smooth oreo	0.029	2.90	0.032	2.87		

	Females	Males	Unsexed
6. Length at recruitment (cm, TL)			
Black oreo	-	-	-
Smooth oreo	34	-	
7. Length at maturity (cm, TL)			
Black oreo	34	-	-
Smooth oreo	40	-	-
8. Recruitment variability (σ_R)			
Black oreo	0.65	0.65	0.65
Smooth oreo	0.65	0.65	
9. Recruitment steepness			
Black oreo	0.75	0.75	0.75
Smooth oreo	0.75	0.75	

A first estimate of natural mortality (*M*), 0.044 (yr^{-1}), was made in 1997 using the Puysegur growth data only. This estimate is uncertain because it appeared that the otolith samples were taken from a well fished part of the Puysegur area.

Black oreo appear to settle over a wide range of depths on the south Chatham Rise, but appear to prefer to live in the depth interval 600–800 m that is often dominated by individuals with a modal size of 28 cm TL.

2.2 Smooth oreo

Smooth oreo occur from 650 m to about 1500 m depth. It is a southern species and is abundant on the south Chatham Rise, along the east coast of the South Island, the north and east slope of Pukaki Rise, the Bounty Platform, the Snares slope, Puysegur Bank and the northern end of the Macquarie Ridge. They most likely occur all around the slope of the Campbell Plateau but the geographical distribution south of about 45° S is not well known.

Spawning occurs from late October to at least December and is widespread on the south Chatham Rise in small aggregations. Mean length at maturity for females, estimated from Chatham Rise trawl surveys (1986–87, 1990, 1991–93) using macroscopic gonad staging, is 40 cm TL.

They appear to have a pelagic juvenile phase, but little is known about this phase because only about six fish less than 16 cm TL have ever been caught. The pelagic phase may last for 5–6 years with lengths of up to 16–19 cm TL.

Unvalidated age estimates were obtained for Chatham Rise and Puysegur-Snares fish in 1995 and 1997 respectively using counts of the zones (assumed to be annual) observed in thin sections of otoliths. These estimates indicate that smooth oreo is slow growing and long lived. The maximum estimated age was 86 years (51.3 cm TL fish). Australian workers used the same methods, i.e., sections of otoliths, and reported similar results. A von Bertalanffy growth curve was fitted to the age estimates from Chatham Rise and Puysegur-Snares fish combined and the parameters estimated for the growth curve are in Table 1. Estimated age at maturity for females was 31 years.

An estimate of natural mortality, 0.063 (yr^{-1}), was made in 1997 (Doonan et al 1997). The estimate was from a moderately exploited population of fish from the Puysegur region.

There are concentrations of recently settled smooth oreo south and south west of Chatham Island, although small individuals (16–19 cm TL) occur widely over the south Chatham Rise at depths of 650–800 m.

3. STOCKS AND AREAS

3.1 Black oreo

The stock structure of Australian and New Zealand samples was examined using genetic (allozyme and mitochondrial DNA) and morphological counts (fin rays, etc.). It was concluded that the New Zealand samples constituted a stock distinct from the Australian sample based on “small but significant difference in mtDNA haplotype frequencies (with no detected allozyme differences), supported by differences in pyloric caeca and lateral line counts”. The genetic methods used may not be suitable tools for stock discrimination around New Zealand.

A New Zealand pilot study examined stock relationships using samples from four management areas (OEO 1, OEO 3A, OEO 4 and OEO 6) of the New Zealand EEZ. Techniques used included genetic (nuclear and mitochondrial DNA), lateral line scale counts, settlement zone counts, parasites, otolith microchemistry, and otolith shape. Lateral line scale and pyloric caeca counts were different between samples from OEO 6 and the other three areas. The relative abundance of three parasites differed significantly between all areas. Otolith shape from OEO 3A samples was different to that from OEO 1 and OEO 4, but OEO 1, OEO 4 and OEO 6 otolith samples were not morphologically different. Genetic, otolith microchemistry, and settlement zone analyses showed no regional differences.

3.2 Smooth oreo

Stock structure of Australian and New Zealand samples was examined using genetic (allozyme and mitochondrial DNA) and morphological counts (fin rays, etc.). No differences between New Zealand and Australian samples were found using the above techniques. A broad scale stock is suggested by these results but this seems unlikely given the large distances between New Zealand and Australia. The genetic methods used may not be suitable tools for stock discrimination around New Zealand.

A New Zealand pilot study examined stock relationships using samples from four management areas (OEO 1, OEO 3A, OEO 4 and OEO 6) of the New Zealand EEZ. Techniques used included genetic (nuclear and mitochondrial DNA), lateral line scale counts, settlement zone counts, parasites, otolith microchemistry, and otolith shape. Otolith shape from OEO 1 and OEO 6 was different to that from OEO 3A and OEO 4 samples. Weak evidence from parasite data, one gene locus and otolith microchemistry suggested that northern OEO 3A samples were different from other areas. Lateral line scale and otolith settlement zone counts showed no differences between areas.

These data suggest that the stock boundaries given in previous assessment documents should be retained until more definitive evidence for stock relationships is obtained, i.e., retain the areas OEO 1, OEO 3A, OEO 4, and OEO 6 (see the figure on the first page of the Oreos assessment report above).

The four species of oreos (black oreo, smooth oreo, spiky oreo, and warty oreo) are managed with separate catch limits for black and smooth in some areas. Each species could be managed separately. They have different depth and geographical distributions, different stock sizes, rates of growth, and productivity.

4. FISHERY SUMMARY

4.1 Commercial fisheries

Commercial fisheries occur for black oreo (BOE) and smooth oreo (SSO). Oreos are managed as a species group, which also includes spiky oreo (SOR). The Chatham Rise (OEO 3A and OEO 4) is the main fishing area, but other fisheries occur off Southland on the east coast of the South Island (OEO 1/OEO 3A), and on the Pukaki Rise, Macquarie Ridge, and Bounty Plateau (OEO 6). In the past oreo catch has been taken as bycatch of the more valuable orange roughy fisheries but target fisheries for smooth or black oreo are now much more common in most areas.

Total reported landings and TACs are shown in Table 2, while Figure 1 depicts the historical landings and TACC values for the main OEO stocks. OEO 3A and OEO 4 were introduced into the QMS in 1982–83, while OEO 1 and OEO 6 were introduced later in 1986–87. Reported estimated catches by species from tow by tow data recorded in catch and effort logbooks (Deepwater, TCEPR, and CELR) and the ratio of estimated to landed catch reported are given in Table 3.

OEO 1 was fished under the adaptive management programme up to the end of 1997–98. The OEO 1 TAC reverted back to pre-adaptive management levels from 1998–99. Landings have declined since then, and from 1 October 2007 the TAC was reduced to 2500 t; other sources of mortality were allocated 168 t.

Oreo landings from OEO 3A were less than the TAC from 1992–93 to 1995–96, substantially so in 1994–95 and 1995–96. The OEO 3A TAC was reduced from 10 106 to 6600 t in 1996–97. A voluntary agreement between the fishing industry and the Minister of Fisheries to limit catch of smooth oreo from OEO 3A to 1400 t of the total oreo TAC of 6600 t was implemented in 1998–99. Subsequently the total OEO 3A TAC was reduced to 5900 t in 1999–00, 4400 in 2000–01, 4095 in 2001–02 and 3100 t in 2002–03. In 2009–10 the OREO 3A TAC was increased slightly to 3350 t and landings have been close to the TAC since then, averaging 3340 t between 2009–10 and 2018–19.

Total oreo landings from OEO 4 exceeded the TAC from 1991–92 to 1994–95 and was close to the TAC from 1995–96 to 2000–01 (Table 2). Landings remained high in OEO 4 while the orange roughy fishery has declined. The OEO 4 TAC was reduced from 7000 to 5460 t in 2001–02 but was restored to 7000 t in 2003–04. In 2015–16, following an assessment of SSO 4, the OEO 4 TAC was reduced to 3000 t and the landings of smooth oreo were approximately 2000 t. The OEO 4 TAC was increased to 3600 t for the fishing year 2018–19, and just under 3300 t of all oreo species combined were landed.

Landings from the Sub-Antarctic area (OEO 6) increased substantially in 1994–95 and exceeded the TAC in 1995–96. The OEO 6 TAC was increased from 3000 to 6000 t in 1996–97. Landings exceeded the TAC slightly in 2002–03 and in 2005–06, but dropped substantially after 2009–10. Following a period of very low landings ranging from just 136 t to 367 t in 2012–13 to 2014–15, landings recovered slightly, averaging just over 1500 t between 2015–16 and 2018–19. There was also a voluntary agreement which started in 1998–99 not to fish for oreo in the Puysegur area.

Table 2: Total reported landings (t) for all oreo species combined by Fishstock from 1978–79 to present and TACs (t) from 1982–83 to present.

Fishing	OEO 1		OEO 3A		OEO 4		OEO 6		Totals	
year	Landings	TAC	Landings	TAC	Landings	TAC	Landings	TAC	Landings	TAC
1978–79*	2 808	-	1 366	-	8 041	-	17	-	12 231	-
1979–80*	143	-	10 958	-	680	-	18	-	11 791	-
1981–82*	21	-	12 750	-	9 296	-	4 380	-	25 851	-
1982–83*	162	-	8 576	10 000	3 927	6 750	765	-	26 514	-
1983–83#	39	-	4 409	#	3 209	#	354	-	13 680	17 000
1983–84†	3 241	-	9 190	10 000	6 104	6 750	3 568	-	8 015	#
1984–85†	1480	-	8 284	10 000	6 390	6 750	2 044	-	22 111	17 000
1985–86†	5 390	-	5 331	10 000	5 883	6 750	126	-	18 204	17 000
1986–87†	532	4 000	7 222	10 000	6 830	6 750	0	3 000	16 820	17 000
1987–88†	1 193	4 000	9 049	10 000	8 674	7 000	197	3 000	15 093	24 000
1988–89†	432	4 233	10 191	10 000	8 447	7 000	7	3 000	19 159	24 000
1989–90†	2 069	5 033	9 286	10 106	7 348	7 000	0	3 000	19 077	24 233
1990–91†	4 563	5 033	9 827	10 106	6 936	7 000	288	3 000	18 703	25 139
1991–92†	4 156	5 033	10 072	10 106	7 457	7 000	33	3 000	21 614	25 139
1992–93†	5 739	6 044	9 290	10 106	7 976	7 000	815	3 000	21 718	25 139
1993–94†	4 910	6 044	9 106	10 106	8 319	7 000	983	3 000	23 820	26 160
1994–95†	1 483	6 044	6 600	10 106	7 680	7 000	2 528	3 000	23 318	26 160
1995–96†	4 783	6 044	7 786	10 106	6 806	7 000	4 435	3 000	18 291	26 160
1996–97†	5 181	6 044	6 991	6 600	6 962	7 000	5 645	6 000	23 810	26 160
1997–98†	2 681	6 044	6 336	6 600	7 010	7 000	5 222	6 000	24 779	25 644
1998–99†	4 102	5 033	5 763	6 600	6 931	7 000	5 287	6 000	21 249	25 644
1999–00†	3 711	5 033	5 859	5 900	7 034	7 000	5 914	6 000	22 083	24 633
2000–01†	4 852	5 033	4 577	4 400	7 358	7 000	5 932	6 000	22 518	23 933
2001–02†	4 197	5 033	3 923	4 095	4 864	5 460	5 737	6 000	22 719	22 433
2002–03†	3 034	5 033	3 070	3 100	5 402	5 460	6 115	6 000	18 721	20 588
2003–04†	1 703	5 033	2 856	3 100	6 735	7 000	5 811	6 000	17 621	19 593
2004–05†	1 025	5 033	3 061	3 100	7 390	7 000	5 744	6 000	17 105	21 133
2005–06†	850	5 033	3 333	3 100	6 829	7 000	6 463	6 000	17 220	21 133
2006–07†	903	5 033	3 073	3 100	7 211	7 000	5 926	6 000	17 475	21 133
2007–08†	947	2 500	3 092	3 100	7 038	7 000	5 902	6 000	17 113	21 133
2008–09†	582	2 500	2 848	3 100	6 907	7 000	5 540	6 000	16 979	18 600
2009–10†	464	2 500	3 550	3 350	7 047	7 000	5 730	6 000	15 877	18 600
2010–11†	381	2 500	3 370	3 350	7 061	7 000	3 610	6 000	16 791	18 850
2011–12†	581	2 500	3 324	3 350	6 858	7 000	2 325	6 000	14 422	18 860
2012–13	652	2 500	3 245	3 350	6 944	7 000	136	6 000	13 088	18 860
2013–14	386	2 500	3 473	3 350	7 024	7 000	367	6 000	11 251	18 860
2014–15	277	2 500	3 352	3 350	7 274	7 000	156	6 000	11 059	18 860
2015–16	523	2 500	3 334	3 350	2 898	3 000	1 357	6 000	8 111	14 860
2016–17	603	2 500	3 206	3 350	3 011	3 000	1 200	6 000	8 020	14 860
2017–18	601	2 500	3 177	3 350	2 867	3 000	2 138	6 000	8 783	14 860
2018–19	689	2 500	3 365	3 350	3 283	3 600	1 613	6 000	8 950	15 460

Source: FSU from 1978–79 to 1987–88; QMS/MFish/MPI from 1988–89 to 2013–14. *, 1 April to 31 March. #, 1 April to 30 September. Interim TACs applied. †, 1 October to 30 September. Data prior to 1983 were adjusted up due to a conversion factor change

Table 3: Reported estimated catch (t) by species (smooth oreo (SSO), black oreo (BOE) by Fishstock from 1978–79 to 2007–08 and the ratio (percentage) of the total estimated SSO plus BOE, to the total reported landings (from Table 2. -, less than 1. No catch split available for 2008–09. [Continued on next page]

	SSO				BOE				Total	Estimated landings
Year	OEO 1	OEO 3A	OEO 4	OEO 6	OEO 1	OEO 3A	OEO 4	OEO 6	estimated	(%)
1978–79*	0	0	0	0	9	0	0	0	9	-
1979–80*	16	5 075	114	0	118	5 588	566	18	11 495	98
1980–81*	1	1 522	849	2	66	8 758	5 224	215	16 637	64
1981–82*	21	1 283	3 352	2	0	11 419	5 641	4 378	26 096	98
1982–83*	28	2 138	2 796	60	6	6 438	1 088	705	13 259	97
1983–83#	9	713	1 861	0	1	3 693	1 340	354	7 971	100
1983–84†	1 246	3 594	4 871	1 315	1 751	5 524	1 214	2 254	21 769	99
1984–85†	828	4 311	4 729	472	544	3 897	1 651	1 572	18 004	99
1985–86†	4 257	3 135	4 921	72	1 060	2 184	961	54	16 644	99
1986–87†	326	3 186	5 670	0	163	4 026	1 160	0	14 531	96
1987–88†	1 050	5 897	7 771	197	114	3 140	903	0	19 072	100
1988–89†	261	5 864	6 427	-	86	2 719	1 087	0	16 444	86
1989–90†	1 141	5 355	5 320	-	872	2 344	439	-	15 471	83
1990–91†	1 437	4 422	5 262	81	2 314	4 177	793	222	18 708	87
1991–92†	1 008	6 096	4 797	2	2 384	3 176	1 702	15	19 180	88
1992–93†	1 716	3 461	3 814	529	3 768	3 957	1 326	69	18 640	78
1993–94†	2 000	4 767	4 805	808	2 615	4 016	1 553	35	20 599	88
1994–95†	835	3 589	5 272	1 811	385	2 052	545	230	14 719	81
1995–96†	2 517	3 591	5 236	2 562	1 296	3 361	364	1 166	20 093	84
1996–97†	2 203	3 063	5 390	2 492	2 578	3 549	530	1 950	21 755	88
1997–98†	1 510	4 790	5 868	2 531	1 027	1 623	811	1 982	20 142	95

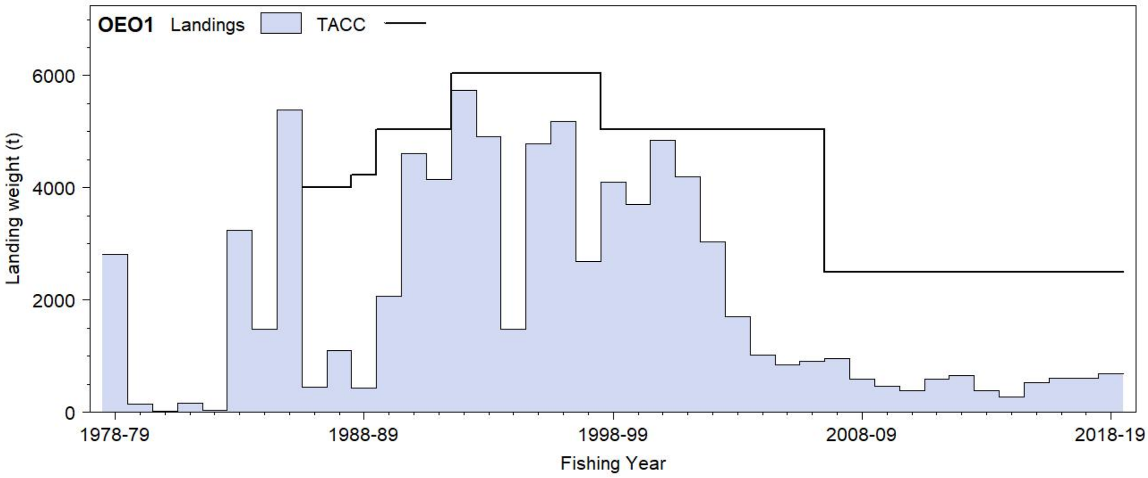
Table 3 [Continued]:

Year	SSO				BOE				Total estimated	Estimated landings (%)
	OEO 1	OEO 3A	OEO 4	OEO 6	OEO 1	OEO 3A	OEO 4	OEO 6		
1998–99†	2 958	2367	5 613	3 462	820	3 147	844	1 231	20 442	93
1999–00†	2 533	1 733	5 985	4 306	970	3 943	628	1 043	21 142	94
2001–02†	2 973	1 769	3 806	4 470	697	2 378	515	983	17 591	94
2002–03†	2 521	1 395	4 105	3 941	481	1 636	868	1 640	16 587	94
2003–04†	1 046	1 244	5 082	3 767	458	1 590	973	1 496	15 656	92
2004–05†	665	1 447	5 848	3 840	234	1 594	851	1 580	16 059	93
2005–06†	529	1 354	5 145	3 289	265	1 770	763	2 616	15 731	90
2006–07†	530	1 220	5 863	2 214	263	1 651	795	3 071	15 607	91
2007–08†	407	1 482	6 150	2 182	429	1 521	592	3 022	15 785	93

Source: FSU from 1978–79 to 1987–88 and MFish from 1988–89 to 2006–07 * 1 April to 31 March. #, 1 April to 30 September. †, 1 October to 30 September.

Descriptive analyses of the main New Zealand oreo fisheries were updated with data from 2006–07 in 2008. Standardised CPUE analyses of black and smooth oreo were then updated as follows:

- smooth oreo in OEO 3A in 2009;
- black oreo in OEO 4 in 2009;
- black oreo in OEO 6 (Pukaki) in 2009;
- smooth oreo OEO 6 (Bounty) in 2008;
- black oreo in OEO 3A in 2008;
- smooth oreo in OEO 4 in 2007;
- smooth oreo in Southland (OEO 1 and OEO 3A)in 2007;
- smooth oreo OEO 6 (Pukaki) in 2006.



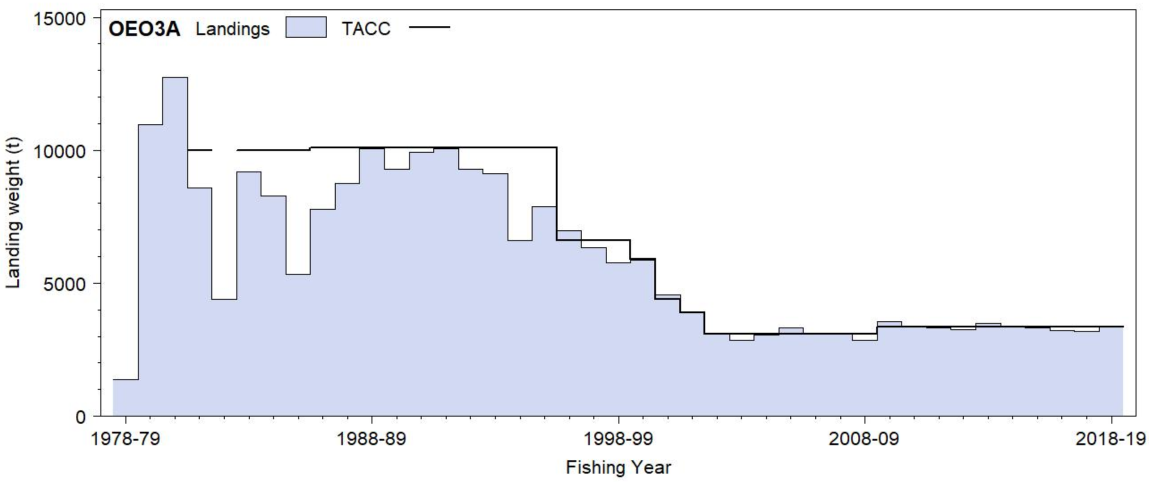
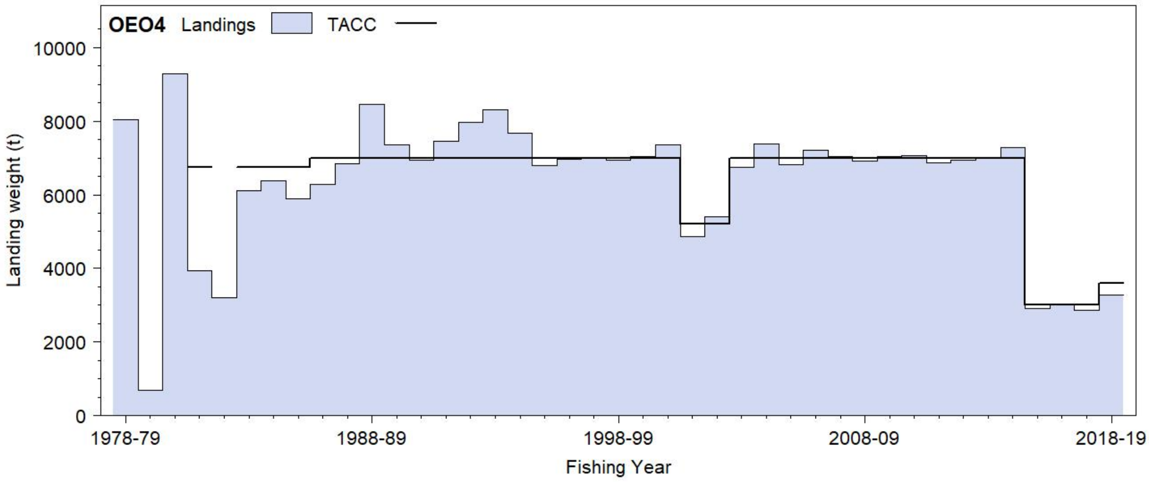


Figure 1: Reported commercial landings and TACC for the four main OEO stocks. From top: OEO 1 (Central East - Wairarapa, Auckland, Central Egmont, Challenger, Southland, South East Catlin Coast), OEO 3A (South East Cook Strait/Kaikoura/Strathallan). [Continued on next page].



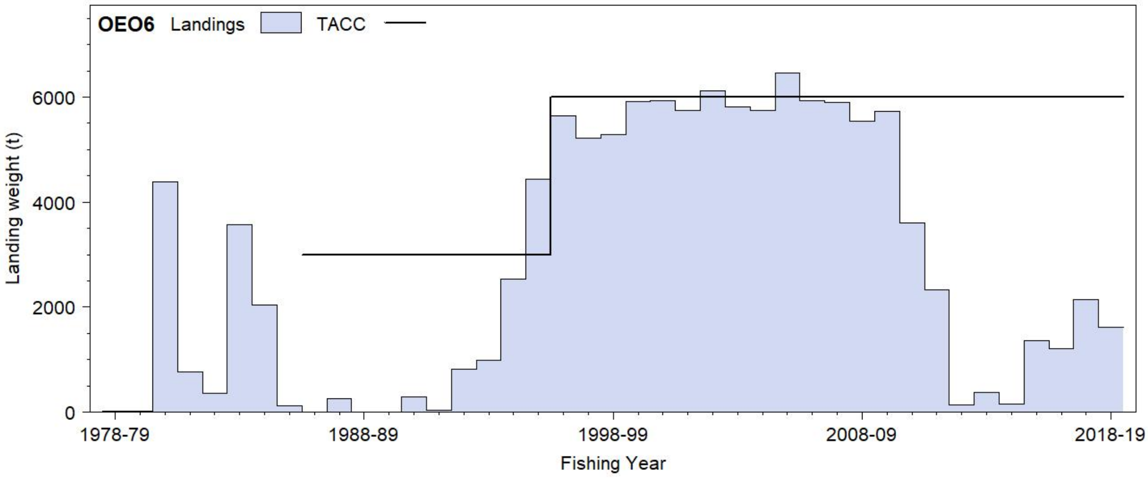


Figure 1 [Continued]: Reported commercial landings and TACC for the four main OEO stocks. From top: OEO 4 (South East Chatham Rise), and OEO 6 (Sub-Antarctic).

4.2 Recreational fisheries

There are no known recreational fisheries for black oreo and smooth oreo.

4.3 Customary non-commercial fisheries

There is no known customary non-commercial fishing for black oreo and smooth oreo.

4.4 Illegal catch

Estimates of illegal catch are not available.

4.5 Other sources of mortality

Dumping of unwanted or small fish and accidental loss of fish (lost codends, ripped codends, etc.) were features of oreo fisheries in the early years. These sources of mortality were probably substantial in those early years but are now thought to be relatively small. No estimate of mortality from these sources has been made because of the lack of hard data and because mortality now appears to be small. Estimates of discards of oreos were made for 1994–95 and 1995–96 from MFish observer data. This involved calculating the ratio of discarded oreo catch to retained oreo catch and then multiplying the annual total oreo catch from the New Zealand EEZ by this ratio. Estimates were 207 and 270 t for 1994–95 and 1995–96 respectively.

5. ENVIRONMENTAL AND ECOSYSTEM CONSIDERATIONS

This section was updated for the 2020 Fishery Assessment Plenary. A more detailed summary from an issue-by-issue perspective is available in the 2018 Aquatic Environment & Biodiversity Annual Review (Fisheries New Zealand 2019, https://www.mpi.govt.nz/dmsdocument/34854-aquatic-environment-and-biodiversity-annual-review-aebar-2018-a-summary-of-environmental-interactions-between-the-seafood-sector-and-the-aquatic-environment).

5.1 Role in the ecosystem

Smooth and black oreo dominate trawl survey relative abundance estimates of demersal fish species at 650–1200 m on the south and southwest slope of the Chatham Rise (e.g., Hart & McMillan 1998). They are probably also dominant at those depths on the southeast slope of the South Island and other southern New Zealand slope areas including Bounty Plateau, and Pukaki Rise. They are replaced at depths of about 700–1200 m on the east and northern slope of Chatham Rise by orange roughy. The south Chatham Rise oreo fisheries are relatively long-standing, dating from Soviet fishing in the 1970s but the effects of extracting approximately 6000 t per year of smooth oreo from the south Chatham Rise (OEO 4) ecosystem between 1983–84 and 2012–13 are unknown.

5.1.1 Trophic interactions

Smooth oreo feed mainly on salps (80%), molluscs (9%, of which 8% are squids but also including octopods), and teleosts (5%) (percentage frequency of occurrence in stomachs with food, Stevens et al 2011). Black oreo feed on teleosts (48%), crustaceans (36%), salps (24%), and cephalopods (mainly squid, 6%) (Stevens et al 2011). Diet varies with fish size but salps remained the main prey for smooth oreo in the largest fish with small numbers of Scyphozoa, fish and squids. Salps were the main prey for smaller black oreo but amphipods and natant decapod crustaceans were important for intermediate sized fish (Clark et al 1989). Smooth oreo and black oreo occur with orange roughy at times. Orange roughy diet was mainly crustaceans (58%), teleosts (41%), and molluscs (10%, particularly squids) (frequency of occurrence, Stevens et al 2011) suggesting little overlap with the salp-dominated diet of smooth oreo. Where they co-occur, orange roughy and black oreo may compete for teleost and crustacean prey.

Predators of oreos probably change with fish size. Larger smooth oreo, black oreo and orange roughy were observed with healed soft flesh wounds, typically in the dorso-posterior region. Wound shape and size suggest they may be caused by one of the deepwater dogfishes (Dunn et al 2010).

5.1.2 Ecosystem indicators

Tuck et al (2009, 2014) used data from the Sub-Antarctic and Chatham Rise middle-depth trawl surveys to derive indicators of fish diversity, size, and trophic level. However, fishing for oreos occurs mostly deeper than the depth range of these surveys and is only a small component of fishing in the areas considered by Tuck et al (2009, 2014).

5.2 Non-target fish and invertebrate catch

Anderson et al (2017) summarised the bycatch of oreo trawl fisheries from 2001–02 to 2014–15. Since 2001–02, oreo species (five species, mainly smooth oreo and black oreo) accounted for about 95% of the total estimated catch from all observed trawls targeting oreos. In total, over 500 species or species groups were identified by observers in the target fishery. Total annual fish bycatch in the oreo fishery ranged from 580–1575 t between 2001–02 and 2009–10 and declined to lower levels (350–535 t) in subsequent years. Orange roughy (1.9%) was the main bycatch species, with no other species or group of species accounting for more than 0.6% of the total catch. Other recorded bycatch species included deepwater dogfish (1%; mostly Baxter's dogfish *Etmopterus granulosus*), rattails (0.6%), hoki (0.4%), and slickheads (0.15%), all of which were usually discarded. Estimated annual bycatch of non-QMS species was roughly equal to that of QMS species. From 2001–02 to 2014–15, the overall discard fraction value was 0.01 kg (range of 0.01–0.05 kg) and tended to be lower in recent years.

Non-QMS invertebrate bycatch made up a very small fraction of the overall catch (0.3%) and included corals (0.1%), warty squid (0.06%), and echinoderms (0.02%) (Anderson et al 2017). Other observed species or species groups each accounted for less than 0.01% of the observed catch. Tracey et al (2011) analysed the distribution of nine groups of protected corals based on bycatch records from observed trawl effort from 2007–08 to 2009–10, primarily from 800–1000 m depth. For the oreo target fishery, the highest catches were reported from the north and south slopes of the Chatham Rise, east of the Pukaki Rise, and on the Macquarie Ridge.

Finucci et al (2019) analysed bycatch trends in deepwater fisheries, including oreo trawl, from 1990–91 until 2016–17. They found that the most common bycatch species by weight (t) were orange roughy (ORH), unspecified sharks (SHA), and Baxter's dogfish (ETB). Moreover, among the 228 bycatch species examined, 40 showed a decrease in catch over time (7 were statistically significant) and 44 showed an increase (9 were significant). The species showing the greatest decline were dark ghost shark (*Hydrolagus novaezealandiae*, GSH), unspecified shark (SHA), and lanternshark (*Etmopterus* sp., ETM), while the greatest increases were found for longnose velvet dogfish (*Centroscymnus crepidater*, CYP), ridge scaled rattail (*Macrourus carinatus*, MCA), and Baxter's dogfish (*Etmopterus granulosus*, ETB). The decline in unspecified shark could be linked to better identification of specimens through time, which would match the increases seen in other deepwater shark bycatch.

5.3 Incidental capture of Protected Species (seabirds, mammals, and protected fish)

For protected species, capture estimates presented here include all animals recovered to the deck of fishing vessels (alive, injured or dead), but do not include any cryptic mortality (e.g., a seabird struck by a warp but not brought on board the vessel, Middleton & Abraham 2007, Brothers et al 2010). Ramm (2011, 2012a, 2012b) summarised observer data for combined bottom trawl fisheries for orange roughy, oreos, cardinalfish and listed annual captures of seabirds, and mammals from 2008–09 to 2010–11.

5.3.1 Marine mammal interactions

Trawlers targeting orange roughy, oreo, and black cardinalfish occasionally catch New Zealand fur seal (which were classified as "Not Threatened" under the New Zealand Threat Classification System in 2010, Baker et al 2016). Between 2002–03 and 2007–08, there were 14 observed captures of New Zealand fur seal in orange roughy, oreo, and black cardinalfish trawl fisheries. There has been one observed capture in the period between 2008–09 and 2017–18, during which time the average level of annual observer coverage was 27% (Table 4). Corresponding annual estimated captures between 2008–09 and 2015–16 ranged 0–4 (mean 1.75) based on statistical capture models (Thompson et al 2013; Abraham et al 2016). All observed fur seal captures occurred in the Sub-Antarctic region.

Table 4: Number of tows by fishing year and observed and model-estimated total New Zealand fur seal captures in orange roughy, oreo, and cardinalfish trawl fisheries, 2002–03 to 2017–18. No. Obs, number of observed tows; % obs, percentage of tows observed; Rate, number of captures per 100 observed tows, % inc, percentage of total effort included in the statistical model. Estimates are based on methods described in Abraham et al (2016), available via https://data.dragonfly.co.nz/psc . Estimates for 2002–03 to 2015–16 are based on data version 2018v1.

				Observed		Estimated	
	Tows	No.obs	%ob	Captures	Rate	Capture	95%c.i.
2002–03	8 871	1 383	15.6	0	0.0	4	0–13
2003–04	8 005	1 262	15.8	2	0.2	10	3–26
2004–05	8 425	1 619	19.2	4	0.2	15	6–32
2005–06	8 289	1 358	16.4	2	0.1	11	4–25
2006–07	7 368	2 324	31.5	2	0.1	3	2–7
2007–08	6 730	2 811	41.8	5	0.2	8	5–14
2008–09	6 134	2 372	38.7	0	0.0	2	0–8
2009–10	6 011	2 135	35.5	0	0.0	3	0–9
2010–11	4 178	1 205	28.8	0	0.0	4	0–11
2011–12	3 654	922	25.2	0	0.0	1	0–5
2012–13	3 098	346	11.2	0	0.0	0	0–3
2013–14	3 606	434	12.0	0	0.0	1	0–4
2014–15	3 812	978	25.7	1	0.1	2	1–4
2015–16	4 083	1 421	34.8	0	0.0	1	0–3
2016–17	3 972	1 226	30.9	0	0.0		
201718	3 744	903	24.1	0	0.0		

5.3.2 Seabird interactions

Annual observed seabird capture rates ranged from 0 to 0.9 per 100 tows in orange roughy, oreo, and cardinalfish trawl fisheries between 2002–03 and 2017–18 (Baird 2001, 2004 a, b, 2005, Baird & Smith

2004, Abraham & Thompson 2009, Abraham et al 2009, Abraham & Thompson 2011, Abraham et al 2016, Abraham & Richard 2017, 2018). Capture rates have fluctuated without obvious trend at this low level. In the 2017–18 fishing year, there were 4 observed captures of birds, and 2 in 2016–17, in orange roughy, oreo, and cardinalfish trawl fisheries at a rate of 0.4 to 0.2 birds (respectively) per 100 observed tows (Table 5). The average capture rate in deepwater trawl fisheries (including orange roughy, oreo and cardinalfish) for the period from 2002–03 to 2017–18 is about 0.31 birds per 100 tows, a very low rate relative to other New Zealand trawl fisheries, e.g. for scampi (4.02 birds per 100 tows) and squid (13.31 birds per 100 tows) over the same years.

Table 5: Number of tows by fishing year and observed seabird captures in orange roughy, oreo, and cardinalfish trawl fisheries, 2002–03 to 2017–18. No. obs, number of observed tows; % obs, percentage of tows observed; Rate, number of captures per 100 observed tows. Estimates are based on methods described in Abraham et al (2016) and Abraham & Richard (2017, 2018) and available via https://data.dragonfly.co.nz/psc. Estimates for 2002–03 to 2017–18 are based on data version 2019v1.

	Fishing effort			Observed captures		Estimated captures	
	Tows	No. obs	% obs	Captures	Rate	Mean	95% c.i.
2002–03	8 870	1 382	15.6	0	0.0	34	20–52
2003–04	8 007	1 262	15.8	3	0.2	32	19–47
2004–05	8 427	1 619	19.2	7	0.4	43	28–62
2005–06	8 291	1 359	16.4	8	0.6	39	25–55
2006–07	7 379	2 324	31.5	1	0.0	20	10–31
2007–08	6 731	2 811	41.8	7	0.2	23	14–33
2008–09	6 133	2 372	38.7	7	0.3	23	15–34
2009–10	6 012	2 132	35.5	19	0.9	35	27–46
2010–11	4 177	1 205	28.8	1	0.1	16	8–26
2011–12	3 655	923	25.3	2	0.2	12	6–21
2012–13	3 099	346	11.2	2	0.6	14	7–23
2013–14	3 608	434	12.0	2	0.5	16	8–26
2014–15	3 818	978	25.6	0	0.0	14	6–23
2015–16	4 084	1 421	34.8	4	0.3	14	8–22
2016–17	3 967	1 226	30.9	2	0.2	13	6–21
201718	3 748	903	24.1	4	0.4	16	9–25

Table 6: Number of observed seabird captures in orange roughy, oreo, and cardinalfish fisheries, 2002–03 to 2017–18, by species and area. These data are available via https://data.dragonfly.co.nz/psc, based on data version 2019v1.

Species	Risk Category	Chatham Rise	ECSI	Fiordland	Sub-Antarctic	Stewart Snares Shelf	WCSI	Total
Salvin's albatross	High	11	4	0	3	0	0	18
Southern Buller's albatross	High	3	0	1	0	0	0	4
Chatham Island albatross	Medium	7	0	0	1	0	0	8
New Zealand white-capped albatross	High	4	0	0	0	0	2	6
Gibson's albatross	High	1	0	0	0	0	0	1
Antipodean albatross	Medium	1	0	0	0	0	0	1
Northern royal albatross	Low	1	0	0	0	0	0	1
Southern royal albatross	Negligible	1	0	0	0	0	0	1
Albatrosses		1	2					3
Total albatrosses	**-**	**30**	**6**	**1**	**4**	**0**	**2**	**43**
Northern giant petrel	Medium	1	0	0	0	0	0	1
White-chinned petrel	Negligible	2	1	0	0	1	0	4
Grey petrel	Negligible	1	0	0	1	0	0	2
Sooty shearwater	Negligible	0	3	0	0	0	1	4
Common diving petrel	Negligible	2	0	0	0	0	0	2
White-faced storm petrels	Negligible	3	0	0	0	0	0	3
Cape petrel	-	8	1	0	0	0	0	9
Petrels, prions and shearwaters	-	0	0	0	1	0	0	1
Total other birds	**-**	**17**	**5**	**0**	**2**	**1**	**1**	**26**
Grand Total		**47**	**11**	**1**	**6**	**1**	**3**	**69**

Salvin's albatross was the most frequently captured albatross (42% of observed albatross captures) but eight different species have been observed captured since 2002–03. Cape petrels were the most frequently captured other taxon (35%, Table 6). Seabird captures in the orange roughy, oreo, and cardinalfish fisheries have been observed mostly around the Chatham Rise and off the east coast South Island. These numbers should be regarded as only a general guide on the distribution of captures because the observer coverage is not uniform across areas and may not be representative.

The deepwater trawl fisheries (including the cardinal fish target fishery) contributes to the total risk posed by New Zealand commercial fishing to seabirds (see Table 7). The two species to which the fishery poses the most risk are Chatham Island albatross and Salvin's albatross, with this suite of fisheries posing 0.06 and 0.022 of Population Sustainability Threshold (PST) (Table 7). Chatham Island albatross and Salvin's albatross were assessed as high risk (Richard et al 2020).

Table 7: Risk ratio of seabirds predicted by the level two risk assessment for the oreo and all fisheries included in the level two risk assessment, 2006–07 to 2016–17, showing seabird species with a risk ratio of at least 0.001 of PST (from Richard et al 2017 and Richard et al 2020, where full details of the risk assessment approach can be found). The risk ratio is an estimate of aggregate potential fatalities across trawl and longline fisheries relative to the PST. The DOC threat classifications are shown (Robertson et al 2017 at http://www.doc.govt.nz/documents/science-and-technical/nztcs19entire.pdf).

		Risk ratio			
Species name	**PST (mean)**	**OEO, ORH, CDL target trawl***	**TOTAL**	**Risk category**	**DOC Threat Classification**
Chatham Island albatross	428	0.060	0.28	High	At Risk: Naturally Uncommon
Salvin's albatross	3 460	0.022	0.65	High	Threatened: Nationally Critical
Northern giant petrel	337	0.005	0.15	Medium	At Risk: Naturally Uncommon
Northern Buller's albatross	1 640	0.002	0.26	Medium	At Risk: Naturally Uncommon
Black petrel	447	0.002	1.23	Very high	Threatened: Nationally Vulnerable
Antipodean albatross	369	0.002	0.17	Medium	Threatened: Nationally Critical
Gibson's albatross	497	0.002	0.31	High	Threatened: Nationally Critical
Northern royal albatross	723	0.001	0.05	Low	At Risk: Naturally Uncommon

* OEO, ORH, CDL target trawl from Richard et al 2017

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

5.3.3 Protected fish species interactions

Deepwater trawling for orange roughy and oreo exceeds the depth at which protected fish species are usually found. Fisheries-reported records include the capture of a basking shark (*Cetorhinus maximus*) in 2019, a species classified as "Endangered" by IUCN in 2013 and as "Threatened – Nationally Vulnerable" in 2016, under the New Zealand Threat Classification System (Duffy et al 2018). Basking shark has been a protected species in New Zealand since 2010, under the Wildlife Act 1953, and is also listed in Appendix II of the CITES convention. However, basking sharks have been occasionally confused with bluntnose sixgill shark (*Hexanchus griseus*), a "Not Threatened" species according to the DOC latest assessment (Duffy et al 2018), and this report is being verified.

5.4 Benthic interactions

The spatial extent of seabed contact by trawl fishing gear in New Zealand's EEZ and Territorial Sea has been estimated and mapped in numerous studies for trawl fisheries targeting deepwater species (Baird et al 2011, Black et al 2013, Black & Tilney 2015, Black & Tilney 2017, Baird & Wood 2018 and Baird & Mules 2019, 2020b) and species in waters shallower than 250 m (Baird et al. 2015, Baird & Mules 2020a). The most recent assessment of the deepwater trawl footprint was for the period 1989–90 to 2017–18 (Baird & Mules 2020b). Orange roughy, oreos, and cardinalfish are taken using bottom trawls and accounted for about 14% of all tows reported on TCEPR forms to have fished on or close to the bottom between 1989–90 and 2004–05 (Baird et al 2011). Tows are located in Benthic-optimised

Marine Environment Classification (BOMEC, Leathwick et al 2012) classes J, K (mid-slope), M (mid-lower slope), N, and O (lower slope and deeper waters) (Baird & Wood 2012), and 94% were between 700 and 1200 m depth (Baird et al 2011). Deepsea corals in the New Zealand region are abundant and diverse and, because of their fragility, are at risk from anthropogenic activities such as bottom trawling (Clark & O'Driscoll 2003, Clark & Rowden 2009, Williams et al 2010). All deepwater hard corals are protected under Schedule 7A of the Wildlife Act 1953. Baird et al (2013) mapped the likely coral distributions using predictive models and concluded that the fisheries that pose the most risk to protected corals are these deepwater trawl fisheries.

During 1989–90 to 2015–16, about 59 130 bottom trawls targeting oreo species were reported on TCEPRs (Baird & Wood 2018): between 1600–2500 tows were reported a year during 1989–90 to 1994–95; 2000–3300 tows between 1995–96 and 2009–10; and annual tows decreased from almost 2000 tows in 2010–11 to under 800 tows in 2015–16. The total footprint generated from these tows was estimated at about 15 960 km^2. This footprint represented coverage of 0.4% of the seafloor of the combined EEZ and the Territorial Sea areas; 1.1% of the 'fishable area', that is, the seafloor area open to trawling, in depths of less than 1600 m. For the 2016–17 fishing year, 685 oreo bottom tows had an estimated footprint of 255 km^2 which represented coverage of less than 0.1% of the EEZ and Territorial Sea and less than 0.1% of the fishable area (Baird & Mules 2019). There was little change to the percentage of fishable area contacted by the 2017–18 estimated footprint of 386 km^2 (Baird & Mules 2020b).

The overall trawl footprint for oreo (1989–90 to 2015–16) covered 4% of the seafloor in 800–1000 m, 3% of 1000–1200 m seafloor, and 0.8% of the 1200–1600 m seafloor (Baird & Wood 2018). The oreo footprint contacted 0.1%, less than 0.1%, and less than 0.1% of those depth ranges in 2016–17 and 2017–18, respectively (Baird & Mules 2019, 2020b). The BOMEC areas with the highest proportion of area covered by the oreo footprint were classes J (comprising mainly the Challenger Plateau and northern and southern slopes of the Chatham Rise) and M (shallower waters of the Southern Plateau). In 2016–17, the oreo footprint covered about 0.04% of the 311 360 km^2 of class J and 0.04% of the 233 825 km^2 of class M (Baird & Mules 2019). In 2017–18, 0.06% of class J and 0.7% of class M were contacted by the oreo footprint.

Trawling for orange roughy, oreo, and cardinalfish, like trawling for other species, is likely to have effects on benthic community structure and function (e.g., Rice 2006) and there may be consequences for benthic productivity (e.g., Jennings et al 2001, Hermsen et al 2003, Hiddink et al 2006, Reiss et al 2009). These consequences are not considered in detail here but are discussed in the Aquatic Environment and Biodiversity Annual Review 2019 (Fisheries New Zealand 2020).

The New Zealand EEZ contains Benthic Protection Areas (BPAs) and seamount closures that are closed to bottom trawl fishing for the protection of benthic biodiversity. These combined areas include 28% of underwater topographic features (including seamounts), 52% of all seamounts over 1000 m elevation and 88% of identified hydrothermal vents.

5.5 Other considerations

5.5.1 Spawning disruption

Fishing during spawning may disrupt spawning activity or success. Morgan et al (1999) concluded that Atlantic cod (*Gadus morhua*) "exposed to a chronic stressor are able to spawn successfully, but there appears to be a negative impact of this stress on their reproductive output, particularly through the production of abnormal larvae". Morgan et al (1997) also reported that "Following passage of the trawl, a 300-m-wide "hole" in the [cod spawning] aggregation spanned the trawl track. Disturbance was detected for 77 min after passage of the trawl." There is no research on the disruption of spawning smooth oreo and black oreo by fishing in New Zealand, but spawning of both species appears to be over a protracted period (October to February) and over a wide area (O'Driscoll et al 2003). Fishing continues during the spawning period, possibly because localised spawning schools of smooth oreo, in particular, may provide good catch rates.

5.5.2 Genetic effects

Fishing and environmental changes, including those caused by climate change or pollution, could alter the genetic composition or diversity of a species. There are no known studies of the genetic diversity of smooth or black oreo from New Zealand. Genetic studies for stock discrimination are reported under "stocks and areas".

5.5.3 Habitat of particular significance to fisheries management

Habitat of particular significance for fisheries management does not have a policy definition. O'Driscoll et al (2003) identified the south Chatham Rise as important for smooth oreo spawning, and the north, east and south slope as important for juveniles. The south Chatham Rise is also important for black oreo spawning and juveniles. Deepsea corals such as the reef-forming scleractinian corals and gorgonian sea fan corals are thought to provide prey and refuge for deep-sea fish (Fosså et al 2002, Stone 2006, Mortensen et al 2008). Large aggregations of deepwater species like orange roughy, oreos, and cardinalfish occur above seamounts with high densities of such "reef-like" taxa, but it is not known if there are any direct linkages between the fish and corals. Bottom trawling for orange roughy, oreos, and cardinalfish has the potential to affect features of the habitat that could qualify as habitat of particular significance to fisheries management.

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OREOS — OEO 3A BLACK OREO AND SMOOTH OREO

1. FISHERY SUMMARY

This is presented in the Fishery Summary section at the beginning of the Oreos report.

2. BIOLOGY

This is presented in the Biology section at the beginning of the Oreos report.

3. STOCKS AND AREAS

This is presented in the Stocks and Areas section at the beginning of the Oreos report.

4. STOCK ASSESSMENT

The smooth oreo stock assessment is unchanged from 2009. The black oreo stock assessment for 2008 has been withdrawn but the CPUE series has been updated to 2012.

4.1 Introduction

The following assumptions were made in the stock assessment analyses to estimate biomasses and yields for black oreo and smooth oreo.

(a) The acoustic abundance estimates were unbiased absolute values.
(b) The CPUE analyses provided indices of abundance for either black oreo or smooth oreo in the whole of OEO 3A. Most of the oreo commercial catches came from the CPUE study areas. Research trawl surveys indicated that there was little habitat for, and biomass of, black oreo or smooth oreo outside those areas.
(c) The ranges used for the biological values covered their true values.
(d) The maximum fishing mortality (F_{MAX}) was assumed to be 0.9, varying this value from 0.5 to 3.5 altered B_0 for smooth oreo in OEO 3A by only about 6% in the 1996 assessment.
(e) Recruitment was deterministic and followed a Beverton and Holt relationship with steepness of 0.75.
(f) Catch overruns were 0% during the period of reported catch.
(g) The populations of black oreo and smooth oreo in OEO 3A were discrete stocks or production units.
(h) The catch histories were accurate.

4.1.1 Black oreo

The last accepted assessment was in 2008. A three-area population model was used to accommodate the structure of the catch and length data, with age-dependent migration between areas. However, new age data collected within each area suggest that, based on 2013 analyses, assumptions made by this model are incorrect. Specifically, differences in the size distribution between areas now seem likely to be due to differential growth rates, rather than to movement. The model applied in 2008 was therefore considered inadequate and has been withdrawn. No stock assessment is presented here; a new approach needs to be developed.

4.1.2 Smooth oreo

A new assessment of smooth oreo in OEO 3A was completed in 2009. This used a CASAL age-structured population model employing Bayesian methods. Input data included research and observer-collected length data, one absolute abundance estimate from a research acoustic survey carried out in 1997 (TAN9713), and three relative abundance indices from standardised catch per unit effort analyses.

4.2 Black oreo

Partition of the main fishery into 3 areas
The main fishery area was split into three areas: a northern area that contained small fish and was generally shallow (Area 1), a southern area that contained large fish in the period before 1993 and which was generally deeper (Area 3), and a transition area (Area 2) that lay between Areas 1 and 3 (Figure 1).

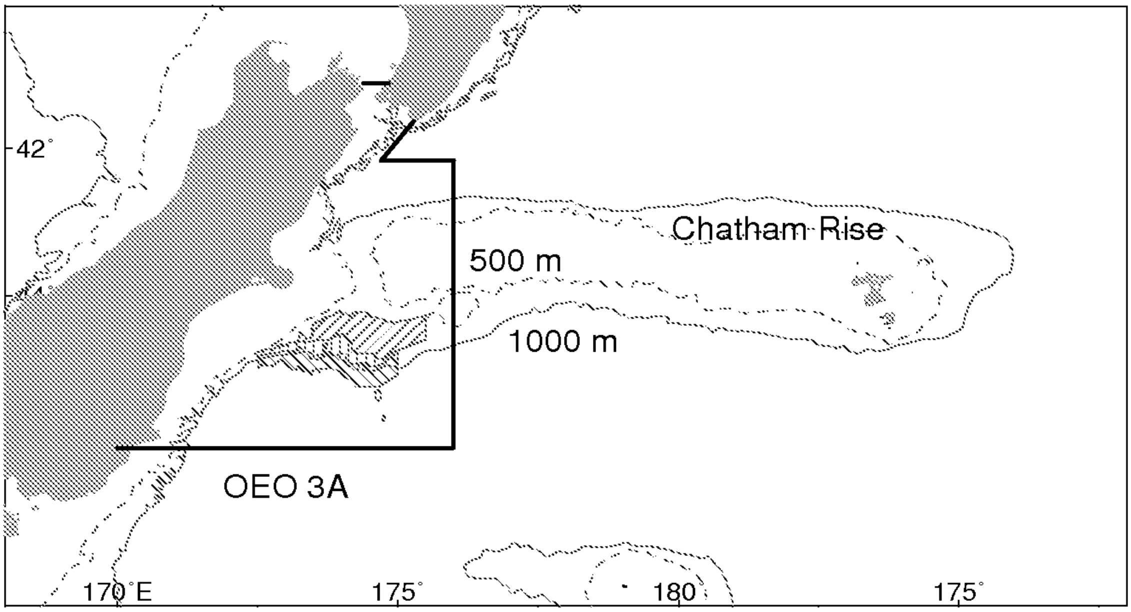


Figure 1: The three spatial areas used in the CASAL model and 2002 acoustic abundance survey. Area 1 at the top with right sloping shading; Area 2 in the middle with vertical shading; Area 3 at the bottom with left sloping shading. The thick dark line encloses management area OEO 3A.

The boundary between Areas 1 and 2 was defined in terms of the northern edge of the area that enclosed 90% of the total catch from the fishery. Areas 2 and 3 contained most of the fishery while Area 1 consisted of lightly fished and unfished ground. The boundary between Areas 2 and 3 was defined by the 32.5 cm contour in mean fish length for data before 1993 so that the fishery is split into an area containing smaller fish and another that has larger fish. The population outside the main fishery was assumed to follow the same relative dynamics.

Rejection of spatial model based on migration
The previous model reconciled the differences in commercial length distribution by using three areas. No age data were incorporated and instead lengths were used as a proxy for age. The dynamics were assumed to be recruitment in the shallow area (Area 1), with migration from Area 1 to Area 2, and also from Area 2 to Area 3, i.e., a one way movement to generally deeper water. The differences in the length distributions between areas drove the estimated migration rates by age. The stock assessment predicted that mature fish in the relatively unfished area (Area 1) comprised about 25% B_0 and so there were no sustainability concerns as this area was largely not fished.

To test the above migration hypothesis, otoliths sampled from acoustic survey mark identification trawls were aged and age distributions estimated for Area 1 and for the combined Areas 2 and 3 (Doonan, pers. comm.). The results showed deficiencies in the use of length data as a proxy for age in the stock assessment model. The age frequency in Area 1 was similar to that from Areas 2 and 3, but the model predicted them to be very different. Growth in Areas 2 and 3 appears to be faster than in Area 1 and this may drive the observed differences in length distributions. The migration model assumed the same growth in all areas. Maturity may be related to length rather than age, but it is age-based in the model. For these reasons, the Working Group rejected the stock assessment model in 2013. No formal stock assessment is presented here.

4.2.1 Estimates of fishery parameters and abundance

Catches by area

Catches were partitioned into the three areas by scaling up the estimated catch of black oreo from each area to the total reported catch (see tables 2 and 3 in the Fishery Summary section at the beginning of the Oreos report) and are given in Table 1.

Table 1: Estimated black oreo catch (tonnes) for each fishing year in the three spatial model areas.

Year	Area 1	Area 2	Area 3	Total
1972–73	110	2 010	1 320	†3 440
1973–74	130	2 214	1 456	†3 800
1974–75	170	2 970	1 960	†5 100
1975–76	40	736	484	†1 260
1976–77	130	2 260	1 490	†3 880
1977–78	190	3 350	2 210	†5 750
1978–79	27	750	30	806
1979–80	39	2 189	4 762	6 990
1980–81	793	7 813	4 090	12 696
1981–82	12	7 616	3 851	11 479
1982–83	57	3 384	2 577	6 018
1983–84	682	5 925	3 192	9 800
1984–85	148	1 478	2 218	3 844
1985–86	13	814	1 112	1 938
1986–87	33	1 863	1 908	3 805
1987–88	49	2 399	1 439	3 888
1988–89	244	3 532	811	4 588
1989–90	696	1 164	1 288	3 148
1990–91	753	1 947	1 330	4 030
1991–92	289	1 250	1 816	3 355
1992–93	180	2 221	1 717	4 117
1993–94	339	2 509	1 353	4 200
1994–95	139	1 894	845	2 878
1995–96	231	2 744	1 099	4 074
1996–97	418	2 095	1 035	3 548
1997–98	257	874	1 267	2 397
1998–99	138	2 047	572	2 756
1999–00	133	2 246	906	3 285
2000–01	89	1 804	761	2 653
2001–02	58	1 447	620	2 126
2002–03	82	997	236	1 314
2003–04	233	775	464	1 471
2004–05	61	766	360	1 187
2005–06	55	1 315	312	1 682
2006–07	48	914	698	1 659
2007–08	53	926	629	1 607
2008–09	59	920	671	1 649
2009–10	115	973	885	1 973
2010–11	38	859	762	1 659
2011–12	31	534	910	1 475

† Soviet catch, assumed to be mostly from OEO 3A and to be 50:50 black oreo: smooth oreo.

Observer length frequencies by area

Catch at length data collected by observers in Areas 1, 2, and 3 were extracted from the *obs_lfs* database (Table 2). Derived length frequencies for each group were calculated from the sample length frequencies weighted by the catch weight of each sample.

Table 2: Number of observed commercial tows where black oreo was measured for length frequency. A total of 60 tows were excluded because they had fewer than 30 fish measured, extreme mean lengths or missing catch information.

Year	Area 1	Area 2	Area 3	Other
1985–86	0	1	0	0
1986–87	0	2	6	0
1987–88	0	6	3	0
1988–89	30	8	4	2
1989–90	12	6	1	0
1990–91	2	5	7	1
1991–92	0	10	1	0
1992–93	0	0	0	0
1993–94	8	16	2	5
1994–95	0	4	2	2
1995–96	2	3	2	6
1996–97	0	1	1	2
1997–98	13	2	5	0
1998–99	2	1	0	3
1999–00	7	94	11	6
2000–01	3	110	22	2
2001–02	8	23	8	5
2002–03	3	17	4	4
2003–04	9	1	2	3
2004–05	3	5	3	1
2005–06	0	38	7	7
2006–07	6	1	2	5
2007–08	0	9	5	7
2008–09	4	16	9	3
2009–10	4	14	4	2
2010–11	1	15	7	2
2011–12	3	6	1	0

Research acoustic survey length frequencies by area

The 1997, 2002, 2006 and 2011 acoustic survey abundance at length data were converted to a length frequency using the combined sexes fixed length-weight relationship (“unsexed” in table 1, Biology section above) to convert the abundance to numbers at length (Table 3).

Absolute abundance estimates from the 1997, 2002, 2006 and 2011 acoustic surveys

Absolute estimates of abundance for black oreo are available from four acoustic surveys of oreos carried out from 10 November to 19 December 1997 (TAN9713), 25 September to 7 October 2002 (TAN0213), 17–30 October 2006 (TAN0615) and 17 November to 1 December 2011 (SWA1102). The 1997 survey covered the “flat” with a series of random north-south transects over six strata at depths of 600–1200 m. Seamounts were also sampled using parallel and “starburst” transects. Targeted and some random (background) trawling was carried out to identify targets and to determine species composition. The 2002 survey was limited to flat ground with 77 acoustic transect and 21 mark identification tows completed. The 2006 (78 transects and 22 tows) and 2011 (72 transects and 25 tows) surveys were very similar to the 2002 survey and covered the main area of the black oreo fishery. The estimated total abundance (immature plus mature) for each survey by area is shown in Table 4.

Relative abundance estimates from standardised CPUE analysis

Standardised CPUE indices were obtained for each area. Because of the apparent changes in fishing practice attributable to the introduction of GPS, the data were split into pre- and post-GPS series. There were also major changes in the fishery from 1998–99 to 2001–02 when there were TACC reductions and the start of a voluntary industry catch limit on smooth oreo (1998–99). Two post-GPS series were therefore developed. The first of these was from 1992–93 to 1997–98 (early series) and the second was from 2002–03 onwards (late series) with data from the intervening years ignored. Since there are no new data for either the pre-GPS series or the post-GPS early series, these are left unchanged from previous standardisation results. Only the post-GPS late series is updated here, using data that extends from 2002–03 to 2011–12.

Table 3: Research length frequency proportions for the model area for the 1997, 2002, 2006 and 2011 acoustic surveys. - no data for 1997 to 2006, lengths below 25 cm and greater than 38 were pooled.

	1997			2002			2006			2011		
Length (cm)	Area 1	Area 2	Area 3	Area 1	Area 2	Area 3	Area 1	Area 2	Area 3	Area 1	Area 2	Area 3
22	-	-	-	-	-	-	-	-	-	0.001	0.001	0.000
23	-	-	-	-	-	-	-	-	-	0.007	0.008	0.002
24	-	-	-	-	-	-	-	-	-	0.021	0.019	0.007
25	0.015	0.013	0.009	0.022	0.016	0.008	0.009	0.017	0.015	0.031	0.029	0.010
26	0.035	0.027	0.019	0.039	0.030	0.013	0.026	0.035	0.032	0.027	0.027	0.019
27	0.113	0.061	0.029	0.051	0.038	0.018	0.066	0.073	0.055	0.044	0.047	0.032
28	0.165	0.090	0.038	0.085	0.062	0.029	0.118	0.105	0.077	0.083	0.086	0.055
29	0.153	0.104	0.064	0.117	0.091	0.044	0.152	0.143	0.113	0.112	0.114	0.072
30	0.143	0.105	0.065	0.139	0.119	0.060	0.175	0.153	0.132	0.153	0.154	0.107
31	0.131	0.119	0.089	0.123	0.122	0.086	0.156	0.157	0.154	0.159	0.157	0.125
32	0.102	0.121	0.105	0.137	0.133	0.127	0.117	0.136	0.169	0.121	0.119	0.153
33	0.046	0.094	0.098	0.112	0.123	0.141	0.073	0.089	0.119	0.121	0.118	0.175
34	0.041	0.086	0.097	0.065	0.084	0.138	0.059	0.056	0.076	0.069	0.067	0.126
35	0.029	0.058	0.083	0.054	0.064	0.100	0.032	0.026	0.037	0.026	0.029	0.057
36	0.015	0.043	0.091	0.021	0.052	0.104	0.014	0.009	0.014	0.018	0.018	0.034
37	0.006	0.037	0.080	0.015	0.025	0.049	0.001	0.001	0.004	0.005	0.005	0.018
38	0.006	0.042	0.131	0.020	0.041	0.083	0.003	0.001	0.003	0.002	0.002	0.005
39	-	-	-	-	-	-	-	-	-	0.000	0.000	0.002
40	-	-	-	-	-	-	-	-	-	0.000	0.000	0.000
41	-	-	-	-	-	-	-	-	-	0.000	0.000	0.000
42	-	-	-	-	-	-	-	-	-	0.000	0.000	0.000

Table 4: Total (immature plus mature) black oreo abundance estimates (t) and CVs for the 1997, 2002, 2006 and 2011 acoustic surveys for the three model areas in OEO 3A.

Acoustic survey	Area 1	Area 2	Area 3	Total
1997	148 000 (29)	10 000 (26)	5 240 (25)	163 000 (26)
2002	43 300 (31)	15 400 (27)	4 710 (38)	64 000 (22)
2006	56 400 (37)	16 400 (30)	5 880 (34)	78 700 (30)
2011	138 100 (27)	36 800 (30)	7 400 (34)	182 300 (25)

Only data within a pre-defined spatial area were considered useful for assessing abundance (Figure 2).

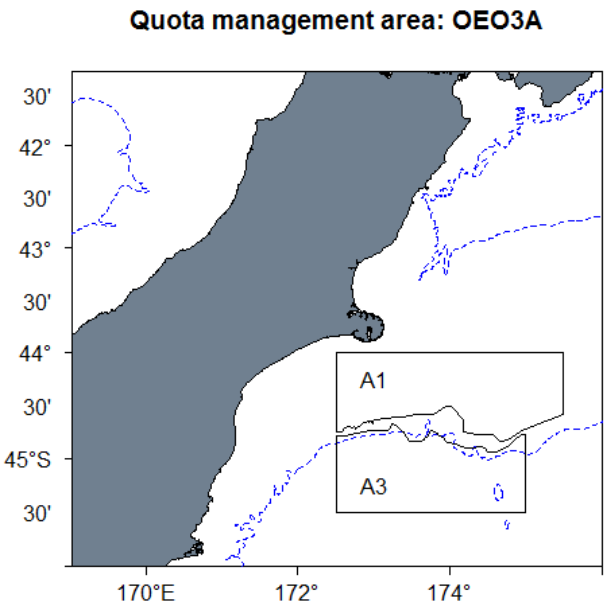


Figure 2: Spatial areas from which CPUE data were collected for inclusion in the standardisation. Areas A1 and A3 are shown, with A2 being the area between the two.

This area corresponds to the main fishing area and overlaps with the acoustic survey area (Figure 1). Tows were initially selected for inclusion in the CPUE standardisation if they targeted or caught black oreo within this area.

Uncertainty was assessed by bootstrapping the data, re-estimating the indices for each iteration, and estimating the coefficient of variation (CV) for each year/area from this distribution. The indices and CV estimates are listed in Table 5 and shown in Figure 3.

Table 5: OEO 3A black oreo pre-GPS and post-GPS time series of standardised catch per unit effort indices and bootstrapped CV estimates (%). Values for each series have been renormalized to a geometric mean of one. -, no estimate.

Fishing	Pre-GPS						Post-GPS					
Year	Area1		Area2		Area3		Area1		Area2		Area3	
	Index	CV	Index	CV	Index	CV	Index	CV	Index	CV	Index	CV
1979–80	-	-	1.45	39	1.52	125	-	-	-	-	-	-
1980–81	-	-	1.84	17	2.55	15	-	-	-	-	-	-
1981–82	-	-	1.71	22	2.15	9	-	-	-	-	-	-
1982–83	-	-	1.41	8	1.80	14	-	-	-	-	-	-
1983–84	-	-	0.99	8	1.04	19	-	-	-	-	-	-
1984–85	-	-	0.95	27	0.99	12	-	-	-	-	-	-
1985–86	-	-	0.63	31	0.66	33	-	-	-	-	-	-
1986–87	-	-	0.81	22	0.88	36	-	-	-	-	-	-
1987–88	-	-	0.45	20	0.49	23	-	-	-	-	-	-
1988–89	-	-	0.72	21	0.23	44	-	-	-	-	-	-
1989–90	-	-	-	-	-	-	-	-	-	-	-	-
1990–91	-	-	-	-	-	-	-	-	-	-	-	-
1991–92	-	-	-	-	-	-	-	-	Early series			
1992–93	-	-	-	-	-	-	-	-	1.62	14	2.46	20
1993–94	-	-	-	-	-	-	-	-	1.17	17	1.20	15
1994–95	-	-	-	-	-	-	-	-	0.96	13	0.82	17
1995–96	-	-	-	-	-	-	-	-	0.89	15	0.68	22
1996–97	-	-	-	-	-	-	-	-	1.06	18	0.96	17
1997–98	-	-	-	-	-	-	-	-	0.58	47	0.64	63
1998–99	-	-	-	-	-	-	-	-	-	-	-	-
1999–00	-	-	-	-	-	-	-	-	-	-	-	-
2000–01	-	-	-	-	-	-	-	-	-	-	-	-
2001–02	-	-	-	-	-	-	Late series					
2002–03	-	-	-	-	-	-	0.62	90	1.11	24	0.9	38
2003–04	-	-	-	-	-	-	0.99	45	1.15	27	1.05	37
2004–05	-	-	-	-	-	-	1.33	63	0.85	32	0.8	56
2005–06	-	-	-	-	-	-	1.1	63	1.34	23	0.99	31
2006–07	-	-	-	-	-	-	0.51	78	1.05	27	1.49	24
2007–08	-	-	-	-	-	-	1.52	44	0.67	66	0.84	33
2008–09	-	-	-	-	-	-	0.65	73	0.84	44	0.75	30
2009–10	-	-	-	-	-	-	1.17	29	1.02	26	1.06	30
2010–11	-	-	-	-	-	-	1.38	52	0.89	30	0.9	22
2011–12	-	-	-	-	-	-	1.37	44	1.28	24	1.49	18

4.3 Smooth oreo

2009 assessment

The stock assessment analyses were conducted using the CASAL age-structured population model employing Bayesian statistical techniques. The 2005 assessment was updated by including five more years of catch, CPUE and observer length data, and used two new series of post-GPS standardised CPUE, one before and the second after major TACC and catch limit changes. The modelling took account of the sex and maturity status of the fish and treated OEO 3A as a single smooth oreo fishery, i.e., no sub-areas were recognised. The base case model used the 1997 absolute acoustic abundance estimate, pre-GPS and early and late post-GPS series of standardised CPUE indices, and the mean natural mortality estimate (0.063 yr^{-1}). Acoustic and observer length frequencies were used in a preliminary model run to estimate selectivity and the base case fixed these selectivity estimates but did not use the length frequencies. Other cases investigated the sensitivity of the model to data sources including:

- Use of the upper and lower 95% confidence interval values for estimates of natural mortality (0.042–0.099 yr^{-1});
- Use of only the left hand limb of the 1994 observer length frequency (plus the 1997 acoustic survey length frequency) with growth not estimated by the model.

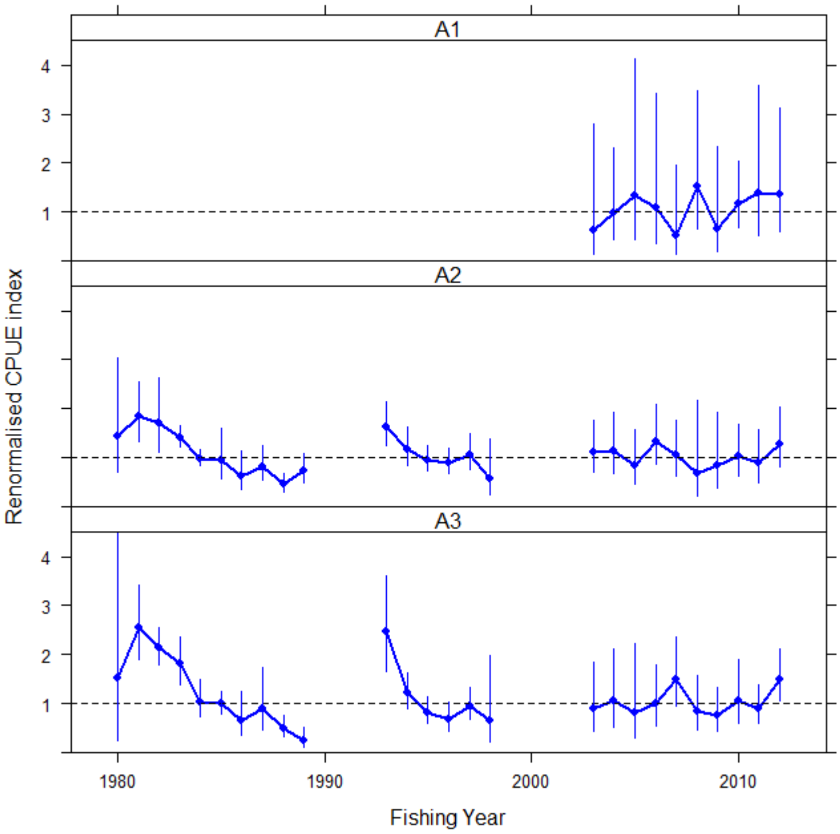


Figure 3: Standardised commercial CPUE series for black oreo in each area within OEO 3A. Pre-GPS and post-GPS (early and late) series are shown, each renormalized to a geometric mean of one. Error bars represent the 95% confidence intervals assuming a log-normal error distribution and using the CVs listed in Table 5.

4.3.1 Estimates of fishery parameters and abundance

Catch history

The estimated catches were scaled up to the total reported catch (see tables 2 and 3 in the Fishery Summary section at the beginning of the Oreos report) and are given in Table 6.

Table 6: Reconstructed catch history (t)

Year	Catch	Year	Catch	Year	Catch	Year	Catch
1972–73	†3 440	1981–82	1 288	1990–91	5 054	1999–00	1 789
1973–74	†3 800	1982–83	2 495	1991–92	6 622	2000–01	1 621
1974–75	†5 100	1983–84	3 979	1992–93	4 334	2001–02	1 673
1975–76	†1 260	1984–85	4 351	1993–94	4 942	2002–03	1 412
1976–77	†3 880	1985–86	3 142	1994–95	4 199	2003–04	1 254
1977–78	†5 750	1986–87	3 190	1995–96	4 022	2004–05	1 457
1978–79	650	1987–88	5 905	1996–97	3 239	2005–06	1 445
1979–80	5 215	1988–89	6 963	1997–98	4 733	2006–07	1 306
1980–81	2 196	1989–90	6 459	1998–99	2 474	2007–08	1 526

† Soviet catch, assumed to be mostly from OEO 3A and to be 50:50 black oreo:smooth oreo.

Observer length frequencies

Observer length data were extracted from the observer database. These data represent proportional catch at length and sex. All length samples were from the CPUE study area (see Figure 4). Only samples where 30 or more fish were measured, and the catch weight and a valid depth were recorded, were included in the analysis. Data from adjacent years were pooled because of the paucity of data in some years. The pooled length frequencies were applied in the model at the year that the median observation of the grouped samples was taken (Table 7).

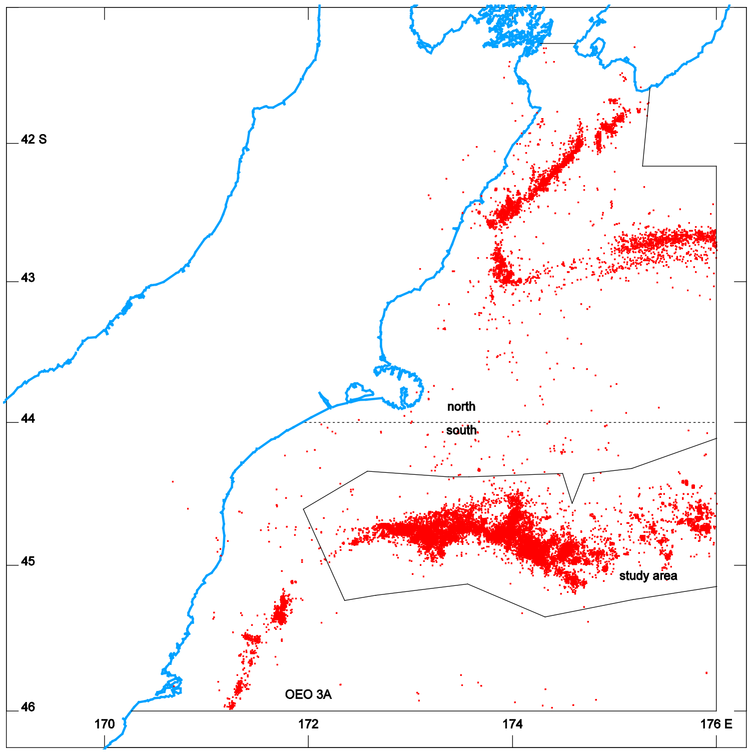


Figure 4: Locations of all tows in OEO 3A with a reported catch of smooth oreo from 1979–80 to 2002–03 (dots). The study area is shown along with the line chosen to split north from south Chatham rise catches.

Table 7: Observer length frequencies; numbers of length samples (tows sampled), number of fish measured, groups of pooled years, and the year that the length data were applied in the stock assessment model. -, not applicable.

Year	Number of length samples	Number of fish measured	Year group code	Year the grouped data were applied
1979–80	32	3 499	1	Applied
1980–81	0	0	-	-
1981–82	0	0	-	-
1982–83	0	0	-	-
1983–84	0	0	-	-
1984–85	0	0	-	-
1985–86	1	106	2	-
1986–87	4	387	2	-
1987–88	10	1 300	2	Applied
1988–89	14	1 512	2	-
1989–90	0	0	-	-
1991–92	9	919	3	-
1992–93	0	0	-	-
1993–94	13	1 365	4	Applied
1994–95	7	752	4	-
1995–96	2	207	4	-
1996–97	3	365	5	-
1997–98	13	1 720	5	-
1998–99	5	770	5	-
1999–00	77	7 595	5	Applied
2000–01	93	9 389	6	Applied
2001–02	20	3 030	7	Applied
2002–03	14	1 427	8	Applied
2003–04	4	321	8	-
2004–05	9	840	8	-
2005–06	26	3 207	9	Applied
2006–07	2	205	9	-
2007–08	8	816	9	-

Length frequency data from the 1997 acoustic survey

Length data collected during the 1997 survey were used to generate a population length frequency by sex. A length frequency was generated from the trawls in each mark-type and also for the seamounts. These frequencies were combined using the fraction of smooth oreo abundance in each mark-type. The overall frequency was normalised over both male and female frequencies so that the sum of the frequencies over both sexes was 100%. The CV for each length class was given by the regression, log(CV) = 0.86 + 8.75/log(proportion). This regression was estimated from the CVs obtained by bootstrapping the data and provides a smoothed estimate of the CVs. The estimated length frequency is in Figure 5.

Absolute abundance estimates from the 1997 acoustic survey

Absolute estimates of abundance for smooth oreo are available from the acoustic survey on oreos carried out from 10 November to 19 December 1997 (TAN9713) using the same approach as described for OEO 3A black oreo. The abundance estimates used in the 1999 OEO 3A smooth oreo assessment were revised in 2005 using new target strength estimates for smooth oreo, black oreo and a number of bycatch species. The revised estimate was 25 200 t with a CV of 23% (the 1999 estimate was 35 100 t with a CV of 27%). There is uncertainty in the estimates of biomass because the acoustic estimate includes smooth oreo in layers that are a mixture of species for which the acoustic method has potential bias problems.

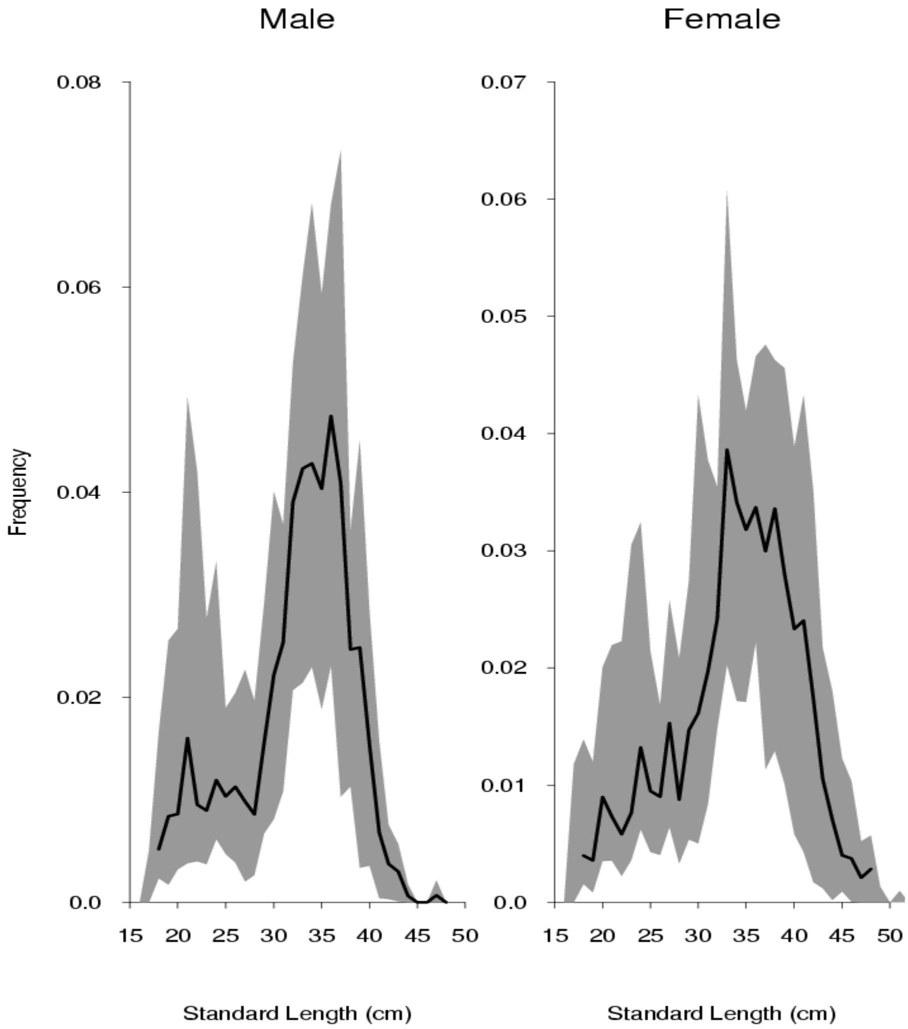


Figure 5: Population length frequency derived from the 1997 acoustic survey data. The bold line is the estimated value and the shaded area is the spread from 300 bootstraps.

Relative abundance estimates from standardised CPUE analysis

The CPUE study area is shown in Figure 4. Three analyses were carried out; a pre-GPS analysis (unchanged from 2005) that included data from 1980–81 to 1988–89 and two post-GPS analyses that included data from 1992–93 to 1997–98 and 2002–03 to 2007–08. The years from 1998–99 to 2001–02 were not included because a voluntary smooth oreo catch limit (1400 t) was introduced and substantial oreo TACC reductions were made during that time (6600 down to 3100 t). The pre-GPS series shows a downward trend, and declines to approximately a third of the initial level over the nine-year period. The early post-GPS also has a downward trend but the late post-GPS series has an upward trend and then flattens out. The base case stock assessment used all three indices (Table 8).

Fishing Industry members of the Deepwater Fishery Assessment Working Group expressed concern about the accuracy of the historical Soviet catch and effort data (pre-GPS series) and felt that it was inappropriate to use those data in the stock assessment.

Table 8: CPUE indices by year and jackknife CV (%) estimates from the pre-GPS and the two post-GPS analyses.

	Pre-GPS							Post-GPS
Year	**Index**	**CV**	**Year**	**Index**	**CV**	**Year**	**Index**	**CV**
1980–81	1.00	27	1992–93	1.00	24	2002–03	0.55	23
1981–82	0.82	26	1993–94	0.88	11	2003–04	0.77	22
1982–83	0.72	62	1994–95	0.74	14	2004–05	0.99	22
1983–84	0.59	61	1995–96	0.48	17	2005–06	0.96	31
1984–85	0.72	22	1996–97	0.56	15	2006–07	1.00	20
1985–86	0.61	19	1997–98	0.50	19	2007–08	0.92	21
1986–87	0.46	16						
1987–88	0.42	16						
1988–89	0.26	28						

4.3.2 Biomass estimates

The posterior distributions from the MCMC on the base case are shown in Figure 6. The probability that the current mature biomass (2008–09) and the biomass 5 years out (2013–14) are above 20% B_0 is 1 for both.

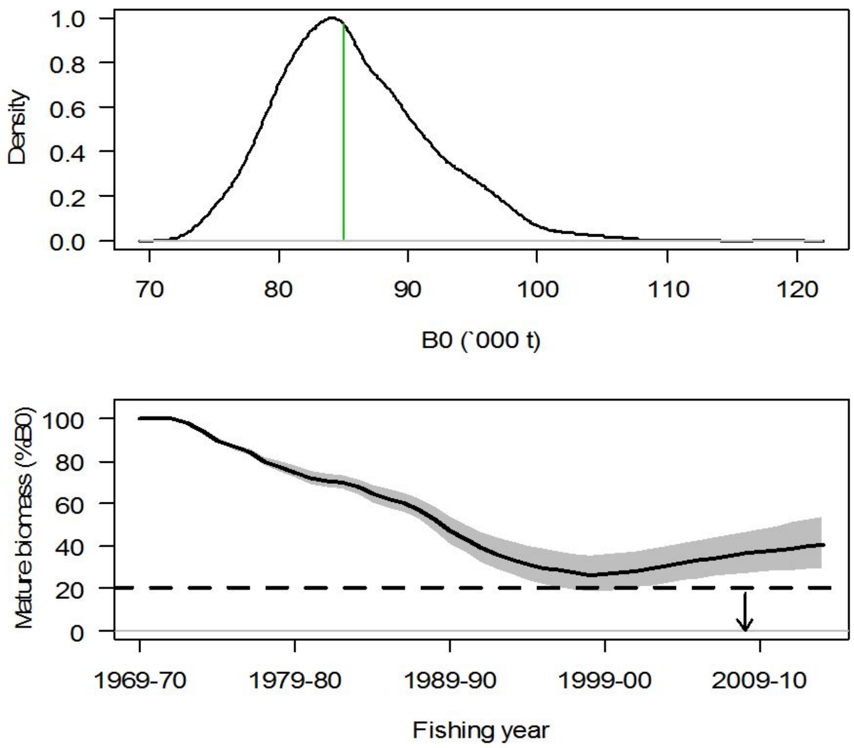


Figure 6: Smooth oreo OEO 3A: posterior distribution for the virgin biomass (top plot) and the mature biomass trajectories as a percentage of virgin biomass (bottom plot) from the MCMC analysis of the "NoLF" case with M = 0.063 (base case). In the top plot, the vertical line is the median of the distribution. In the bottom plot, the grey area is the point-wise 95% confidence intervals of the trajectories and the solid line is the median.

Biomass estimates derived from the MCMC are in Table 9. Total mature biomass for 2008–09 was estimated to be 36% of the initial biomass (B_0). Sensitivity case results for the base case using the lower and upper 95% confidence interval value estimates for M gave estimates of current biomass between 26% and 49% of B_0. The sensitivity case that used the left hand limb of the 1994 observer length frequency (plus the 1997 acoustic survey length frequency) with growth not estimated by the model gave estimates of current biomass for the mean estimate of M (0.063 yr^{-1}) of 30 % of B_0 while estimates using the lower and upper 95% confidence interval value estimates for M gave estimates of 2008 biomass between 12% and 59% of B_0.

Projections were carried out for five years with the current catch limit of 1400 t. The trajectory shows increasing biomass (Figure 6).

Table 9 (a): Base case (in bold) and sensitivity to M values (biomass estimates). Bcurr is 2008.

	M = 0.063			†M = 0.042			†M = 0.099		
	Median	**CI.05**	**CI.95**	Median	CI.05	CI.95	Median	CI.05	CI.95
B_0	**85 000**	**77 300**	**96 500**	97 700	90 100	110 000	68 500	60 300	79 600
B_cur	**30 900**	**22 400**	**43 000**	26 300	18 000	38 800	33 800	25 000	45 500
$B\_cur(\%B_0)$	**36**	**29**	**45**	27	20	35	49	41	57

(b) Sensitivity (biomass estimates). In these runs the left hand limb of the 1994 observer length was fitted, the 1997 acoustic survey length frequency was included and growth was not estimated by the model:

	†M = 0.063			†M = 0.042			†M = 0.099		
	Median	CI.05	CI.95	Median	CI.05	CI.95	Median	CI.05	CI.95
B_0	77 400	74 800	80 200	82 800	81 600	84 200	82 300	76 700	89 200
B_cur	23 100	19 900	26 400	10 200	8 480	12 100	48 800	42 900	56 200
$B\_cur(\%B_0)$	30	27	33	12	10	14	59	56	63

4.3.3 Other factors

Because of differences in biological parameters between the species, it would be appropriate to split the current TACC for black oreo and smooth oreo. The WG noted that separate species catch limits are in place to reduce the risk of over- or under-fishing either smooth oreo or black oreo.

The model estimates of uncertainty are unrealistically low. Uncertainties that are not included in the model include:

- the assumption that recruitment is deterministic;
- that the acoustic index is assumed to be an absolute estimate of abundance;
- the selectivity in the base case is fixed at the MPD estimate from the preliminary case where all length data is used;
- uncertainty in the estimate of *M*.

In addition, the growth is fixed and known. The WG has previously noted the impact of the different ages of maturity for males and females. Due to the fact that males mature at a much smaller size than females (age at 50% maturity is 18–19 years for males and 25–26 for females), the sex ratio needs to be taken into account when assessing the sustainability of any particular catch level.

5. STATUS OF THE STOCKS

The smooth oreo stock assessment is unchanged from 2009. The black oreo stock assessment is updated using CPUE data up to 2011–12.

Stock Structure Assumptions

The two oreo stocks in FMA 3A are assessed separately but managed as a single stock. For both the black oreo and smooth oreo stocks it is assumed that there is potential mixing with stocks outside of the OEO 3A area.

- **OEO 3A (Black Oreo)**

Stock Status	
Year of Most Recent Assessment	2013
Assessment Runs Presented	Age-structured CASAL spatial assessment model rejected by the Working Group; CPUE accepted
Reference Points	Target: 40% B_0 Soft Limit: 20% B_0 Hard Limit: 10% B_0 Overfishing threshold: $F_{40\% B0}$
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	
-	
Fishery and Stock Trends	
Recent Trend in Biomass or Proxy	Unknown
Recent Trend in Fishing Intensity or Proxy	Catch has decreased with TACC since the early 1990s and remained low and relatively constant over the last 10 years.
Other Abundance Indices	CPUE since 2002–03 has stabilised in all three areas after significant declines in the two deeper areas in the 1980s and 1990s.
Trends in Other Relevant Indicators or Variables	-

Projections and Prognosis	
Stock Projections or Prognosis	**-**
Probability of Current Catch or TACC causing Biomass to remain below or to decline below Limits	Soft Limit: Unknown Hard Limit: Unknown
Probability of Current Catch or TACC causing Overfishing to continue or to commence	Unknown

Assessment Methodology and Evaluation		
Assessment Type	Level 2 – Partial Quantitative Stock Assessment	
Assessment Method	CPUE	
Assessment Dates	Latest assessment: 2013	Next assessment: 2019
Overall assessment quality rank	1 – High Quality	
Main data inputs (rank)	CPUE abundance	1 – High Quality
Data not used (rank)		
Changes to Model Structure and Assumptions	The three area model with migration based on age is thought to be flawed and the previous model has been withdrawn.	
Major Sources of Uncertainty	-	

Qualifying Comments
-

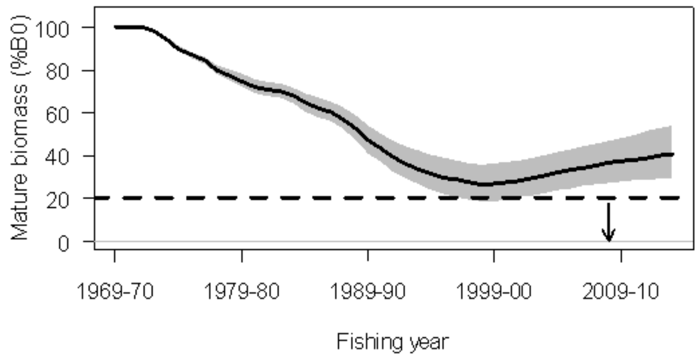
Fishery Interactions
Both species of oreo are sometimes taken as bycatch in orange roughy target fisheries, mostly in other areas e.g. OEO 4. The main bycatch species in the OEO 3A black oreo target fishery include smooth oreo, hoki, javelinfish, Baxter's dogfish, pale ghost shark, ridge scaled rattail, and basketwork eel. Bycatch species that may be vulnerable to overfishing include deepwater sharks and rays. Protected species catches include seabirds and deepwater corals. Oreo are caught using bottom trawl gear. Bottom trawling interacts with benthic habitats.

- **OEO 3A (Smooth Oreos)**

Stock Status	
Year of Most Recent Assessment	2009
Assessment Runs Presented	One base case and 5 sensitivity runs
Reference Points	Target: 40% B_0 Soft Limit: 20% B_0 Hard Limit: 10% B_0 Overfishing threshold:
Status in relation to Target	For the base case, B_{2009} was estimated at 36% B_0, About as Likely as Not (40–60%) to be at or above the target.

Status in relation to Limits	B_{2009} is Unlikely (< 40%) to be below the Soft Limit and Very Unlikely (< 10%) to be below the Hard Limit.

Historical Stock Status Trajectory and Current Status



Mature biomass trajectories as a percentage of virgin biomass from the base case. The grey area is the point-wise 95% confidence intervals of the trajectories and the solid line is the median.

Fishery and Stock Trends	
Recent Trend in Biomass or Proxy	Biomass is projected to have been increasing since the late 1990s.
Recent Trend in Fishing Mortality or Proxy	Unknown
Other Abundance Indices	-
Trends in Other Relevant Indicators or Variables	-

Projections and Prognosis (2009)	
Stock Projections or Prognosis	The biomass is expected to increase over the next 5 years given the current catch limit of 1400 t.
Probability of Current Catch or TACC causing Biomass to remain below or to decline below Limits	Soft Limit: Very Unlikely (< 10%) Hard Limit: Very Unlikely (< 10%)
Probability of Current Catch or TACC causing Overfishing to continue or to commence	-

Assessment Methodology		
Assessment Type	Level 1 - Quantitative stock assessment	
Assessment Method	Age-structured CASAL model with Bayesian estimation of posterior distributions	
Assessment dates	Latest assessment: 2009	Next assessment: 2019
Overall assessment quality rank	-	
Main data inputs (rank)	- One acoustic absolute abundance estimate (1997) - three standardised CPUE indices (1981–82 to 1988–89, 1992–93 to 1997–98, 2002–03 to 2007–08) - Natural mortality estimate (0.063) - Selectivity estimated from acoustic and observer length frequencies New information from previous (2005) assessment: - Updated with additional catch, CPUE, observer length data collected since last assessment - two new standardised post-GPS CPUE series	
Changes to Model Structure and Assumptions	-	
Major Sources of Uncertainty	- The single acoustic index (1997) is assumed to be an absolute estimate of abundance	

	- Sex ratio needs to be taken into account, as males mature at a much smaller size than females. - Recruitment is assumed to be deterministic. - Uncertainty in the estimates of natural mortality (*M*) - Selectivity is fixed in the base case at the MPD estimate from the preliminary study

Qualifying Comments
-

Fishery Interactions
Both species of oreo are sometimes taken as bycatch in orange roughy target fisheries, mostly in other areas e.g. OEO 4. The main bycatch species in the OEO 3A smooth oreo target fishery include black oreo, hoki, javelinfish, Baxter's dogfish, pale ghost shark, ridge scaled rattail and basketwork eel. Low productivity bycatch species include deepwater sharks and rays. Protected species catches include seabirds and deepwater corals. Oreo are caught using bottom trawl gear. Bottom trawling interacts with benthic habitats.

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OREOS – OEO 4 BLACK OREO AND SMOOTH OREO

1. FISHERY SUMMARY

This is presented in the Fishery Summary section at the beginning of the Oreo report.

2. BIOLOGY

This is presented in the Biology section at the beginning of the Oreo report.

3. STOCKS AND AREAS

This is presented in the Stocks and Areas section at the beginning of the Oreo report.

4. STOCK ASSESMENT

4.1 Introduction
In 2018, the stock assessment was updated for smooth oreo in OEO 4.

4.2 Black oreo
Investigations were carried out in 2009 using age-based single sex single step preliminary models in CASAL. The data used in these models were four standardised CPUE indices (pre– and post–GPS in the east and west), and observer length frequencies. Growth and maturity were also estimated in some of the runs.

4.2.1 Estimates of fishery parameters and abundance

Absolute abundance estimates from the 1998 acoustic survey
Absolute estimates of abundance were available from an acoustic survey on oreos which was carried out from 26 September to 30 October 1998 on *Tangaroa* (voyage TAN9812). Transects on flat ground were surveyed to a stratified random design and a random sample of seamounts were surveyed with either a random transect (large seamounts) or a systematic “star” transect design. For some seamounts the flat ground nearby was also surveyed to compare the abundance of fish on and near the seamount either by extending the length of the star transects or by extra parallel transects. Acoustic data were collected concurrently for flat and seamounts using both towed and hull mounted transducers. The OEO 4 survey covered 59 transects on the flat and 29 on seamounts. A total of 95 tows were carried out for target identification and to estimate target strength and species composition. In situ and swimbladder samples for target strength data were collected and these have yielded revised estimates of target strength for both black oreo and smooth oreo.

Acoustic abundance estimates for recruit black oreo from seamounts and flat for the whole of OEO 4 are in Table 1. About 59% of the black oreo abundance came from the background mark-type. This mark-type is not normally fished by the commercial fleet and this implies that the abundance estimate did not cover the fish normally taken by the fishery. In addition the scaling factor to convert the acoustic area estimate to the trawl survey area estimate was 4.3, i.e., the acoustic survey area only had about 23% of the abundance. The magnitude of this ratio suggests that the size of the area surveyed was borderline for providing a reliable abundance estimate.

Relative abundance estimates from standardised CPUE analyses – 2009 analysis
The CPUE analysis method involved regression based methods on the positive catches only. Sensitivities were run where the positive catch tow data and the zero catch tow data were analysed separately to produce positive catch and zero catch indices. All data were included, whether they were target or bycatch fisheries, with the target offered to the model (and not accepted).

Table 1: OEO 4 recruit black oreo seamount, flat, and total acoustic abundance estimates (t) and recruit CV (%) based on knife-edge recruitment (23 years).

	Abundance (t)	CV (%)
Seamount	127	91
Flat	13 800	56
Total	13 900	55

The best data-split was investigated using the Akaike Information Criteria (AIC) on a number of potential regressions. Four indices were subsequently used, pre- and post-GPS in the east and west areas respectively. These two areas are very distinct: the west consists of flat fishing and the east of hill fishing, the west area was fished 10 years prior to the east, and there has been a move by the fishery since the early 1990s from the west to the east. However, despite these differences, the two series present almost identical patterns of decline in relative standardised CPUEs from the time fishing started in earnest (1980 in the west and 1992 in the east) which would suggest that for this fishery CPUE might be a reasonable index of abundance (because less influenced by technology, fishing patterns, hills or flats etc).

The standardised CPUE series and CVs are described in Table 2. Over comparable time periods and data sets, the trends from the updated series were similar to those from the 2000 analyses (Coburn et al 2001b). The west CPUE reduced to between 5% of the 1980 value and 15% of the 1981 value by 1990. The post-GPS west series is either flat or slightly increasing. The east CPUE reduced to 4% of the 1984 value and 21% of the 1985 value by 1990 even though catches were low. The post-GPS east series showed a further steep initial decline with total reduction to 15% of the 1993 value by 2008.

Table 2: OEO 4 black oreo standardised CPUE analyses in 2009 (expressed in t / tow).

Fishing year	Pre-GPS east		Pre-GPS west		Fishing year	Post-GPS east		Post-GPS west	
	Index	CV	Index	CV		Index	CV	Index	CV
1980			8.97	0.17	1993	0.71	0.15	0.73	0.41
1981			4.00	0.11	1994	0.63	0.13	0.45	0.32
1982			2.24	0.10	1995	0.31	0.15	0.41	0.31
1983			2.20	0.09	1996	0.21	0.15	0.28	0.27
1984	0.47	0.95	1.54	0.10	1997	0.24	0.12	0.61	0.27
1985	0.41	0.28	1.51	0.07	1998	0.20	0.11	0.45	0.23
1986	0.38	0.32	1.28	0.10	1999	0.16	0.12	0.46	0.23
1987	0.65	0.30	0.67	0.10	2000	0.17	0.12	0.68	0.25
1988	0.10	0.18	0.54	0.13	2001	0.14	0.08	0.62	0.24
1989	0.02	0.20	0.48	0.12	2002	0.18	0.07	0.47	0.29
					2003	0.13	0.06	0.49	0.24
					2004	0.13	0.06	0.93	0.24
					2005	0.14	0.07	0.91	0.26
					2006	0.13	0.07	0.68	0.26
					2007	0.12	0.07	1.00	0.27
					2008	0.10	0.09	0.88	0.24

Relative abundance estimates from trawl surveys

The estimates, and their CVs, from the four standard *Tangaroa* south Chatham Rise trawl surveys are treated as relative abundance indices (Table 3).

Table 3: OEO 4 black oreo research survey abundance estimates (t). N is the number of stations. Estimates were made using knife-edge recruitment set at 33 cm TL. Previously knife-edge recruitment was set at 27 cm and estimates of abundance based on that value are also provided for comparison.

Year	Mean abundance		CV (%)	N
	27 cm	33 cm		
1991	34 407	13 065	40	105
1992	29 948	12 839	46	122
1993	20 953	6 515	30	124
1995	29 305	9 238	30	153

Observer length frequencies

Observer length frequencies were available for about 20% of the yearly catch from 1989 to 2008. Analyses conducted on these data indicated that they were not representative of the spatial spread of the fishery. When stratified by depth, the length frequencies had double-modes, centred around 28 cm and 38 cm, with inconsistent trends in the modes between years. Alternative stratification by subarea, hill, etc, did not resolve the problem; some tows showed bimodality. These patterns in length frequencies were an issue because the yearly shifts in length frequencies and double mode cannot be representative of the underlying fish population since black oreo is a slow growing long-lived fish. They are more likely linked with discrete spatial sub-groups of the population.

A similar double mode was reported for some strata in the same area from the 1994 *Tangaroa* trawl survey (Tracey & Fenaughty 1997). It is likely that there is further spatial stock structure that is currently unaccounted for.

4.2.2 Biomass estimates

The 2009 stock assessment of OEO 4 black oreo was inconclusive as assessment models were unable to represent the observer length frequency structure, and were considered unreliable. The CPUE was fitted satisfactorily under a two-stock model but could not be fitted in a single homogeneous stock model. However, the WG agreed that:

1. The CPUE indices are consistent with a two-stock structure or at least a minimally-mixing single stock.
2. The updated CPUE estimates were probably a reasonable indicator of abundance (at the spatial scale of the east and west analyses).

4.2.3 Estimation of Maximum Constant Yield (MCY)

In 2000, MCY was estimated using the equation, MCY = $c*Y_{AV}$ (Method 4). There was no trend in the annual catches, nominal CPUE, or effort from 1982–83 to 1987–88 so that period was used to calculate the MCY estimate (1200 t). The MCY calculation was not updated in 2009.

4.2.4 Estimation of Current Annual Yield (CAY)

CAY cannot be estimated because of the lack of current biomass estimates.

4.3 Smooth oreo

Smooth oreo was assessed in 2018 using a CASAL age-structured population model with Bayesian estimation, incorporating stochastic recruitment, life history parameters (table 1 of the Biology section at the beginning of the Oreo report), and catch history up to 2017–18. In early assessments (Doonan et al 2001, 2003, 2008), the stock area was split at 178° 20′ W into a west and an east fishery based on an analysis of commercial catch, standardised CPUE, and research trawl and acoustic result, and data fitted in the model included acoustic survey abundance estimates, standardised CPUE indices, observer length data, and the acoustic survey length data. In 2012, the Deepwater Working Group decided that using CPUE to index abundance should be discontinued, due to changes in fishing patterns over time within the stock area. With no CPUE indices, the 2012 assessment was simplified to a single area model using only the observations of vulnerable biomass from acoustic surveys carried out in 1998, 2001, 2005, and 2009.

A 2014 stock assessment updated the 2012 assessment model using the same single area model structure and used an additional observation of biomass from the research acoustic survey carried out in 2012. The assessment also revised the previous assessments by including the age frequency estimates from the 1998 and 2005 acoustic surveys and by estimating relative year class strengths. The 2018 assessment updated the 2014 assessment with the inclusion of an additional acoustic survey biomass estimate in 2016 and the associated age frequency. An age frequency from a 1991 trawl survey was also included together with an age frequency from the commercial fishery in 2009. With the addition of three new age frequencies natural mortality was estimated within the model (with a Normal prior with the mean equal to 0.063 and CV=25% – see table 1 in the Biology section).

Year class strengths (YCS) were estimated for 1940–2005 (based on the range of age estimates in the age frequency data). A “near uniform” prior was used (parameterised as a lognormal distribution with a mode of 1 and sigma of 4), which places minimum constraint on the free YCS parameters (Haist parameterisation).

An informed prior was used for the acoustic survey proportionality constant q (lognormal with mean of 0.83 and CV of 0.3). The prior was based on limited information on target strength, the QMA scaling-factor, and the proportion of vulnerable biomass in the vulnerable acoustic marks (Fu & Doonan 2013).

A brief description of the base case and sensitivity runs presented are summarised in Table 4. The following assumptions were made in the stock assessment analyses:

(a) Recruitment followed a Beverton–Holt relationship with steepness of 0.75.
(b) Catch overruns were 0% during the period of reported catch.
(c) The population of smooth oreo in OEO 4 was a discrete stock or production unit.
(d) The acoustic biomass selectivity and the commercial fishery selectivity were assumed to be identical (logistic, estimated within the model).
(e) A separate selectivity was estimated for the age frequencies that were derived from trawl catches during the acoustic surveys (double normal, estimated within the model).

Bayesian estimation was used in the assessment to capture the uncertainties in model estimates of biomass and other parameters:

1. Model parameters were estimated using maximum likelihood and the prior probabilities;
2. Samples from the joint posterior distribution of parameters were generated with the Monte Carlo Markov Chain procedure (MCMC) using the Hastings-Metropolis algorithm;
3. A marginal posterior distribution was found for each quantity of interest by integrating the product of the likelihood and the priors over all model parameters; each marginal posterior distribution was described by its median and a 95% credibility interval (95% CI).

Bayesian estimates were based on results from three 15 million long MCMC chains. After a burn-in of 1 million, the last 14 million of the chain was sampled at each 1000th value. Posterior distributions were obtained from samples combined over the three chains (after the burn-in).

Table 4: Descriptions of the model runs of the 2018 smooth oreo assessment. LN, lognormal distribution with mean and CV given in the bracket. N, normal distribution with mean and CV in the bracket. All use Haist parameterisation for YCS.

Model run	Description
Base	Acoustic q estimated with a LN(0.83, 0.3) prior, nearly uniform prior on YCS, *M* estimated with a N(0.063, 0.25) prior, adult biomass indices (school marks)
LowM-Highq	M fixed at 0.0632 (20% less than the base estimate) and the mean of the acoustic q prior 20% higher
HighM-Lowq	M fixed at 0.0948 (20% higher than the base estimate) and the mean of the acoustic q prior 20% lower
Plus LFs	Base but with commercial length frequencies included
Fixed M	Base but with fixed M = 0.063 (as assumed in the 2014 assessment)

4.3.1 Estimates of fishery parameters and abundance

The 2018 assessment incorporated the catch history and the adult acoustic biomass indices. Five age frequencies were fitted. Commercial length frequencies (five scaled length frequencies between 1996 and 2008) were not included in the base model but were fitted in a sensitivity run (see Table 4).

Catch history

A catch history for smooth oreo in OEO 4 was developed by scaling the estimated catch to the QMS values (Table 5). A catch of 2876 t was recorded for 2017–18.

Biomass estimates from the 1998, 2001, 2005, 2009, 2012, and 2016 acoustic surveys

Estimates of biomass were available from six acoustic surveys:

(i) 26 September to 30 October 1998 on *Tangaroa* (voyage TAN9812);
(ii) 16 October to 14 November 2001 using *Tangaroa* for acoustic work (voyage TAN0117) and *Amaltal Explorer* (voyage AEX0101) for trawling;

(iii) 3–22 November 2005 using *Tangaroa* for acoustic work (voyage TAN0514) and 3–20 November 2005 using *San Waitaki* (SWA0501) for mark identification trawling;
(iv) 2–18 November 2009 using *Tangaroa* for acoustic work (voyage TAN0910) and 2–18 November 2009 using *San Waitaki* (SWA0901) for mark identification trawling;
(v) 8–26 November 2012 using *Tangaroa* for acoustic work (voyage TAN01214) and 8–26 November 2012 using *San Waitaki* (SWA1201) for mark identification trawling;
(vi) 16 October to 17 November 2016 on *Amaltal Explorer* (AEX1602).

Table 5: Catch history for OEO 4 smooth oreo

Year	Catch (t)	Year	Catch (t)
1978–79	1 321	1999–00	6 357
1979–80	112	2000–01	6 491
1980–81	1 435	2001–02	4 291
1981–82	3 461	2002–03	4 462
1982–83	3 764	2003–04	5 656
1983–84	5 759	2004–05	6 473
1984–85	4 741	2005–06	5 955
1985–86	4 895	2006–07	6 363
1986–87	5 672	2007–08	6 422
1987–88	7 764	2008–09	6 090
1988–89	7 223	2009–10	6 118
1989–90	6 789	2010–11	6 518
1990–91	6 019	2011–12	6 357
1991–92	5 508	2012–13	5 964
1992–93	5 911	2013–14	6 016
1933–94	6 283	2014–15	6 318
1994–95	6 936	2015–16	1 992
1995–96	6 378	2016–17	2 279
1996–97	6 359	2017–18	2 867
1997–98	6 248		
1998–99	6 030		

The method of estimating variance and bias was the same as in previous oreo surveys (Doonan et al 1998, 2000). Variance was estimated separately for the flat and for hills and then combined. Sources of variance were:

- sampling error in the mean backscatter
- the proportion of smooth oreo and black oreo in the acoustic survey area
- sampling error in catches which affects the estimate of the proportion of smooth oreo
- error in the target strengths of other species in the mix
- variance in the estimate of smooth oreo target strength
- sampling error of fish lengths (negligible)
- variance of the mean weight, for smooth oreo

Vulnerable smooth oreo was estimated based on the acoustic mark types, where vulnerable biomass was the sum over two flat mark types: DEEP SCHOOLS and SHALLOW SCHOOLS, with the hill biomass added on. These estimates were made for smooth oreo in the whole of OEO 4 (Table 6).

One major source of uncertainty in the 2012 survey estimates was that about 25% of the total estimate came from one school mark on the flat. The species composition of this mark was not able to be verified by trawling. Excluding this mark, i.e., assuming they were not smooth oreo, reduced the total biomass for smooth oreos to 36 550 t. However, the consensus of skippers consulted about the mark is that it was likely to be smooth oreo.

Table 6: Estimated smooth oreo vulnerable biomass (t) and CV (%, after the addition of 20% process error) from acoustic surveys in 1998, 2001, 2005, and 2009, 2012, and 2016; includes school marks and hills.

Year	Biomass (t)	CV (%)
1998	65 679	33
2001	81 633	33
2005	63 237	32
2009	26 953	33
2012	58 603	36
2016	34 022	38

Age frequencies from the 1998, 2005, and 2016 acoustic surveys
Age frequency distributions were derived from trawl samples taken for smooth oreo in OEO 4 during three acoustic surveys carried out in 1998 and 2005 (Doonan et al 2008) and 2016. All of the sampled otoliths (n = 546) from the 1998 survey and randomly selected otoliths (n = 500) from the 1800 otoliths collected during the 2005 survey were read, with 398 otoliths used from the 2016 survey.

The age frequency distribution was estimated using the aged otoliths from tows in each mark-type weighted by the catch rates and the proportion of abundance in the mark-type. Age frequencies were estimated by sex and combined over sexes. The variance was estimated by bootstrapping the tows within mark-types (e.g., Doonan et al 2008). The ageing error was estimated by comparing age estimates from two readers and also by using repeated readings from the same reader. The age frequencies had a mean weighted CV of 36% (1998) and 45% (2005). The ageing error was estimated to be about 8.5% which was used in the assessment. The age frequencies (male and female combined) were included in order to estimate year class strength.

Other age frequencies
Two additional age frequencies were constructed for the 2018 assessment. The first was for the commercial catch in 2008–2009. The 1284 otoliths available from the observer programme were sampled at random (with replacement) until 400 unique otoliths were obtained. The probability of selection was proportional to the tow catch and inversely proportional to the number of otoliths sampled in the tow. The mean weighted CV was 30% (obtained by bootstrapping). The second age frequency was constructed for the 1991 trawl survey of OEO 4 (TAN9104). Otoliths collected during the trawl survey were sampled at random until 400 unique otoliths were obtained. The probability of selection was proportional to the stratum biomass estimate and by tow catch within stratum, divided by the number of otoliths available from the tow. The mean weighted CV was 35% (obtained by bootstrapping).

Observer length frequencies
Observer length data were extracted from the observer database. These data were stratified by season (October-March and April-September) and into west and east parts. The length frequencies were combined over strata by the proportion of catch in each stratum.

Five scaled length frequencies from 1996 to 2008 were used in a sensitivity run but not used in the base model.

4.3.2 Biomass estimates, year class strengths, and exploitation rates
For the base model, and all of the sensitivities, B_0 was estimated at about 140 000 t with 95% CIs ranging from about 110 000 t to 210 000 t (Table 7). Current stock status is estimated to be at the target level of 40% for the base case. However, it is estimated to be just above 30% B_0 for the LowM-Highq and Fixed M runs (Table 7). For all of the runs the estimated probability of current stock status being below the soft limit of 20% B_0 is less than 5% (Table 7). The probability of current stock status being below the hard limit of 10% B_0 was estimated at 0 for all runs (Table 7).

Table 7: Bayesian estimates of M, B_0, and current stock status (B_{18}/B_0) for the base model and sensitivities (the median and 95% CIs are given). The probability of current stock status being below 10% or 20% B_0 is also given.

	M (yr^{-1})	B_0 (000 t)	ss_{18} (%B_0)	P(ss_{18} < 10%)	P(ss_{18} < 20%)
Base	0.079 (0.057–0.01)	138 (111–184)	40 ((23–59)	0.00	0.01
LowM-Highq	0.0632	138 (118–173)	31 (19–46)	0.00	0.04
HighM-Lowq	0.0948	146 (111–208)	50 (33–67)	0.00	0.00
Incl. LFs	0.085 (0.067–0.011)	133 (111–172)	42 (26–60)	0.00	0.00
Fixed M	0.063	143 (121–184)	33 (21–50)	0.00	0.02

The spawning biomass trajectory for the base model shows a decreasing trend from the start of the fishery in the 1980s with a flattening off in 2015–16 when catches were substantially reduced (Figure 1, Table 5). Current stock status is estimated to be at the target biomass although the 95% CIs are very wide (Figure 1, Table 7).

The estimated year class strengths show a pattern (in the medians) from 1972 to 1987 of above average cohort strength with below average cohort strength from 1990 to 2005 (Figure 2), consistent with the age composition data.

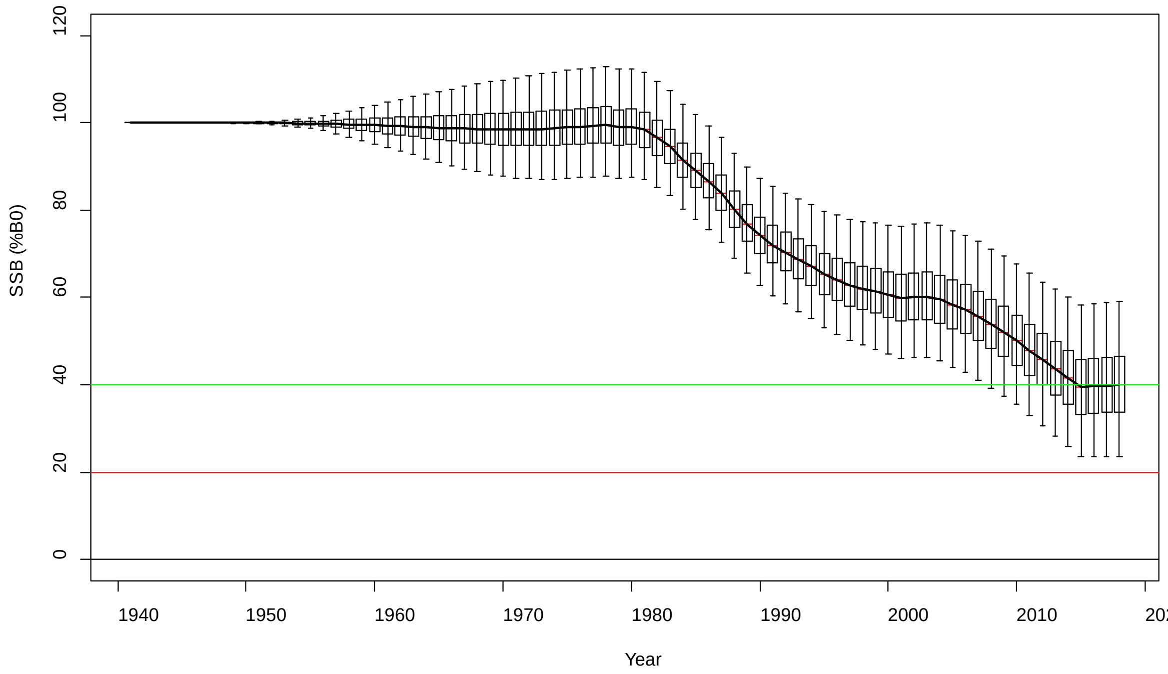


Figure 1: Base, MCMC estimated spawning-stock biomass trajectory. The box in each year covers 50% of the distribution and the whiskers extend to 95% of the distribution. The soft limit (red) and target biomass (green) are marked by horizontal lines.

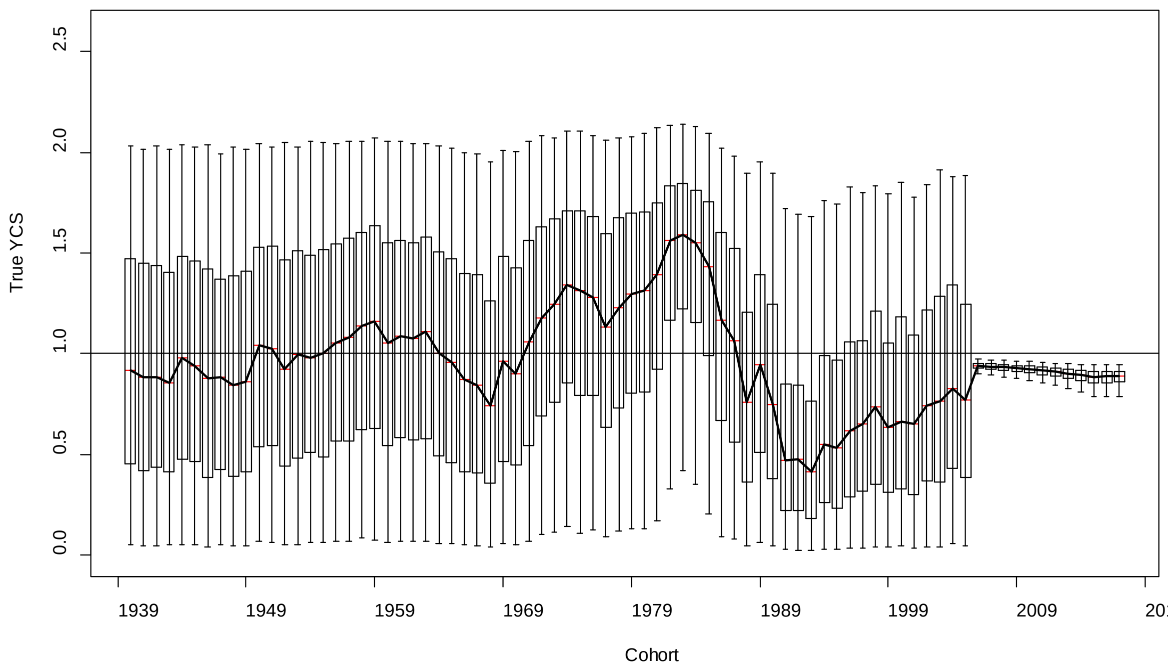


Figure 2: Base, MCMC estimated "true" YCS (R_y/R_0). The box in each year covers 50% of the distribution and the whiskers extend to 95% of the distribution.

Exploitation rates in the fishery were estimated to be generally increasing from the start of the fishery up until 2014–15 (Figure 3). Catches in the years immediately prior to the TACC reduction in 2015–16 were at a level increasingly above the exploitation rate corresponding to the target biomass, $U_{40\%B0}$.

With the substantial catch reduction in 2015–16 the estimated exploitation rate (median) dropped to below 5% where it has remained (Figure 3).

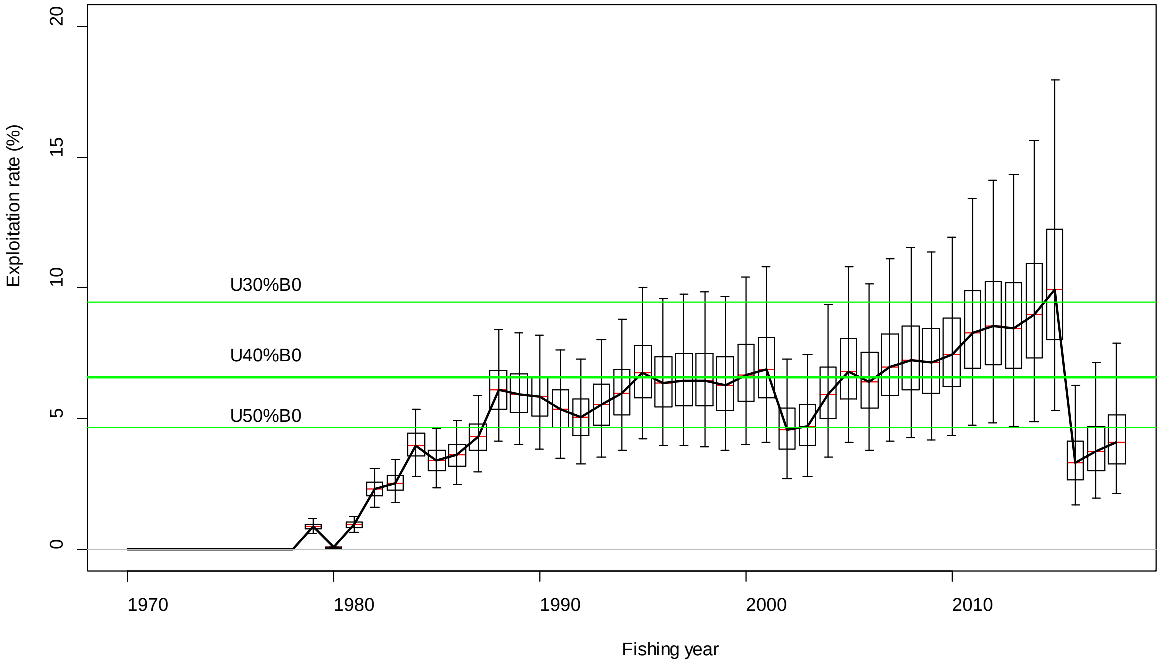


Figure 3: Base, MCMC estimated exploitation rate trajectory. The box in each year covers 50% of the distribution and the whiskers extend to 95% of the distribution. The exploitation rate, $U_{40\%B0}$, corresponding to the biomass target of 40% B_0 is marked by the middle horizontal line ($U_{x\%B0}$ is the exploitation rate that will drive deterministic spawning biomass to x% B_0). $U_{30\%B0}$ and $U_{50\%B0}$ are also marked by horizontal lines.

4.3.3 Yield estimates and projections

Five year projections were made from the base model at a constant catch of 2300 t which is the approximate level of the last reported annual catch (2279 t in 2016–17) and also at 3000 t (the TACC for OEO 4). Year class strengths from 2006 onwards were sampled at random from the last 10 estimated year class strengths (1996–2005). Based on the projections, stock status is expected to stay fairly constant over the next five years for annual catches in the range 2300–3000 t (Figures 4 and 5, Table 8). There is a small upward trend in median stock status at annual catches of 2300 t (Figure 4, Table 8).

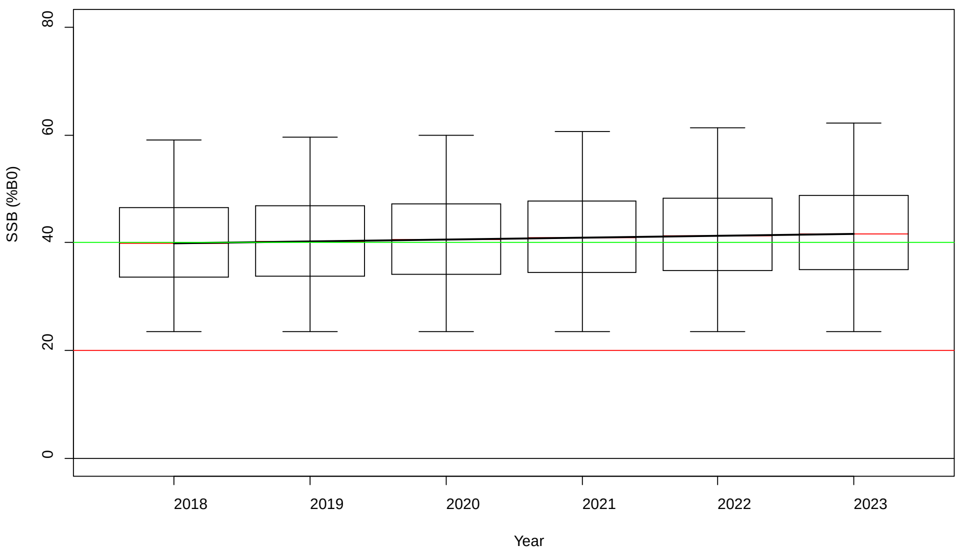


Figure 4: Base, MCMC projections at a constant annual catch of 2300 t. The box in each year covers 50% of the distribution and the whiskers extend to 95% of the distribution. The target biomass (40% B_0) is marked by the horizontal green line and the soft limit (20% B_0) by the horizontal red line.

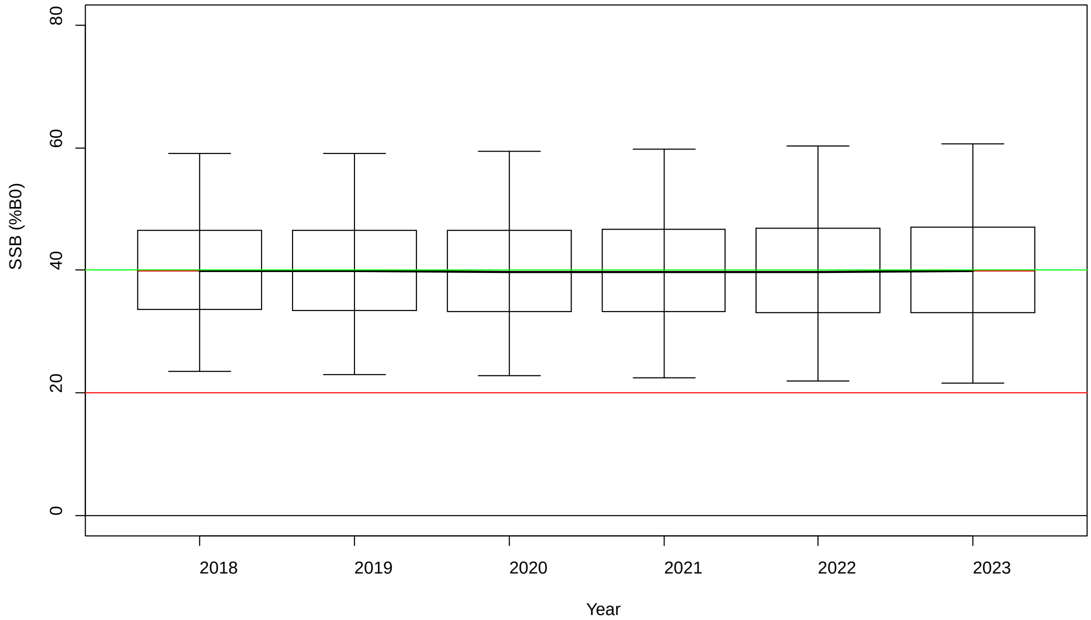


Figure 5: Base, MCMC projections at a constant annual catch of 3000 t. The box in each year covers 50% of the distribution and the whiskers extend to 95% of the distribution. The target biomass (40% B_0) is marked by the horizontal green line and the soft limit (20% B_0) by the horizontal red line.

Table 8: The expected value of stock status in 2023 (E(ss$_{23}$)) and the probabilities of being above the target biomass (40% B_0) or below the soft limit (20% B_0) or below the hard limit (10% B_0) under projected annual catches of 2300 t or 3000 t.

Annual catch (t)	E(ss$_{23}$) (%B_0)	P(ss_{23} > 40%)	P(ss_{23} < 20%)	P(ss_{23} < 10%)
2300	42	0.57	0.01	0.00
3000	40	0.49	0.02	0.00

4.3.4 Other factors

The Working Group considered that there were a number of other factors that should be considered in relation to the stock assessment results presented here. These include:

- uncertainty in the estimates of species composition of catch histories,
- confounding of estimates of M with others parameters in the model, and
- the assumption that acoustic selectivity is the same as the commercial selectivity.

4.3.5 Future research considerations

- Regular acoustic surveys are required to monitor the trend in adult biomass.
- Improved estimates of smooth oreo target strength would reduce the uncertainty in the assessment as would additional age frequency data.
- A continued emphasis on mark identification of large schools during the surveys is important.
- Sensitivities to assumptions about the species composition in deriving catch histories could be insightful.
- It would also be useful to investigate correlations between model parameters.
- A more generic research consideration, possibly to be undertaken by the Stock Assessment Methods Working Group, is to develop guidelines for when M should be estimated in models, and when (and how) it should be independently estimated.

5. STATUS OF THE STOCKS

There is an updated stock assessment in 2018 for the smooth oreo stock in OEO 4.

Stock Structure Assumptions
Black and smooth oreo in OEO 4 are assessed separately but managed as a single stock (although catches are often estimated separately). For black oreos the population has been found to be genetically similar to other oreo stocks and it is likely that some mixing occurs. Smooth oreos in OEO 4 are assumed to be distinct from OEO 1 and 6 stocks but may mix with the 3A stock.

- **OEO 4 (Black Oreos)**

Stock Status	
Year of Most Recent Assessment	2009
Assessment Runs Presented	No quantitative stock assessment model
Reference Points	Target: 40% B_0 Soft Limit: 20% B_0 Hard Limit: 10% B_0 Overfishing threshold: Not defined
Status in relation to Target	Unknown
Status in relation to Limits	Unknown
Status in relation to Overfishing	-

Historical Stock Status Trajectory and Current Status
<No plot available>

Fishery and Stock Trends	
Recent Trend in Biomass or Proxy	CPUE has been stable for the last 5 years, after initial substantial decline during the 1980s and 1990s.
Recent Trend in Fishing Mortality or Proxy	Unknown
Other Abundance Indices	-
Trends in Other Relevant Indicators or Variables	-

Projections and Prognosis	
Stock Projections or Prognosis	Unknown
Probability of Current Catch or TACC causing Biomass to remain below or to decline below Limits	Soft Limit: Unknown Hard Limit: Unknown
Probability of Current Catch or TACC causing Overfishing to continue or to commence	Unknown

Assessment Methodology and Evaluation		
Assessment Type	Level 2 – Partial Quantitative Stock Assessment	
Assessment Method	Age-based model in CASAL	
Period of Assessment	Latest assessment: 2009	Next assessment: Unknown
Overall assessment quality rank	-	
Main data inputs (rank)	- 4 standardised CPUE indices (pre/post GPS and east/west) - Observer length frequencies	- -
Data not used (rank)	N/A	
Changes to Model Structure and Assumptions	None	
Major Sources of Uncertainty	- Assessments unable to represent observer length frequency data.	

	- CPUE could be fitted to a two-stock model but not a homogenous model. - A portion of the abundance estimates were based on data from areas not normally covered by the trawl fishery, and the surveyed area was scaled by a factor of 4.3 – the area surveyed was borderline for providing a reliable abundance estimate.

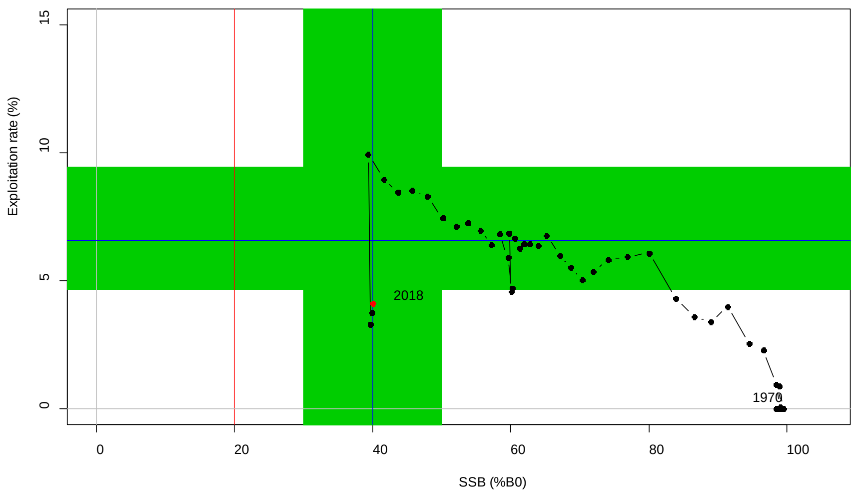
Qualifying Comments
The Working Group agreed that the stock might be split into east and west areas that were independent or at least minimally mixing for future assessments.

Fishery Interactions
Both species of oreo are sometimes taken as bycatch in orange roughy target fisheries and in smaller numbers in hoki target fisheries. Target fisheries for oreos do exist, with main bycatch being orange roughy, rattails and deepwater sharks. Bycatch species recorded include deepwater sharks and rays, seabirds and deepwater corals. Oreo are caught using bottom trawl gear. Bottom trawling interacts with benthic habitats.

- **OEO 4 (Smooth Oreos)**

Stock Status	
Year of Most Recent Assessment	2018
Assessment Runs Presented	Base model fitted to vulnerable acoustic biomass estimates, based on school marks, and age frequencies
Reference Points	Target: 40% B_0 Soft limit: 20% B_0 Hard limit: 10% B_0 Overfishing threshold: $U_{40\%B0}$
Status in relation to Target	B_{2018} was estimated at 40% B_0 for the base model. B_{2018} is About as Likely as Not (40-60%) to be at or above the target.
Status in relation to Limits	B_{2018} is Very Unlikely (< 10%) to be below the Soft limit and Exceptionally Unlikely (< 1%) to be below the Hard Limit.
Status in relation to Overfishing	Overfishing is Unlikely (< 40%) to be occurring.

Historical Stock Status and Exploitation Rate Trajectory



Historical trajectory of spawning biomass (%B_0) and exploitation rate (%) (base model, medians of the marginal posteriors). A reference range of 30-50% B_0 and the corresponding exploitation rate range are coloured in green. The soft limit (20% B_0) is marked by a red line and the target biomass (40% B_0) and corresponding exploitation rate are marked by blue lines.

Fishery and Stock Trends	
Recent Trend in Biomass or Proxy	There has been little change in estimated biomass in the last 4 years.
Recent Trend in Fishing Intensity or Proxy	Following the large reduction in TACC and catch in 2015–16, estimated exploitation rates declined.
Other Abundance Indices	-
Trends in Other Relevant Indicators or Variables	Below average cohort strength was estimated from 1990 to 2005.

Projections and Prognosis	
Stock Projections or Prognosis	Little change in projected biomass over the next five years at annual catches of 2300–3000 t
Probability of Current Catch or TACC causing Biomass to remain below or to decline below Limits	Soft Limit: Very Unlikely (< 10%) Hard Limit: Exceptionally Unlikely (< 1%)
Probability of Current Catch or TACC causing Overfishing to continue or to commence	Unlikely (< 40%) for the current catch or TACC

Assessment Methodology and Evaluation		
Assessment Type	Type 1 – Full Quantitative Stock Assessment	
Assessment Method	Age-structured CASAL model with Bayesian estimation of posterior distributions	
Assessment Dates	Latest assessment : 2018	Next assessment: 2022
Overall assessment quality rank	1 – High Quality	
Main data inputs (rank)	- Six acoustic biomass indices (1998, 2001, 2005, 2009, 2012, 2016)	1 – High Quality
	- Age frequencies from acoustic surveys (1998, 2005, 2016)	1 – High Quality
	- Trawl survey age frequency (1991)	1 – High Quality
	- Commercial age frequency (2009)	1 – High Quality
	- Observer length data (used in a sensitivity)	1 – High Quality
Data not used (rank)	- Commercial CPUE	3 – Low Quality: substantial changes in fishing patterns over time
Changes to Model Structure and Assumptions	- Added age data (trawl survey and commercial) and estimated M in the model	
Major Sources of Uncertainty	- Uncertainties in the prior for the survey catchability (q) o estimated target strength o scaling factor from the trawl survey area to acoustic area o scaling factor from acoustic area to the QMA area o proportion of vulnerable biomass in the surveyed marks o acoustic mark identification - Single commercial age frequency - Confounding of estimates of M with other parameters in the model - Assumption that acoustic selectivity is the same as the commercial selectivity	

Qualifying Comments
-

Fishery Interactions
Both species of oreo are sometimes taken as bycatch in orange roughy target fisheries and in smaller numbers in hoki target fisheries. Target fisheries for oreos do exist, with main bycatch being orange roughy, rattails and deepwater sharks. Low productivity species taken in oreo fisheries include orange roughy, rattails, and deepwater sharks and rays. Incidental captures have also been recorded for seabirds and deepwater corals. Oreo are caught using bottom trawl gear. Bottom trawling interacts with benthic habitats.

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OREOS - OEO 1 AND OEO 6 BLACK OREO AND SMOOTH OREO

1. FISHERY SUMMARY

This is presented in the Fishery Summary section at the beginning of the Oreos report.

2. BIOLOGY

This is presented in the Biology section at the beginning of the Oreos report.

3. STOCKS AND AREAS

This is presented in the Stocks and Areas section at the beginning of the Oreos report.

4. STOCK ASSESSMENT

4.1 Introduction

New assessments for Pukaki Rise black oreo and Pukaki Rise smooth oreo were attempted in 2013 but were rejected by the Working Group and are only briefly discussed here. The previously reported assessments for Southland (OEO 1/OEO 3A) and Bounty Plateau smooth oreo (only MPD results) are repeated.

4.2 Southland smooth oreo fishery

This assessment was updated in 2007 and applies only to the study area as defined in Figure 1 and does not include areas to the north (Waitaki) and east (Eastern canyon) of the main fishing grounds.

This fishery is mostly in OEO 1 on the east coast of the South Island but catches at the northern end of the fishery straddle and cross the boundary line between OEO 1 and OEO 3A at 46ºS. This is an old fishery with catch and effort data available from 1977–78. Smooth oreo catch from Southland was about 480 t (mean of 2003–04 to 2005–06). There is an industry catch limit of 400 t smooth oreo implemented after the previous (2003) assessment. There were no fishery-independent abundance estimates, so relative abundance estimates from pre- and post-GPS standardised CPUE analyses and length frequency data collected by Ministry (SOP) and industry (ORMC) observers were used.

The following assumptions were made in this analysis.

1. The CPUE analysis indexed the abundance of smooth oreo in the study area of OEO 1/3A.
2. The length frequency samples were representative of the population being fished.
3. The ranges used for the biological values covered their true values.
4. Recruitment was deterministic and followed a Beverton-Holt relationship with steepness of 0.75.
5. The population of smooth oreo in the study area was a discrete stock or production unit.
6. Catch overruns were 0% during the period of reported catch.
7. The catch histories were accurate.
8. The maximum fishing pressure (U_{MAX}) was 0.58.

An age-structured CASAL model employing Bayesian statistical techniques was developed. A two-fishery model was employed with a split into deep and shallow fisheries because of a strong relationship found between smaller fish in shallow water and large fish in deeper water. The boundary between deep and shallow was 975 m. The 2007 analysis used five extra years of catch and observer length frequency data compared to the 2003 assessment. The model was partitioned by the sex and maturity status of the fish and used population parameters previously estimated from fish sampled on the Chatham Rise and Puysegur Bank fisheries. The maturity ogive used was estimated from Chatham Rise research samples.

4.2.1 Estimates of fishery parameters and abundance

Catch history

A catch history (Table 1) was derived using declared catches of OEO from OEO 1 (see table 2 in the Fishery Summary section at the beginning of the Oreos report) and tow-by-tow records of catch from the study area (Figure 1). The tow-by-tow data were used to estimate the species ratio (SSO/BOE) and therefore the SSO taken. It was assumed that the reported landings provided the best information on total catch quantity and that the tow-by-tow data provided the best information on the species and area breakdown of catch.

Table 1: Catch history of smooth oreo from Southland rounded to the nearest 10 t.

Fishing year	Shallow	Deep	Fishing year	Shallow	Deep
1977–78	210	0	1992–93	410	250
1978–79	10	0	1993–94	220	150
1979–80	40	0	1994–95	80	150
1980–81	0	0	1995–96	600	500
1981–82	0	0	1996–97	440	70
1982–83	0	0	1997–98	320	230
1983–84	480	660	1998–99	480	620
1984–85	170	510	1999–00	650	480
1985–86	480	3 760	2000–01	400	610
1986–87	30	160	2001–02	580	1 470
1987–88	130	860	2002–03	130	1 320
1988–89	0	240	2003–04	330	420
1989–90	210	430	2004–05	140	290
1990–91	410	420	2005–06	120	140
1991–92	530	380			

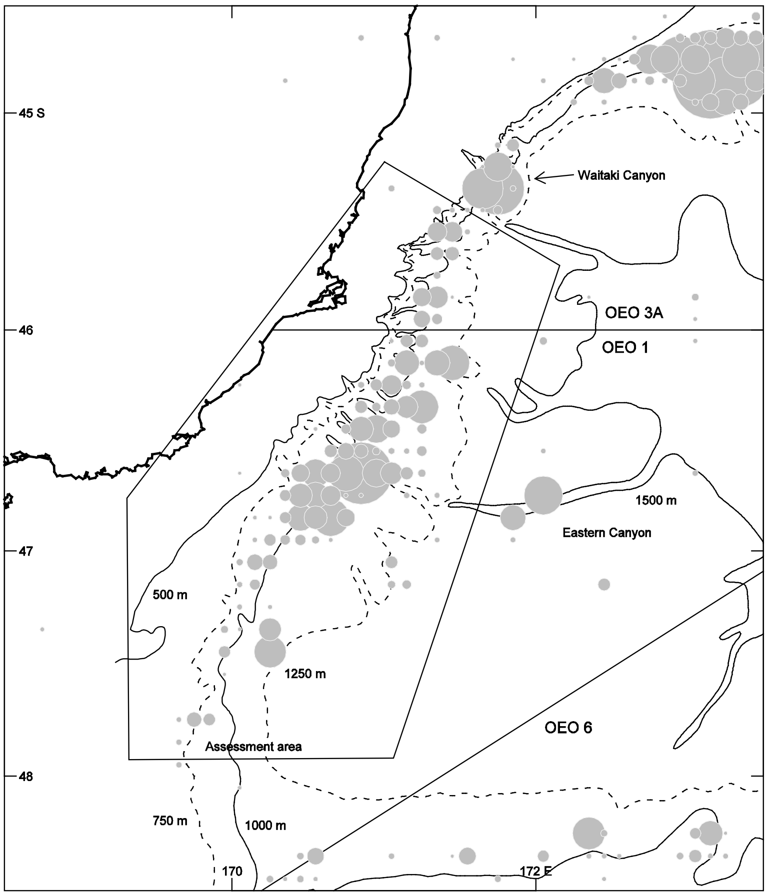


Figure 1: Smooth oreo estimated catch from all years up to (and including) 2005–06. The area was divided into cells that are 0.1 degrees square and catches were summed for each cell. Circles proportional in area to the catch are plotted centred on the cells. Catches less than 10 tonnes per cell are not shown. Circles are layered so that smaller circles are never hidden by larger ones. The assessment area and bottom topography are also shown.

Length data

All SOP records where smooth oreo were measured from within the assessment area are shown in Table 2: 78 samples were shallow and 51 deep. Only 13 shallow and 4 deep samples were collected before 1999–2000 (Table 2). Composite length frequency distributions were calculated for each year. Each sample was weighted by the catch weight of the tow from which the sample was taken. This was modified slightly by estimating the number of fish that would be in a unit weight of catch and multiplying by that.

Table 2: Summary of length frequency data for smooth oreo available for the study area. Year group, year applied, and the total number of length frequency samples for the shallow and deep year groups.

Year group	Year applied	No. of lfs
Shallow		
a=1993–94 to 1997–98	1995–96	13
b=1999–2000	1999–00	30
c=2000–01 to 2001–02	2001–02	22
d=2002–03 to 2005–06	2004–05	13
Deep		
e=1997–98 to 2001–02	2001–02	27
f=2002–03 to 2004–05	2003–04	21

Relative abundance estimates from CPUE analyses

The standardised CPUE analyses used a two part model which separately analysed the tows which caught smooth oreo using a log-linear regression (referred to as the positive catch regression) and a binomial part which used a Generalised Linear Model with a logit link for the proportion of successful tows (referred to as the zero catch regression). The binomial part used all the tows, but considered only whether or not the species was caught and not the amount caught. The yearly indices from the two parts of the analysis (positive catch index and zero catch index) were multiplied together to give a combined index. The pre-GPS data covering the years from 1983–84 to 1987–88, has been left unmodified since 2003, and was used as an index of the deep fishery as most fishing in that period was deep (Table 3). The post-GPS data covered 1992–93 to 2005–06 split into shallow and deep fisheries but the indices for the last two years (2004–05, 2005–06) were dropped because catch was constrained by the industry catch limit of 400 t for smooth oreo introduced after the 2003 assessment (Table 4).

Table 3: Smooth oreo pre-GPS combined index estimates by year, and jackknife CV estimates from analysis of all tows in the study area that targeted smooth oreo, black oreo, or unspecified oreo.

Year	Combined index	Jackknife CV (%)
1983–84	1.75	22
1984–85	1.65	29
1985–86	1.19	33
1986–87	0.48	23
1987–88	0.61	27

Table 4: Smooth oreo post-GPS combined index estimates by year, and jackknife CV estimates from analysis of all tows in the study area that targeted smooth oreo, black oreo, or unspecified oreo.

	Shallow		Deep	
Fishing year	Index (kg/tow)	Bootstrap CV (%)	Index (kg/tow)	Bootstrap CV (%)
1992–93	1 489	57	1 401	73
1993–94	956	47	916	53
1994–95	1 521	72	428	121
1995–96	1 173	37	1 862	84
1996–97	511	84	2 117	41
1997–98	1 477	39	502	59
1998–99	939	42	915	50
1999–00	842	44	611	48
2000–01	758	46	385	72
2001–02	573	44	658	53
2002–03	303	48	406	76
2003–04	480	57	719	218

4.2.2 Biomass estimates

Biomass estimates were made based on a Markov chain Monte Carlo analysis which produced a total of about 1.4 million iterations. The first 100 000 iterations were discarded and every 1000^{th} point was retained, giving a final converged chain of about 1300 points.

Biomass estimates for the base case are given in Table 5 and Figure 2. These biomass estimates are uncertain because of the reliance on commercial CPUE data for abundance indices.

Table 5: Biomass estimates (t) for the base case.

		5%	Median	Mean	95%	CV (%)
Free parameters						
Virgin mature biomass (B_0)		15 600	17 400	17 900	21 700	12
Selectivity, shallow	a1	17.2	19.0	19.0	21.0	6
	sL	3.9	4.8	4.8	5.8	12
	sR	5.9	8.3	8.4	11.2	20
Selectivity, deep	a50	22.1	26.0	26.2	30.8	10
	to95	1.9	7.1	7.0	11.0	37
Derived quantities						
Current mature biomass (% initial)		19	27	28	41	25
Current selected shallow biomass (% initial)		56	65	65	73	8
Current selected deep biomass (% initial)		12	20	22	36	36

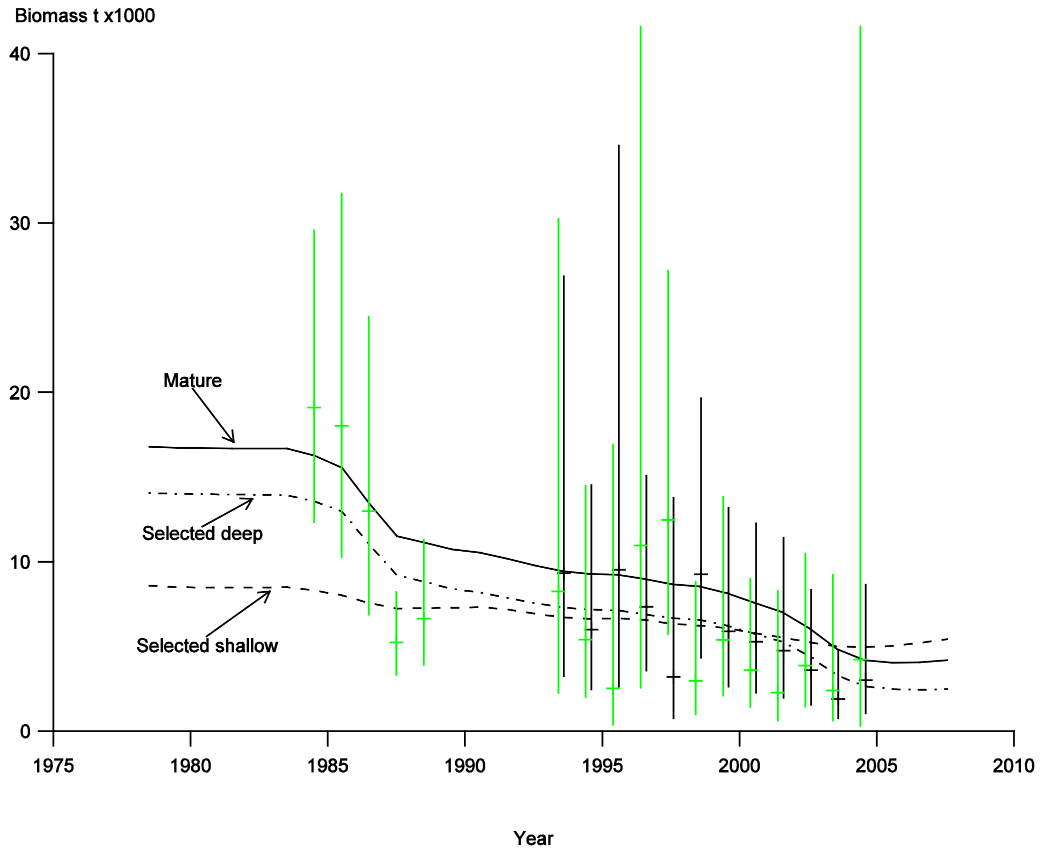


Figure 2: Estimated biomass trajectories from the 2007 base case assessment — mature biomass and selected biomass for the shallow and deep fisheries. Also shown are the CPUE indices from the pre- and post-GPS analysis for the deep fishery (in gray) and the post-GPS analyses for the shallow fishery (in black). CPUE indices are shown with ±2 s.e. confidence interval indicated by the vertical lines (the post-GPS CPUE data are slightly offset to avoid over plotting). The CPUE data were scaled by catchability coefficients to match the biomass scale.

4.3 Pukaki Rise smooth oreo fishery (part of OEO 6)

A second assessment for this fishery was attempted in 2013, applying only to the assessment area as defined in Figure 3. The first assessment for this fishery was in 2006–07 (Coburn et al 2007;

McKenzie 2007). This is the main smooth oreo fishery in OEO 6 with an annual catch in 2011–12 of 290 t, taken mainly by New Zealand vessels, down substantially from previous years (Table 6). There was also a small early Soviet fishery (1980–81 to 1985–86) with mean annual catches of less than 100 t. There were no fishery-independent abundance estimates, so relative abundance estimates from a post-GPS standardised CPUE analysis and length frequency data collected by Ministry and industry observers were considered. Biological parameter values estimated for Chatham Rise and Puysegur Bank smooth oreo were used in the assessment because there are no research data from Pukaki Rise. However, the CPUE analysis was not accepted as an index of abundance for smooth oreo in the Pukaki Rise (OEO 6) assessment area, principally due to the complex temporal and spatial patterns of this fishery and associated fisheries, and the small number of vessels. As a result, the assessment was not accepted by the Working Group, and only catch history, length frequencies and unstandardised catch and effort data are reported here.

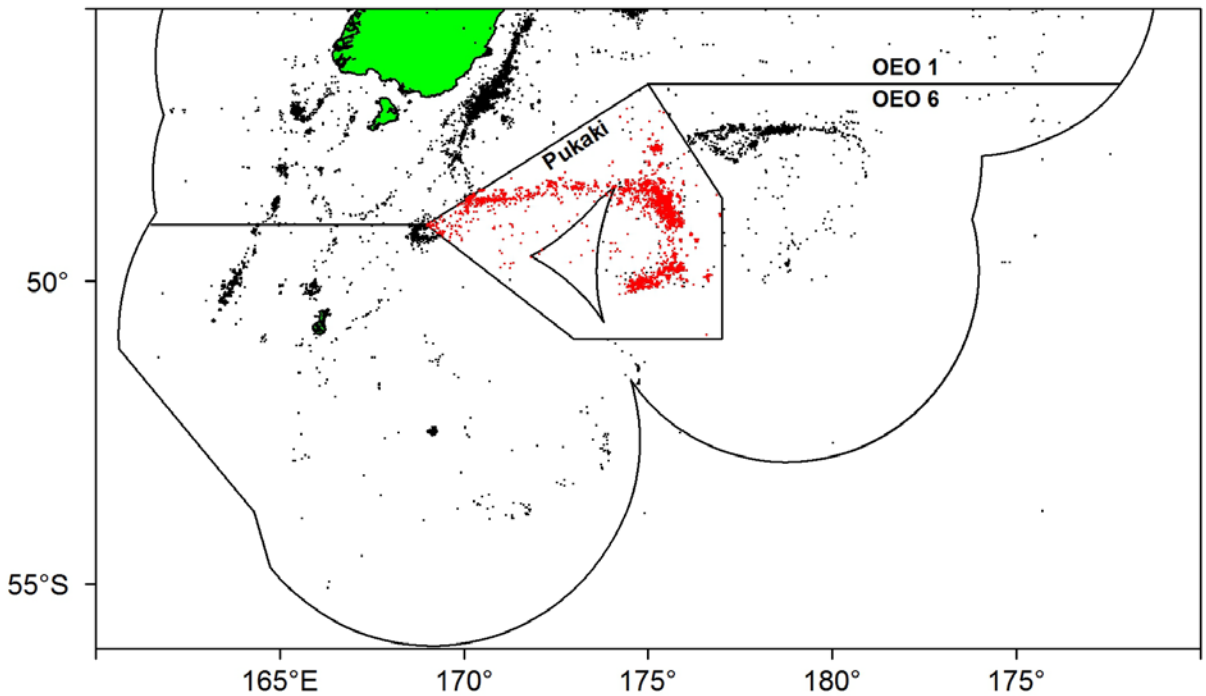


Figure 3: The Pukaki Rise fishery assessment area (polygon) abutting the north boundary of OEO 6. The dots show all tows where the target species or catch was OEO, SSO, BOE or ORH, with the red dots being those within the Pukaki assessment area.

4.3.1 Estimates of fishery parameters and abundance

Catch history

A catch history was derived using declared catches of OEO from OEO 6 (table 2 in the "Fishery Summary" section of the Oreos report) and tow-by-tow records of catch from the assessment area (Figure 3). The tow-by-tow data were used to estimate the species ratio (SSO/BOE) and therefore the amount of SSO taken. It was assumed that the reported landings provided the best information on total catch quantity and that the tow-by-tow data provided the best information on the species and area breakdown of catch. There may be unreported catch from before records started, although this is thought to be small. Before the 1983–84 fishing year the species catch data were combined over years to get an average figure that was then applied in each of those early years. For the years from 1983–84 onwards, each year's calculation was made independently. The catch history used in the population model is given in Table 6.

Length data

Smooth oreo length frequency data collected by observers are available for the years 1997–98 to 2011–12 (Table 7). An in-depth analysis of these data in the previous assessment (covering fishing years 1998–2005) indicated that they were reasonably representative of the fishery in terms of spatial, depth and temporal coverage in those years that had adequate data (Coburn et al 2007). The depths fished by the sampled fleet varied between years so the length data were stratified by depth resulting in shallow (less than 900 m), middle (900–990 m) and deep strata (greater than 990 m). The data from adjacent years were also grouped because some years had few samples. The resulting length frequencies are shown in Figure 4. There is a trend towards a flatter distribution over the last three grouped distributions (2000–01, 02, and 03–05).

Table 6: Catch history of smooth oreo from the Pukaki Rise fishery assessment area. Catches are rounded to the nearest 10 t.

Year	Catch	Year	Catch	Year	Catch	Year	Catch
1980–81	30	1988–89	0	1996–97	1 650	2004–05	1 370
1981–82	20	1989–90	0	1997–98	1 340	2005–06	1 470
1982–83	0	1990–91	10	1998–99	1 370	2006–07	1 790
1983–84	640	1991–92	0	1999–00	2 270	2007–08	1 260
1984–85	340	1992–93	70	2000–01	2 580	2008–09	1 200
1985–86	10	1993–94	0	2001–02	2 020	2009–10	770
1986–87	0	1994–95	130	2002–03	1 340	2010–11	820
1987–88	180	1995–96	1 360	2003–04	1 660	2011–12	290
						2012–13	136

Table 7: Summary of length frequency data for smooth oreo available for the assessment area. The table shows the number of tows sampled by year, the sample source, and the year group. -, no data.

	Year group	Number of tows sampled		
Year		**ORMC**	**SOP**	**All**
1997–98	98–99	-	15	15
1998–99	98–99	64	9	73
1999–00	00–01	5	36	41
2000–01	00–01	37	17	54
2001–02	01–02	42	22	64
2002–03	03–04	4	12	16
2003–04	03–04	-	19	19
2004–05	05–06	-	30	30
2005–06	05–06	-	20	20
2006–07	06–07	-	205	205
2007–08	07–08	-	124	124
2008–09	08–09	-	66	66
2009–10	09–10	-	46	46
2010–11	10–11	-	107	107
2011–12	10–11	-	21	21
Totals		152	149	301

Catch and effort data

Core vessels for the fishery were defined in order to develop a standardised CPUE series, but the standardised series was rejected by the Working group. Unstandardised catch and effort data are presented in Table 8.

Table 8: Catch and effort data for vessels with three or more consecutive years with at least 10 records from 1995–96 to 2011–12.

	No. of tows	No. of vessels	Estimated catch (t)	Mean t/tow	Zero catch tows (%)	SSO target (%)
1996	193	2	810	4.20	-	6
1997	322	3	1 270	3.90	4	4
1998	264	4	1 020	3.90	6	9
1999	262	4	1 050	4	1	15
2000	528	5	2 030	3.90	32	37
2001	588	7	2 280	3.90	49	52
2002	409	5	1 920	4.70	9	9
2003	498	5	1 230	2.50	14	18
2004	512	4	1 300	2.50	9	13
2005	588	6	1 170	2	21	27
2006	656	5	1 260	1.90	13	14
2007	806	5	1 550	1.90	23	25
2008	933	2	1 110	1.20	13	16
2009	918	3	1 200	1.30	21	23
2010	948	3	740	0.80	8	11
2011	593	3	720	1.20	22	25
2012	397	2	260	0.70	10	12

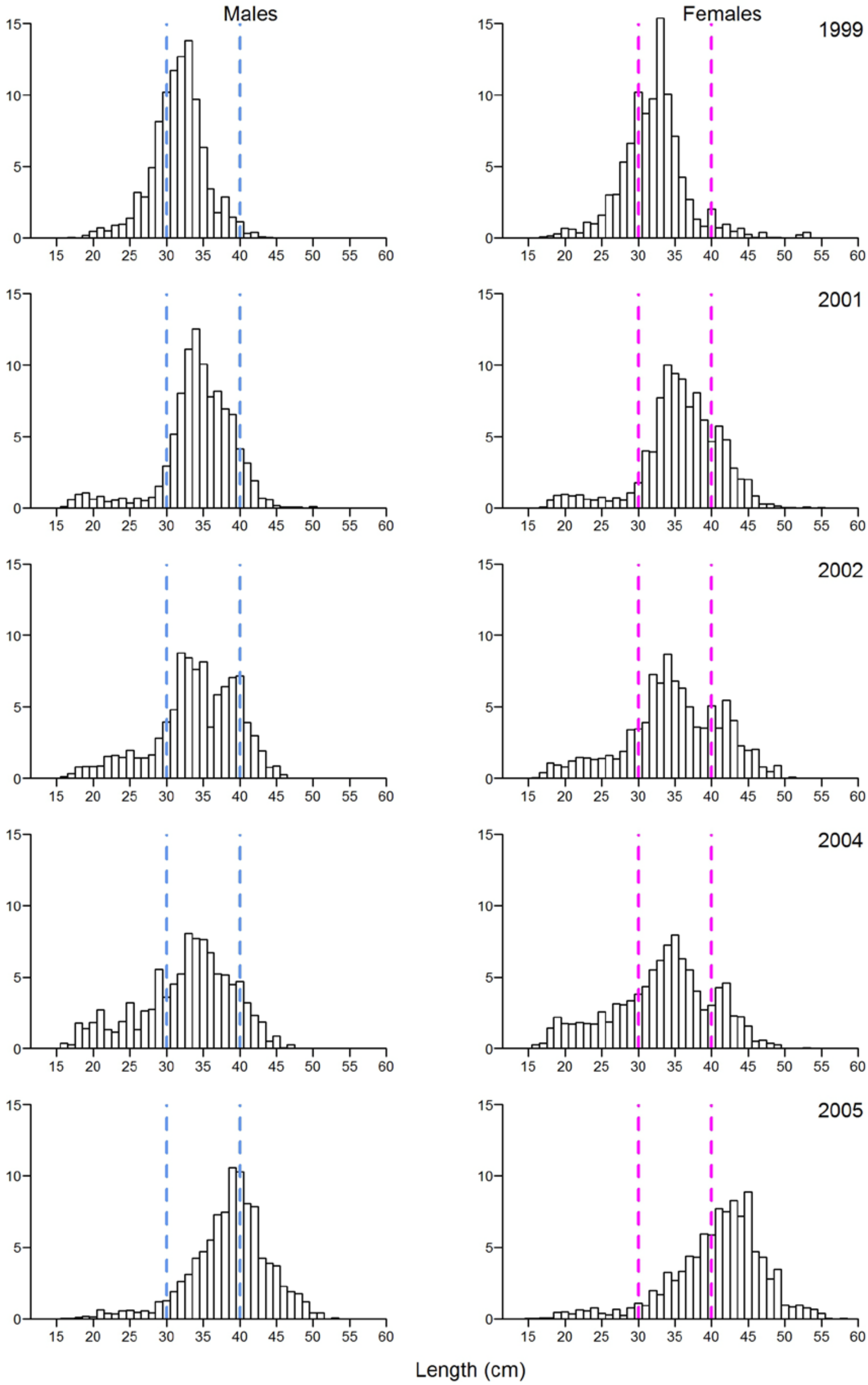


Figure 4: Length frequencies for Pukaki Rise smooth oreo, stratified by depth (see text), and grouped by years. [Continued on next page].

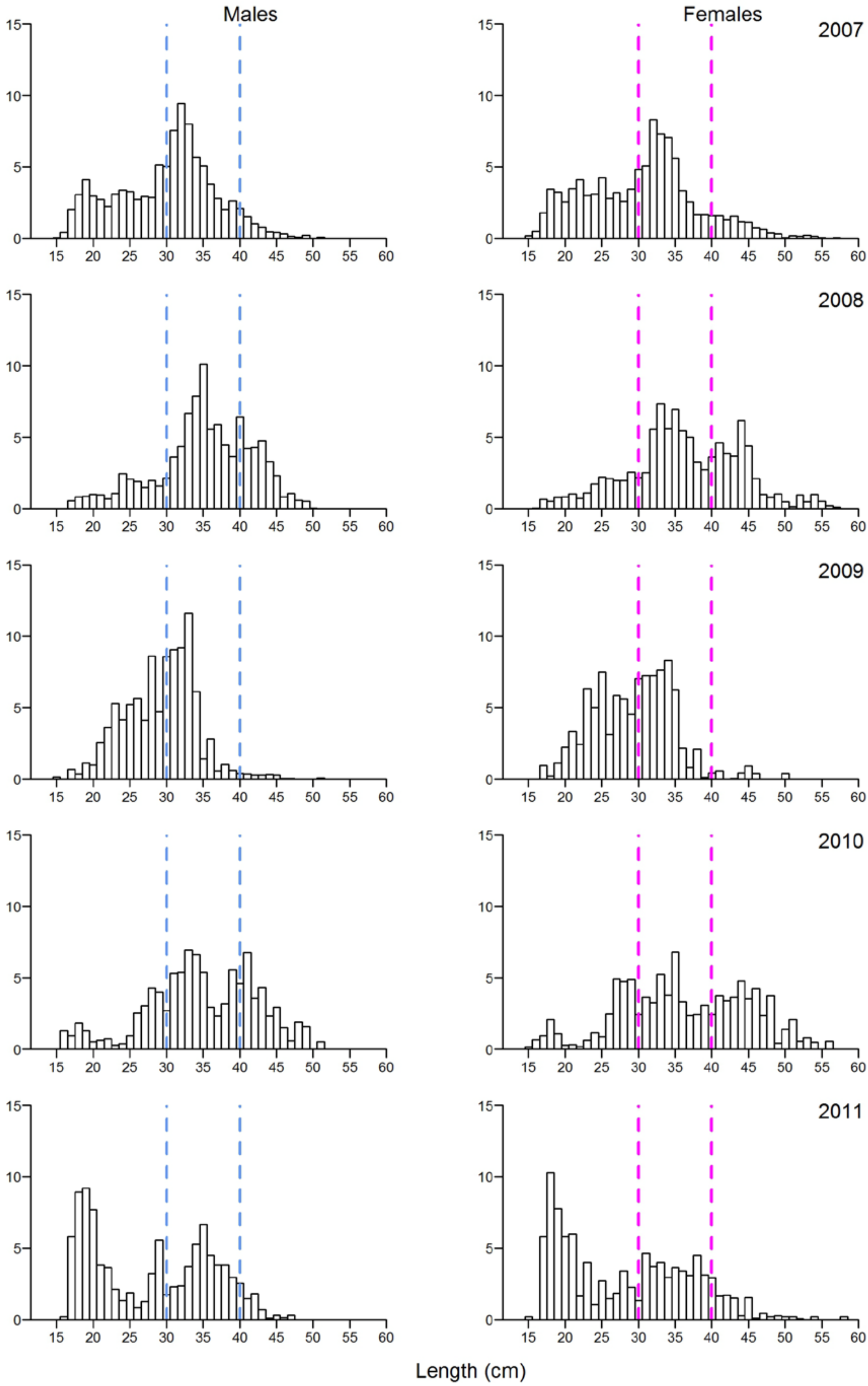


Figure 4 [Continued].

4.4 Bounty Plateau smooth oreo fishery (part of OEO 6)

The first assessment for this fishery was developed in 2008 and applies only to the study area as defined in Figure 5. There were no fishery-independent abundance estimates, so relative abundance estimates from a post-GPS standardised CPUE analysis and length frequency data collected by Ministry (SOP) and industry (ORMC) observers were considered. Biological parameter values estimated for Chatham Rise and Puysegur Bank smooth oreo were used in the assessment because there are no research data from Bounty Plateau.

The following assumptions were made in this analysis.

1. The CPUE analysis indexed the abundance of smooth oreo in the Bounty Plateau (OEO 6) assessment area.
2. The length frequency samples were representative of the population being fished.
3. The biological parameters values used (from other assessment areas) are close to the true values.
4. Recruitment was deterministic and followed a Beverton & Holt relationship with steepness of 0.75.
5. The population of smooth oreo in the assessment area was a discrete stock or production unit.
6. Catch overruns were 0% during the period of reported catch.
7. The catch histories were accurate.
8. The maximum exploitation rate (E_{MAX}) was 0.58.

Data inputs included catch history, relative abundance estimates from a standardised CPUE analysis, and length data from SOP and ORMC observers. The observational data were incorporated into an age-based Bayesian stock assessment (CASAL) with deterministic recruitment to estimate stock size. The stock was considered to reside in a single area, with a partition by sex. Age groups were 1–70 years, with a plus group of 70+ years.

The length-weight and length-at-age population parameters are from fish sampled on the Chatham Rise and Puysegur Bank fisheries (table 1 of the "Biology" section of the Oreos report). The natural mortality estimate is based on fish sampled from the Puysegur Bank fishery. The maturity ogive is from fish sampled on the Chatham Rise, and the age at which 50% are mature is between 18 and 19 years for males and between 25 and 26 years for females.

4.4.1 Estimates of fishery parameters and abundance

Catch history

Table 9: Catch history (t) of smooth oreo from the Bounty Plateau fishery assessment area. Catches are rounded to the nearest 10 t.

Year	Catch	Year	Catch
1983–84	620	1996–97	610
1984–85	0	1997–98	650
1985–86	0	1998–99	1 200
1986–87	0	1999–00	870
1987–88	10	2000–01	550
1988–89	0	2001–02	980
1989–90	0	2002–03	1 530
1990–91	20	2003–04	1 420
1991–92	0	2004–05	2 190
1992–93	110	2005–06	1 790
1993–94	490	2006–07	670
1994–95	1 450	2007–08	670
1995–96	900		

A catch history was derived using declared catches of oreo from OEO 6 (table 2 in the "Fishery Summary" section of the Oreos report) and tow-by-tow records of catch from the assessment area (Figure 5). The tow-by-tow data were used to estimate the species ratio (SSO/BOE) and therefore the SSO taken. The catch history used in the population model is given in Table 9.

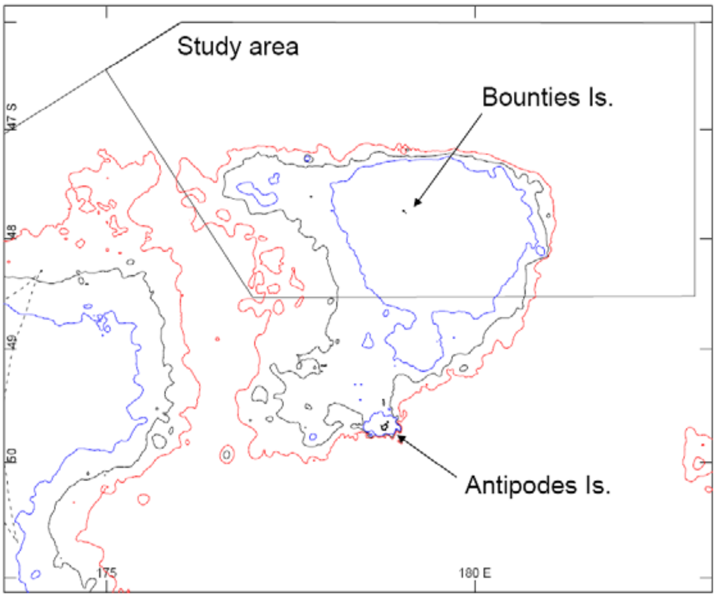


Figure 5: The Bounty Plateau fishery assessment study area.

Length data

Smooth oreo length frequency data collected by SOP and ORMC observers are available from 1991–92. An in-depth analysis indicated that these data were reasonably representative of the fishery in terms of spatial, depth and temporal coverage in those years that had adequate data. Length frequencies were based on tows from the core area (a subset of the study area where about 80% of the catch is taken). The data from adjacent years were grouped because some years had few samples (Table 10). The resulting length frequencies are shown in Figure 6. In the final model runs the 1994–95 year of the length frequency series was omitted as it contained very few samples.

Table 10: Core length analysis year group, year applied and the number of length frequency samples. Smooth oreo sample catch weight, fishery catch and sample catch as percentage of the fishery.

Year group	Year applied	No. of lfs	Catch sampled (t)	Fishery catch (t)	% fishery
1991–92 to 1995–96	1994–95	7	88	1 505	6
1998–99 to 1999–2000	1998–99	30	246	1 121	22
2000–2001 to 2002–03	2001–02	25	398	2 261	18
2003–04 to 2004–05	2004–05	29	261	2 280	11
2005–06	2005–06	32	379	1 121	34
2006–07 to 2007–08	2006–07	17	168	494	34

Relative abundance estimates from CPUE analyses

The small early Soviet fishery had too few data for a standardised CPUE analysis. The standardised CPUE analysis was, therefore, from the New Zealand vessel fishery and only included data from those vessels that had fished at least three years. Just a single vessel puts in significant continuous effort from 1995–2007, with the rest of the vessels' effort confined to mainly either 1995–2000 (early) or 2001–2007 (late). Because of this, in addition to the single standardised CPUE covering the entire time period, two separate standardised CPUE indices were calculated covering the early and late periods. The final indices are shown in Tables 11 and 12.

4.4.2 Biomass estimates

In all preliminary model runs the length-frequency data series were not well fitted, and gave a strong but contrasting biomass signal relative to the CPUE indices. Therefore, for final model runs, the length frequency data was down-weighted by using just the 1999 length frequency.

The base case model used early and late period CPUE indices, and the 1999 length frequency data. Current mature biomass was estimated to be 33% of a virgin biomass of 17 400 t (Figure 7).

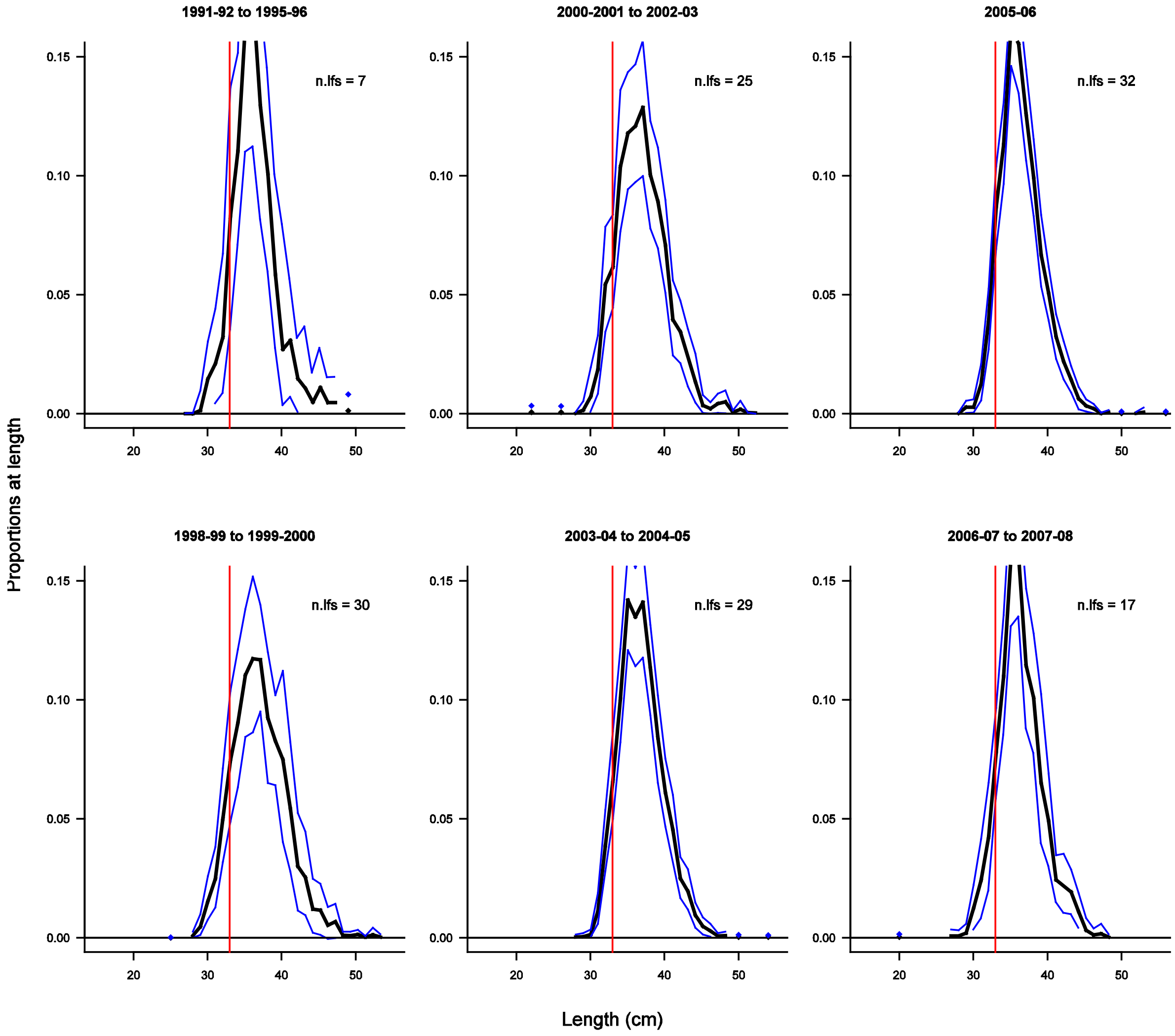


Figure 6: Length frequency distribution plots for core data only (thick lines) with 95% confidence interval (thin lines).

Table 11: Early and late period CPUE combined index estimates by year, and bootstrap CV estimates.

Year Early	Kg/tow	CV	Late period	Kg/tow	CV
1995–96	3 551	0.423	2000–01	850	0.487
1996–97	3 322	0.496	2001–02	2 976	0.274
1997–98	2 306	0.980	2002–03	1 489	0.243
1998–99	781	0.391	2003–04	1 727	0.260
1999–2000	1 536	0.306	2004–05	1 604	0.227
			2005–06	1 386	0.310
			2006–07	966	0.232

Table 12: Single period CPUE combined index estimates by year, and bootstrap CV estimates.

Year	Kg/tow	CV
1995–96	7 472	0.286
1996–97	4 453	0.735
1997–98	3 366	1.264
1998–99	1 444	0.406
1999–2000	2 835	0.286
2000–01	2 817	0.436
2001–02	632	0.680
2002–03	1 973	0.663
2003–04	1 296	0.615
2004–05	1 284	0.445
2005–06	1 289	0.563
2006–07	1 056	1.200

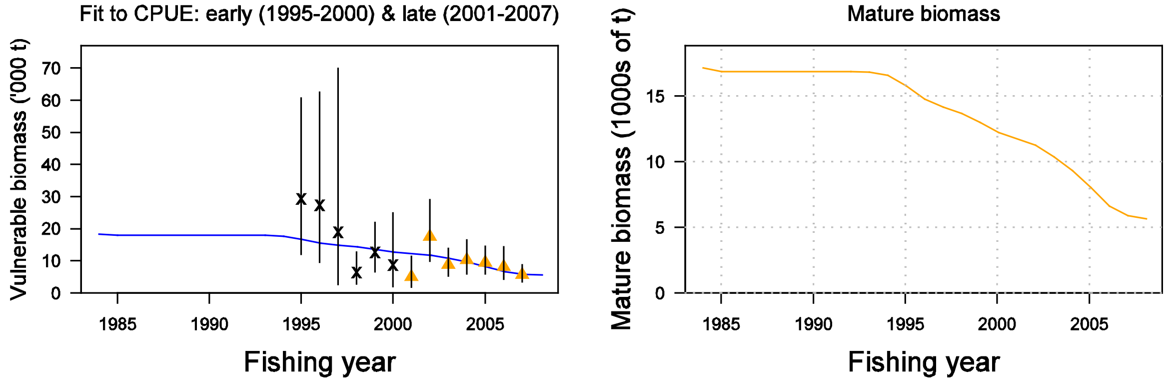


Figure 7: Model run showing the MPD fit to the CPUE data (vertical lines are the 95% confidence intervals for the indices) and the trajectory of mature biomass.

Two sensitivity model runs were carried out with the 1999 length frequency data dropped from the model, but retaining the fishery selectivity estimated using the length data. The first model run used the early and late period CPUE indices and current biomass was estimated to be 39% of a virgin biomass of 19 300 t. The second model run used the single CPUE series covering the same period and current biomass was estimated to be 17% of a virgin biomass of 13 900 t. No MCMC runs were carried out with the base case model as the sensitivity runs showed that the assessment was quite different if the CPUE analysis was not split into two series.

Biomass estimates are uncertain because of the reliance on commercial CPUE data, the use of biological parameter estimates from other oreo stocks, and because of contrasting biomass signals from using either a single or split CPUE indices.

4.4.3 Projections

No projections were made because of the uncertainty in the assessment.

4.5 Pukaki Rise black oreo stock (part of OEO 6)

A second assessment for this fishery was attempted in 2013, applying only to the assessment area as defined in Figure 8. The first assessment for this fishery was in 2009 (Doonan et al 2010). This is currently the largest black oreo fishery in the New Zealand EEZ with both current (2011–12) and mean (1994–95 to 2011–12) annual catches of 1900 t, but with annual catches of 2800–3400 t between 2005–06 and 2009–10. There was an early Soviet and Korean fishery (1980–81 to 1984–85) with mean annual catches of about 1700 t. Fishery-independent abundance estimates were not available, so a series of relative abundance indices, based on an analysis of post-GPS standardised CPUE, was developed. Length frequency data collected by Ministry (SOP) and industry (ORMC) observers were included in the model. The assessment used biological parameter values estimated for Chatham Rise and Puysegur Bank black oreo because no biological data from Pukaki Rise are available. As stated above, the Pukaki Rise smooth oreo CPUE was thought to be unreliable until further investigations have been conducted. Since the black oreo fishery is in the same area, the Working Group determined that the black oreo CPUE analysis also could not be accepted as an index of abundance of black oreo in the Pukaki Rise (OEO 6) assessment area, and as a result the assessment was rejected. Therefore, only catch history, length frequencies and unstandardised catch and effort data are reported here.

4.5.1 Estimates of fishery parameters and abundance

Catch history

A catch history for black oreo was derived (Table 13) using declared catches of OEO from OEO 6 (table 2 in the "Fishery summary" section of the Oreos report) and tow-by-tow records of catch from the assessment area (Figure 8). The catch history used in the assessment is given in Table 13.

Table 13: Catch history (t) of black oreo from the Pukaki Rise fishery assessment area.

Year	Catch	Year	Catch	Year	Catch
1978–79	17	1990–91	15	2002–03	1 701
1979–80	5	1991–92	27	2003–04	1 530
1980–81	283	1992–93	27	2004–05	1 588
1981–82	4 180	1993–94	10	2005–06	2 811
1982–83	1 084	1994–95	242	2006–07	3 434
1983–84	1 150	1995–96	1 352	2007–08	3 346
1984–85	1 704	1996–97	2 413	2008–09	2 818
1985–86	46	1997–98	2 244	2009–10	3 093
1986–87	0	1998–99	1 181	2010–11	1 641
1987–88	0	1999–00	1 061	2011–12	1 671
1988–89	0	2000–01	1 158		
1989–90	0	2001–02	988		

Length data

Black oreo length frequency data collected by SOP and ORMC observers are available from 1996–97 to 2011–12 (Table 14). An analysis indicated that there was a trend in fish size across years (with smaller mean lengths in more recent years) and with depth (deeper fish being larger). The length data were considered to be representative of the fishery in terms of the spatial, depth, and temporal coverage for those years that had adequate data. The length data were stratified into two depth bins: shallow (less than 900 m), and deep (greater than 900 m). Length data from adjacent years were grouped because of the low number of samples in some years (Figure 9). There is no trend in mean length over the first six year-groups, but fish sizes appear to be generally smaller in the later year-groups, with the mode of the distributions shifting to the left between 2005–06 and 2007–08.

Table 14: Summary of length frequency data for black oreo available from the assessment area. The table shows the number of tows sampled by year, the sample source, and the year group.

		Number of tows sampled		
Year	Year group	SOP	ORMC	All
1996–97	97–98	7	0	7
1997–98	97–98	25	0	25
1998–99	99–00	7	44	51
1999–00	99–00	6	0	6
2000–01	01–02	8	18	26
2001–02	01–02	2	8	10
2002–03	03–05	7	2	9
2003–04	03–05	18	0	18
2004–05	03–05	21	0	21
2005–06	06	21	42	63
2006–07	07	154	11	165
2007–08	08	31	9	40
2008–09	08	61	9	70
2009–10	09	46	0	46
2010–11	10	57	0	57
2011–12	11–12	13	0	13
Total		477	134	611

Catch and effort data

The fishery taking Pukaki Rise black oreo divides into two distinct periods: a pre-GPS period 1980–81 to 1984–85 when much of the catch was taken by Soviet and Korean vessels, and a post-GPS period, 1995–96 to 2011–12 when most of the catch was taken by New Zealand vessels. The intervening period was characterised by low catches and the introduction of GPS technology in the fleet. Standardisation of CPUE for the pre-GPS period was attempted but rejected due to poor linkage of vessels across years and the shifting of fishing effort between areas. For the post-GPS period, the Working Group rejected CPUE as an index of abundance because of the variability in recorded target species over time and space in the overlapping Pukaki fisheries for black oreo, smooth oreo, and orange roughy. The Working Group believed that recording of target species in these fisheries was likely to have been inconsistent between vessels and skippers over time and that the practice of separately examining these fisheries according to recorded target species was inappropriate. Unstandardised catch and effort data for defined core vessels are presented in Table 15.

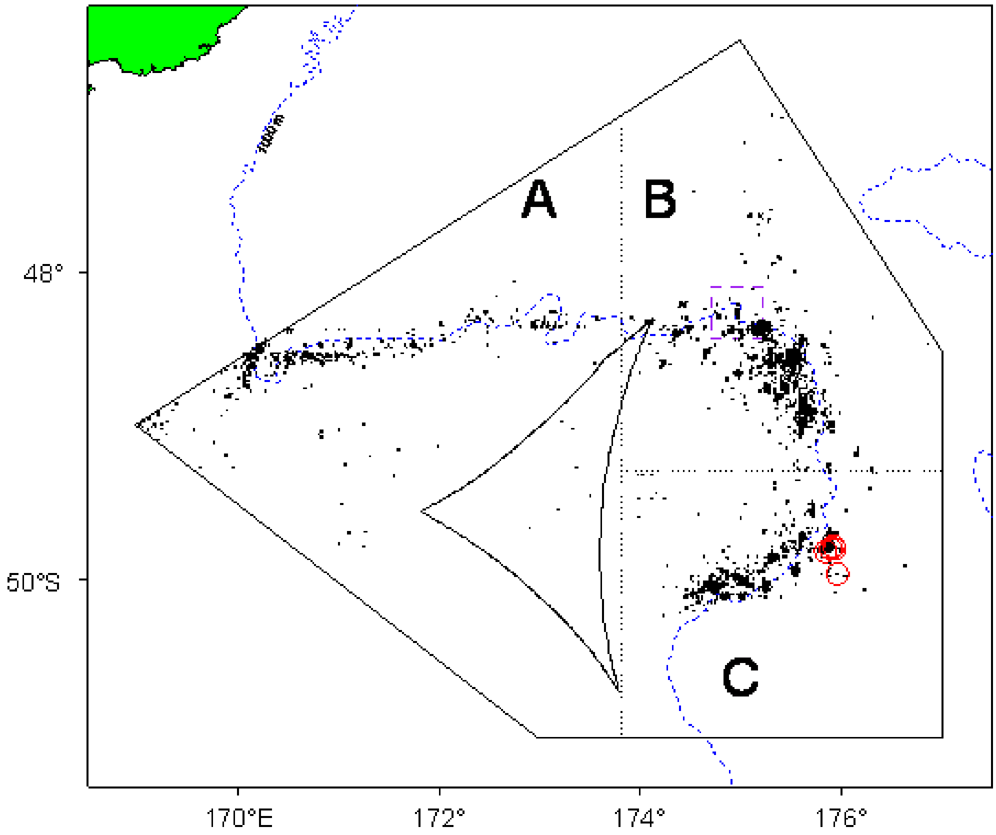


Figure 8: The Pukaki Rise fishery black oreo assessment area (polygon) abutting the boundary of OEO 6/OEO 1 in the north-west. The dots show tow positions where black oreo catch was reported between 1980–81 and 2011–12. A, B, and C are the three areas defined in the standardised CPUE analysis.

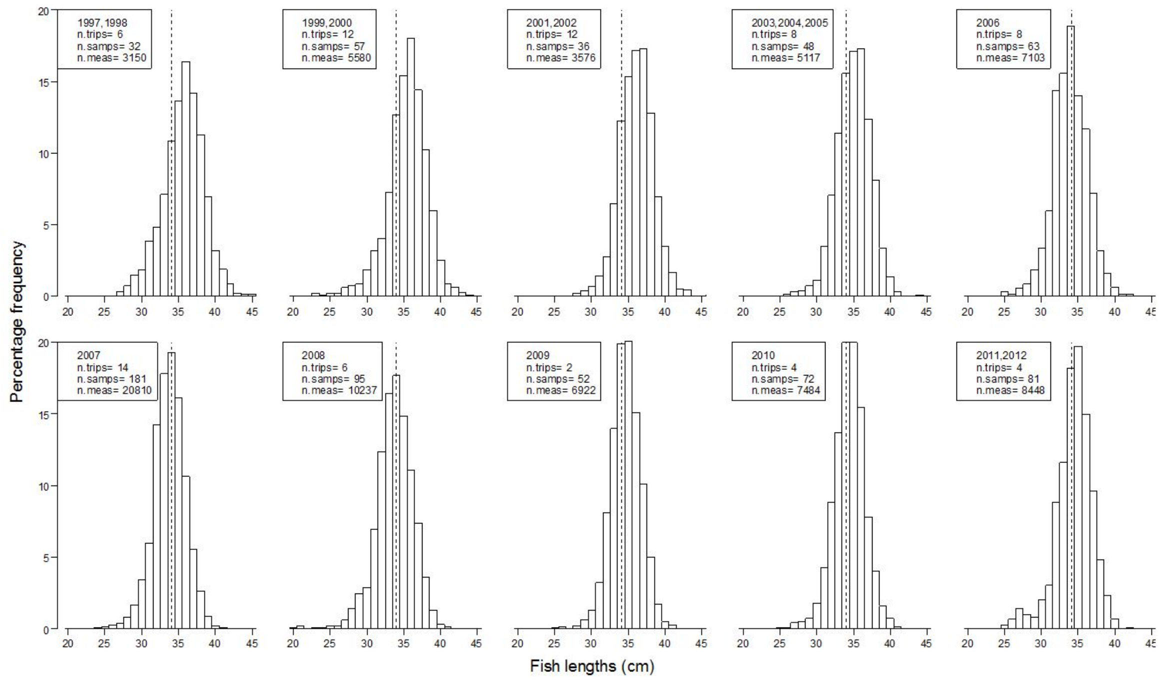


Figure 9: Observer length frequencies for Pukaki Rise black oreo, stratified by depth (see text), and grouped by years (in the legends 1997=1996–97 etc.). The vertical dashed lines indicate the approximate overall mean length as an aid to comparing the distributions.

Table 15: Catch and effort data for vessels fishing in the eastern areas (B and C in Figure 8) with a minimum of 15 successful tows for black oreo in at least three years from 1995–96 to 2011–12.

Year	No. of	CPUE	CV	Year	No. of	CPUE	CV
1995–96	63	1.94	0.09	2004–05	309	0.73	0.13
1996–97	55	1.44	0.13	2005–06	481	0.88	0.09
1997–98	219	1.53	0.07	2006–07	650	0.80	0.09
1998–99	235	0.98	0.11	2007–08	795	0.62	0.12
1999–00	252	0.82	0.12	2008–09	734	0.61	0.12
2000–01	199	1.11	0.10	2009–10	979	0.33	0.21
2001–02	175	1.07	0.11	2010–11	450	0.51	0.16
2002–03	320	0.91	0.10	2011–12	430	0.72	0.12
2003–04	343	0.97	0.09				

No projections were made because the assessment was not accepted by the Working Group.

4.5.2 Biomass estimates
No biomass estimates are reported.

4.5.3 Yield estimates and projections
No yield estimates were made.

4.6 Other oreo fisheries in OEO 1 and OEO 6

4.6.1 Estimates of fishery parameters and abundance

Relative abundance estimates from trawl surveys
Two comparable trawl surveys were carried out in the Puysegur area of OEO 1 (TAN9208 and TAN9409). The 1994 oreo abundance estimates are markedly lower than the 1992 values (Table 16).

4.6.2 Biomass estimates
Estimates of virgin and current biomass are not yet available.

4.6.3 Yield estimates and projections
MCY cannot be estimated because of the lack of current biomass estimates for the other stocks.

CAY cannot be estimated because of the lack of current biomass estimates for the other stocks.

4.6.4 Other factors
Recent catch data from this fishery may be of poor quality because of area misreporting.

Table 16: OEO 1. Research survey abundance estimates (t) for oreos from the Puysegur and Snares areas. N is the number of stations. Estimates for smooth oreo were made based on a recruited length of 34 cm TL. Estimates for black oreo were made using knife-edge recruitment set at 27 cm TL.

Smooth oreo					
Puysegur area (strata 0110–0502)					
	Mean biomass	Lower bound	Upper bound	CV (%)	N
1992	1 397	736	2 058	23	82
1994	529	86	972	41	87
Snares area (strata 0801–0802)					
	Mean biomass	Lower bound	Upper bound	CV (%)	N
1992	2 433	0	5 316	59	8
1994	118	0	246	54	7
Black oreo					
Puysegur area (strata 0110–0502)					
	Mean biomass	Lower bound	Upper bound	CV (%)	N
1992	2 009	915	3 103	27	82
1994	618	0	1 247	50	87
Snares area (strata 0801–0802)					
	Mean biomass	Lower bound	Upper bound	CV (%)	N
1992	3 983	0	8 211	53	8
1994	1 564	0	3 566	64	7

5. STATUS OF THE STOCKS

Stock Structure Assumptions

Oreos in the OEO 1 and 6 FMAs are managed as a single stock but assessed as four separate stocks, separated by species and geography.

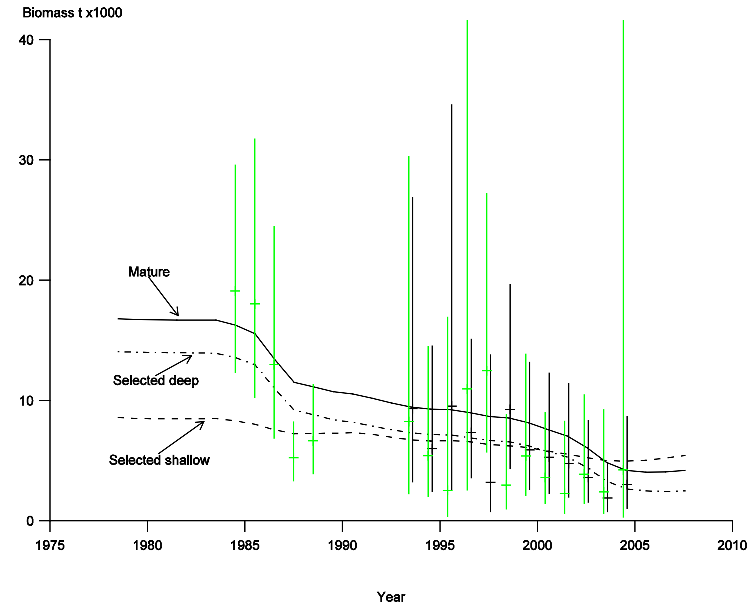
The Southland smooth oreo stock is based along the east coast of the South Island in OEO 1 but extends slightly into OEO 3. It does not include the Waitaki and Eastern canyon areas but is likely to have some level of mixing with other smooth oreo fishstocks. The Pukaki Rise smooth oreo stock comprises the major part of OEO 6 stocks and is centred on its namesake. Some mixing with other smooth oreo fishstocks is thought to occur. The Bounty Plateau smooth oreo stock is located across the Bounty Plateau and the Bounty Islands. Some mixing is thought to occur with other smooth oreo fishstocks.

The Pukaki Rise black oreo stock is the main black oreo fishstock in OEO 6 and the largest black oreo fishstock in the New Zealand EEZ. It extends the entire length of the Rise towards OEO 1. It is assessed separately to other fishstocks but managed as a part of OEO 6. Black oreo on the Pukaki Rise are thought to be non-mixing with other black oreo fishstocks.

- **OEO 1 and OEO 3A Southland (Smooth Oreo)**

Stock Status	
Year of Most Recent Assessment	2007
Assessment Runs Presented	One base case only
Reference Points	Target: 40% B_0 Soft Limit: 20% B_0 Hard Limit: 10% B_0 Overfishing threshold:
Status in relation to Target	B_{2007} was estimated at 27% B_0, Unlikely (< 40%) to be at or above the target.
Status in relation to Limits	B_{2007} was estimated to be Unlikely (< 40%) to be below the Soft Limit and Very Unlikely (< 10%) to be below the Hard Limit.
Status in relation to Overfishing	-

Historical Stock Status Trajectory and Current Status



Predicted biomass trajectories for the 2007 base case assessment— mature biomass and selected biomass for the shallow and deep fisheries. Also shown are the CPUE indices from the pre- and post-GPS analysis for the deep fishery (in gray) and the post-GPS analyses for the shallow fishery (in black). CPUE indices are shown with ±2 s.e.

confidence interval indicated by the vertical lines (the post-GPS CPUE data are slightly offset to avoid over plotting). The CPUE data were scaled by catchability coefficients to match the biomass scale.	
Fishery and Stock Trends	
Recent Trend in Biomass or Proxy	Biomass has been declining at a steady rate since the late 1980s.
Recent Trend in Fishing Mortality or Proxy	Unknown
Other Abundance Indices	-
Trends in Other Relevant Indicators or Variables	-

Projections and Prognosis	
Stock Projections or Prognosis	None because of assessment uncertainty.
Probability of Current Catch or TACC causing Biomass to remain below or to decline below Limits	Soft Limit: Unknown Hard Limit: Unknown
Probability of Current Catch or TACC causing Overfishing to continue or to commence	-

Assessment Methodology		
Assessment Type	Type 1 - Quantitative Stock Assessment	
Assessment Method	Age-structured CASAL model with Bayesian estimation of posterior distributions.	
Assessment Dates	Latest assessment: 2007	Next assessment: Unknown
Overall assessment quality rank	-	
Main data inputs (rank)	- Length-frequency data collected by SOP and ORMC observers - A second, earlier fishery based on Soviet vessels was included in the assessment using historical catch data. - Standardised CPUE indices were derived from the historical and modern datasets.	
Data not used (rank)	-	
Changes to Model Structure and Assumptions	-	
Major Sources of Uncertainty	- Scarcity of observer length frequency data - Poor quality area catch data due to significant misreporting - Lack of fishery-independent abundance estimates creates reliance on commercial CPUE data.	

Qualifying Comments
-

Fishery Interactions
Both species of oreo are sometimes taken as bycatch in orange roughy target fisheries and in smaller numbers in hoki target fisheries. Target fisheries for oreos do exist, with main bycatch being orange roughy, rattails and deepwater sharks and rays. Other bycatch species recorded include seabirds and deepwater corals. Oreo are caught using bottom trawl gear. Bottom trawling interacts with benthic habitats.

- **OEO 6 Pukaki Rise (Smooth Oreo)**

Stock Status	
Year of Most Recent Assessment	2013
Assessment Runs Presented	CASAL assessment based on CPUE rejected
Reference Points	Target: 40% B_0 Soft Limit: 20% B_0 Hard Limit: 10% B_0 Overfishing threshold: $F_{40\%\ B0}$
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
-

Fishery and Stock Trends	
Recent Trend in Biomass or Proxy	Biomass is likely to have been declining since 1996.
Recent Trend in Fishing Intensity or Proxy	Unknown
Other Abundance Indices	CPUE has steadily declined.
Trends in Other Relevant Indicators or Variables	-
Projections and Prognosis	
Stock Projections or Prognosis	No projections were made due to the uncertainties in the assessment.
Probability of Current Catch or TACC causing Biomass to remain below or to decline below Limits	Soft Limit: Unknown Hard Limit: Unknown
Probability of Current Catch or TACC causing Overfishing to continue or to commence	Unknown

Assessment Methodology and Evaluation		
Assessment Type	Type 1 – Quantitative Stock Assessment, but rejected.	
Assessment Method	CASAL assessment based on CPUE (rejected)	
Assessment Dates	Latest assessment: 2013	Next assessment: Unknown
Overall assessment quality rank	3 – Low Quality	
Main data inputs (rank)	-	
Data not used (rank)	Commercial CPUE	3 – Low Quality: does not track stock biomass
Changes to Model Structure and Assumptions	-	
Major Sources of Uncertainty	- Lack of fishery-independent biomass estimates creates reliance on commercial CPUE data. - Lack of biological parameters specific to Smooth Oreo in the target area – data from Chatham Rise/Puysegur Bank had to be substituted instead.	

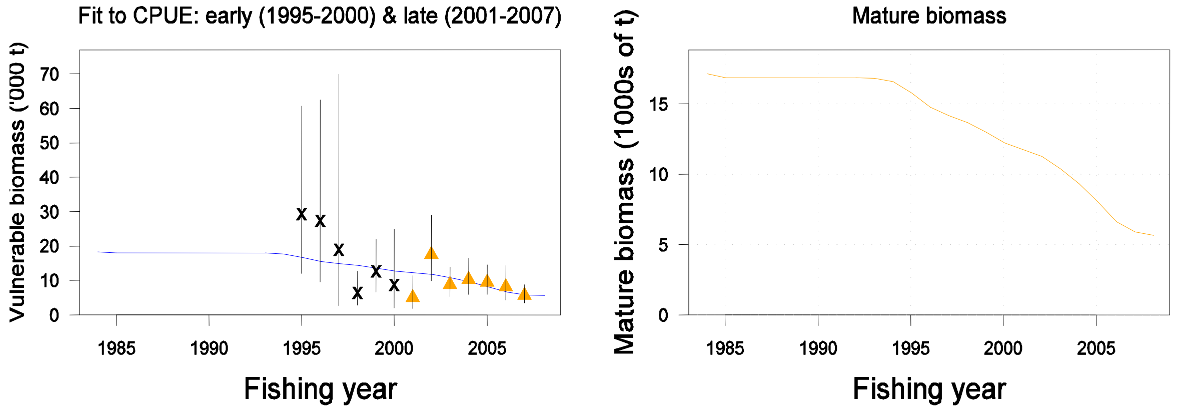
Qualifying Comments
Further investigations into CPUE are required.

Fishery Interactions
Both species of oreo are sometimes taken as bycatch in orange roughy target fisheries and in smaller numbers in hoki target fisheries. Target fisheries for oreos do exist, with main bycatch being orange roughy, rattails and deepwater sharks. Low productivity bycatch species include deepwater sharks and rays. Protected species interactions occur with seabirds and deepwater corals.

- **OEO 6 Bounty Plateau (Smooth Oreo)**

Stock Status	
Year of Most Recent Assessment	2008
Assessment Runs Presented	A base case with two sensitivity runs
Reference Points	Target: 40% B_0 Soft Limit: 20% B_0 Hard Limit: 10% B_0
Status in relation to Targe	B_{2008} was estimated at 33% B_0; Unlikely (< 40%) to be at or above the target.
Status in relation to Limits	B_{2008} is Unlikely (< 40%) to be below the Soft Limit and Very Unlikely (< 10%) to be below the Hard Limit.
Status in relation to Overfishing	-

Historical Stock Status Trajectory and Current Status



Model run showing the MPD fit to the CPUE data (vertical lines are the 95% confidence intervals for the indices) and the trajectory of mature biomass.

Fishery and Stock Trends	
Recent Trend in Biomass or Proxy	Biomass is estimated to have been decreasing rapidly since 1995.
Recent Trend in Fishing Mortality or Proxy	Unknown
Other Abundance Indices	-
Trends in Other Relevant Indicators or Variables	-

Projections and Prognosis	
Stock Projections or Prognosis	No projections were made because of the uncertainty of the assessment.
Probability of Current Catch or TACC causing Biomass to remain below or to decline below Limits	Soft Limit: Unknown Hard Limit: Unknown
Probability of Current Catch or TACC causing overfishing to continue or to commence	Unknown

Assessment Methodology and Evaluation		
Assessment Type	Type 1 - Quantitative Stock Assessment	
Assessment Method	Age-structured CASAL model with Bayesian estimation of posterior distributions	
Assessment Dates	Latest assessment: 2008	Next assessment: Unknown
Overall assessment quality rank		
Main data inputs (rank)	- Catch history - Abundance estimates derived from a standardised CPUE - Length data from SOP and ORMC observers	
Data not used (rank)	-	
Changes to Model Structure and Assumptions	-	
Major Sources of Uncertainty	- Reliance on commercial CPUE data - To estimate biological parameters, data was used from different stocks (Puysegur Bank + Chatham Rise) to the target stock - Using a single CPUE index instead of split indices gives contrasting biomass signals	

Qualifying Comments
-

Fishery Interactions
Both species of oreo are sometimes taken as bycatch in orange roughy target fisheries and in smaller numbers in hoki target fisheries. Target fisheries for oreos do exist, with main bycatch being orange roughy, rattails and deepwater sharks. Other bycatch species recorded include deepwater sharks and rays, seabirds and deepwater corals. Oreo are caught using bottom trawl gear. Bottom trawling interacts with benthic habitats.

- **OEO 6 Pukaki Rise (Black Oreo)**

Stock Status	
Year of Most Recent Assessment	2013
Assessment Runs Presented	CASAL assessment based on CPUE rejected
Reference Points	Target: 40% B_0 Soft Limit: 20% B_0 Hard Limit: 10% B_0 Overfishing threshold: $F_{40\% B0}$
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	

Fishery and Stock Trends	
Recent Trend in Biomass or Proxy	Biomass is likely to have been decreasing since the 1980s with a major decline starting about 1995.
Recent Trend in Fishing Intensity or Proxy	Unknown
Other Abundance Indices	CPUE declined, but has levelled out in the last four years.
Trends in Other Relevant Indicators or Variables	-

Projections and Prognosis		
Stock Projections or Prognosis	-	
Probability of Current Catch or TACC causing Biomass to remain below or to decline below Limits	Soft Limit: Unknown Hard Limit: Unknown	
Probability of Current Catch or TACC causing Overfishing to continue or to commence	Unknown	

Assessment Methodology and Evaluation		
Assessment Type	Type 1 - Quantitative Stock Assessment	
Assessment Method	CASAL assessment based on CPUE (rejected)	
Assessment Dates	Latest assessment: 2009	Next assessment: Unknown
Overall assessment quality rank	3 – Low Quality	
Main data inputs (rank)	-	
Data not used (rank)	Commercial CPUE	3 – Low Quality: does not track stock biomass
Changes to Model Structure and Assumptions	-	
Major Sources of Uncertainty	- Lack of fisheries-independent data causes reliance on commercial CPUE data - Lack of biological parameter estimates specific to black oreo in this assessment area	

Qualifying Comments
Further investigations into CPUE are needed.

Fishery Interactions
Both species of oreo are sometimes taken as bycatch in orange roughy target fisheries and in smaller numbers in hoki target fisheries. Target fisheries for oreos do exist, with main bycatch being orange roughy, rattails and deepwater sharks. Low productivity bycatch species include deepwater sharks and rays. Protected species interactions occur with seabirds and deepwater corals. Oreo are caught using bottom trawl gear. Bottom trawling interacts with benthic habitats.

6. FOR FURTHER INFORMATION

Coburn, R P; Doonan, I J; McMillan, P J (2002) CPUE analyses for the Southland black oreo and smooth oreo fisheries, 1977–78 to 1999–2000. *New Zealand Fisheries Assessment Report 2002/3.* 28 p.

Coburn, R P; Doonan, I J; McMillan, P J (2002) CPUE analyses for the major black oreo and smooth oreo fisheries in OEO 6, 1980–81 to 1999–2000. *New Zealand Fisheries Assessment Report 2002/6.* 29 p.

Coburn, R P; Doonan, I J; McMillan, P J (2003) Stock assessment of smooth oreo in the Southland fishery (OEO 1 and 3A) for 2003. *New Zealand Fisheries Assessment Report 2003/62*. 32 p.

Coburn, R P; Doonan, I J; McMillan, P J (2008) A stock assessment of smooth oreo in Southland (part of OEO 1 & OEO 3A). *New Zealand Fisheries Assessment Report 2008/37*. 43 p.

Coburn, R P; McMillan, P J; Gilbert, D J (2007) Inputs for a stock assessment of smooth oreo, Pukaki Rise (part of OEO 6). *New Zealand Fisheries Assessment Report 2007/23*. 32 p

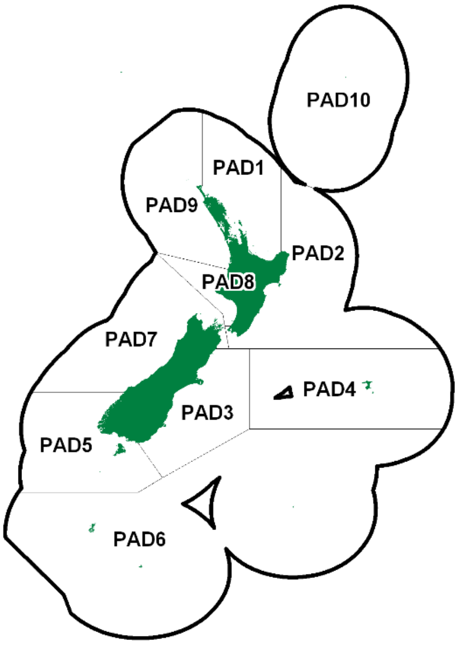
Doonan, I J; Anderson, O F; McMillan, P J (2010) Assessment of Pukaki (OEO 6) black oreo for 2008–09. *New Zealand Fisheries Assessment Report 2010/39*.

McKenzie, A (2007) Stock assessment for east Pukaki Rise smooth oreo (part of OEO 6). *New Zealand Fisheries Assessment Report 2007/34*. 27 p.

McMillan, P J; Coburn, R P; Hart, A C; Doonan, I J (2002) Descriptions of black oreo and smooth oreo fisheries in OEO 1, OEO 3A, OEO 4, and OEO 6 from 1977–78 to the 2000–01 fishing year. *New Zealand Fisheries Assessment Report. 2002/40*.

PADDLE CRABS (PAD)

(Ovalipes catharus)
Papaka



1. FISHERY SUMMARY

1.1 Commercial fisheries

Paddlecrabs were introduced into the QMS from 1 October 2002 with recreational and customary non-commercial allowances, TACCs and TACs summarised in Table 1.

Table 1: Current Total allowable catches (TAC, t) allowances for customary fishing, recreational fishing (t) and Total Allowable Commercial Catches (TACC, t) for paddle crabs, by Fishstock.

Fishstock	TAC	Customary	Recreational	TACC
PAD 1	250	10	20	220
PAD 2	125	5	10	110
PAD 3	110	2	8	100
PAD 4	30	1	4	25
PAD 5	55	1	4	50
PAD 6	0	0	0	0
PAD 7	105	1	4	100
PAD 8	65	1	4	60
PAD 9	130	10	20	100
PAD 10	0	0	0	0

Commercial interest in paddle crabs was first realised in New Zealand in 1977–78 when good numbers of large crabs were caught off Westshore Beach, Napier in baited lift and set-pots. Annual catches have varied, mainly due to marketing problems, and estimates are likely to be conservative. Landings increased in the early fishery, from 775 kg in 1977 to 306 t in 1985, and ranging from 403 t to 519 t from 1995–96 to 1999-00, but have since generally decreased. In 2017-18 and 2018-19 landings (mostly originating from PAD 3) dropped to the lowest levels since the 1980s, with just 27 t and 22 t recorded respectively. Paddle crabs are known to be discarded from inshore trawl operations targeting species such as flatfish, and this may have resulted in under-reporting of catches. Crabs are marketed live, as whole cooked crabs, or as crab meat. Attempts were made to establish a soft-shelled crab industry in New Zealand in the late 1980s.

Bycatch is commonly taken during trawl, dredge and setnetting operations. Catch rates vary considerably with method, season and area, and there is no clear seasonal trend to paddle crab landings. It is likely that catches are related to the availability of fishers and/or market demands. Commercial landings from 1989–90 until the present are shown in Table 2, while Figure 1 shows the historical landings and TACC for the six main PAD stocks.

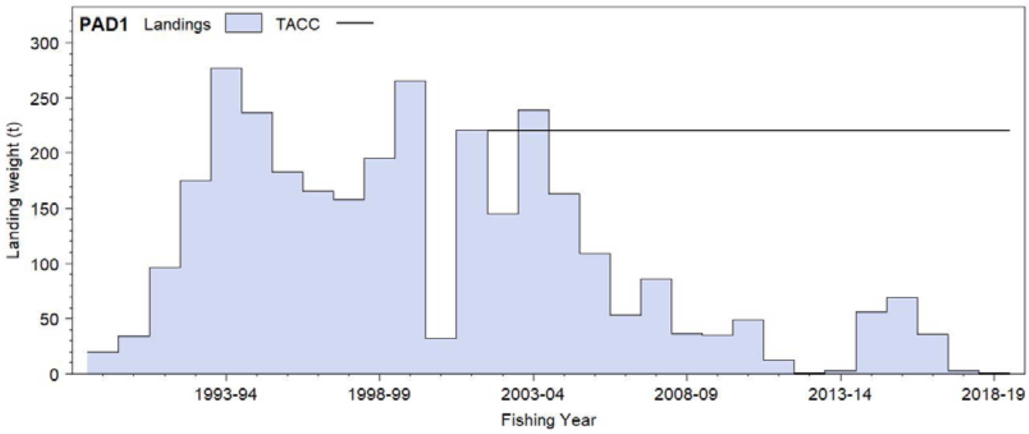
Table 2: Reported landings (t) of paddle crabs by QMA and fishing year, from CLR and $CELR_{landed}$ data since 1989–90. **[Continued on next page]**

QMA	PAD 1		PAD 2		PAD 3		PAD 4		PAD 5	
	Landing	TACC	Landing	TACC	Landing	TACC	Landing	TACC	Landing	TACC
1989–90	20	-	57	-	38	-	< 1	-	< 1	-
1990–91	34	-	37	-	26	-	0	-	6	-
1991–92	96	-	32	-	31	-	< 1	-	< 1	-
1992–93	175	-	14	-	36	-	0	-	< 1	-
1993–94	277	-	18	-	46	-	0	-	< 1	-
1994–95	237	-	6	-	36	-	< 1	-	< 1	-
1995–96	183	-	5	-	18	-	< 1	-	1	-
1996–97	165	-	25	-	36	-	0	-	1	-
1997–98	158	-	126	-	18	-	< 1	-	13	-
1998–99	195	-	197	-	21	-	< 1	-	2	-
1999–00	265	-	21	-	27	-	1	-	14	-
2000–01	32	-	10	-	17	-	0	-	0	-
2001–02	221	-	34	-	22	-	0	-	2	-
2002–03	145	220	65	110	18	100	< 1	25	< 1	50
2003–04	239	220	46	110	20	100	0	25	0	50
2004–05	163	220	44	110	30	100	0	25	0	50
2005–06	109	220	49	110	11	100	0	25	< 1	50
2006–07	53	220	21	110	13	100	0	25	3	50
2007–08	86	220	9	110	19	100	0	25	< 1	50
2008–09	36	220	14	110	37	100	0	25	1	50
2009–10	35	220	17	110	37	100	0	25	< 1	50
2010–11	49	220	18	110	47	100	0	25	<1	50
2011–12	12	220	41	110	47	100	< 1	25	< 1	50
2012–13	< 1	220	36	110	39	100	< 1	25	< 1	50
2013–14	3	220	6	110	74	100	1	25	<1	50
2014–15	23	220	1	110	45	100	0	25	<1	50
2015–16	69	220	6	110	48	100	0	25	<1	50
2016–17	36	220	12	110	18	100	<1	25	<1	50
2017–18	3	220	5	110	17	100	<1	25	0	50
2018–19	1	220	3	110	16	100	<1	25	<1	50

QMA	PAD 6		PAD 7		PAD 8		PAD 9		PAD 10	
	Landing	TACC	Landing	TACC	Landing	TACC	Landing	TACC	Landing	TACC
1989–90	0	-	94	-	22	-	0	-	0	-
1990–91	0	-	68	-	12	-	0	-	0	-
1991–92	0	-	83	-	21	-	0	-	0	-
1992–93	0	-	59	-	24	-	0	-	0	-
1993–94	0	-	49	-	27	-	5	-	0	-
1994–95	0	-	71	-	46	-	< 1	-	0	-
1995–96	55	-	82	-	58	-	< 1	-	< 1	-
1996–97	25	-	106	-	44	-	< 1	-	1	-
1997–98	7	-	63	-	25	-	< 1	-	< 1	-
1998–99	10	-	59	-	34	-	0	-	1	-
1999–00	14	-	45	-	50	-	0	-	< 1	-
2000–01	0	-	0	-	< 1	-	0	-	0	-
2001–02	22	-	33	-	24	-	0	-	0	-
2002–03	< 1	0	42	100	11	60	0	100	0	0
2003–04	0	0	50	100	17	60	< 1	100	0	0
2004–05	0	0	40	100	14	60	1	100	0	0
2005–06	0	0	48	100	14	60	1	100	0	0
2006–07	0	0	32	100	11	60	< 1	100	0	0
2007–08	0	0	47	100	7	60	0	100	0	0
2008–09	0	0	35	100	11	60	0	100	0	0
2009–10	0	0	17	100	13	60	0	100	0	0
2010–11	0	0	11	100	14	60	0	100	0	0
2011–12	0	0	7	100	14	60	0	100	0	0
2012–13	0	0	11	100	17	60	0	100	0	0
2013–14	0	0	4	100	13	60	0	100	0	0
2014–15	0	0	0	100	1	60	0	100	0	0
2015–16	0	0	0	100	4	60	0	100	0	0
2016–17	0	0	<1	100	3	60	0	100	0	0
2017–18	0	0	<1	100	1	60	0	100	0	0
2018–19	0	0	0	100	1	60	0	100	0	0

Table 2 [Continued]: Reported landings (t) of paddle crabs by QMA and fishing year, from CLR and CELR$_{landed}$ **data since 1989–90.**

QMA		Total
	Landings	TACC
1989–90	231	-
1990–91	183	-
1991–92	264	-
1992–93	308	-
1993–94	423	-
1994–95	397	-
1995–96	403	-
1996–97	403	-
1997–98	410	-
1998–99	519	-
1999–00	437	-
2000–01	59	-
2001–02	358	-
2002–03	281	765
2003–04	372	765
2004–05	292	765
2005–06	232	765
2006–07	132	765
2007–08	168	765
2008–09	134	765
2009–10	120	765
2010–11	140	765
2011–12	121	765
2012–13	103	765
2013–14	101	765
2014–15	71	765
2015–16	127	765
2016–17	66	765
2017–18	27	765
2018–19	22	765



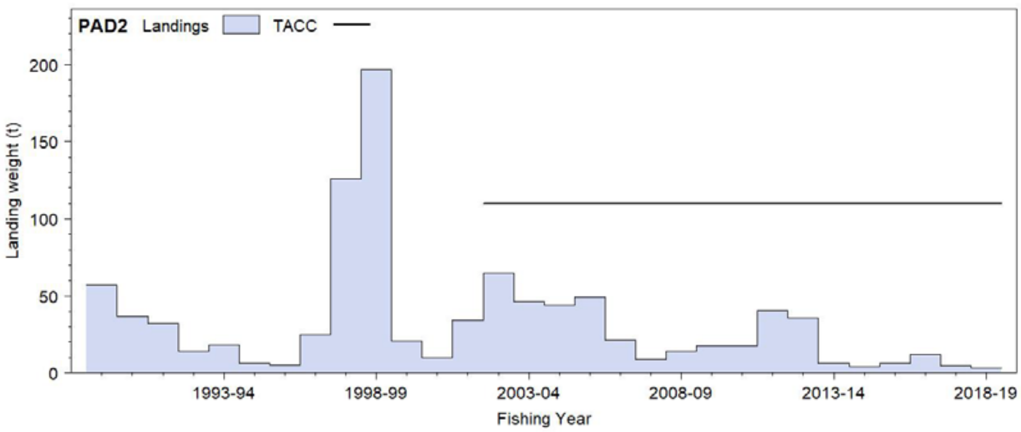


Figure 1: Reported commercial landings and TACCs for the six main PAD stocks: PAD 1 (Auckland East) and PAD 2 (Central East). [Continued on next page]

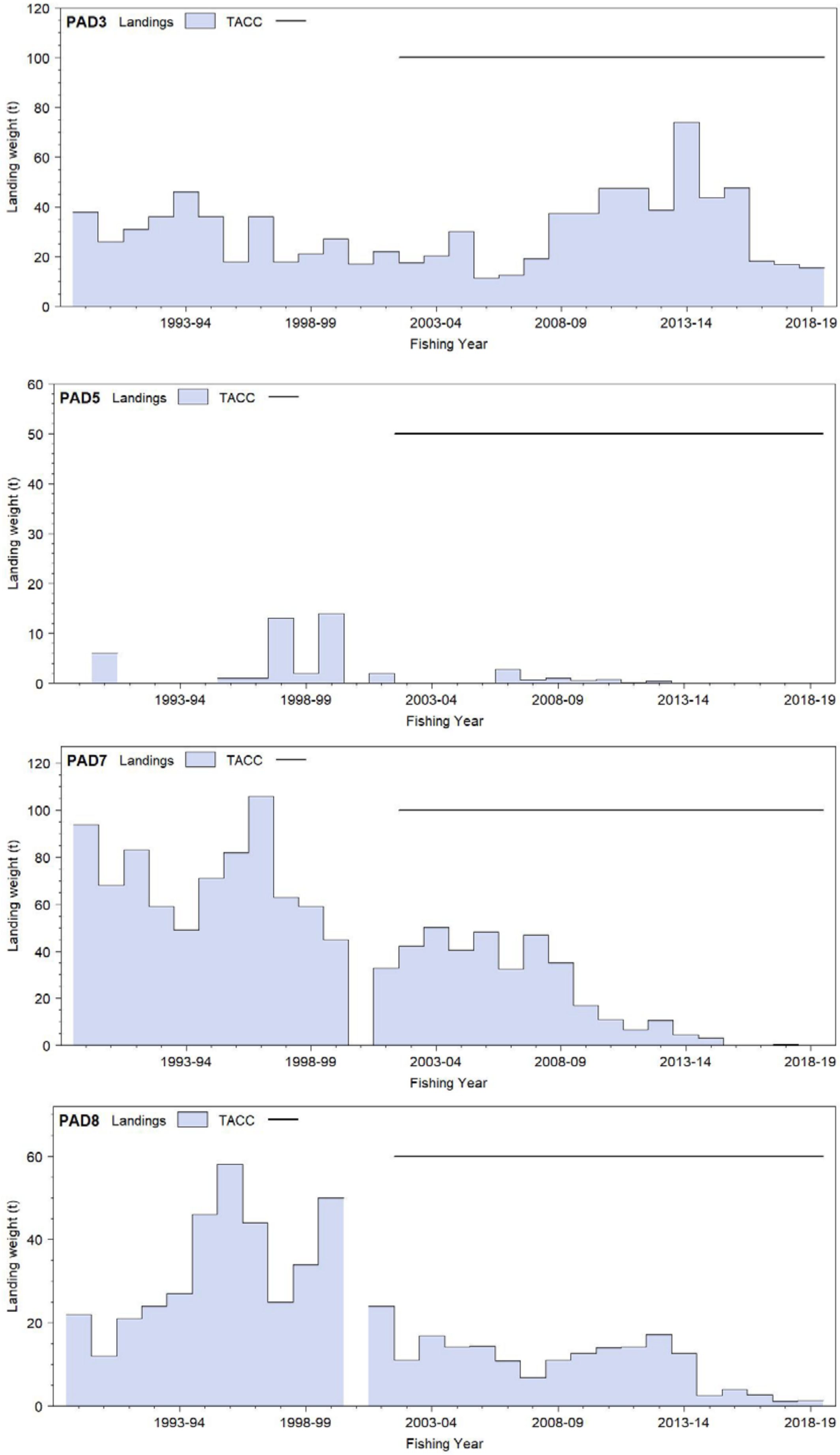


Figure 1 [Continued]: Reported commercial landings and TACCs for the six main PAD stocks: PAD 3 (south East Coast), PAD 5 (Southland), PAD 7 (Challenger) and PAD 8 (Central Egmont).

1.2 Recreational fisheries

Paddle crabs are taken as a bycatch of beach and estuarine seining and in setnets throughout much of their geographical range. A National Panel Survey of recreational fishers was conducted for the first time throughout the 2011–12 fishing year (Wynne-Jones et al. 2014). The panel survey used face-to-face interviews of a random sample of 30 390 New Zealand households to recruit a panel of fishers and non-fishers for a full year. The panel members were contacted regularly about their fishing activities and harvest information collected in standardised phone interviews. A repeat of the National Panel Survey was conducted over the 2017–18 October fishing year with 34 431 households contacted (Wynne-Jones et al 2019).

Harvest estimates for the two National Panel Surveys are given in Table 3 (from Wynne-Jones et al 2014, Wynne-Jones et al 2019; no estimates of mean weight were available from ramp surveys). These estimates are all very uncertain because of the small number of fishers reporting catch.

Table 3: Recreational harvest estimates for paddle crab stocks from the national panel surveys (2011–12 and 2017–18). *: no estimates of mean weights were available to convert catches in numbers to tonnes. From Wynne-Jones et al. 2014 and Wynne-Jones et al. 2019.

Area	Number (thousands)	CV	Catch (t)*
2011–12 (national panel survey)			
PAD 1	2 003	0.86	-
PAD 2	827	1.02	-
PAD 3	1 768	1.01	-
PAD 5	2 532	1.02	-
PAD 8	2 225	0.71	-
PAD total	9 354	0.43	-
2017–18 (national panel survey)			
PAD 1	775	0.84	-
PAD 7	5 139	1.00	-
PAD total	5 914		

1.3 Customary non-commercial fisheries

Very limited quantitative information on the level of customary take is available from Fisheries New Zealand (Table 4). These numbers are likely to be an underestimate of customary harvest as only the catch in numbers and kilograms are reported in the table below.

Table 4: Fisheries New Zealand records of customary harvest of paddle crabs (reported as weight (kg) and numbers), since 2007-08. – no data.

		Weight (kg)		Numbers	
Stock	Fishing year	Approved	Harvested	Approved	Harvested
PAD 1	2010–11	10	0	50	0
PAD 3	2007–08	–	–	50	0

1.4 Illegal catch

There is qualitative data to suggest illegal, unreported, unregulated (IUU) activity in this Fishery.

1.5 Other sources of mortality

There is no quantitative information available on other sources of mortality, although unknown quantities of paddle crabs have been discarded from commercial fishing operations such as the inshore trawl, setnet and dredge fisheries.

2. BIOLOGY

The paddle crab is found off sandy beaches, and in harbours and estuaries throughout mainland New Zealand, the Chatham Islands, and east and South Australia. They are abundant from the intertidal zone to at least 10 m depth, although they do occur in much deeper water. Paddle crabs are mainly active in early evening or at night, when they move into the shallow intertidal zone to feed.

Paddle crabs are versatile and opportunistic predators. They feed mainly on either molluscs or crustaceans, but also on polychaetes, several fish species, cumaceans, and occasionally on algae. A high proportion of the molluscs eaten are *Paphies* species. These include: tuatua (*P. subtriangulata);* pipi (*P. australis);* and toheroa (*P. ventricosa).* The burrowing ghost shrimp *Callianassa filholi,* isopods and amphipods are important crustacean prey items. Cannibalism is common, particularly on small crabs and during the winter moulting season.

Anecdotal information suggests there has been a significant increase in paddle crab numbers since the 1970s. Concern has been expressed as to the impact of an increased number of paddle crabs on bivalve shellfish stocks in coastal waters. Feeding studies have shown that although paddle crabs do eat large adult toheroa and other shellfish, they more usually eat bivalve shellfish spat which are found in abundance.

Mating generally occurs during winter and spring (May to November) in sheltered inshore waters. Female paddle crabs can only mate when they are soft-shelled. Male crabs protect and carry pre-moult females to ensure copulation. Female crabs are thought to migrate to deeper water to spawn over the warmer months (September to March). After spawning the eggs are incubated until they hatch. *Ovalipes catharus* has an extended larval life characterised by eight zoea stages and a (crab-like) megalopa. The larvae are thought to live offshore in deeper water, migrating inshore in the megalopa stage to settle from January to May.

Two spawning mechanisms have been observed in *O. catharus*. In Wellington, Tasman Bay, and Canterbury, spawning does not appear to be synchronised and females may spawn several times during the season (non-synchronous spawning). In Blueskin Bay, Otago, paddle crabs are group-synchronous, with one clutch of eggs developing to maturity over winter, and spawned from September to February.

Annual fecundity is determined by the number of eggs per brood (brood fecundity) and the number of broods per year. Both these parameters are size dependent and highly variable. Brood fecundity estimates vary considerably geographically from between 82 000–638 000 in Wellington waters, to 100 000–1 200 000 in Canterbury waters, and 931 000–2 122 807 in Otago waters. The number of broods per year also varies geographically from 1.2–3.3 in Wellington waters, to 1.2–2.2 in Canterbury waters, and 1 brood per year in Otago waters (group synchronous spawning).
O. catharus is a relatively large and fast growing species of *Ovalipes.* In Canterbury waters, paddle crabs reach a maximum size of 130 mm carapace width (CW - males only) after 13 postlarval moults and 3 to 4 years after settlement. Other studies have reported maximum sizes up to 150 mm CW. In Wellington waters, crabs of approximately 100 mm carapace width, of either sex, would be at least 3 years old, while larger crabs could be 4 or 5 years old.

The differences in growth rate, size at first maturity, and fecundity (particularly the number of broods) appear to be largely environmentally regulated. At lower temperatures and higher latitudes, paddle crabs grow slower, mature at a larger size, have a shorter breeding season, and produce fewer broods per year.

Estimates of biological parameters relevant to stock assessment are presented in Table 5.

Table 5: Estimates of biological parameters.

Fishstock			**Estimate**		**Source**
1. Natural mortality (females only)					
(Percentage mortality at each instar stage)					
Instar	Tasman Bay (QMA 7)		Canterbury (QMA 3)		
8	15.3		15.0		Osborne (1987)
9	31.2		30.0		
10 (68–75 mm CW)	78.1		39.1		
11	30.7		38.9		
12	55.6		18.2		
13 (> 100 mm CW)	100		100		
2. $\log_{10}$(weight) = a + b* $\log_{10}$(CW) (carapace width)					
	Females		Males		
Canterbury (QMA 3)	a	b	a	b	Davidson & Marsden (1987)
	-3.32	2.79	-3.46	2.89	

3. STOCKS AND AREAS

It is not known whether biologically distinct stocks occur, although this seems unlikely given that the species is found throughout New Zealand waters, and from tagging experiments, appears to be highly migratory. There is probably also widespread larval dispersal as larvae spend two months offshore in deeper water (to at least 700 m). Genetically distinct populations may occur in isolated areas such as the Chatham Islands.

4. STOCK ASSESSMENT

4.1 Estimates of fishery parameters and abundance

None are available at present.

4.2 Biomass estimates

No estimates of current or virgin biomass are available. The landings, CPUE, and area data are considered too unreliable or incomplete to allow modelling.

4.3 Yield estimates and projections

MCY cannot be estimated.

CAY cannot be estimated because of the lack of current biomass estimates.

5. STATUS OF THE STOCKS

Estimates of current and reference biomass are not available. Landings have fluctuated significantly in most QMAs, mainly due to market variations. Paddle crabs are abundant throughout most of their range and the fishery is probably only lightly exploited.

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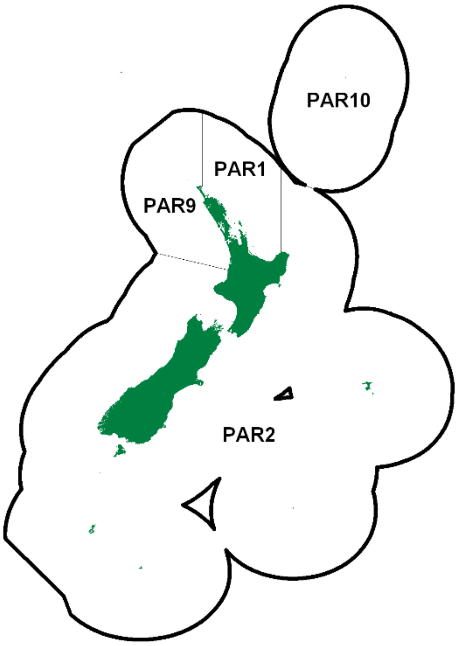
PARORE (PAR)

(Girella tricuspidata)
Parore



1. FISHERY SUMMARY

Parore was introduced into the Quota Management System (QMS) on 1 October 2004 with the TACs, TACCs and allowances shown in Table 1.

Table 1: TACs (t), TACCs (t) and allowances (t) for parore.

Fishstock	Recreational Allowance	Customary non-commercial Allowance	Other sources of mortality	TACC	TAC
PAR 1	6	3	4	61	74
PAR 2	1	1	0	2	4
PAR 9	2	1	1	21	25
PAR 10	0	0	0	0	0
Total	9	5	5	84	103

1.1 Commercial fisheries

Parore is principally caught as a bycatch in the grey mullet, flatfish and trevally setnet fisheries in northern New Zealand. Most of the catch comes from eastern Northland and the Firth of Thames (FMA 1) and the Kaipara and Manukau Harbours (FMA 9) (Figure 1). Highest catch rates occur during September to October. Few parore are caught in the other FMAs.

Historical estimated and recent reported parore landings and TACCs are shown in Tables 2, 3 and 4. Between 2004-05 and 2018-19 total landings ranged between 56 t and 92 t. Landings exceeded the PAR 1 TACC by 9 t in 2009-10 and slightly in 2010-11 and 2012-13. In PAR 9 landings have remained below the TACC in most years, only slightly exceeding the TACC in 209-10. In 2018-19 landings in both PAR 1 and PAR 9 reached the TACCs of 61 t and 21 t respectively (Table 4).

Fishers may confuse the codes PAR (parore) and POR (porae) when reporting catches, but given that both species occur in shallow northern waters, misreporting is difficult to discern.

1.2 Recreational fisheries

Parore is taken by recreational fishers in northern areas as a bycatch when targeting other species such as snapper, trevally, and mullet using rod and line or set net. There is some opportunistic targeting by spear fishers. No estimates of recreational harvest of leatherjacket were generated from the telephone-diary surveys conducted in 1994, 1996 and 2000 because so few were reported. A National Panel Survey was conducted for the first time throughout 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 (Wynne-Jones et al 2014). The panel members were contacted regularly about their fishing activities and harvest information collected in standardised phone interviews. The national panel survey was repeated during the 2017–18 fishing year using very similar methods to produce directly comparable results (Wynne-Jones et al 2019). Recreational catch estimates from the two national panel surveys are given in Table 1. Note that national panel survey estimates do not include recreational harvest taken under s111 general approvals.

1.3 Customary non-commercial fisheries

There is no quantitative information on customary harvest of parore. Customary fishers are likely to catch small quantities of parore when targeting other species such as snapper, trevally, and mullet. Parore is considered to be a low value customary species and current catches are likely to be low.

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

Year	PAR 1	PAR 2	PAR 9	Year	PAR 1	PAR 2	PAR 9
1931–32	0	0	0	1957	19	0	0
1932–33	0	0	0	1958	22	0	1
1933–34	0	0	0	1959	13	0	1
1934–35	0	0	0	1960	6	0	0
1935–36	0	0	0	1961	12	0	1
1936–37	0	0	0	1962	28	0	2
1937–38	0	0	0	1963	29	0	2
1938–39	1	0	0	1964	62	0	2
1939–40	0	0	0	1965	56	0	2
1940–41	0	0	0	1966	42	0	2
1941–42	0	0	0	1967	19	0	2
1942–43	15	0	0	1968	39	0	0
1943–44	13	0	0	1969	67	0	2
1944	21	0	0	1970	69	1	4
1945	41	0	0	1971	82	0	3
1946	75	0	0	1972	67	0	3
1947	31	0	0	1973	50	0	5
1948	4	0	0	1974	55	0	2
1949	7	0	0	1975	37	1	7
1950	13	0	0	1976	67	1	13
1951	7	0	0	1977	65	0	7
1952	20	0	0	1978	62	0	3
1953	11	0	0	1979	53	0	5
1954	16	0	0	1980	40	6	6
1955	12	0	1	1981	50	0	6
1956	7	0	0	1982	52	1	12

Notes:
1. The 1931–1943 years are April–March but from 1944 onwards are calendar years.
2. Data for the period 1931 to 1982 are based on reported landings by harbour and are likely to be underestimated as a result of under-reporting and discarding practices. Data includes both foreign and domestic landings

Table 3: Reported landings (t) of parore by FMA, fishing years 1989–90 to 2003–04.

	FMA 1	FMA 2	FMA 3	FMA 4	FMA 5	FMA 7	FMA 8	FMA 9
1989–90	18	< 1	0	0	< 1	< 1	0	< 1
1990–91	81	2	< 1	< 1	< 1	< 1	< 1	0
1991–92	100	< 1	< 1	0	0	2	0	0
1992–93	109	< 1	< 1	0	< 1	< 1	0	0
1993–94	95	< 1	0	< 1	0	< 1	< 1	0
1994–95	95	< 1	< 1	0	0	< 1	0	3
1995–96	89	< 1	0	0	0	< 1	< 1	9
1996–97	70	< 1	< 1	< 1	0	3	< 1	6
1997–98	73	< 1	< 1	0	0	< 1	< 1	5
1998–99	73	< 1	< 1	< 1	0	< 1	< 1	6
1999–00	79	< 1	< 1	0	< 1	< 1	< 1	4
2000–01	91	< 1	< 1	0	0	< 1	< 1	9
2001–02	67	1	< 1	0	< 1	< 1	0	3
2002–03	89	0	0	0	0	0	0	4
2003–04	49	< 1	< 1	0	0	0	< 1	6

Table 4: Reported domestic landings (t) of Parore Fishstocks and TACC, fishing years 2004–05 to 2018–19.

Fishstock		PAR 1		PAR 2		PAR 9		
FMA		1		2,3,4,5,6,7&8		9		Total
	Landings	TACC	Landings	TACC	Landings	TACC	Landings	TACC
2004–05	42	61	< 1	2	14	21	56	84
2005–06	48	61	< 1	2	15	21	63	84
2006–07	52	61	< 1	2	10	21	61	84
2007–08	57	61	< 1	2	11	21	68	84
2008–09	59	61	< 1	2	20	21	79	84
2009–10	70	61	< 1	2	22	21	92	84
2010–11	62	61	< 1	2	18	21	80	84
2011–12	61	61	< 1	2	18	21	78	84
2012–13	65	61	<1	2	18	21	83	84
2013–14	53	61	<1	2	18	21	72	84
2014–15	49	61	<1	2	19	21	68	84
2015–16	49	61	<1	2	17	21	66	84
2016–17	49	61	0	2	20	21	70	84
2017–18	50	61	0	2	15	21	65	84
2018–19	61	61	0	2	21	21	82	84

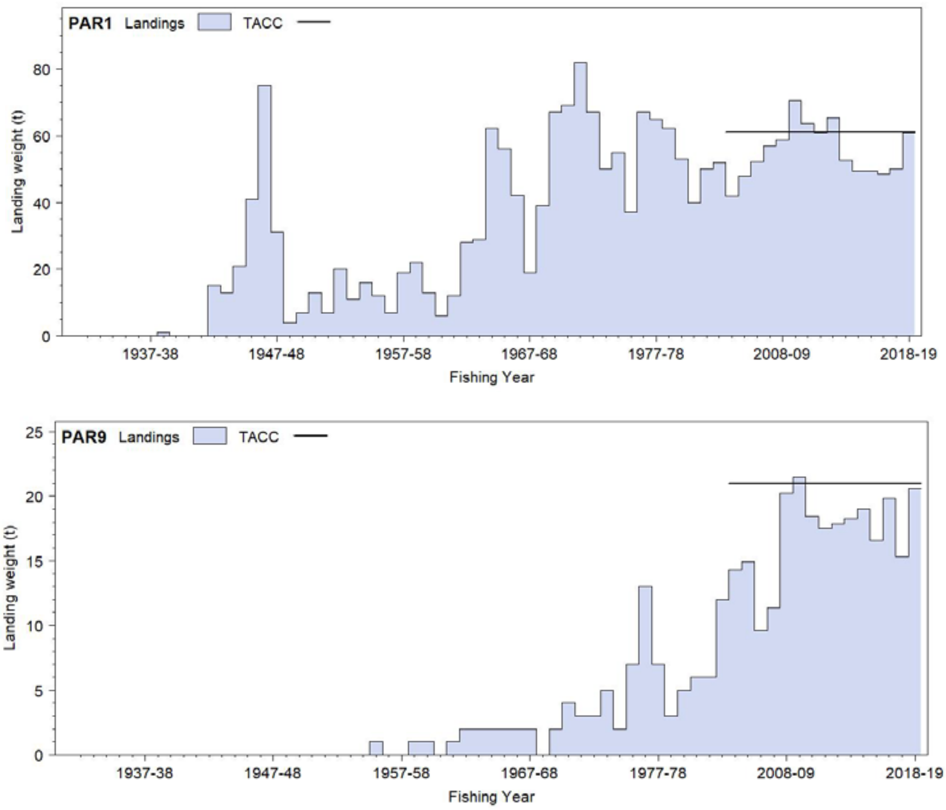


Figure 1: Reported commercial landings and TACC for the two main PAR stocks. From top PAR 1 (Auckland East) and PAR 9 (Auckland West).

Table 5: Recreational harvest estimates (in numbers of fish) for parore stocks (Wynne-Jones et al 2014, 2019).

Stock	Year	Method	Number of fish	Total weight (t)	CV
PAR 1	2011/12	Panel survey	4 328	-	0.50
	2017/18	Panel survey	7 302	-	0.34
PAR 2	2011/12	Panel survey	-	-	-
	2017/18	Panel survey	109	-	1.01
PAR 9	2011/12	Panel survey	-	-	-
	2017/18	Panel survey	834	-	0.70

2. BIOLOGY

Parore (*Girella tricuspidata*) occur along both east and west coasts of the North Island, from North Cape to Cook Strait (Anderson et al 1998). It has not been recorded around the Chatham Islands. They usually occur in schools, ranging from half a dozen to several hundred individuals. Although there is evidence that large individuals display territorial behaviour on some reef systems, work in Australia has shown that parore are capable of moving distances of hundreds of kilometres (Pollock 1981).

Parore grow to a maximum size of at least 600 mm, but most adult fish are around 300–400 mm in length. The maximum age for this species on the North Island east coast, as estimated by scale ring counts (validated by seasonal increments), is 10 years (Morrison 1990). As scales tend to provide underestimates of the age of older fish, maximum age could be considerably higher. Growth is relatively rapid in the first year of life, with fish reaching a size of about 100 mm at age one. Fish reach a length of 300 mm by age five, at which time growth slows. Growth rates of males and females, and of open coast and estuarine populations, appear similar. No growth studies have been undertaken on the west coast of the North Island, but large parore (about 600 mm) are sometimes taken in harbour set-nets as bycatch. Parore reach sexual maturity at a length of 280 mm and spawning takes place in late spring to early summer (Morrison 1990). Larvae are neustonic, occurring near the ocean's surface, often in association with drifting material such as seaweed clumps.

Juveniles enter estuaries in January at a length of about 11 mm. They are initially found on seagrass meadows and beds of Neptune's Necklace (*Hormosira banksii*) on shallow reefs, but after 3–4 months move down the estuary to other habitats e.g., brown kelp beds. At approximately one year old, they move out to coastal reefs in the immediate vicinity of estuary mouths and over the following 2–3 years move to reef systems further off- and along-shore (Morrison 1990).

Parore are important herbivores in coastal systems and may play a major role in structuring algal assemblages (Morrison 1990). Juvenile parore have been found in the stomachs of kahawai and John dory.

3. STOCKS AND AREAS

There is insufficient biological information available on this species to indicate the existence of separate stocks around New Zealand. However, reliance on localized nursery areas suggests that more than one biological stock may exist.

4. STOCK ASSESSMENT

There has been no scientific assessment of the maximum sustainable yield for parore stocks.

5. STATUS OF THE STOCK

There is no fishery independent information to determine the stock status of parore. Biomass estimates cannot be determined for this species with existing data. Estimates of current and reference biomass are not available. It is not known if recent catch levels or TACs are sustainable. The status of PAR 1, 2 and 9 relative to B_{MSY} is unknown.

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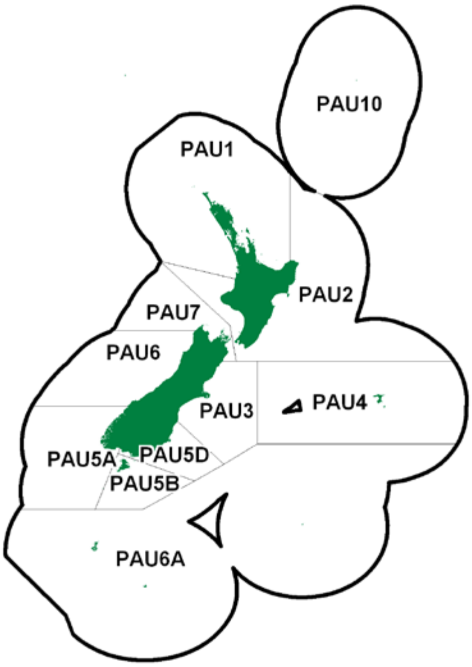
PĀUA (PAU)

(*Haliotis iris, Haliotis australis*)



1. INTRODUCTION

Specific Working Group reports are given separately for PAU 2, PAU 3, PAU 4, PAU 5A, PAU 5B, PAU 5D and PAU 7. The TACC for PAU 1, PAU 6 and PAU 10 is 1.93 t, 1 t and 1 t respectively. Commercial landings for PAU 10 since 1983 have been 0 t.

1.1 Commercial fisheries

The commercial fishery for pāua dates from the mid-1940s. In the early years of this commercial fishery the meat was generally discarded and only the shell was marketed, however by the late 1950s both meat and shell were being sold. Since the 1986–87 fishing season, the eight Quota Management Areas have been managed with an individual transferable quota system and a total allowable catch (TAC) that is made up of total allowed commercial catch (TACC), recreational and customary catch and other sources of mortality.

Fishers gather pāua by hand while free diving. The use of underwater breathing apparatus (UBA) is not permitted except in the PAU 4 fishery. Due to safety concerns concerning great white shark interactions, the use of UBAs has been permitted in the Chatham Island pāua fishery (PAU 4) since 2012. Most of the catch is from the Wairarapa coast southwards: the major fishing areas are in the South Island, Marlborough (PAU 7), Stewart Island (PAU 5A, 5B and 5D) and the Chatham Islands (PAU 4). Virtually the entire commercial fishery is for the black-foot pāua, *Haliotis iris*, with a minimum legal size for harvesting of 125 mm shell length. The yellow-foot pāua, *H. australis* is less abundant than *H. iris* and is caught only in small quantities; it has a minimum legal size of 80 mm. Catch statistics include both *H. iris* and *H. australis*.

2016 saw PAU 7 TACC reductions and voluntary ACE shelving by quota owners forgoing catching a portion of their quota, by 50 percent. A further 10% of the PAU 7 TACC was shelved in 2017 to remove any excess commercial fishing effort in areas either side of the earthquake closure; this shelving is still current for the 2018–19 fishing year.

Up until the 2002 fishing year, catch was reported by general statistical areas, however from 2002 onwards, a more fine scale system of pāua specific statistical areas were put in place throughout each QMA (refer to the QMA specific Plenary chapters). Figure 1 shows the historical landings for the main

PAU stocks. On 1 October 1995 PAU 5 was divided into three separate QMAs: PAU 5A, PAU 5B and PAU 5D.

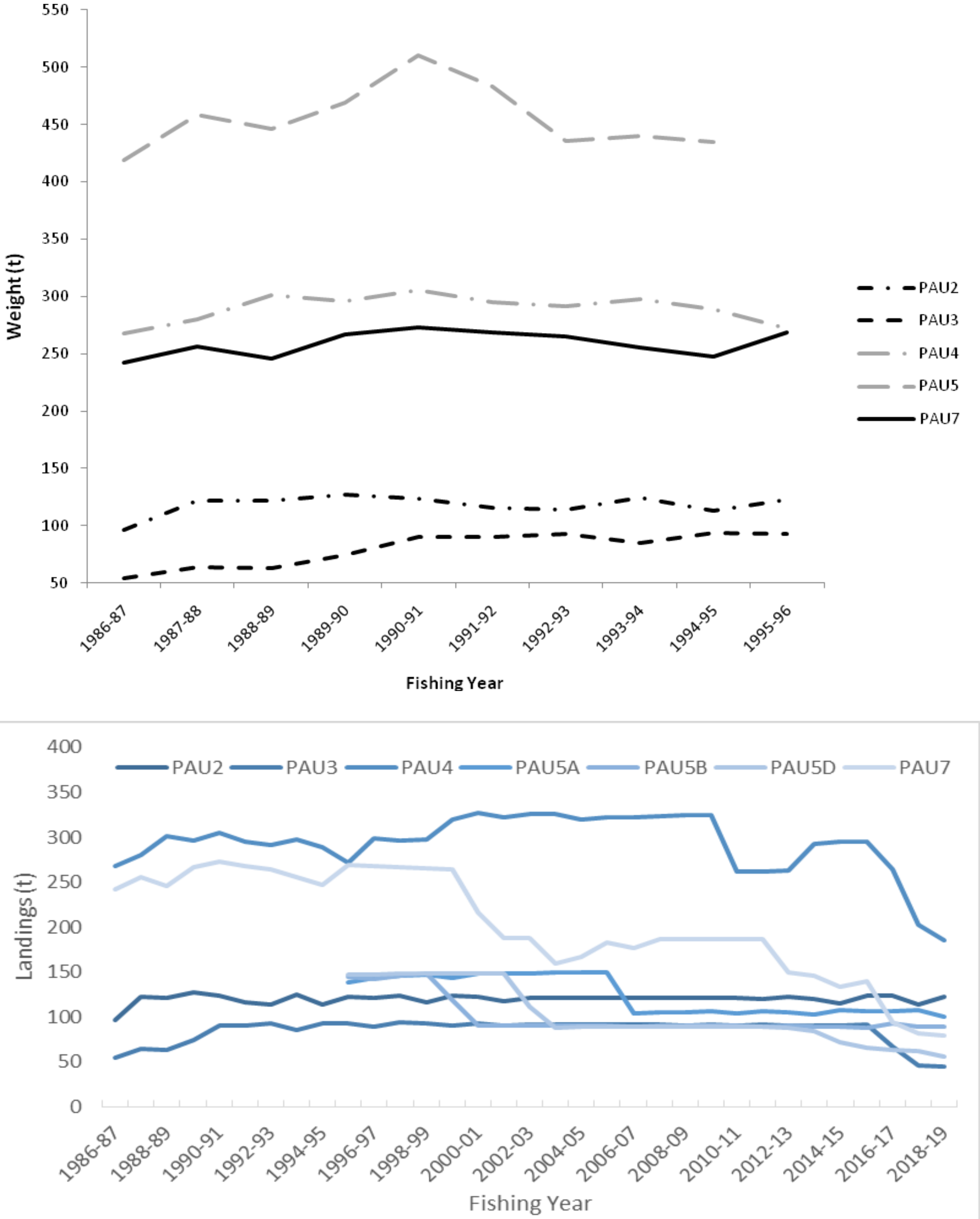


Figure 1: Historic landings for the major pāua QMAs from 1983–84 to 1995–96 (top) and from 1996–97 to 2018-19 (lower).

Landings for PAU 1, PAU 6, PAU 10 and PAU 5 (prior to 1995) are shown in Table 1. PAU 1 landings have been below the TACC since its introduction in 1986–87, with no landings recorded for 2017–18 and just 0.22 t recorded in 2018–19. In contrast PAU 6 landings have been close to the TACC since the fishing year 2006–07. For information on landings specific to other pāua QMAs refer to the specific Working Group reports.

1.2 Recreational fisheries

There is a large recreational fishery for pāua. Estimated catches from telephone and diary surveys of recreational fishers (Teirney et al 1997, Bradford 1998, Boyd & Reilly 2004, Boyd et al 2004) are shown in Table 2.

The harvest estimates provided by telephone-diary surveys between 1993 and 2001 are no longer considered reliable for various reasons. A Recreational Technical Working Group concluded that these harvest estimates should be used only with the following qualifications: a) they may be very inaccurate; b) the 1996 and earlier surveys contain a methodological error; and c) the 2000 and 2001 estimates are implausibly high for many important fisheries. In response to these problems and the cost and scale challenges associated with onsite methods, a National Panel Survey was conducted for the first time throughout the 2011–12 fishing year. The panel survey used face-to-face interviews of a random sample of 30 390 New Zealand households to recruit a panel of fishers and non-fishers for a full year. The panel members were contacted regularly about their fishing activities and harvest information collected in standardised phone interviews. The panel survey was repeated in 2017–18 (Wynne-Jones et al 2019). Harvest estimates for pāua are given in Table 3 (from Wynne-Jones et al 2014 using mean weights from Hartill & Davey 2015 and from Wynne-Jones et al 2019).

Table 1: TACCs and reported landings (t) of pāua by Fishstock from 1983–84 to present.

	PAU 1		PAU 5		PAU 6		PAU 10	
PAU	Landings	TACC	Landings	TACC	Landings	TACC	Landings	TACC
1983–84*	1	-	550	-	0.00	-	0.00	-
1984–85*	0	-	353	-	3.00	-	0.00	-
1985–86*	0	-	228	-	0.00	-	0.00	-
1986–87*	0.01	1.00	418.9	445	0.00	1.00	0.00	1.00
1987–88*	0.98	1.00	465	448.98	0.00	1.00	0.00	1.00
1988–89*	0.05	1.93	427.97	449.64	0.00	1.00	0.00	1.00
1989–90	0.28	1.93	459.46	459.48	0.00	1.00	0.00	1.00
1990–91	0.16	1.93	528.16	484.94	0.23	1.00	0.00	1.00
1991–92	0.27	1.93	486.76	492.06	0.00	1.00	0.00	1.00
1992–93	1.37	1.93	440.15	442.85	0.88	1.00	0.00	1.00
1993–94	1.05	1.93	440.39	442.85	0.10	1.00	0.00	1.00
1994–95	0.26	1.93	436.13	442.85	18.21H	1.00	0.00	1.00
1995–96	0.99	1.93	-	-	28.62H	1.00	0.00	1.00
1996–97	1.28	1.93	-	-	0.11	1.00	0.00	1.00
1997–98	1.28	1.93	-	-	0.00	1.00	0.00	1.00
1998–99	1.13	1.93	-	-	0.00	1.00	0.00	1.00
1999–00	0.69	1.93	-	-	1.04	1.00	0.00	1.00
2000–01	1.00	1.93	-	-	0.00	1.00	0.00	1.00
2001–02	0.32	1.93	-	-	0.00	1.00	0.00	1.00
2002–03	0.00	1.93	-	-	0.00	1.00	0.00	1.00
2003–04	0.05	1.93	-	-	0.00	1.00	0.00	1.00
2004–05	0.27	1.93	-	-	0.00	1.00	0.00	1.00
2005–06	0.45	1.93	-	-	0.00	1.00	0.00	1.00
2006–07	0.76	1.93	-	-	1.00	1.00	0.00	1.00
2007–08	1.14	1.93	-	-	1.00	1.00	0.00	1.00
2008–09	0.47	1.93	-	-	1.00	1.00	0.00	1.00
2009–10	0.20	1.93	-	-	1.00	1.00	0.00	1.00
2010–11	0.12	1.93	-	-	1.00	1.00	0.00	1.00
2011–12	0.77	1.93	-	-	1.00	1.00	0.00	1.00
2012–13	1.06	1.93	-	-	1.00	1.00	0.00	1.00
2013–14	0.71	1.93	-	-	1.00	1.00	0.00	1.00
2014–15	0.47	1.93	-	-	1.00	1.00	0.00	1.00
2015–16	0.13	1.93	-	-	0.84	1.00	0.00	1.00
2016–17	0.25	1.93	-	-	1.06	1.00	0.00	1.00
2017–18	0.00	1.93	-	-	1.04	1.00	0.00	1.00
2018–19	0.22	1.93	-	-	1.00	1.00	0.00	1.00

H experimental landings
* FSU data

Table 2: Estimated annual harvest of pāua (t) by recreational fishers from telephone-diary surveys*.

Fishstock	PAU 1	PAU 2	PAU 3	PAU 5	PAU 5A	PAU 5B	PAU 5D	PAU 6	PAU 7
1991–92	-	-	35–60	50–80	-	-	-	-	-
1992–93	-	37–89	-	-	-	-	-	0–1	2–7
1993–94	29–32	-	-	-	-	-	-	-	-
1995–96	10–20	45–65	-	20–35	-	-	-	-	-
1996–97	-	-	-	N/A	-	-	22.5	-	-
1999–00	40–78	224–606	26–46	36–70	-	-	26–50	2–14	8–23
2000–01	16–37	152–248	31–61	70–121	-	-	43–79	0–3	4–11

*1991–1995 Regional telephone/diary estimates, 1995/96, 1999/00 and 2000/01 National Marine Recreational Fishing Surveys.

1.3 Customary fisheries

There is an important customary use of pāua by Maori for food, and the shells have been used extensively for decorations and fishing devices. Limited quantitative information on the level of customary take is available from Fisheries New Zealand (Table 4). These numbers are likely to be an underestimate of customary harvest as only the catch in kilograms and numbers are reported in the table. In addition, many tangata whenua also harvest pāua under their recreational allowance and these are not included in records of customary catch.

1.4 Illegal catch

There is qualitative data to suggest significant illegal, unreported, unregulated (IUU) activity in this fishery. Current quantitative levels of illegal harvests are not known. In the past, annual estimates of illegal harvest for some Fishstocks were provided by MFish Compliance based on seizures. In the current pāua stock assessments, nominal illegal catches are used.

Table 3: Recreational harvest estimates for pāua stocks from the national panel survey in 2011–12 (Wynne-Jones et al 2014) and 2017–18 (Wynne-Jones et al 2019). Mean fish weights were obtained from boat ramp surveys (Hartill & Davey 2015).

Stock	Fishers	Events	Number of pāua	CV	Total weight (t)	CV
2011–12 (national panel survey)						
PAU 1	39	63	43 480		12.16	0.27
PAU 2	158	378	286 182		81.85	0.15
PAU 3	35	67	60 717		16.98	0.31
PAU 5A	2	3	1 487		0.42	0.76
PAU 5B	5	5	2 945		0.82	0.50
PAU 5D	41	84	80 290		22.45	0.30
PAU 7	19	41	50 534		14.13	0.34
PAU total	299	641	525 635		148.82	0.11
2017–18 (national panel survey)						
PAU 1	27	41	27 707	0.34	8.74	0.34
PAU 2	151	367	283 240	0.15	83.22	0.15
PAU 3	21	46	28 140	0.35	8.79	0.35
PAU 5A	3	4	2 419	0.76	0.85	0.76
PAU 5B	10	21	15 361	0.45	9.85	0.45
PAU 5D	48	88	55	0.21	19.28	0.21
PAU 6	E	e	3 076	0.60	0.95	0.61
PAU 7	11	16	10 576	0.36	3.02	0.36
PAU total	274	590	425 661		134.70	

Table 4: Fisheries New Zealand records of customary harvest of pāua (reported as weight (kg) and numbers), since 1998-99. – no data. [Continued next page]

				PAU 1				PAU 2
	Weight (kg)		Numbers		Weight (kg)		Numbers	
Fishing year	Approved	Harvested	Approved	Harvested	Approved	Harvested	Approved	Harvested
1998–99	–	–	–	–	40	40	–	–
1999–00	–	–	–	–	–	–	1 400	820
2000–01	–	–	–	–	–	–	–	–
2001–02	–	–	–	–	–	–	–	–
2002–03	–	–	30	30	–	–	–	–
2003–04	–	–	184	146	–	–	4 805	4 685
2004–05	–	–	240	220	–	–	2 780	2 440
2005–06	125	100	40	40	–	–	5 349	4 385
2006–07	705	581	2 175	1 925	–	–	7 088	3 446
2007–08	460	413	2 155	1 618	–	–	11 298	6 164
2008–09	491	191	2 915	2 228	–	–	30 312	24 155
2009–10	184	43	2 825	2 225	–	–	5 505	4 087
2010–11	154	129	5 915	3 952	–	–	20 570	17 062
2011–12	25	8	470	470	243	243	29 759	23 932
2012–13	20	20	1 305	1 193	10	6	51 275	27 653
2013–14	–	–	–	–	–	–	61 486	30 129
2014–15	45	33	700	536	–	–	25 215	16 449
2015–16	50	9	1 425	756	–	–	11 540	6 383
2016–17	–	–	2 190	618	–	–	13 698	6 877
2017–18	15	15	4 612	3 127	–	–	6 960	1 942
2018–19	–	–	1 348	690			8 565	3 189

				PAU 3*				PAU 4
	Weight (kg)		Numbers		Weight (kg)		Numbers	
Fishing year	Approved	Harvested	Approved	Harvested	Approved	Harvested	Approved	Harvested
1998–99	–	–	–	–	–	–	–	–
1999–00	–	–	–	–	–	–	–	–
2000–01	–	–	300	230	–	–	–	–
2001–02	200	50	6 239	4 832	–	–	–	–
2002–03	–	–	3 422	2 449	–	–	–	–
2003–04	–	–	–	–	–	–	–	–
2004–05	–	–	–	–	–	–	–	–
2005–06	–	–	1 580	1 220	–	–	–	–
2006–07	–	–	5 274	4 561	–	–	–	–

Table 4 [Continued]

	PAU 3*				PAU 4			
	Weight (kg)		Numbers		Weight (kg)		Numbers	
Fishing year	Approved	Harvested	Approved	Harvested	Approved	Harvested	Approved	Harvested
2007–08	–	–	7 515	5 790	–	–	–	–
2008–09	–	–	10 848	8 232	–	–	–	–
2009–10	–	–	8 490	6 467	–	–	635	635
2010–11	–	–	8 360	7 449	–	–	–	–
2011–12	–	–	5 675	4 242	–	–	–	–
2012–13	–	–	15 036	12 874	–	–	–	–
2013–14	–	–	10 259	7 566	–	–	110	110
2014–15	–	–	8 761	7 035	–	–	150	150
2015–16	–	–	14 801	11 808	–	–	320	120
2016–17	–	–	11 374	9 217	–	–	366	366
2017–18	–	–	2 708	1 725	50	50	820	764
2018–19			480	278	330	330		

	PAU 5A				PAU 5B			
	Weight (kg)		Numbers		Weight (kg)		Numbers	
Fishing year	Approved	Harvested	Approved	Harvested	Approved	Harvested	Approved	Harvested
1998–99	–	–	–	–	–	–	–	–
1999–00	–	–	–	–	–	–	–	–
2000–01	–	–	–	–	–	–	50	50
2001–02	–	–	80	70	–	–	610	590
2002–03	–	–	–	–	–	–	–	–
2003–04	–	–	–	–	–	–	–	–
2004–05	–	–	–	–	–	–	–	–
2005–06	–	–	–	–	–	–	140	90
2006–07	–	–	–	–	–	–	485	483
2007–08	–	–	100	100	–	–	2 685	2 684
2008–09	–	–	100	100	–	–	3 520	3 444
2009–10	–	–	150	150	–	–	2 680	2 043
2010–11	–	–	150	150	–	–	2 053	1 978
2011–12	–	–	512	462	–	–	495	495
2012–13	–	–	590	527	–	–	1 875	1 828
2013–14	–	–	–	–	–	–	130	130
2014–15	–	–	–	–	–	–	–	–
2015–16	–	–	255	50	–	–	2 195	2 003
2016–17	–	–	–	–	–	–	75	75
2017–18	–	–	200	200	–	–	2 245	2 245
2018–19	–	–	–	–			1 405	1 337

	PAU 5D				PAU 6			
	Weight (kg)		Numbers		Weight (kg)		Numbers	
Fishing year	Approved	Harvested	Approved	Harvested	Approved	Harvested	Approved	Harvested
1998–99	–	–	–	–	–	–	–	–
1999–00	–	–	–	–	–	–	–	–
2000–01	–	–	665	417	–	–	–	–
2001–02	–	–	5 530	3 553	–	–	–	–
2002–03	–	–	2 435	1 351	–	–	–	–
2003–04	–	–	–	–	–	–	–	–
2004–05	–	–	–	–	–	–	–	–
2005–06	–	–	1 560	1 560	–	–	–	–
2006–07	–	–	2 845	2 126	–	–	100	100
2007–08	–	–	5 600	5 327	–	–	60	60
2008–09	–	–	6 646	6 094	–	–	–	–
2009–10	–	–	4 840	4 150	–	–	–	–
2010–11	–	–	15 806	15 291	–	–	230	130
2011–12	–	–	7 935	7 835	–	–	–	–
2012–13	–	–	10 254	8 782	–	–	–	–
2013–14	–	–	5 720	5 358	–	–	–	–
2014–15	–	–	–	–	–	–	–	–
2015–16	–	–	15 922	13 110	–	–	50	50
2016–17	–	–	3 676	3 576	–	–	80	80
2017–18	–	–	3 588	3 310	–	–	–	–
2018–19	–	–	950	894				

	PAU 7			
	Weight (kg)		Numbers	
Fishing year	Approved	Harvested	Approved	Harvested
1998–99	–	–	–	–
1999–00	–	–	–	–
2000–01	–	–	–	–
2001–02	–	–	–	–
2002–03	–	–	–	–
2003–04	–	–	–	–
2004–05	–	–	–	–
2005–06	–	–	–	–
2006–07	–	–	–	–

Table 4 [Continued]

	PAU 7			
	Weight (kg)		Numbers	
Fishing year	Approved	Harvested	Approved	Harvested
2007–08	–	–	1 110	808
2008–09	–	–	1 270	1 014
2009–10	–	–	1 085	936
2010–11	–	–	60	31
2011–12	–	–	20	20
2012–13	–	–	–	–
2013–14	–	–	–	–
2014–15	–	–	–	–
2015–16	–	–	–	–
2016–17	–	–	–	–
2017–18	–	–	–	–
2018–19			–	–

*: data before 2010–11 exclude the area between the Hurunui River and the South Shore (just north of Banks Peninsula), as Tangata Tiaki were not appointed there until November 2009.

1.5 Other sources of mortality

Pāua may die from wounds caused by removal desiccation or osmotic and temperature stress if they are brought to the surface. Sub-legal pāua may be subject to handling mortality by the fishery if they are removed from the substrate to be measured. Further mortality may result indirectly from being returned to unsuitable habitat or being lost to predators or bacterial infection. Gerring (2003) observed pāua (from PAU 7) with a range of wounds in the laboratory and found that only a deep cut in the foot caused significant mortality (40% over 70 days). In the field this injury reduced the ability of pāua to right themselves and clamp securely onto the reef, and consequently made them more vulnerable to predators. The tool generally used by divers in PAU 7 is a custom made stainless steel knife with a rounded tip and no sharp edges. This design makes cutting the pāua very unlikely (although abrasions and shell damage may occur). Gerring (2003) estimated that in PAU 7, 37% of pāua removed from the reef by commercial divers were undersize and were returned to the reef. His estimate of incidental mortality associated with fishing in PAU 7 was 0.3% of the landed catch. Incidental fishing mortality may be higher in areas where other types of tools and fishing practices are used. Mortality may increase if pāua are kept out of the water for a prolonged period or returned onto sand. To date, the stock assessments developed for pāua have assumed that there is no mortality associated with capture of undersize animals.

2. BIOLOGY

Pāua are herbivores which can form large aggregations on reefs in shallow subtidal coastal habitats. Movement is over a sufficiently small spatial scale that the species may be considered sedentary. Pāua are broadcast spawners and spawning is usually annual. Habitat related factors are an important source of variation in the post-settlement survival of pāua. Growth, morphometrics, and recruitment can vary over short distances and may be influenced by factors such as water temperature, wave exposure, habitat structure and the availability of food. Naylor et al (2016) analysed demographic variation in pāua in New Zealand. They concluded that there were large differences in the growth rates and maximum size over a large latitudinal range. Their analysis indicated that water temperature, as indicated by sea surface temperature, was an important determinant of these. Pāua become sexually mature when they are about 70–90 mm long, or 3–5 years old. A summary of generic estimates for biological parameters for pāua is presented in Table 5. Parameters specific to individual pāua QMAs are reported in the specific Working Group reports.

Table 5: Estimates of biological parameters for pāua (H. *iris*).

Fishstock		Estimate	Source
1. Natural mortality (M)			
All		0.02–0.25	Sainsbury (1982)
2. Weight = a (length)^b (weight in kg, shell length in mm)			
	a = 2.99E^{-08}	b = 3.303	Schiel & Breen (1991)

3. STOCKS AND AREAS

Using both mitochondrial and microsatellite markers Will & Gemmell (2008) found high levels of genetic variation within samples of *H. Iris* taken from 25 locations spread throughout New Zealand. They also found two patterns of weak but significant population genetic structure. Firstly, *H. iris* individuals collected from the Chatham Islands were found to be genetically distinct from those collected from coastal sites around the North and South Islands. Secondly a genetic discontinuity was found loosely associated with the Cook Strait region. Genetic discontinuities within the Cook Strait region have previously been identified in sea stars, mussels, limpets, and chitons and are possibly related to contemporary and/or past oceanographic and geological conditions of the region. This split may have some implications for management of the pāua stocks, with populations on the south of the North Island, and the north of the South Island potentially warranting management as separate entities; a status they already receive under the zonation of the current fisheries regions, PAU 2 in the North Island, and PAU 7 on the South Island.

4. ENVIRONMENTAL AND ECOSYSTEM CONSIDERATIONS

This section was updated for the 2020 Fishery Assessment Plenary. A more detailed summary from an issue-by-issue perspective is available in the 2018 Aquatic Environment & Biodiversity Annual Review (Ministry for Primary Industries 2019, https://www.mpi.govt.nz/dmsdocument/34854-aquatic-environment-and-biodiversity-annualreview-aebar-2018-a-summary-of-environmental-interactions-between-the-seafood-sector-and-the-aquatic-environment)

4.1 Ecosystem role

Pāua are eaten by a range of predators, and smaller pāua are generally more vulnerable to predation. Smaller pāua are consumed by blue cod (Carbines & Beentjes 2003), snapper (Francis 2003), banded wrasse (Russell 1983), spotties (McCardle 1983), triplefins (McCardle 1983) and octopus (Andrew & Naylor 2003). Large pāua are generally well protected by their strong shells, but are still vulnerable to rock lobsters (McCardle 1983) and the large predatory starfishes *Astrostole scabra* and *Coscinasterias muricata* (Andrew & Naylor 2003). Large pāua are also vulnerable to predation by eagle rays (McCardle 1983), but Ayling & Cox (1982) suggested that eagle rays feed almost exclusively on Cook’s turban. There are no known predators that feed exclusively on pāua.

Pāua feed preferentially on drift algae but at high densities they also feed by grazing attached algae. They are not generally considered to have a large structural impact upon algal communities but at high densities they may reduce the abundance of algae. There are no recognised interactions with pāua abundance and the abundance or distribution of other species, with the exception of kina which, at very high densities, appear to exclude pāua (Andrew et al 2000). Research at D’Urville Island and on Wellington’s south coast suggests that there is some negative association between pāua and kina (Andrew & MacDiarmid 1999).

4.2 Fish and invertebrate bycatch

Because pāua are harvested by hand gathering, incidental bycatch is limited to epibiota attached to, or within the shell. The most common epibiont on pāua shell is non-geniculate coralline algae, which, along with most other plants and animals which settle and grow on the shell, such as barnacles, oysters, sponges, bryozoans, and algae, appears to have general habitat requirements (i.e. these organisms are not restricted to the shells of pāua). Several boring and spiral-shelled polychaete worms are commonly found in and on the shells of pāua. Most of these are found on several shellfish species, although within New Zealand’s shellfish, the onuphid polychaete *Brevibrachium maculatum* has been found only in pāua shell (Handley 2004). This species; however, has also been reported to burrow into limestone, or attach its tube to the holdfasts of algae (Read 2004). It is also not uncommon for pāua harvesters to collect predators of pāua (mainly large predatory starfish) while fishing and to effectively remove these from the ecosystem. The levels of these removals are unlikely to have a significant effect on starfish populations (nor, in fact, on the mortality of pāua caused by predation).

4.3 Incidental catch (seabirds, mammals, and protected fish)

There is no known bycatch of threatened, endangered, or protected species associated with the hand gathering of pāua.

4.4 Benthic interactions

The environmental impact of pāua harvesting is likely to be minimal because pāua are selectively hand gathered by free divers. Habitat contact by divers at the time of harvest is limited to the area of pāua foot attachment, and pāua are usually removed with a blunt tool to minimise damage to the flesh. The diver's body is also seldom in full contact with the benthos. Vessels anchoring during or after fishing have the potential to cause damage to the reef depending on the type of diving operation (in many cases, vessels do not anchor during fishing). Damage from anchoring is likely to be greater in areas with fragile species such as corals than it is on shallow temperate rocky reefs. Corals are relatively abundant at shallow depths within Fiordland, but there are seven areas within the sounds with significant populations of fragile species where anchoring is prohibited.

4.5 Other considerations

4.5.1 Genetic effects

Fishing, and environmental changes, including those caused by climate change or pollution, could alter the genetic composition or diversity of a species and there is some evidence to suggest that genetic changes may occur in response to fishing of abalones. Miller et al (2009) suggested that, in *Haliotis rubra* in Tasmania, localised depletion will lead to reduced local reproductive output which may, in turn, lead to an increase in genetic diversity because migrant larval recruitment will contribute more to total larval recruitment. Enhancement of pāua stocks with artificially-reared juveniles has the potential to lead to genetic effects if inappropriate broodstocks are used.

4.5.2 Biosecurity issues

Undaria pinnatifida is a highly invasive opportunistic kelp which spreads mainly via fouling on boat hulls. It can form dense stands underwater, potentially resulting in competition for light and space which may lead to the exclusion or displacement of native plant and animal species. *Undaria* may be transported on the hulls of pāua dive tenders to unaffected areas. Bluff Harbour, for example, supports a large population of *Undaria*, and is one of the main ports of departure for fishing vessels harvesting pāua in Fiordland, which appears to be devoid of *Undaria* (R. Naylor, personal observation). In 2010, a small population of *Undaria* was found in Sunday Cove in Breaksea Sound, and attempts to eradicate it appear to have been successful (see http://www.biosecurity.govt.nz/pests/undaria).

4.5.3 Kaikōura Earthquake

Research was undertaken to investigate the influence of the November 2016 Kaikōura earthquake on pāua stocks in the area of the Kaikōura coastline. The results estimated that the seabed uplift led to a loss of up to 50% of the pre-earthquake fished area across PAU 3 statistical areas. More details can be found in the PAU 3 Working Group report.

4.5.4 Marine heatwave

A baseline report summarising trends in climatic and oceanographic conditions in New Zealand that are of potential relevance for fisheries and marine ecosystem resource management in the New Zealand region has been completed (Hurst et al 2012). There is also an updated chapter on oceanic trends in the Aquatic Environment and Biodiversity Annual Review 2018 (Ministry for Primary Industries 2019). Any effects of recent warmer temperatures (such as the high surface temperatures on the WCSI during the 2016 and 2017 spawning seasons, marine heatwaves and general warming of the Tasman Sea (Sutton & Bowen 2019) on fish distribution, growth, or spawning success have yet to be determined.

Shellfish fisheries have been identified as likely to be vulnerable to ocean acidification (Capson & Guinotte 2014). A recent project that has just reached completion describes the state of knowledge of climate change-associated predictions for components of New Zealand's marine environment that are most relevant to fisheries (Cumming et al in press). Past and future projected changes in coastal and ocean properties, including temperature, salinity, stratification and water masses, circulation, oxygen, ocean productivity, detrital flux, ocean acidification, coastal erosion and sediment loading, wind and waves, are reviewed. Responses to climate change for these coastal and ocean properties are discussed, as well as their likely impact on the fisheries sector, where known.

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

5. STOCK ASSESSMENT

The dates of the most recent survey or stock assessment for each QMA are listed in Table 6.

Table 6: Recent survey and stock assessment information for each pāua QMA [Continued next page]

QMA	Type of survey or assessment	Date	Comments
PAU 1	No surveys or assessments have been undertaken		
PAU 2	CPUE standardisation using a Bayesian Generalised Linear Mixed Model (GLMM)	2020	Standardised CPUE showed slight oscillation without trend since 2007.
PAU 3	Quantitative assessment using a Bayesian length based model	2013	For the 2013 stock assessment nine model runs were conducted. The Shellfish Working Group agreed on a base case model which estimated M within the model but fixed the growth parameters as providing a reliable estimate of the status of the stocks in PAU 3 with the caveat that the model most likely underestimated uncertainty in growth but adequately estimated uncertainty in natural mortality. The status of the stock was estimated to be 52% B_0
PAU 4	CPUE Standardisation	2016	In February 2010 the Shellfish Working Group (SFWG) agreed that, due to the lack of data of adequate quality to use in the Bayesian length-based model, a stock assessment for PAU 4 using this model was not appropriate. In 2016 an analysis of the last 14 years of CPUE data was done. This report showed a potential decline in the fishery since the early 2000s, however the poor data quality is causing considerable uncertainty about the real trend in the fishery.
PAU 5A	Quantitative assessment using a Bayesian length based model	2020	The 2020 stock assessment was implemented as a single area model together with a three-area spatial model to corroborate findings from the single area model. The status of the stock was estimated to be 51% B_0. At current levels of catch spawning stock biomass is projected to remain nearly unchanged at 51% B_0 after 3 years, with an equilibrium value of 50% of B_0.
PAU 5B	Quantitative assessment using a Bayesian length based model	2018	The 2018 Plenary accepted this assessment as best scientific information. The status of the stock was estimated to be 47% B_0.

Table 6 [Continued]: Recent survey and stock assessment information for each pāua QMA.

PAU 5D	Quantitative assessment using a Bayesian length based model	2019	The reference case model estimated that the unfished spawning stock biomass (B_0) was about 2029 t (1673–2535 t) and the spawning stock population in 2018 (B_{2018}) was about 40% (25–65%) of B_0. The model projection made for three years assuming current catch levels (which includes commercial catch at and using recruitment re-sampled from the recent model estimates, suggested that the spawning stock abundance will remain at 42% (28–52%) B_0 over the next three years. The projection also indicated that the probability of the spawning stock biomass being above the target (40% B_0) will decrease from about 52% in 2018 to 49% by 2021.
PAU 6	Biomass estimate	1996	This fishery has a TACC of 1 t
PAU 7	Quantitative assessment using a Bayesian length based model	2015	The SFWG agreed that the stock assessment was reliable based on the available data. Currently, spawning stock biomass is estimated to be 18% B_0 and is about as likely as not to be below the soft limit, with fishing intensity very likely to be above the overfishing threshold.
PAU 10	No surveys or assessments have been undertaken		

5.1 Estimates of fishery parameters and abundance

For further information on fishery parameters and abundance specific to each pāua QMA refer to the specific Working Group report.

In 2014 standardised CPUE indices were constructed to assess relative abundance in PAU 2. In QMAs where quantitative stock assessments have been undertaken, standardised CPUE is also used as input data for the Bayesian length-based stock assessment model. There is however a large amount of literature on abalone which suggests that any apparent stability in CPUE should be interpreted with caution and CPUE may not be proportional to abundance as it is possible to maintain high catch rates despite a falling biomass. This occurs because pāua tend to aggregate and, in order to maximise their catch rates, divers move from areas that have been depleted of pāua, to areas with higher density. The consequence of this fishing behaviour is that overall abundance is decreasing while CPUE is remaining stable. This process of hyperstability is believed to be of less concern in PAU 3, PAU 5D and PAU 7 because fishing in these QMAs is consistent across all fishable areas.

In PAU 4, 5A, 5B, 5D and 7 the relative abundance of pāua has also been estimated from independent research diver surveys (RDS). In PAU 7, seven surveys have been completed over a number of years but only two surveys have been conducted in PAU 4. In 2009 and 2010 several reviews were conducted (Cordue (2009) and Haist V (2010)) to assess; i) the reliability of the research diver survey index as a proxy for abundance; and ii) whether the RDS data, when used in the pāua stock assessment models, results in model outputs that do not adequately reflect the status of the stocks. The reviews concluded that:

- Due to inappropriate survey design the RDS data appear to be of very limited use for constructing relative abundance indices.
- There was clear non-linearity in the RDS index, the form of which is unclear and could be potentially complex.
- CVs of RDS index ‘year’ effects are likely to be underestimated, especially at low densities.
- Different abundance trends among strata reduces the reliability of RDS indices, and the CVs are likely to be uninformative about this.
- It is unlikely that the assessment model can determine the true non-linearity of the RDS index-abundance relationship because of the high variability in the RDS indices.
- The non-linearity observed in the RDS indices is likely to be more extreme at low densities, so the RDSI is likely to mask trends when it is most critical to observe them.
- Existing RDS data is likely to be most useful at the research stratum level.

5.2 Biomass estimates
Biomass was estimated for PAU 6 in 1996 (McShane et al 1996). However the survey area was only from Kahurangi Point to the Heaphy River.

Biomass has been estimated, as part of the stock assessments, for PAU 4, 5A, 5B, 5D and 7 (Table 6). For further information on biomass estimates specific to each pāua QMA refer to the specific Working Group report.

5.3 Yield Estimates and Projections
Yield estimates and projections are estimated as part of the stock assessment process. Both are available for PAU 3, PAU 5A, PAU 5B, PAU 5D and PAU 7. For further information on yield estimates and projections specific to each pāua QMA refer to the specific Working Group report.

5.4 Other factors
In the last few years the commercial fishery have been implementing voluntary management actions in the main QMAs. These management actions include raising the minimum harvest size and subdividing QMAs into smaller management areas and capping catch in the different areas and in some QMAs, not catching the full Annual Catch Entitlement (ACE) in a particular fishing year.

6. STATUS OF THE STOCKS

The status of pāua stocks PAU 2, PAU 3, PAU 4, PAU 5A, PAU 5B, PAU 5D and PAU 7 are given in the relevant Working Group reports.

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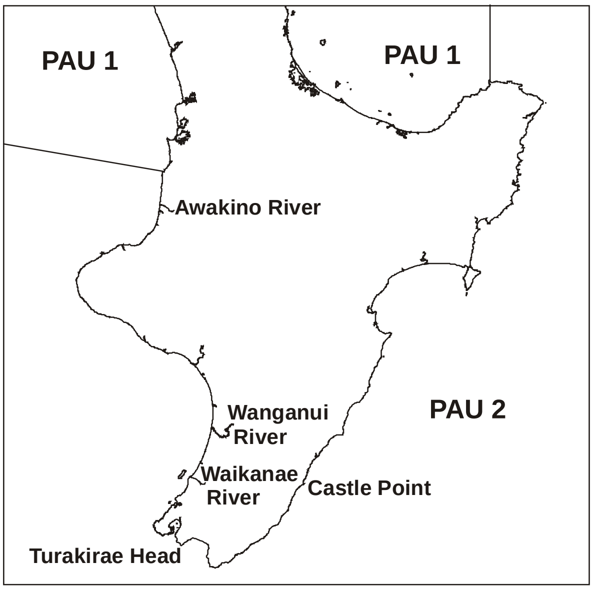
PĀUA (PAU 2) – Wairarapa / Wellington / Taranaki

(*Haliotis iris*)
Pāua



1. FISHERY SUMMARY

PAU 2 was introduced into the Quota Management System in 1986–87 with a TACC of 100 t. As a result of appeals to the Quota Appeal Authority, the TACC was increased to 121.19 t in 1989 and has remained unchanged to the current fishing year (Table 1). There is no TAC for this QMA; before the Fisheries Act (1996) a TAC was not required. When changes have been made to a TACC after 1996, stocks have been assigned a TAC.

Table 1: Total allowable catches (TAC, t), allowances for customary fishing, recreational fishing, and other sources of mortality (t), and Total Allowable Commercial Catches (TACC, t) declared for PAU 2 since introduction to the QMS.

Year	TAC	Customary	Recreational	Other mortality	TACC
1986–1989	–	–	–	–	100
1989–present	–	–	–	–	121.19

1.1 Commercial fisheries

The fishing year runs from 1 October to 30 September. Most of the commercial catch comes from the Wairarapa and Wellington South coasts between Castlepoint and Turakirae Head. The western area between Turakirae Head and the Waikanae River is closed to commercial fishing.

On 1 October 2001 it became mandatory to report catch and effort on PCELRs using the fine-scale reporting areas that had been developed by the New Zealand Pāua Management Company for their voluntary logbook programme (Figure 1). Landings for PAU 2 are shown in Table 2 and Figure 2.

1.2 Recreational fisheries

The most recent recreational fishery survey "The National Panel Survey of Marine Recreational Fishers 2017–18: Harvest Estimates" Wynne-Jones et al (2019), estimated that about 83 t of pāua were harvested by recreational fishers in PAU 2 in 2017–18.

Because pāua around Taranaki are naturally small and never reach the minimum legal size (MLS) of 125 mm, a new MLS of 85 mm was introduced for recreational fishers from 1 October 2009. The new length was on a trial basis for five years and now applies between the Awakino and Wanganui rivers.

For further information on recreational fisheries refer to the introductory PAU Working Group Report.

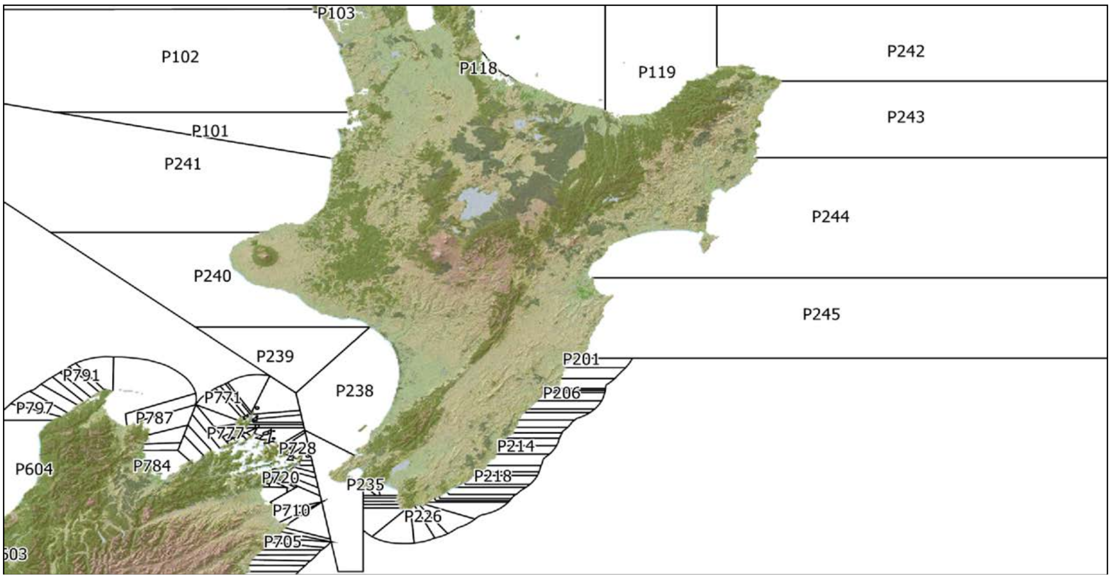


Figure 1: Map of fine-scale statistical reporting areas for PAU 2.

Table 2: TACC and reported landings (t) of pāua in PAU 2 from 1983–84 to the present.

Year	Landings	TACC
1983–84*	110	–
1984–85*	154	–
1985–86*	92	–
1986–87*	96.2	100
1987–88*	122.11	111.33
1988–89*	121.5	120.12
1989–90	127.28	121.19
1990–91	125.82	121.19
1991–92	116.66	121.19
1992–93	119.13	121.19
1993–94	125.22	121.19
1994–95	113.28	121.19
1995–96	119.75	121.19
1996–97	118.86	121.19
1997–98	122.41	121.19
1998–99	115.22	121.19
1999–00	122.48	121.19
2000–01	122.92	121.19
2001–02	116.87	121.19
2002–03	121.19	121.19
2003–04	121.06	121.19
2004–05	121.19	121.19
2005–06	121.14	121.19
2006–07	121.20	121.19
2007–08	121.06	121.19
2008–09	121.18	121.19
2009–10	121.13	121.19
2010–11	121.18	121.19
2011–12	120.01	121.19
2012–13	122	121.19
2013–14	120	121.19
2014–15	115	121.19
2015–16	123.74	121.19
2016–17	123.69	121.19
2017–18	113.87	121.19
2018–19	122.89	121.19

* FSU data.

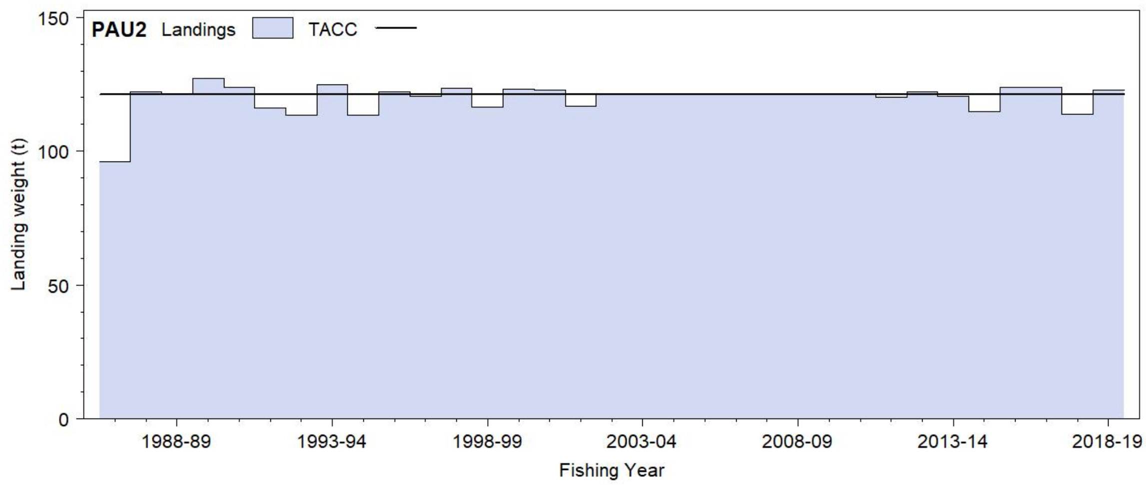


Figure 2: Historical landings and TACC for PAU 2 from 1983–84 to the present. QMS data from 1986–present.

1.3 Customary fisheries

Estimates of customary catch for PAU 2 are given in Table 3. These numbers are likely to be an underestimate of customary harvest because only the catch in kilograms and numbers are reported in the table.

Table 3: Fisheries New Zealand records of customary harvest of pāua (reported as weight (kg) and numbers) of pāua in PAU 2 between 1998-99 and 2018-19. – no data.

	Weight (kg)		Numbers	
Fishing year	**Approved**	**Harvested**	**Approved**	**Harvested**
1998–99	40	40	–	–
1999–00	–	–	1 400	820
2000–01	–	–	–	–
2001–02	–	–	–	–
2002–03	–	–	–	–
2003–04	–	–	4 805	4 685
2004–05	–	–	2 780	2 440
2005–06	–	–	5 349	4 385
2006–07	–	–	7 088	3 446
2007–08	–	–	11 298	6 164
2008–09	–	–	30 312	24 155
2009–10	–	–	5 505	4 087
2010–11	–	–	20 570	17 062
2011–12	243	243	29 759	23 932
2012–13	10	6	51 275	27 653
2013–14	–	–	61 486	30 129
2014–15	–	–	25 215	16 449
2015–16	–	–	11 540	6 383
2016–17	–	–	13 698	6 877
2017–18	–	–	6 960	1 942
2018–19	–	–	8 565	3 189

For further information on customary fisheries refer to the introductory PAU Working Group Report.

1.4 Illegal catch

It is widely believed that the level of illegal harvesting is high around Wellington and on the Wairarapa coast. For further information on illegal catch refer to the introductory PAU Working Group Report.

1.5 Other sources of mortality

For further information on other sources of mortality refer to the introductory PAU Working Group Report.

2. BIOLOGY

For further information on pāua biology refer to the introductory PAU Working Group Report. A summary of published estimates of biological parameters for PAU 2 is presented in Table 3.

Table 4: Estimates of biological parameters (*H. iris*)

Area		**Estimate**	**Source**
1. Size at maturity (shell length)			
Wellington	50% mature	71.7 mm	Naylor et al (2006)
Taranaki	50% mature	58.9 mm	Naylor & Andrew (2000)
2. Fecundity = a (length)^b (eggs, shell length in mm)			
Taranaki	a = 43.98	b = 2.07	Naylor & Andrew (2000)
3. Exponential growth parameters (both sexes combined)			
Wellington	g_{50}	30.58 mm	Naylor et al (2006)
	g_{100}	14.8 mm	
Taranaki	G_{25}	18.4 mm	Naylor & Andrew (2000)
	G_{75}	2.8 mm	

3. STOCKS AND AREAS

For further information on stocks and areas refer to the introductory PAU Working Group Report.

4. STOCK ASSESSMENT

In 2020, the Shellfish Fisheries Assessment Working Group evaluated the overall CPUE trend and concluded (given experience with other QMAs) that the data were potentially sufficient to conduct a full length-based stock assessment in line with those run for other QMAs (e.g., Neubauer & Tremblay-Boyer 2019, Neubauer 2020a). However, the Fisheries Assessment Plenary considered the stock assessment results to be insufficiently robust given concerns about the choice of the base-case scenario and sensitivities, and issues with use of the early CPUE data (i.e., FSU and CELR data). Concerns were also raised about the validity of region-wide CPUE and Catch Sampling Length-Frequency (CSLF) trends given the fine-scale stock structure of pāua. Overall, the Plenary concluded that the stock assessment model that had been developed was promising, but extra work was required before it could be accepted.

4.1 Relative abundance estimates from standardised CPUE analyses

A combined series of standardised CPUE indices that included FSU (1983–1989), CELR (1990–2001), and PCELR (2002–2019) data was initially considered for the 2020 stock assessment. However, the Plenary concluded that the FSU and CELR analyses were unlikely to represent biomass trends and should therefore be excluded. It was requested that the CPUE analysis be run with the PCELR data alone and used to make statements about the status of the stock.

There was little evidence in the data for serial depletion at statutory reporting scales; all main areas (i.e., excluding sporadically fished northern areas) were fished consistently throughout the time series (Figure 3).

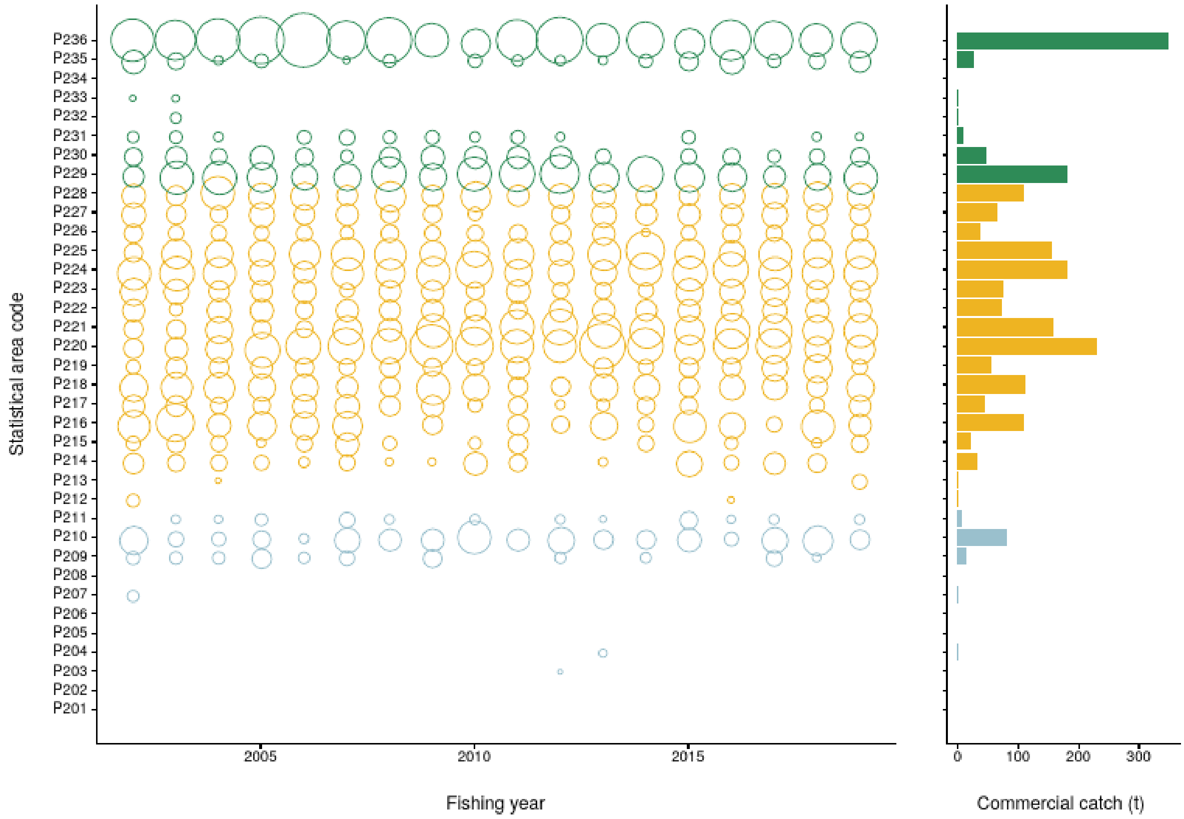


Figure 3: Relative trend in pāua catch (kg) over time by statistical areas in quota management area PAU 2 for the period from 2002 to 2019, with total catch over the same time period (right-hand side). Statistical reporting areas prior to 2002 within PAU 2 are colour coded (green: area 016, orange: area 015, blue: area 014).

Data were groomed to retain only records from statistical areas P201–P236. In addition, the following grooming rules were applied (the final dataset retained 81% of records):

1. Use only events with "diving" (DI) as method.
2. Remove items with missing fields needed for standardisation.
3. Remove events with a correction factor of > 0.2 (discrepancy between estimated catch and reported landings).
4. Remove client/fisher identification numbers (FIN), diver identification, and statistical areas that account for little diving effort (fewer than 20 events over all years).
5. Retain only events with fewer than eight recorded divers, and a recorded fishing duration of ≤ 12 h.

CPUE standardisation was carried out using a Bayesian Generalised Linear Mixed Model (GLMM) which partitioned variation among fixed (research strata) and random variables, and between fine-scale reporting (PCELR) and larger scale variables (CELR level; Neubauer & Tremblay-Boyer 2019). CPUE was defined as the log of daily catch per unit effort. Variables in the model were fishing year, FIN (Fisher Identification Number), research stratum, dive condition, diver ID, and fine-scale statistical area. Variability in CPUE was mostly explained by differences among crews (FINs), with diver ability and dive conditions affecting CPUE (Figure 4).

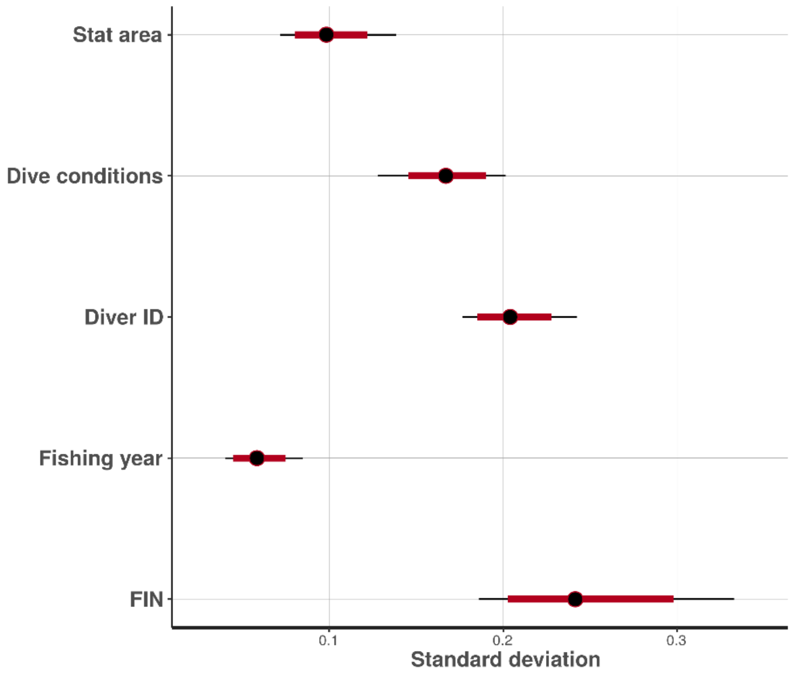


Figure 4: Effect size as variance explained for variables included in the GLMM CPUE standardisation model.

A decline was evident from the early part of the PCELR time series, with relatively stable but fluctuating CPUE since 2007 (Figure 5). In some circumstances, commercial CPUE may not be proportional to abundance because it is possible to maintain catch rates of pāua despite a declining biomass. This occurs because pāua tend to aggregate and divers move among areas to maximise their catch rates. The apparent stability in the CPUE should therefore be interpreted with caution. The assumption of CPUE being proportional to biomass was investigated using an assessment model, but the Plenary felt that, although the model was promising, more work was needed before an assessment could be accepted.

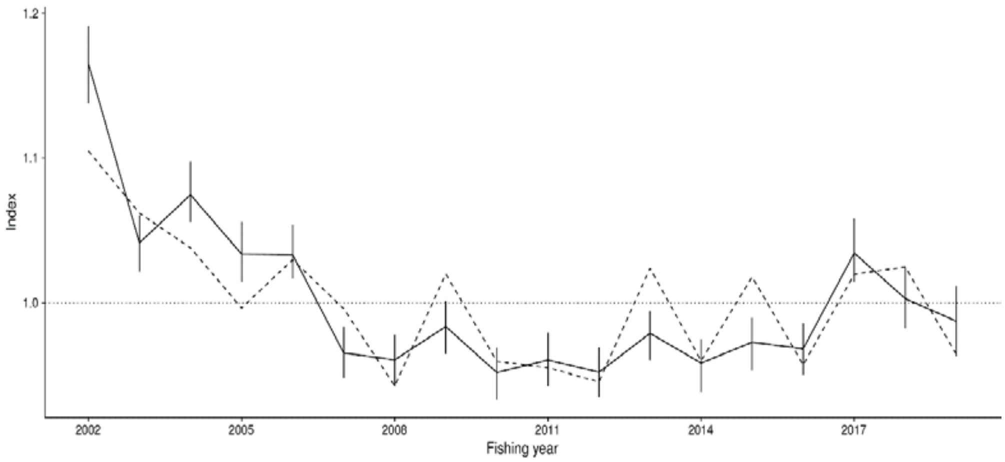


Figure 5: The standardised CPUE indices with 95% confidence intervals (solid line and vertical error bars) and unstandardised geometric CPUE (dashed line) for the PCELR series.

4.2 Future research considerations

The Plenary considered that the stock assessment model was promising, but that it needed extra work before it could be accepted. Accordingly, the following research considerations are split into those that should be implemented using existing data, and those related to longer term considerations (most of which are also applicable to other PAU stocks).

Short term

- The early catch history has considerable uncertainty. A table with best available estimates of commercial, recreational, customary, and illegal catches has been compiled in consultation with those knowledgeable about the fisheries; however, alternative reasonable sensitivities to these catch histories should be constructed and tested. It should probably be assumed that the illegal catch consists of smaller pāua than the other sources of catch.

- The early CPUE data (FSU and CELR) is of low quality and may have too much influence on estimating productivity. FSU data should probably be omitted in its entirety and the CELR and PCELR data should be constructed as two separate time series.
- Consider using measures of fishing success other than the FIN; for example, some measure of vessel experience factor or other measures of improvement to reflect the increasing professionalisation of the fleet over time. This should be incorporated at the stage of developing the CPUE rather than in the assessment model itself.
- Consider constructing the CPUE analysis with catch rather than CPUE as the dependent variable in order to guard against the potential for a non-linear relationship between catch and measures of effort. At the least, both alternative approaches should be considered.
- The model used to scale up the length frequency data may have resulted in a residual pattern. This should be investigated.
- The assessment model developed included a large number of parameters relative to the amount of data available. Consideration should be given to fixing some of these (e.g., M and h), and then conducting sensitivities based on other fixed values.
- More thought needs to be given to the selection of priors. Sensitivities to these priors should be determined to evaluate their influence on the model outcomes.
- A smaller standard deviation for the recruitment deviations could be considered.

Longer term

- It is unclear to what degree large scale aggregate statistics of commercial length frequency distributrions represent changes in the overall length composition of the fishery. Although standardisation of CSLF was carried out for the attempted stock assessment, systematic deviations from stock assessment model expectations point to potential problems with using aggregate CSLF data.
- More tagging is needed in a larger number of representative strata/areas to estimate growth.
- It is unclear whether a single area model (and an aggregate CPUE index) can adequately represent biomass trends for the many sub-populations in PAU stocks. Spatial use trends and variability in biomass trends can induce both positive and negative bias in CPUE, and more sophisticated models may be needed to counter these biases (e.g., spatio-temporal models, Neubauer 2017). Similarly, finer-scale assessment models should be considered to account for potentially different trends within small-scale populations components, although this is difficult when there are inadequate data to support spatial assessments.
- The recreational harvest estimates from national panel surveys should also be examined to determine whether finer-scale information is available.

5. STATUS OF THE STOCKS

Stock Structure Assumptions

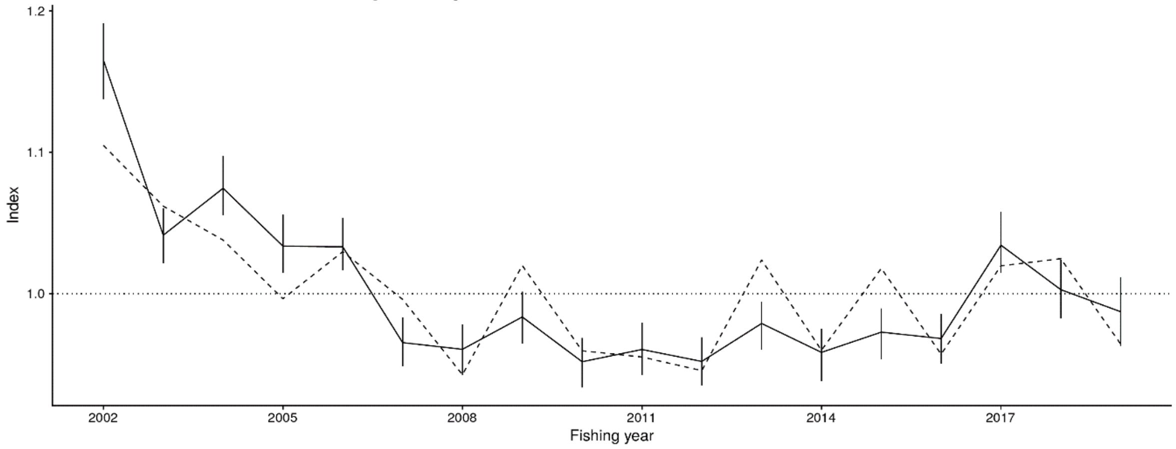
A genetic discontinuity between North Island and South Island pāua populations was found approximately around the area of Cook Strait (Will & Gemmell 2008).

- **PAU 2 -** *Haliotis iris*

Stock Status	
Year of Most Recent Assessment	2020
Assessment Runs Presented	Standardised CPUE index
Reference Points	Target: 40% B_0 (Default as per HSS) Soft Limit: 20% B_0 (Default as per HSS) Hard Limit: 10% B_0 (Default as per HSS)

	Overfishing threshold: $U_{40\%B0}$
Status in relation to Target	Unknown
Status in relation to Limits	B_{2019} is Unlikely (< 10%) to be below the soft and hard limits
Status in relation to Overfishing	Unknown

Historical Stock Status Trajectory and Current Status



The standardised CPUE indices with 95% confidence intervals (solid line and vertical error bars) and unstandardised geometric CPUE (dashed line) for the PCELR series.

Fishery and Stock Trends	
Recent Trend in Biomass or Proxy	Spawning stock biomass has fluctuated without trend since the early 2000s.
Recent Trend in Fishing Mortality or proxy	Unknown
Other Abundance Indices	-
Trends in Other Relevant Indicators or Variables	Commercial length frequency data have shown stable length frequency distributions since the early 2000s.

Projections and Prognosis	
Stock Projections or Prognosis	The CPUE index indicates that at current catch levels, the stock would continue to fluctuate without trend.
Probability of Current Catch or TACC causing Biomass to remain below or to decline below Limits	Soft Limit: Unlikely (< 40%) Hard Limit: Unlikely (< 40%)
Probability of Current Catch or TACC causing Overfishing to continue or commence	Unknown

Assessment Methodology		
Assessment Type	Level 2 - Partial Quantitative Stock Assessment	
Assessment Method	CPUE analysis	
Period of Assessment	Latest assessment: 2020	Next assessment: 2025
Overall assessment quality rank	1 – High Quality	
Main data inputs (rank)	- CPUE indices PCELR series - Commercial sampling length frequencies	1 – High Quality 2 – Medium or Mixed Quality: not believed to be fully representative of the entire QMA
Data not used (rank)	-	-

Changes to Model Structure and Assumptions	-
Major Sources of Uncertainty	-

Qualifying Comments
A large proportion of PAU 2, including the Wellington south coast, is closed to commercial fishing. This means that the CPUE series collected from the commercial catch and effort data are exclusive of this large area and therefore the abundance of pāua in the fishery as a whole may not be captured well by the CPUE index.

Fishery Interactions
-

6. FOR FURTHER INFORMATION

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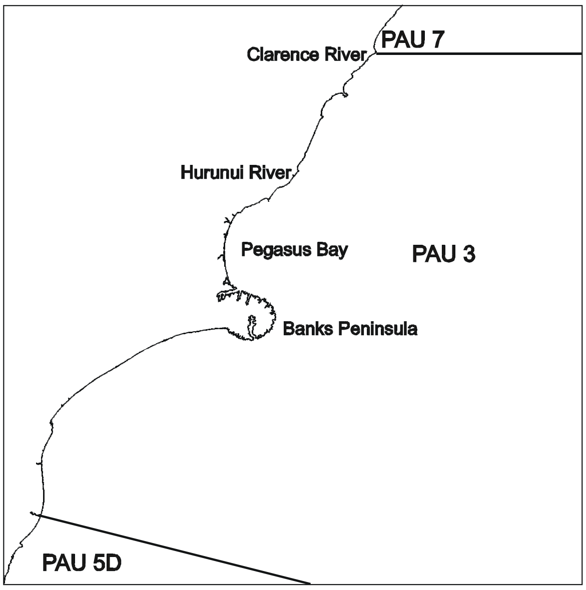
PĀUA (PAU 3) – Canterbury / Kaikōura

(*Haliotis iris*)
Pāua



1. FISHERY SUMMARY

1.1 Commercial fisheries

PAU 3 was introduced into the Quota Management System on 1 October 1986 with a TACC of 57 t. Before the Fisheries Act (1996) a TAC and allowances for customary, recreational, or other mortality were not required. As a result of appeals to the Quota Appeal Authority, the TACC was increased to 91.62 t in 1995. Following the 2016 Kaikōura earthquake which resulted in the loss of pāua habitat due to coastal uplift, TACC was lowered to 45.8 t, and a TAC was set at 79.3 t with a customary allocation of 15 t, a recreational allocation of 8.5 t, and other sources of mortality were at 10 t (Table 1).

Table 1: Total allowable catches (TAC, t) allowances for customary fishing, recreational fishing, and other sources of mortality (t) and Total Allowable Commercial Catches (TACC, t) declared for PAU 3 since introduction to the QMS.

Year	TAC	Customary	Recreational	Other mortality	TACC
1986–1995	–	–	–	–	57
1995–2017	–	–	–	–	91.62
2017 – present	79.3	15	8.5	10	45.8

Landings have closely followed the TACC since the fishing year 1991–92 (Table 2). The reported landings in 2018–2019 were 44.05 t, with a TACC (t) of 45.8. Catch landings in 2018–19 were 97% of the previous year's landings.

Most of the commercial catch used to come from the northern part of the QMA between the northern end of Pegasus Bay and the Clarence River, and from the southern side of Banks Peninsula.

On 1 October 2001 it became mandatory to report catch and effort on Paua Catch Effort Landing Returns (PCELRs) using fine-scale reporting areas that had been developed by the New Zealand Pāua Management Company for their voluntary logbook programme (Figure 1). Reported landings for PAU 3 are shown in Table 2 and Figure 2.

Since 2001, a redistribution of fishing effort within PAU 3 has been undertaken by the industry as a response to fears that the more accessible northern part of the fishery was being overfished. A voluntary subdivision was agreed by PauaMAC3 which divided PAU 3 into four management zones (Table 3). A voluntary harvest cap is placed on each management zone and this cap is reviewed annually. Minimum harvest sizes (MHS) are also agreed for each zone in addition to the legislated Minimum Legal Size (MLS). These are also reviewed annually.

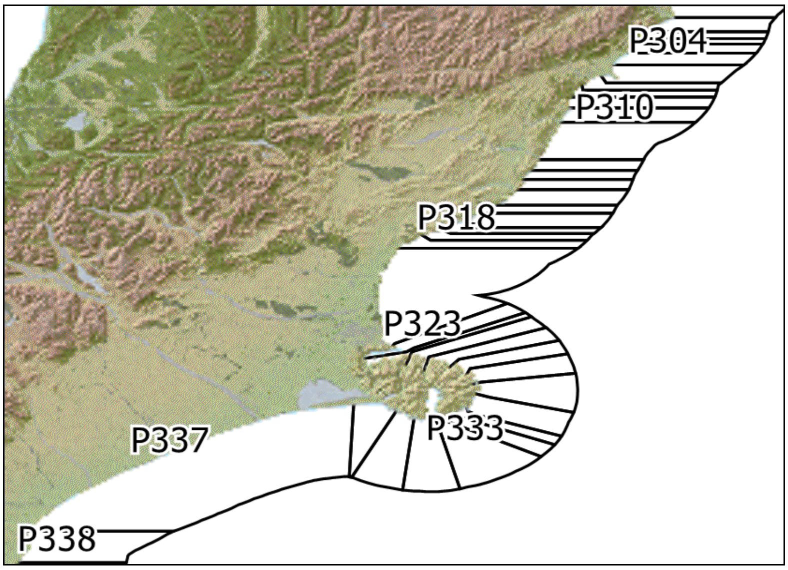


Figure 1: Map of fine scale statistical reporting areas for PAU 3.

Table 2: TACC and reported landings (t) of pāua in PAU 3 from 1983–84 to present. * FSU data.

Year	Landings	TACC
1983–84*	114.00	–
1984–85*	92.00	–
1985–86*	51.00	–
1986–87*	54.02	57.00
1987–88*	62.99	60.49
1988–89*	57.55	66.48
1989–90	73.46	69.43
1990–91	90.68	77.24
1991–92	90.25	91.50
1992–93	94.52	91.50
1993–94	85.09	91.50
1994–95	93.26	91.50
1995–96	92.89	91.62
1996–97	89.65	91.62
1997–98	93.88	91.62
1998–99	92.54	91.62
1999–00	90.30	91.62
2000–01	93.19	91.62
2001–02	89.66	91.62
2002–03	90.92	91.62
2003–04	91.58	91.62
2004–05	91.43	91.62
2005–06	91.60	91.62
2006–07	91.61	91.62
2007–08	91.67	91.62
2008–09	90.84	91.62
2009–10	91.61	91.62
2010–11	90.40	91.62
2011–12	91.14	91.62
2012–13	90.01	91.62
2013-14	90.85	91.62
2014–15	90.44	91.62
2015–16	91.73	91.62
2016–17	66.29	91.62
2017–18	45.59	45.80
2018–19	44.05	45.80

Table 3: Summary of the management zones within PAU 3 as initiated by PāuaMAC3.

Management zone (since 2001)	Area	Statistical area zone
3A	Clarence to Hapuku	P301–P304
3B	Hapuku to Conway	P305–P310
3D	Conway to Waipara	P311–P321
3E	Waipara to Witaki	P322–P329

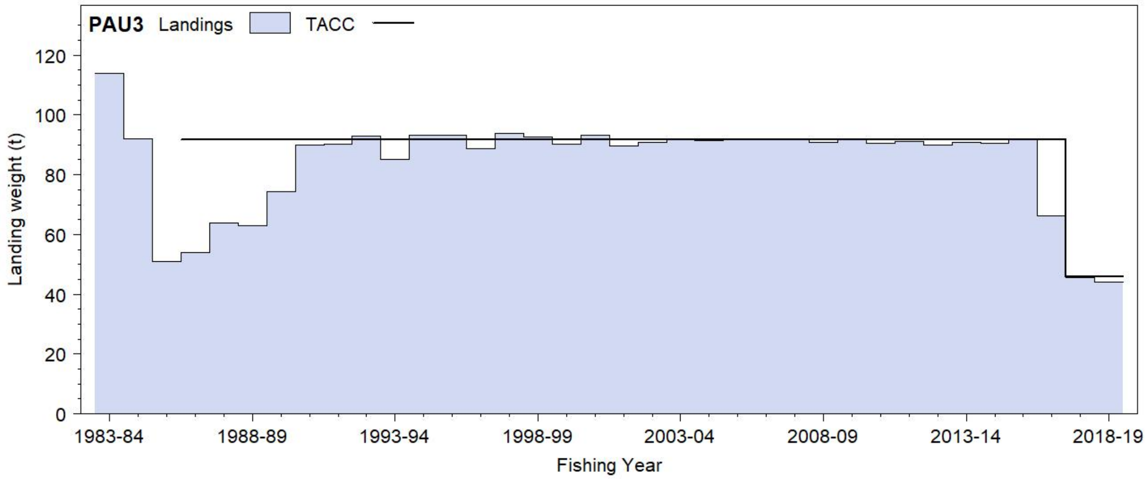


Figure 2: Reported commercial landings and TACC for PAU 3 from 1983–84 to present.

1.2 Recreational fisheries

For further information on recreational fisheries refer to the introductory PAU Working Group Report. The 'National Panel Survey of Marine Recreational Fishers 2017–18: Harvest Estimates' estimated that the recreational harvest for PAU 3 was 8.8 t with a CV of 35%. For the purpose of the 2013 stock assessment, the Shellfish Working Group (SFWG) agreed to assume that the recreational catch rose linearly from 5 t in 1974 to 17 t in 2013.

1.3 Customary fisheries

Estimates of customary catch for PAU 3 are shown in Table 4. These numbers are likely to be an underestimate of customary harvest because only the catch in kilograms and numbers harvested are reported in the table.

Landings before 2010–11 do not include the area between the Hurunui River and the South Shore (just north of Banks Peninsula), because Tangata Tiaki were not appointed there until November 2009. Many tangata whenua also harvest pāua under their recreational allowance and these are not included in records of customary catch.

Table 4: Fisheries New Zealand records of customary harvest of pāua (reported as weight (kilogram) and numbers) of pāua in PAU 3 from 2000–01 to 2018-19. Landings data before 2010–11 exclude the area between the Hurunui River and Pegasus Bay. – no data. [Continued next page]

	Weight (kg)		Numbers	
Fishing year	Approved	Harvested	Approved	Harvested
1998–99	–	–	–	–
1999–00	–	–	–	–
2000–01	–	–	300	230
2001–02	200	50	6 239	4 832
2002–03	–	–	3 422	2 449
2003–04	–	–	–	–
2004–05	–	–	–	–
2005–06	–	–	1 580	1 220
2006–07	–	–	5 274	4 561
2007–08	–	–	7 515	5 790
2008–09	–	–	10 848	8 232
2009–10	–	–	8 490	6 467
2010–11	–	–	8 360	7 449
2011–12	–	–	5 675	4 242
2012–13	–	–	15 036	12 874
2013–14	–	–	10 259	7 566
2014–15	–	–	8 761	7 035

Table 4 [Continued]

	Weight (kg)		Numbers	
Fishing year	**Approved**	**Harvested**	**Approved**	**Harvested**
2015–16	–	–	14 801	11 808
2016–17	–	–	11 374	9 217
2017–18	–	–	2 708	1 725
2018–19	–	–	480	278

1.4 Illegal catch

For further information on illegal catch refer to the introductory PAU Working Group Report.

For the purpose of the 2013 stock assessment, the SFWG agreed to assume that illegal catches rose linearly from 5 t in 1974 to 15 t in 2000, and remained at 15 t between 2001 and 2013.

1.5 Other sources of mortality

The Working Group agreed that handling mortality would not be included in the model.

For further information on other sources of mortality refer to the introductory PAU Working Group Report.

On 16 November 2016 a 7.8 magnitude earthquake hit the upper east coast of the South Island, causing extensive uplift of about 130 km of coastline by as much as 4 m in some areas. This resulted in the widespread mortality of marine organisms, changes to the structure of intertidal and subtidal rocky reefs, and significant alterations to the structure of nearshore reef communities (Alestra et al. 2019). Ongoing monitoring of these nearshore reef communities has revealed signs of recovery in the low intertidal zones, whereas sub-tidally there has been little recovery in areas that were de-vegetated and previously abundant algal stands appear to have become more sparse and fragmented (Alestra et al. 2020).

The whole northern part of the PAU 3 fishery (Pāua Statistical Areas P301 to P310, Figure 3) was impacted to varying degrees by the earthquake. The earthquake caused the direct mortality of a large number of juvenile and adult pāua that became exposed to the terrestrial environment with no means of being able to return to the water. More indirect mortality is also expected from the earthquake due to an immediate loss of pre-earthquake pāua habitat that now lies above the new post-earthquake high tide mark.

Although the impacts of the seabed uplift on pāua populations around Kaikōura will only become clear in the longer term, work was undertaken to evaluate the area utilised by the pāua fishery that is now above the post-earthquake low tide mark (Neubauer 2017). The results estimated that the seabed uplift led to a loss of up to 50% of the pre-earthquake fished area in the pāua statistical areas P301 to P310. In area 301, the habitat loss was 7 ha, which corresponds to 52% of the fished area. However, this area has contributed relatively little to the commercial catch. In area 302, which has contributed a larger proportion of the PAU 3 commercial catch, the area lost was 43 ha, which corresponds to 43% of the fished area. In other affected areas, the area lost was generally less than 10%. Across PAU 3 statistical areas, a total of 21% of the fished area (24% of catch weight as recorded on PCELR forms), was impacted by uplift (Figure 3).

The immediate loss of area to the fishery, assumed to be good habitat for pāua, is only part of the impact that the seabed uplift associated with the Kaikōura earthquake will have on pāua populations. Juvenile pāua recruit in shallow water, and so the loss of juvenile habitat will have been higher than the loss of adult habitat. This will impact on the number of juvenile pāua growing into the fishery over the coming years. This impact will be more difficult to quantify directly, but may affect pāua populations and fisheries over a span of multiple years.

2. BIOLOGY

For further information on pāua biology refer to the introductory PAU Working Group Report. A summary of published estimates of biological parameters for PAU 3 is presented in Table 5.

Table 5: Estimates of biological parameters (*H. iris*) in PAU 3.

	Estimate		Source
1. Natural mortality (*M*)			
	0.135 (0.120–0.153)		Median (5–95% range) of posterior distribution for the base case model
2. Weight = a(length)^b (Weight in g, length in mm shell length)			
All	a	b	
	2.99 x 10^{-5}	3.303	Schiel & Breen (1991)
3. Size at maturity (shell length)			
	50% maturity at 82 mm (80–84)		Median (5–95% range) of posterior distribution for the base case model
	95% maturity at 102 mm (96–108)		Median (5–95% range) of posterior distribution for the base case model

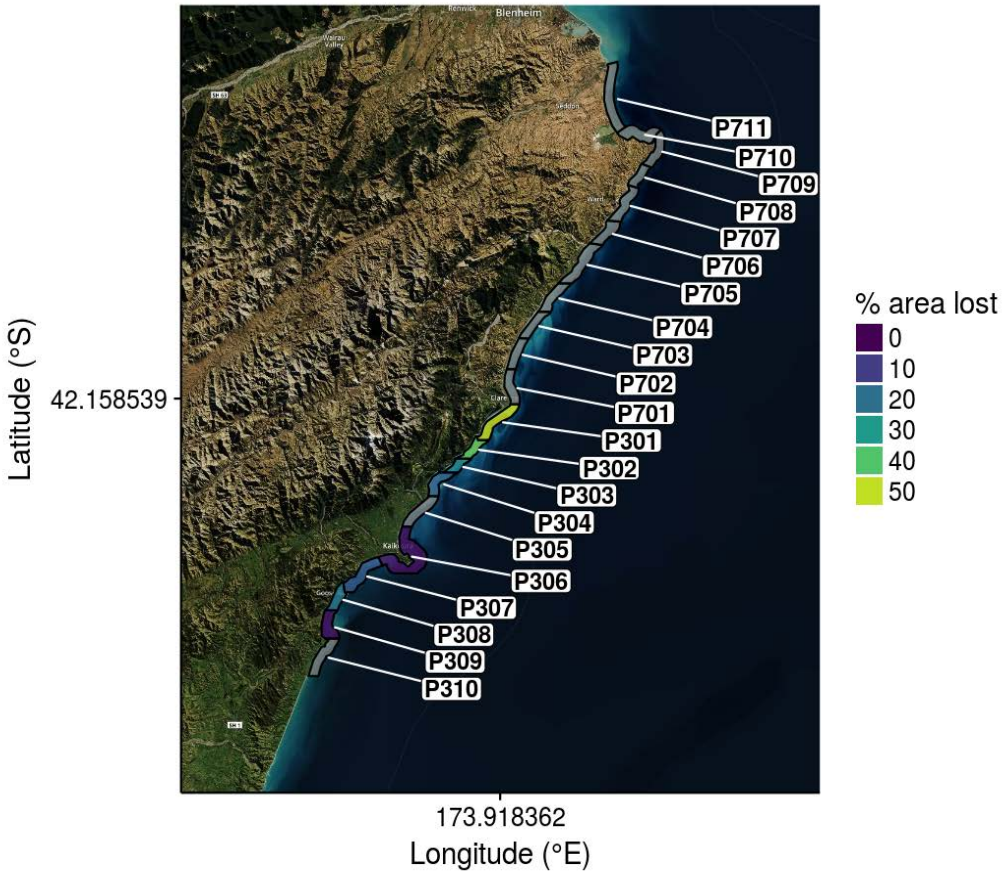


Figure 3: Percent fished area above the post-earthquake low tide mark for statistical areas within the Kaikōura earthquake fishery closure zone. Grey indicates that no post-earthquake elevation data were available.

3. STOCKS AND AREAS

For further information on stocks and areas refer to the introductory PAU Working Group Report.

4. STOCK ASSESSMENT

The last assessment was conducted in 2014; however, given the potential effects of the earthquake, it is unclear how representative estimates from this assessment are for the current pāua stock.

The stock assessment was implemented using a length-based Bayesian estimation model, with parameter point estimates based on the mode of the joint posterior distribution and uncertainty based on marginal posterior distributions generated from Markov chain Monte Carlo (MCMC) simulations. The most recent stock assessment was conducted in 2014 for the fishing year ended 30 September 2013. The Shellfish WG determined a set of model runs where growth and natural mortality parameter values were fixed. The parameter values were thought to cover the plausible range of productivity assumptions for the stock. Markov chain Monte Carlo (MCMC) simulations were conducted on a model agreed to by the SFWG. This particular model (6.1) estimated M within the model (with a lognormal prior with a mean of 0.1) but fixed the growth parameters at the medium value (g_1=20 mm, g_2=6 mm). On reviewing the results of the MCMC simulations the SFWG chose model 6.1 as the base case. The lack of comprehensive growth and length frequency data for PAU 3 and the lack of contrast in the CPUE series means that uncertainty in the model outputs is higher than preferred.

4.1 Estimates of fishery parameters and abundance indices

Assumed prior distributions for model parameters are summarised in Table 6.

Table 6: A summary of estimated model parameters, lower bound, upper bound, type of prior, (U, uniform; N, normal; LN = lognormal), mean and CV of the prior.

Parameter	Prior	μ	CV	Bounds	
				Lower	Upper
ln($R0$)	U	–	–	5	50
M (Natural mortality)	LN	0.1	0.35	0.01	0.5
Ln(q^I) (catchability coefficient of CPUE)	U	–	–	-30	0
Ln(q^J) (catchability coefficient of PCPUE)	U	–	–	-30	0
L_{50} (Length at 50% maturity)	U	–	–	70	145
L_{95-50}(Length between 50% and 95% maturity)	U	–	–	1	50
D_{50}(Length at 50% selectivity for the commercial catch)	U	–	–	70	145
D_{95-50}(Length between 50% and 95% selectivity the commercial catch)	U	–	–	0.01	50
ϵ (Recruitment deviations)	N	0	0.4	-2.3	2.3

The observational data were:

1. A 1990–2001 standardised CPUE series based on CELR data.
2. A 2002–2012 standardised CPUE series based on PCELR data.
3. A commercial catch sampling length frequency series for 2000, 2002–2012.
4. Maturity at length data.

4.1.1 Relative abundance estimates from standardised CPUE analyses

The 2013 stock assessment used two sets of standardised CPUE indices: one based on CELR data covering 1990–2001, and another based on PCELR data covering 2002–2013. For both series, standardised CPUE analyses were carried out using Generalised Linear Models (GLMs). A stepwise procedure was used to select predictor variables, with variables entering the model in the order that gave the maximum decrease in the residual deviance. Predictor variables were accepted into the model only if they explained at least 1% of the deviance.

For both the CELR and PCELR data, the Fisher Identification Number (FIN) was used in the standardisations instead of vessel, because the FIN is associated with a permit holder who may employ a suite of grouped vessels, which implies that there could be linkage in the catch rates among vessels operated under a single FIN.

For the CELR data there is ambiguity in what is recorded for estimated daily fishing duration, and therefore daily fishing duration has not been used in past standardisations as a measure of effort; instead the number of divers has been used. However, there is evidence that the fishing duration for a diver changes over time and, because of this, a subset of the data was selected for which the recorded fishing duration was less ambiguous. The criteria used to subset the data were: (i) just one diver or, (ii) fishing duration ≥ 6 hours and number of divers ≥ 2. This data subset was used for the CELR standardisation, using estimated daily catch and effort measured as either number of divers or fishing duration (both were offered to the standardisation model).

For the PCELR data the unit of catch was diver catch, with effort as diver duration. The diver duration measures the number of hours fished per diver day.

FIN codes were used to select a core group of fishers from the CELR data, with the requirement that there be a minimum of 6 records per year for a minimum of 2 years to qualify for the core fisher group. This retained 84% of the catch over 1990–2001. For the PCELR data the FIN was also used to select a core group of fishers, with the requirement that there be a minimum of 20 records per year for a minimum of 2 years. This retained 84% of the catch over 2002–2013.

For the CELR data, year was forced into the model and other predictor variables offered to the model were FIN, Statistical Area (018, 020, 022), month, fishing duration (as a cubic polynomial), number of divers, and a month:area interaction. Variables accepted into the model were fishing year, month, FIN, and fishing duration. Following previous standardisations, no interaction of fishing year with area was entered into the model as the stock assessment for PAU 3 is a single area model. However, a separate standardisation is also done where a year:area interaction is forced in. Forcing in a year:area interaction indicates that there are differences in standardised CPUE between the area 018 and the two areas 020 and 022. However, in the years where they differ there are very few records to estimate the year effects for areas 020 and 022.

For the PCELR data, fishing year was forced into the model and variables offered to the model were month, diver key, FIN statistical area, diver duration (third degree polynomial), and diving conditions. All the variables were accepted into the final model.

The standardised CPUE from the CELR data is flat from 1990 to 1994, shows a rise of 20% from 1995 to 1998, then declines for the next three years to 2001 (Figure 4, top). The standardised CPUE from the PCELR data shows a gradual decline of 10% from 2002 to 2013 (Figure 4, bottom).

4.2 Biomass survey and monitoring

Following the 2016 Kaikōura earthquake, a biomass survey was implemented to estimate adult pāua abundance and a monitoring programme was put in place, both in the earthquake-affected area, to inform management decisions relating to the re-opening of the paua fishery (McCowan & Neubauer 2018). To estimate abundance, novel methodologies using GPS dive loggers and underwater electronic calipers were developed. Fixed monitoring points within surveyed areas to monitor discrete pāua populations through time were established.

Pāua were mostly found in aggregations, preferentially in shallow water. This was not just the case for small pāua but also for large individuals (i.e., over 120 mm), although smaller individuals (under 100 mm) showed a strongly decreasing trend with depth. Estimated pāua density was 0.028 pāua per square metre (geometric mean; 95% confidence interval (CI) [0.009; 0.08]). Scaling density estimates to total biomass or abundance was difficult due to the lack of robust estimates of habitat area for pāua. In the absence of a defensible solution, only density was calculated.

Eighty-three discrete monitoring points were established throughout the survey sites. Within the time frames of this project, 30 of these points were re-surveyed. Relatively stable length-frequency distributions were observed between survey times across many monitoring points, although some points showed notable decreases or a complete absence of pāua on re-survey.

4.3 Stock assessment methods

The 2013 PAU 3 stock assessment used the same length-based model as the 2012 PAU 5D assessment (Fu 2013). The model was described by Breen et al (2003). This is the first assessment for PAU 3 using the length based Bayesian model (Fu 2014).

The model structure assumed a single sex population residing in a single homogeneous area, with length classes from 70 mm to 170 mm, in 2 mm bins. Growth is length-based, without reference to age, mediated through a growth transition matrix that describes the probability of transition among length classes at each time step. Pāua enter the model following recruitment and are removed by natural mortality and fishing mortality.

The models were run for the years 1965–2013. Catches were collated for 1974–2013 and were assumed to increase linearly between 1965 and 1973 from 0 to the 1974 catch level. Catches included commercial, recreational, customary, and illegal catch, and all catches occurred at the same time step.

Recruitment was assumed to take place at the beginning of the annual cycle, and length at recruitment was defined by a uniform distribution with a range between 70 mm and 80 mm. The stock-recruitment relationship is unknown for pāua. A relationship may exist on small geographical scales, but not be apparent when large geographical scales are modelled (Breen et al 2003). However, the Shellfish Working Group agreed to use a Beverton-Holt stock-recruitment relationship with steepness (*h*) of 0.75 for this assessment.

Maturity is not required in the population partition but is necessary for estimating spawning biomass. The model estimated proportions mature from length-at-maturity data. Growth and natural mortalities were also estimated within the model. The model estimated the commercial fishing selectivity, assumed to follow a logistic curve and asymptote at 1.

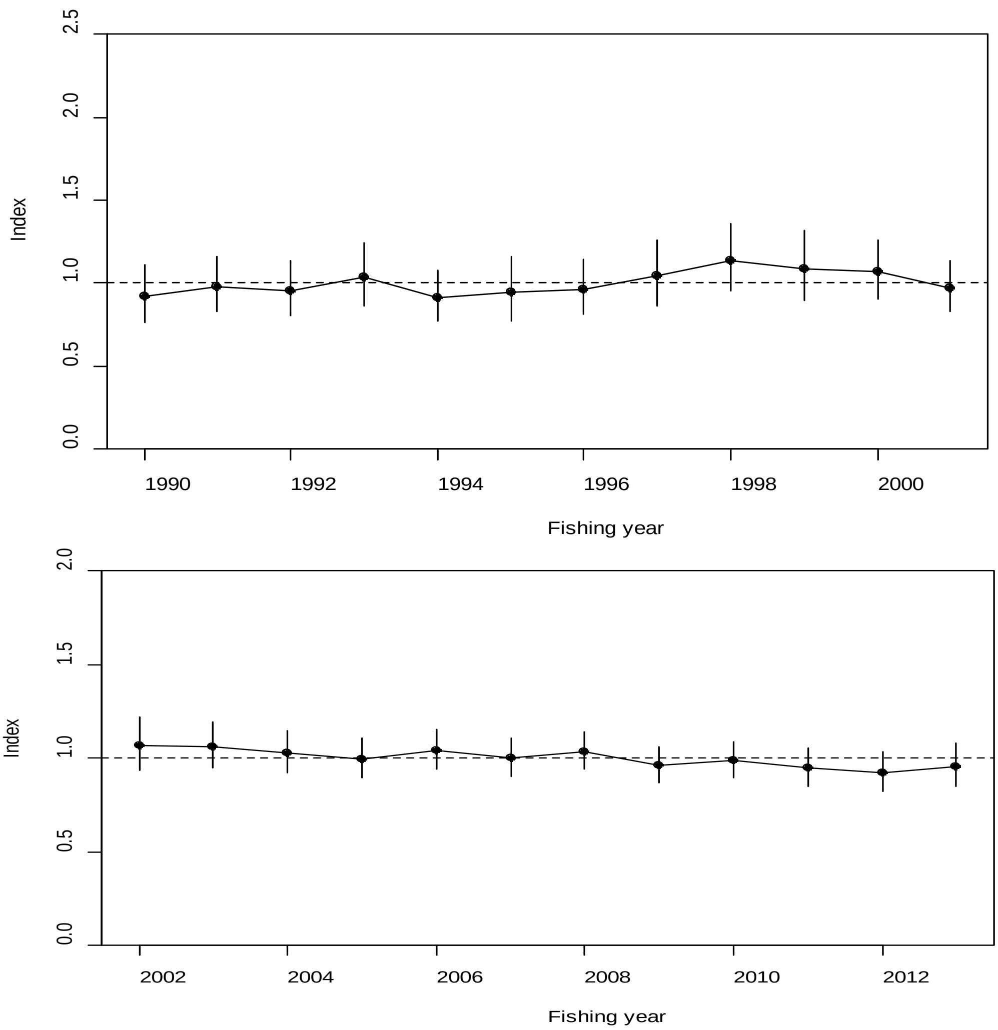


Figure 4: The standardised CPUE indices with 95% confidence intervals for the early CELR/FSU series (top panel) and the recent PCELR series (bottom panel).

The growth data available to the PAU 3 assessment were collected from several sites on Banks Peninsula. Because most of the pāua measured in this experiment were stunted, incorporating these data in the assessment would under-estimate the growth for the whole stock. There were also some growth measurements from an experiment conducted in Cape Campbell (within PAU 7) which is close to the northern boundary of PAU 3, but the sample size is too small to be useful. Therefore the growth parameters were fixed in this assessment.

The growth parameter were fixed at low (g_1=15 mm, g_2=4.5 mm), median (g_1=20 mm, g_2=6 mm), and high (g_1=25 mm, g_2=7.5 mm) values. The median values were based on the estimates of growth using the tag-recapture data from Cape Campbell (Fu 2014). The low and high values were loosely based on the range of growth estimates from assessments of other pāua stocks. For each fixed value of the growth parameters, natural mortality was fixed at three levels, 0.1, 0.15, and 0.2. These values were considered to have covered the plausible range of natural mortality for pāua. In total nine model runs were carried out. The growth and natural mortality parameter values aimed to evaluate the sensitivity of model results to key productivity assumptions and to estimate uncertainty in stock status. Each model run was considered an equally likely scenario. The models were fitted to the data with parameters estimated at the mode of their joint posterior distribution (MPD).

Markov chain Monte Carlo (MCMC) simulations were conducted on a model agreed to by the SFWG to obtain a large set of samples from the joint posterior distribution. This particular model (6.1) estimated *M* within the model (with a lognormal prior with a mean of 0.1) but fixed the growth parameters at the medium value (g_1=20 mm, g_2=6 mm).

The assessment calculates the following quantities from the posterior distributions: the equilibrium spawning stock biomass with recruitment equal to the average recruitment over the period for which recruitment deviations were estimated (B_0,); and the mid-season spawning and recruited biomass for 2013 (B_{2013} and B^r_{2013}) and for the projection period (B_{proj} and B^r_{proj}).

This assessment also reports the following fishery indictors:

- $B\%B_0$ — Current or projected spawning biomass as a percentage of B_0
- $B\%B_{msy}$ — Current or projected spawning biomass as a percentage of B_{msy}
- $\Pr(B_{proj} > B_{msy})$ — Probability that projected spawning biomass is greater than B_{msy}
- $\Pr(B_{proj} > B_{2013})$ — Probability that projected spawning biomass is greater than $B_{current}$
- $B\%B^r_0$ — Current or projected recruited biomass as a percentage of B^r_0
- $B\%B^r_{msy}$ — Current or projected recruited biomass as a percentage of B^r_{msy}
- $\Pr(B_{proj} > B^r_{msy})$ — Probability that projected recruit-sized biomass is greater than B^r_{msy}
- $\Pr(B_{proj} > B^r_{2013})$ — Probability that projected recruit-sized biomass is greater than B^r_{2012}
- $\Pr(B_{proj} > 40\%B_0)$ — Probability that projected spawning biomass is greater than 40% B_0
- $\Pr(B_{proj} < 20\%B_0)$ — Probability that projected spawning biomass is less than 20% B_0
- $\Pr(B_{proj} < 10\%B_0)$ — Probability that projected spawning biomass is less than 10% B_0
- $\Pr(U_{proj} > U_{40\%B0})$ — Probability that projected exploitation rate is greater than $U_{40\%B0}$

4.4 Stock assessment results

For the nine model runs in which growth and natural mortality were fixed B_0 ranged from 1500 t to 2900 t, and $B_{current}$ ranged from 21% to 66% of B_0 (Table 7). All model runs showed an overall deceasing trend in spawning stock biomass but this trend has become slower in recent years (Figure 5). In general, models with higher values for *M* and growth had higher estimates of initial and current biomass, and models with lower *M* and growth had lower estimates of biomass.

Table 7: MPD estimates of B_0, B_{2013}, and U_{2013} for models 3.1–3.3, 4.1–4.3, and 5.1–5.3.

Model	M	g_1	g_2	B_0	B_{2013}	B_{2013}/B_0	U_{2013}
3.1	0.10	25	7.5	2 344	488	0.21	0.32
3.2	0.10	20	6	2 460	672	0.27	0.26
3.3	0.10	15	4.5	2 916	1 231	0.42	0.17
4.1	0.15	25	7.5	1 795	474	0.26	0.39
4.2	0.15	20	6	1 965	718	0.37	0.30
4.3	0.15	15	4.5	2 452	1 262	0.51	0.21
5.1	0.20	25	7.5	1 497	520	0.35	0.40
5.2	0.20	20	6	1 767	848	0.48	0.30
5.3	0.20	15	4.5	2 594	1 708	0.66	0.18

When *M* was fixed at 0.1, the models fitted the CSLF and CPUE data poorly. Model fits improved markedly when *M* was increased to 0.15 or 0.20. The SFWG believed that 0.15 is probably more credible than 0.2 for the natural mortality of pāua. Model fits and likelihood function values did not provide a clear distinction among low, median, or high growth values. Estimates of stock depletion levels were sensitive to the assumed value of the growth parameters.

For model (6.1), the posterior of *M* had a median of 0.14 with a 90% credible interval between 0.12 and 0.15. The posterior distributions of spawning stock biomass showed a gradual declining trend (Figure 6), estimated B_0 was about 2670 t (2470–2960 t) and $B_{current}$ was about 52% (45–60%) of B_0 (Table 8). The SFWG agreed for this model to be adopted as the base case model, but noted that the model underestimates uncertainty in stock biomass and status because of uncertainty in growth.

The estimates of recruitment deviations showed a period of relatively low recruitment between 1980 the 1990, and that recruitment in recent years (after 2002) has been above the long term average. Exploitation rates showed a gradual upward trend since the 2000s, and the estimated exploitation rate in 2013 was about 0.16 (0.09–0.14) (Table 8).

Model projections, assuming current catch levels and using recruitments re-sampled from the recent model estimates, suggested that the spawning stock abundance would slightly decrease to about 51% (41–63) of B_0 over the following three years (Table 9). The projections indicated that the probability of the spawning stock biomass being above the target (40% B_0) over the following three years was close to 100%.

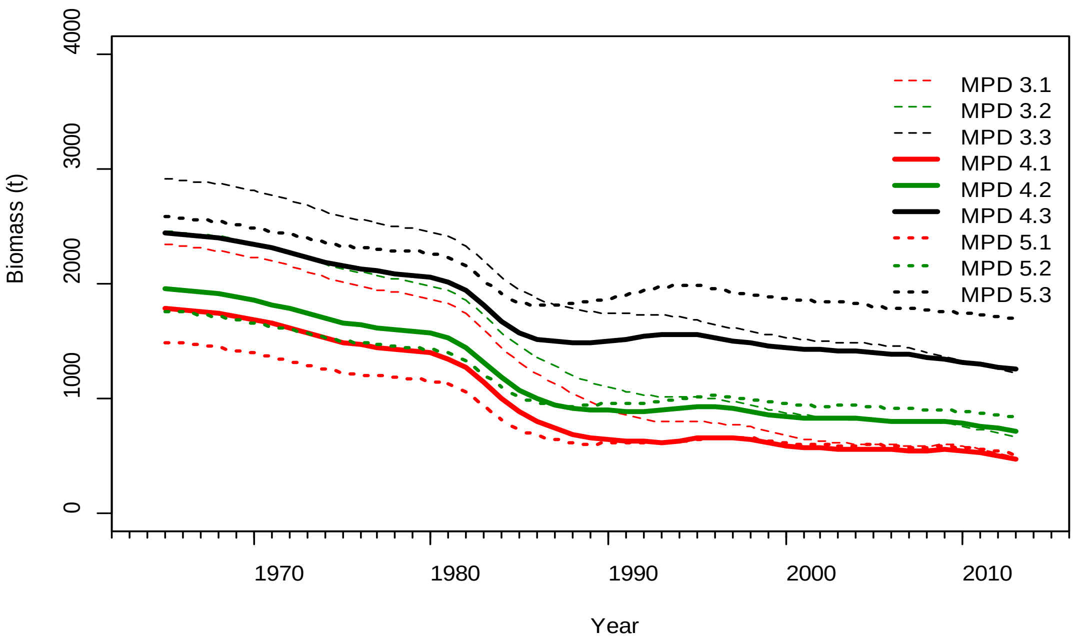


Figure 5: Estimates of spawning stock biomass this page and estimates of spawning stock biomass as a ratio of B_0 (next page) for MPD models 3.1, 3.2, 3.3, 4.1, 4.2, 4.3, 5.1, 5.2, and 5.3. [Continued on next page]

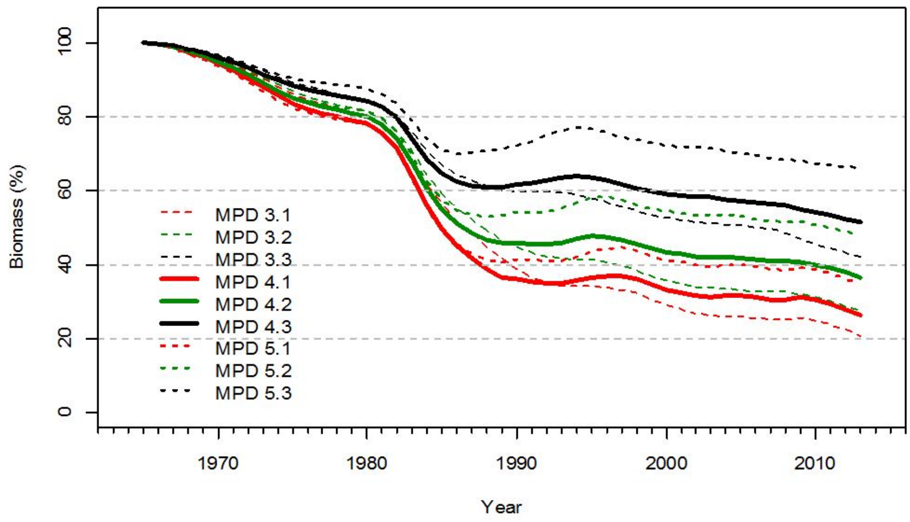


Figure 5 [Continued]: Estimates of spawning stock biomass (previous page) and estimates of spawning stock biomass as a ratio of B_0 (this pagel) for MPD models 3.1, 3.2, 3.3, 4.1, 4.2, 4.3, 5.1, 5.2, and 5.3.

Table 8: Summary of the marginal posterior distributions of key biomass indicators from the MCMC chain from the base case (Model 6.1). The columns show the median, the 5th, and 95th percentiles values observed in the 1000 samples. Biomass is in tonnes.

	5%	Median	95%
B_0	2 470	2 666	2 957
B_{msy}	687	741	834
B_{2013}	1 133	1 390	1 727
B_{2013} %B_0	45	52	60
B_{2013} %B_{msy}	163	187	214
B_{msy} %B_0	27	28	29
rB_0	1 700	1 880	2 100
rB_{msy}	78	126	195
rB_{2013}	502	657	874
rB_{2013} /rB_0	0.28	0.35	0.43
rB_{2013}/rB_{msy}	3.22	5.17	9.32
rB_{msy}/rB_0	0.04	0.07	0.09
MSY	116	131	155
$U_{40\%B0}$	0.39	0.56	0.79
U_{msy}	0.19	0.25	0.34
U_{2013}	0.12	0.16	0.21

Table 9: Summary of current and projected indicators for the base case with future commercial catch set to current TACC: biomass as a percentage of the virgin and current stock status, for spawning stock and recruit-sized biomass. B( ) (current or projected biomass), U( ) (current or projected exploitation rate).

	2013	2014	2015
B_t	1 390 (1 088–1 858)	1 379 (1 067–1 855)	1 371 (1 041–1 847)
% B_0	52 (43.9–62.0)	51.5 (42.9–62.0)	51.3 (41.2–63.1)
% B_{msy}	187 (158–218)	185 (155–220)	184 (149–224)
Pr(>B_{msy})	1.00	1.00	1.00
Pr(>$B_{current}$)	0.35	0.32	0.32
Pr(>40% B_0)	1.00	0.99	0.99
Pr(<20% B_0)	0.00	0.00	0.00
Pr(<10% B_0)	0.00	0.00	0.00
rB_t	657 (481–946)	643 (462–926)	626 (443–915)
% rB_0	34.9 (26.7–45.5)	34.1 (25.2–44.6)	33.2 (24.1–43.9)
% rB_{msy}	517 (295–1 045)	504 (283–1 035)	491 (273–1 019)
Pr(>rB_{msy})	1.00	1.00	1.00
Pr(>$rB_{current}$)	0.12	0.09	0.05
Pr($U_{proj>}U_{40\% B0}$)	0.03	0.04	0.05

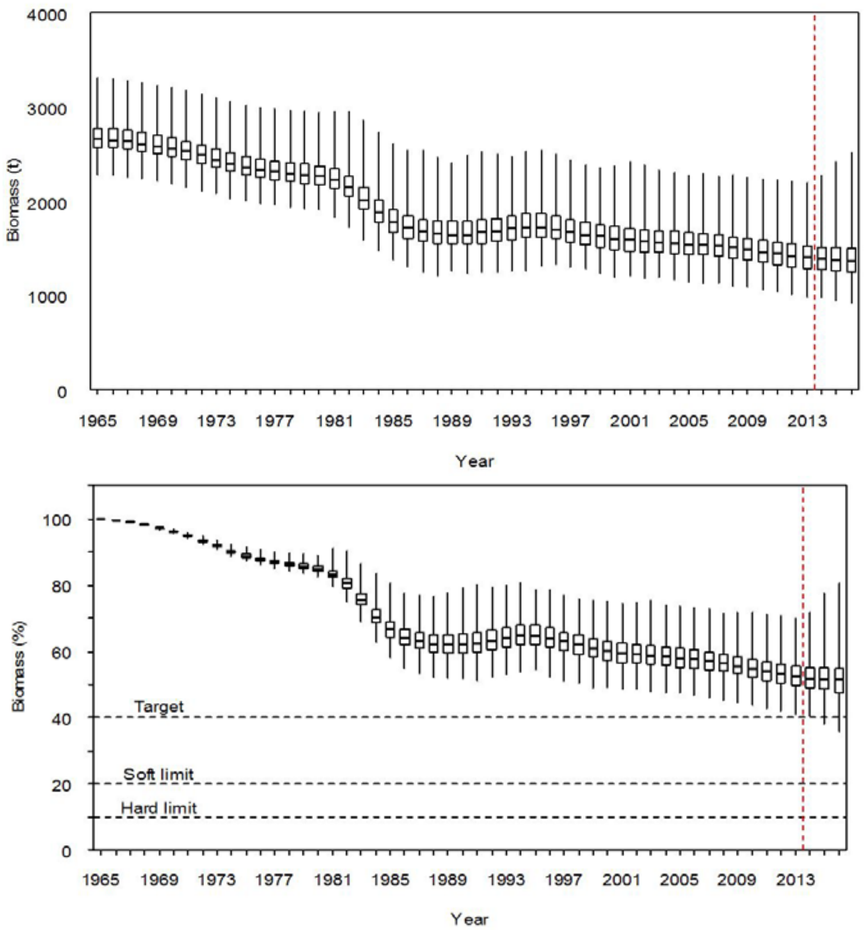


Figure 6: Posterior distributions of spawning stock biomass (top panel) and spawning stock biomass as a percentage of virgin level (bottom panel) from MCMC 6.1 (including projections). The box shows the median of the posterior distribution (horizontal bar), the 25th, and 75th percentiles (box), with the whiskers representing the full range of the distribution.

4.5 Other factors

The assessment used CPUE as an index of abundance. The assumption that CPUE indexes abundance is questionable. The literature on abalone suggests that CPUE is difficult to use in abalone stock assessments because of serial depletion. This can happen when fishers deplete unfished or lightly fished beds and maintain their catch rates by moving to new areas. Thus CPUE stays high while the biomass is decreasing. In PAU 3, both the early and recent CPUE indices have shown a relatively flat trend (the recent CPUE decreased slightly). It is unknown to what extent the CPUE series tracks stock abundance in PAU 3. Information from commercial fishers indicates that the stock is in relatively good shape suggesting that the trend in CPUE series may be credible.

Even if the CPUE indices are credible, they are not very useful in informing estimates of B_0 because they have shown a relatively flat trend. Therefore the catch sampling length frequencies are the most important observations that provide information on the initial size of the stock. The catch sampling coverage in PAU 3 is considered to be reasonably adequate and the CSLF data are likely to have been representative of the stock.

Another source of uncertainty is the catch data. The commercial catch is known with accuracy since 1985, but is probably not well estimated before that. In addition, non-commercial catch estimates are poorly determined. The estimate of illegal catch is uncertain. Anecdotal evidence suggested the recreational catch in PAU 3 is very likely to have increased substantially in recent years and could be much higher than what was assumed in the model. However, the increase in non-commercial catch (if it is true) has not been reflected in the recent CPUE indices, which showed an almost flat trend. One possible reason is that the commercial divers may have fished deeper than recreational fishers and could be fishing different sections of the population. If there is substantial bias in estimates of catches, the model could significantly under-estimate the stock depletion level. Therefore better information on the scale and trend in recreational catch needs to be collated for more accurate assessment of the stock status.

Another source of uncertainty is that fishing may cause spatial contraction of populations (Shepherd & Partington 1995), or that some populations become relatively unproductive after initial fishing (Gorfine & Dixon 2000). If this happens, the model will overestimate productivity in the population as a whole. Past recruitments estimated by the model might instead have been the result of serial depletion.

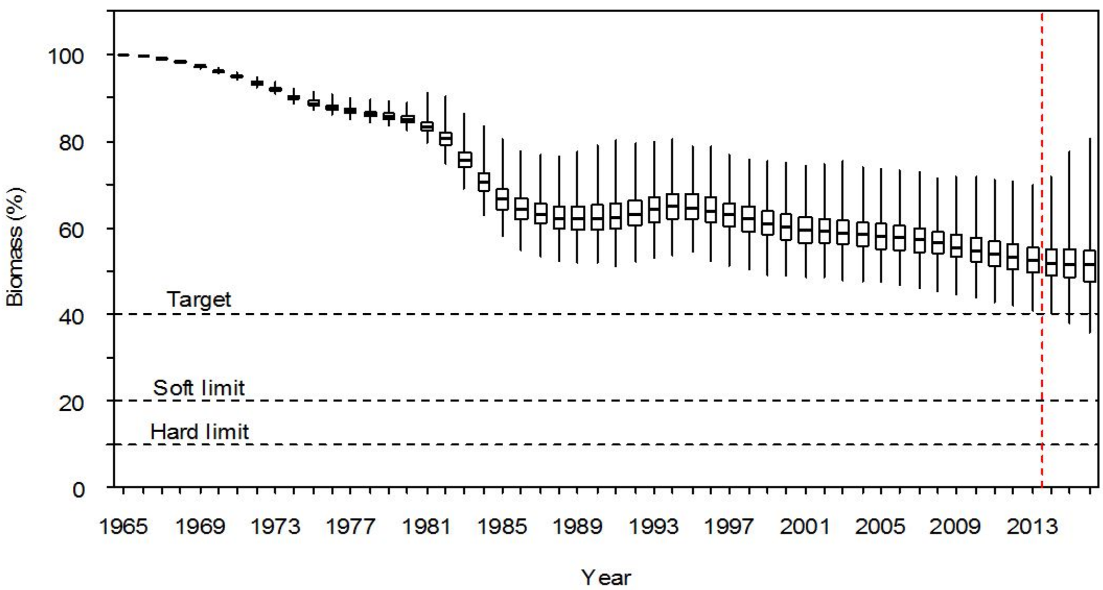
5. STATUS OF THE STOCK

Stock Structure Assumptions
PAU 3 is assumed to be a homogenous stock for purposes of the stock assessment however there is evidence to show this may not be correct (Naylor et al 2006).

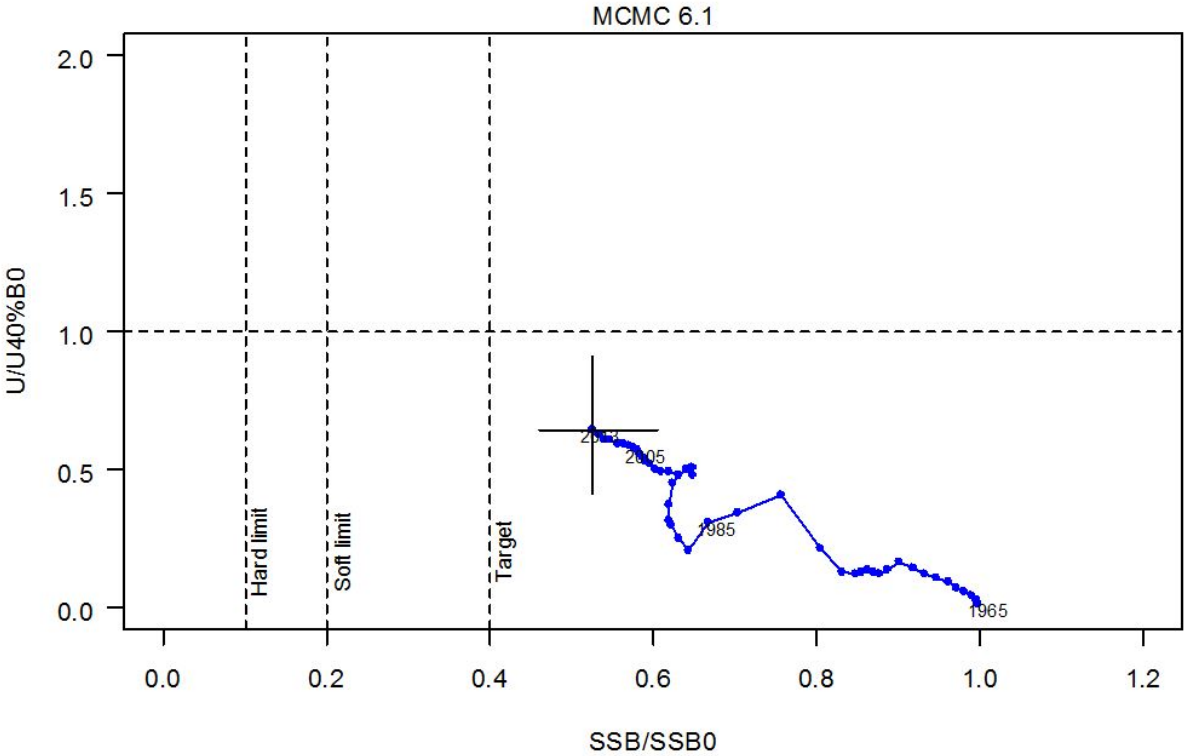
- **PAU 3 - *Haliotis iris***

Stock Status	
Year of Most Recent Assessment	2014; however, given the potential effects of the earthquake, it is unclear how representative estimates from this assessment are for the current pāua stock
Assessment Runs Presented	MCMC 6.1 base case (M estimated, g_1 fixed at 20 mm and g_2 fixed at 6.0 mm)
Reference Points	Target: 40% B_0 (Default as per HSS) Soft Limit: 20% B_0 (Default as per HSS) Hard Limit: 10% B_0 (Default as per HSS) Overfishing threshold: $U_{40\%B0}$
Status in relation to Target	B_{2013} estimated to be 52% B_0 : Very Likely (> 60%) to be at or above the target
Status in relation to Limits	Very Unlikely (< 10%) to be below the soft and hard limits
Status in relation to Overfishing	Overfishing is Very Unlikely (< 10%) to be occurring

Historical Stock Status Trajectory and Current Status



Posterior distributions of spawning stock biomass as a percentage of virgin level from MCMC 6.1 (including projections). The box shows the median of the posterior distribution (horizontal bar), the 25th and 75th percentiles (box), with the whiskers representing the full range of the distribution.



Trajectory of exploitation rate as a ratio U%40B0 and spawning stock biomass as a ratio of B_0 from the start of assessment period 1965 to 2013 for MCMC 6.1 (base case). The vertical lines at 10%, 20%, 40% B_0 represent the hard limit, the soft limit, and the target respectively. U%40B_0 is the exploitation rate at which the spawning stock biomass would stabilise at 40% B_0 over the long term. Each point on trajectory represents the estimated annual stock status: the value on x axis is the mid-season spawning stock biomass (as a ratio of B_0) and the value on the y axis is the corresponding exploitation rate (as a ratio U%40B_0) for that year. The Estimates are based on MCMC median and the 2013 90% CI is shown by the cross line.

Fishery and Stock Trends	
Recent Trend in Biomass or Proxy	Spawning stock biomass has shown an overall deceasing trend but this has become much slower in recent years.
Recent Trend in Fishing Intensity or Proxy	The exploitation rate has shown a gradual upward trend since the 2000s and was about 0.16 (0.09–0.14) in 2013.
Other Abundance Indices	Standardised CPUE remained relatively flat until the early 2000s, and has declined only slightly since then.
Trends in Other Relevant Indicators or Variables	Estimated recruitment was relatively low between 1980 and 1990 but since 2002 has been above the long term average.

Projections and Prognosis	
Stock Projections or Prognosis	The projected spawning stock abundance will slightly decrease over the next three years but will still be remaining above the target
Probability of Current Catch or TACC causing Biomass to remain below or to decline below Limits	Results from all model runs suggest it is very unlikely (< 10%) that current catch or TACC will cause a decline below the limits.
Probability of Current Catch or TACC causing Overfishing to continue or to commence	-

Assessment Methodology and Evaluation		
Assessment Type	Full quantitative stock assessment	
Assessment Method	Length based Bayesian model	
Assessment Dates	Latest: 2014	Next: unknown
Overall assessment quality (rank)	1 – High Quality	

Main data inputs (rank)	- Catch history - CPUE indices early series - CPUE indices later series - Commercial sampling length frequencies - Tag recapture data (to estimate growth) - Maturity at length data	1 – High Quality for commercial catch 2 – Medium or Mixed Quality for recreational catch, which is not believed to be fully representative over the history of the fishery 2 – Medium or Mixed Quality: not believed to proportional to abundance 1 – High Quality 1 – High Quality 2 – Medium or Mixed Quality: not believed to be fully representative of the whole QMA 1 – High Quality
Data not used (rank)	N/A	
Changes to Model Structure and Assumptions	New model	
Major Sources of Uncertainty	- Very little growth data available and growth is not well known. - CPUE may not be a reliable index of abundance. - The model treats the whole of the assessed area of PAU 3 as if it were a single stock with homogeneous biology, habitat and fishing pressures. - Recreational catch in PAU 3 is very likely to have increased substantially in recent years and could be much higher than what was assumed in the model.	

Qualifying Comments:
-The last assessment was conducted in 2014 however, given the potential effects of the earthquake, it is unclear how representative estimates from this assessment are for the current pāua stock. -The lack of comprehensive growth and length frequency data for PAU 3 and the lack of contrast in the CPUE series cause uncertainty in the model outputs. -The SFWG agreed to adopt model 6.1 as the base case model, but noted that the model underestimates uncertainty in stock biomass and stock status because of uncertainty in growth.

Fishery Interactions
-

6. FOR FURTHER INFORMATION

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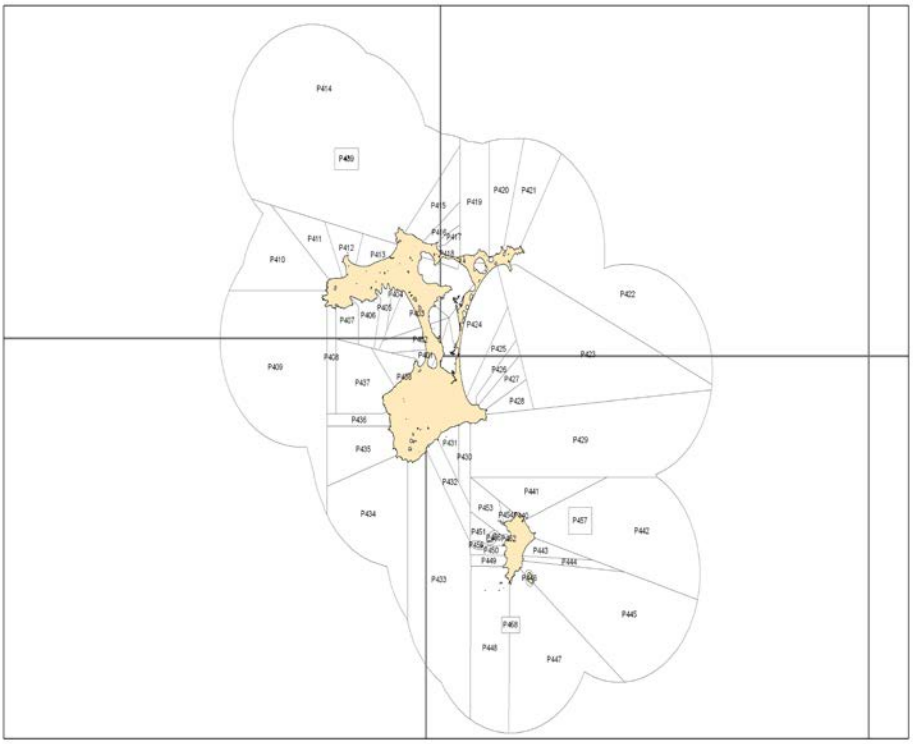
PĀUA (PAU 4) – Chatham Islands

(Haliotis iris)
Pāua



1. FISHERY SUMMARY

PAU 4 was introduced into the Quota Management System (QMS) in 1986–87 with a TACC of 261 t. The TACC was increased to 269 t in 1987–88, 271 t in 1988–89, and 287 in 1989–90. As a result of appeals to the Quota Appeal Authority, the TACC was further increased in 1995–96 to 326 t and has remained unchanged to the current fishing year (Table 1). Before the Fisheries Act (1996) a TAC was not required, and only a TACC was required when PAU 4 entered the QMS.

As a result of a court injunction a review of sustainability measures was undertaken for the 2019–20 fishing year, beginning 1 October 2019. The agreement reached resulted in a TAC, as well as allowances for Māori customary and recreational fishers being set. The TAC was set at 334 t, the TACC at 326.543 t, other mortality at 2 t, customary allowance at 3 t, and the recreational allowance at 3 t.

Because the pāua biomass appears to be declining, the PAU 4 Fishery Plan (approved in 2019 under section 11A of the Fisheries Act 1996) provides a commitment by PAU 4 quota owners to shelve 40% of the PAU 4 ACE.

Table 1: Total allowable catches (TAC, t) allowances for customary fishing, recreational fishing, and other sources of mortality (t) and Total Allowable Commercial Catches (TACC, t) declared for PAU 4 since introduction into the QMS.

Year	TAC	Customary	Recreational	Other mortality	TACC
1986–1987	–	–	–	–	261
1987–1988	–	–	–	–	269
1988–1989	–	–	–	–	271
1989–1995	–	–	–	–	287
1995–2019	–	–	–	–	326
2019 onwards	334	3	3	2	326

1.1 Commercial fisheries

The fishing year runs from 1 October to 30 September. On 1 October 2001 it became mandatory to report catch and effort on PCELRs using fine-scale reporting areas that had been developed by the New Zealand Pāua Management Company for their voluntary logbook programme (see figure above).

At the beginning of the 2009–10 fishing year, reporting of catch in PAU 4 was changed from reporting in greenweight to reporting in meatweight. The TACC is still set in greenweight but fishers are now required to report greenweight catch that is estimated from the meatweight measured by the licensed fish receiver (LFR). The meatweight to greenweight conversion factor is 2.50 (equivalent to 40% meatweight recovery). The change was made to curb the practice of converting meatweight to landed greenweight after shucking to obtain artificially high recovery rates. It was also made to encourage catch spreading by making it commercially viable for fishers to harvest areas where shells are heavily fouled and meatweight recovery is low. Heavy fouling on shells is a problem that occurs in a number of areas around the Chatham Islands. However this reporting requirement was changed back to greenweight at the beginning of the 2017–18 year.

Reported landings have remained below the TACC since 2010–11, averaging 276 t in 2010–11 to 2016–17 before decreasing to 203 t in 2017–18 and 185 t in 2018–19. Landings for PAU 4 are shown in Table 2 and Figure 1.

Table 2: TACC and reported landings (t) of pāua in PAU 4 from 1983–84 to the present.

Year	Landings	TACC
1983–84*	409.00	–
1984–85*	278.00	–
1985–86*	221.00	–
1986–87*	267.37	261.00
1987–88*	279.57	269.08
1988–89*	284.73	270.69
1989–90	287.38	287.25
1990–91	253.61	287.25
1991–92	281.59	287.25
1992–93	266.38	287.25
1993–94	297.76	287.25
1994–95	282.10	287.25
1995–96	220.17	326.54
1996–97	251.71	326.54
1997–98	301.69	326.54
1998–99	281.76	326.54
1999–00	321.56	326.54
2000–01	326.89	326.54
2001–02	321.64	326.54
2002–03	325.62	326.54
2003–04	325.85	326.54
2004–05	319.24	326.54
2005–06	322.53	326.54
2006–07	322.76	326.54
2007–08	323.98	326.54
2008–09	324.18	326.54
2009–10	323.57	326.54
2010–11	262.15	326.54
2011–12	262.07	326.54
2012–13	263.33	326.54
2013–14	291.98	326.54
2014–15	295.16	326.54
2015–16	294.73	326.54
2016–17	264.63	326.54
2017–18	203.03	326.54
2018–19	185.06	326.54

* FSU data

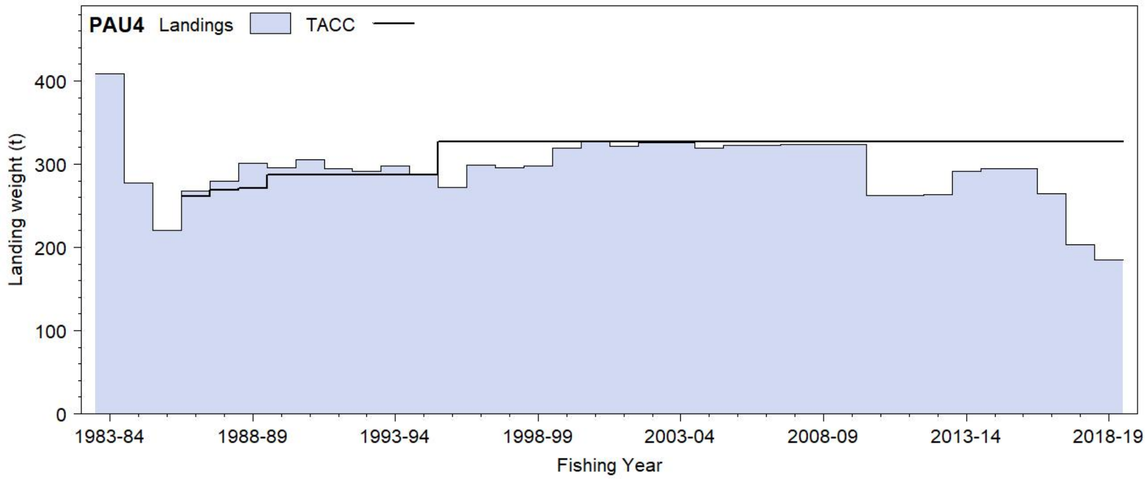


Figure 1: Reported commercial landings and TACC for PAU 4 from 1983–84 to the present.

1.2 Recreational fisheries

There are no estimates of recreational catch for PAU 4. The 1996, 1999–2000, and 2000–01 national marine recreational fishing surveys and the 2011–12 and the 2017–18 national panel surveys did not include PAU 4.

1.3 Customary fisheries

Estimates of customary catch for PAU 4 are shown in Table 3. These numbers are likely to be an underestimate of customary harvest because only the catch in kilograms and numbers are reported in the table.

For the 2004 stock assessment the customary catch was assumed to be zero.

For further information on customary fisheries refer to the introductory PAU Working Group Report.

Table 3: Reported customary landings (number of individuals) of pāua in PAU 4 from 2009–10 to 2018-19. – no data.

	Weight (kg)		Numbers	
Fishing year	**Approved**	**Harvested**	**Approved**	**Harvested**
2009–10	–	–	635	635
2010–11	–	–	–	–
2011–12	–	–	–	–
2012–13	–	–	–	–
2013–14	–	–	110	110
2014–15	–	–	150	150
2015–16	–	–	320	120
2016–17	–	–	366	366
2017–18	50	50	820	764
2018–19	330	330		

1.4 Illegal catch

There are no estimates of illegal catch for PAU 4. For the 2004 stock assessment this catch was assumed to be zero. For further information on illegal catch refer to the introductory PAU Working Group Report.

1.5 Other sources of mortality

For further information on other sources of mortality refer to the introductory PAU Working Group Report.

2. BIOLOGY

For further information on pāua biology refer to the introductory PAU Working Group Report.

3. STOCKS AND AREAS

For further information on stocks and areas refer to the introductory PAU Working Group Report.

4. STOCK ASSESSMENT

4.1 Estimates of fishery parameters and abundance

A standardised CPUE analysis for PAU 4 (Fu 2010) from 1989–90 to 2007–08 was completed in February 2010.

The Shellfish Working Group (SFWG) agreed that, because of extensive misreporting of catch in PAU 4, catch and effort data from the Fisheries Statistical Unit and from the CELR and PCELR forms might be misleading in CPUE analyses and therefore, CPUE cannot be used as an index of abundance in this fishery.

4.2 Stock assessment 2004

The last stock assessment for PAU 4 was completed in 2004 (Breen & Kim 2004). A Bayesian length-based stock assessment model was applied to PAU 4 data to estimate stock status and yield. A reference period from 1991–93 was chosen: this was a period after which exploitation rates increased and then leveled off, and after which biomass declined somewhat and then stabilised. It was not intended as a target. Assessment results suggested that then-current recruited biomass was just above $B_{AV,}$ but with high uncertainty (83% to 125%). and current spawning biomass appeared higher than S_{AV}, (130%), but with cautions related to maturity ogives. Projections suggested that 2007 recruited and spawning biomasses could be above B_{AV}, but this was uncertain.

The SFWG advised that major uncertainties in the assessment required the results to be treated with great caution. The major uncertainties included very sparse research diver survey data, misreported CELR and PCELR data, growth and length frequency data most likely not being representative of the whole population, and the assumption that CPUE was an index of abundance.

In February 2010 the SFWG agreed that, because of the lack of adequate data as input into the Bayesian length-based model, a stock assessment for PAU 4 using this model was not appropriate.

4.3 Biomass estimates

There are no current biomass estimates for PAU 4.

4.4 Yield estimates and projections

There are no estimates of PAU 4.

5. STATUS OF THE STOCKS

Stock Structure Assumptions

H. iris individuals collected from the Chatham Islands were found to be genetically distinct from those collected from costal sites around the North and South Islands (Will & Gemmell 2008).

PAU 4 - *Haliotis iris*

Stock Status	
Year of Most Recent Assessment	2004
Assessment Runs Presented	None
Reference Points	Target: 40% B_0 (Default as per HSS) Soft Limit: 20% B_0 (Default as per HSS) Hard Limit: 10% B_0 (Default as per HSS) Overfishing threshold: U40%B0
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
In 2010 the SFWG rejected CPUE as an index of abundance, therefore the 2004 stock assessment (Breen & Kim 2004) is no longer considered reliable.

Fishery and Stock Trends	
Recent Trend in Biomass or Proxy	Unknown
Recent Trend in Fishing Intensity or Proxy	Unknown
Other Abundance Indices	None
Trends in Other Relevant Indicators or Variables	None

Projections and Prognosis	
Stock Projections or Prognosis	The 2004 stock assessment is no longer considered reliable
Probability of Current Catch or TACC causing Biomass to remain below or to decline below Limits	Soft Limit: Unknown Hard Limit: Unknown
Probability of Current Catch or TACC causing Overfishing to continue or to commence	Unknown

Assessment Methodology and Evaluation		
Assessment Type	Full Quantitative Stock Assessment, but subsequently rejected	
Assessment Method	Length-based Bayesian model	
Assessment Dates	Last assessment: 2004	Next assessment: No fixed date
Overall assessment quality rank	3 - Low Quality	
Main data inputs (rank)	Catch history CPUE indices Tag recapture growth data Research diver abundance survey data Research diver length frequency data	3 - Low Quality 3 - Low Quality 2- Medium Quality 2- Medium Quality 2- Medium Quality
Data not used (rank)	-	
Changes to Model Structure and Assumptions	-	
Major Sources of Uncertainty	• Potential bias in RDSI • Unreliable reporting of catch and effort data • Assuming CPUE as a reliable index of abundance • Model assumes a homogeneous population • Other model assumptions may be violated	

Qualifying Comments
The 2004 full quantitative stock assessment is no longer considered reliable; *i.e.* the previous assessment has been rejected and there is currently no valid assessment for this stock.

Fishery Interactions
-

6. FOR FURTHER INFORMATION

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Schiel, D R (1992) The paua (abalone) fishery of New Zealand. *In:* Shepherd, S A; Tegner, M J; Guzman del Proo, S (Eds.), *Abalone of the World: Biology, fisheries, and culture.* Blackwell Scientific, Oxford.

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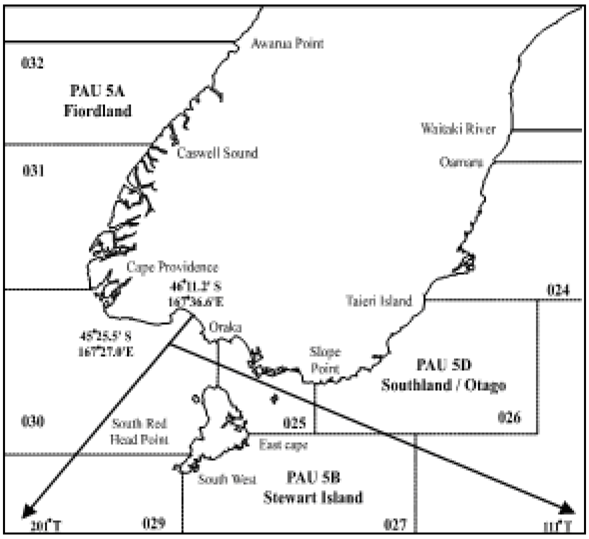
Will, M C; Gemmell, N J (2008) Genetic Population Structure of Black Foot paua. Final Research Report for project GEN2007A. 37 p. (Unpublished report held by Fisheries New Zealand.)

PĀUA (PAU 5A) – Fiordland

(Haliotis iris)
Pāua



1. FISHERY SUMMARY

Prior to 1995, PAU 5A was part of the PAU 5 QMA, which was introduced into the QMS in 1986 with a TACC of 445 t. As a result of appeals to the Quota Appeal Authority, the TACC increased to 492 t in the 1991–92 fishing year; PAU 5 was then the largest QMA by number of quota holders and TACC. Concerns about the status of the PAU 5 stock led to a voluntary 10% reduction in the TACC in 1994–95. On 1 October 1995, PAU 5 was divided into three QMAs (PAU 5A, PAU 5B, and PAU 5D; see the figure above) and the TACC was divided equally among them; the PAU 5A quota was set at 148.98 t.

There is no TAC for PAU 5A (Table 1): before the Fisheries Act (1996) a TAC was not required. When changes have been made to a TACC after 1996, stocks have been assigned a TAC. No allowances have been made for customary, recreational or other mortality.

Table 1: Total allowable catches (TAC, t) allowances for customary fishing, recreational fishing, and other sources of mortality (t) and Total Allowable Commercial Catches (TACC, t) declared for PAU 5 and PAU 5A since introduction to the QMS.

Year	TAC	Customary	Recreational	Other mortality	TACC
1986–1991*	-	-	-	-	445
1991–1994*	-	-	-	-	492
1994–1995*	-	-	-	-	442.8
1995–present	-	-	-	-	148.98

*PAU 5 TACC figures

1.1 Commercial fisheries

The fishing year runs from 1 October to 30 September.

On 1 October 2001 it became mandatory to report catch and effort on Pāua Catch Effort Landing Returns (PCELRs) using fine-scale reporting areas that had been developed by the New Zealand Pāua Management Company for their voluntary logbook programme (Figure 1).

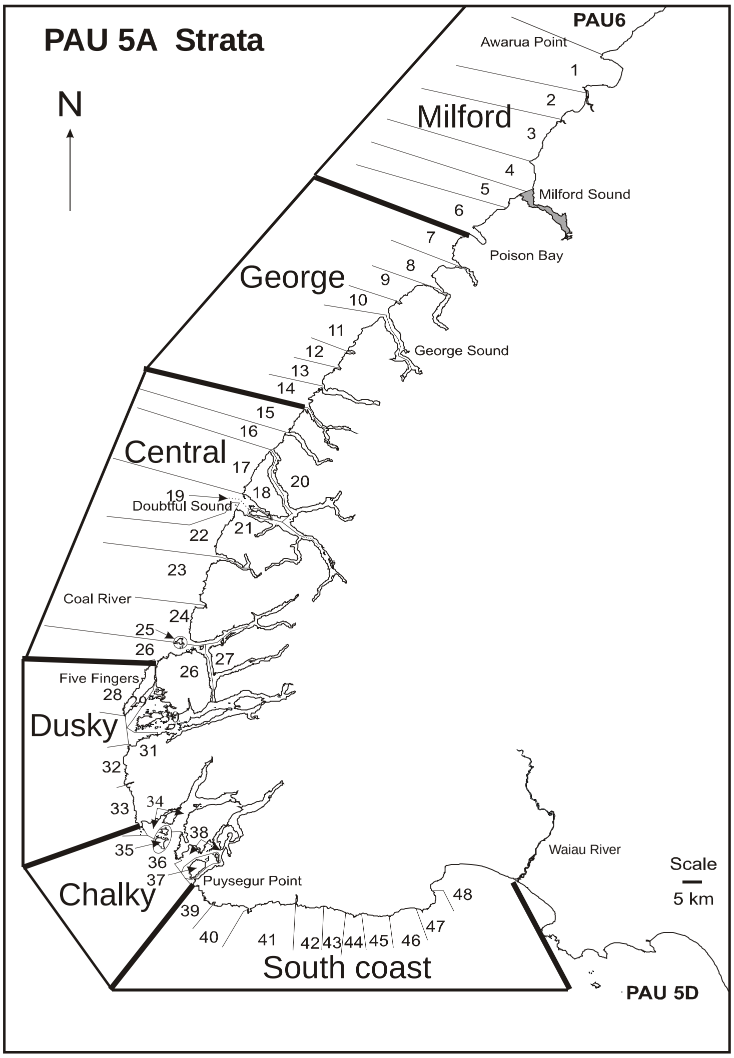


Figure 1: Map of Pāua Statistical Areas, and voluntary management strata in PAU 5A.

PAU 5A landings were close to the TACC from the fishing year 1995–96 to 2005–06, but dropped to an average of 105 t a year from 2006–07 onwards (Table 2 and Figure 2). Landings for PAU 5 prior to 1995–96 are reported in the introductory PAU Working Group Report.

Table 2: TACC and reported landings (t) of pāua in PAU 5A from 1995–96 to the present from MHR returns.

Year	Landings	TACC
1995–96	139.53	148.98
1996–97	141.91	148.98
1997–98	145.22	148.98
1998–99	147.36	148.98
1999–00	143.91	148.98
2000–01	147.70	148.98
2001–02	148.53	148.98
2002–03	148.76	148.98
2003–04	148.98	148.98
2004–05	148.95	148.98
2005–06	148.92	148.98
2006–07	104.03	148.98
2007–08	105.13	148.98
2008–09	104.82	148.98
2009–10	105.74	148.98
2010–11	104.40	148.98
2011–12	106.23	148.98
2012–13	105.56	148.98
2013–14	102.30	148.98
2014–15	106.95	148.98
2015–16	106.84	148.98
2016–17	106.50	148.98
2017–18	107.45	148.98
2018–19	99.66	148.98

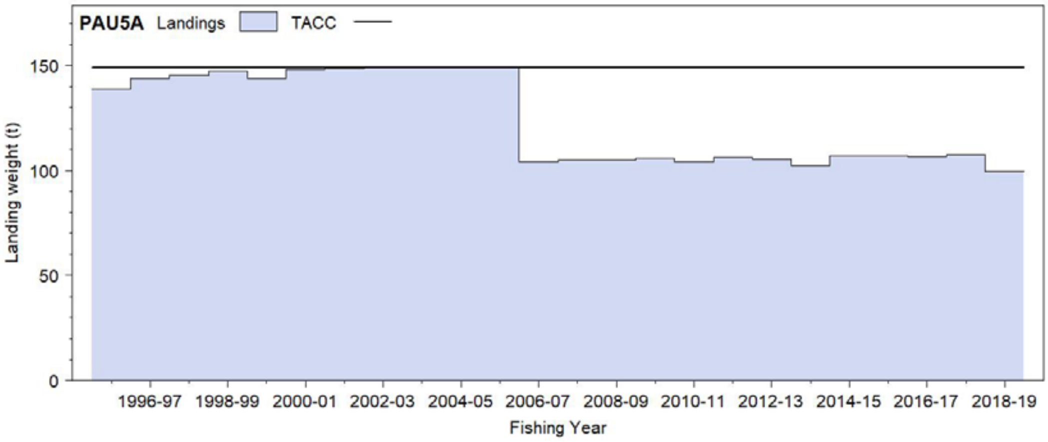


Figure 2: Landings and TACC for PAU 5A from 1995–96 to the present. For historical landings in PAU 5 prior to 1995–96, refer to figure 1 and table 1 in the introductory PAU Working Group Report.

1.2 Recreational fisheries

The National Panel Survey of Marine Recreational Fishers 2011–12: Harvest Estimates Wynne-Jones et al (2014), estimated that about 0.42 t of pāua were harvested by recreational fishers in PAU 5A in 2011–12.

The national panel survey was repeated in 2017–18 (Wynne-Jones et al 2019) and the estimated harvest for PAU 5A was 0.85 t (CV = 0.76). For the purpose of the 2020 stock assessment, the SFWG agreed to assume that the recreational catch rose linearly from 1965 to 1 t in 1974, and has remained at 1 t since 1974.

For further information on recreational fisheries refer to the introductory PAU Working Group Report.

1.3 Customary fisheries

Estimates of customary catch for PAU 5A are shown in Table 3. These numbers are likely to be an underestimate of customary harvest as only the catch in numbers are reported in the table.

Records of customary non-commercial catch taken under the South Island Regulations show that about 70 pāua were taken in 2001–2002, then nothing until 2007–08. From 2007–08 to 2012–13, 100 to 500 pāua were collected each year. Since then, less pāua have been reported as caught (maximum 200 t in 2017–18).

Table 3: Fisheries New Zealand records of customary harvest of pāua (reported in numbers) of pāua in PAU 5A since 2001–02. – no data.

Fishing year	Approved	Harvested
2001–02	80	70
2002–03	–	–
2003–04	–	–
2004–05	–	–
2005–06	–	–
2006–07	–	–
2007–08	100	100
2008–09	100	100
2009–10	150	150
2010–11	150	150
2011–12	512	462
2012–13	590	527
2013–14	–	–
2014–15	–	–
2015–16	255	50
2016–17	–	–
2017–18	200	200
2018–19	–	–

For the purpose of the 2020 stock assessment model, the SFWG agreed to assume that customary catch has been constant at 1 t.

For further information on customary fisheries refer to the introductory PAU Working Group Report.

1.4 Illegal catch

There is qualitative data to suggest Illegal, unreported, unregulated (IUU) activity in this Fishery. There are no quantitative estimates of illegal catch for PAU 5A. For the purpose of the 2020 stock assessment model, the SFWG agreed to assume that illegal catches have been a constant 5 t.

1.5 Other sources of mortality

For further information on other sources of mortality refer to the introductory PAU Working Group Report.

2. BIOLOGY

For further information on pāua biology refer to the introductory PAU Working Group Report. Biological parameters derived using data collected from PAU 5A are summarised in Table 4. Size-at-maturity, natural mortality and annual growth increment parameters were estimated within the assessment model.

Table 4: Estimates of biological parameters (*H. iris*). All estimates are external to the model.

Stock area		Estimate	Source
1. Weight = a (length)^b (weight in kg, shell length in mm)			
PAU 5A	a = 2.99E-08	b = 3.303	Schiel & Breen (1991)
2. Size at maturity (shell length)			
PAU 5A	50% mature	91 mm (89–93)	Median (5–95% range) estimated outside of the assessment
	95% mature	103 mm (101–105)	
3. Estimated annual growth increments (both sexes combined)			
PAU 5A	At 75 mm	16.65 mm (15.96–24.29)	Median (5–95% range) estimated outside of the assessment
	At 120 mm	4.57 mm (3.27–6.40)	

3. STOCKS AND AREAS

For further information on stocks and areas refer to the introductory PAU Working Group Report.

4. STOCK ASSESSMENT

For 2010 and 2014, the stock assessments for PAU 5A had split PAU 5A into two subareas; the southern area which included the Chalky and South Coast strata, and the northern area which included the Milford, George, Central, and Dusky strata (Figure 1). Separate stock assessments were conducted in each subarea. The division was based on the availability of data, differences in exploitation history and management initiatives. Prior to 2010 the area was assessed as a single area. The 2020 assessment re-evaluated the split of PAU 5A into two subareas, and concluded that the data used for the separate assessments did not adequately reflect the differences in these areas, and the 2020 assessment was therefore run in two configurations: as a single area assessment over all of PAU 5A, and by splitting the area into three areas (statistical areas around Milford Sound (large scale Statistical Area 032) were separated from the previously defined Northern area due to slower growth) and fitting a spatial version of the assessment model (Neubauer 2020a). Initial assessment runs suggested no difference in key estimated quantities between the spatial and single-area models, and the SFWG decided to proceed with the more parsimonious single area model.

4.1 Estimates of fishery parameters and abundance

Parameters estimated in the base case model (for both the southern and northern areas) and their assumed Bayesian priors are summarised in Table 5.

Table 5: A summary of estimated model parameters, lower bound, upper bound, type of prior, (U=uniform; N= normal; LN=lognormal; Beta = beta distribution), mean and CV of the prior.

Parameter	Prior	μ	sd	Bounds Lower	Bounds Upper
ln(*R0*)	LN	13.5	0.5	10	20
D_{50}(Length at 50% selectivity for the commercial catch)	LN	123	0.05	100	145
D_{95-50}(Length between 50% and 95% selectivity the commercial catch)	LN	5	0.5	0.01	50
Steepness (h)	Beta	0.8	0.17	0	1
ϵ (Recruitment deviations)	LN	0	2	0	-

The observational data were:

1. A standardised CPUE series covering 1989–2018 based on combined CELR and PCELR data.
2. A commercial catch sampling length frequency

4.1.1 Relative abundance estimates from standardised CPUE analyses

A combined series of standardised CPUE indices that included FSU (1983–1989), CELR data covering 1990–2001, and PCELR data covering 2002–2019 was used for the 2020 stock assessment (Figure 3). CPUE standardisation was carried out using a Bayesian Generalised Linear Mixed Model (GLMM) which partitioned variation among fixed (research strata) and random variables, and between fine-scale reporting (PCELR) and larger scale variables (CELR). The FSU data contained no standardising variables. The variation explained by fine-scale variables (e.g. fine scale statistical areas or divers) in PCELR data was considered unexplained in the CELR and FSU portion of the model and therefore added to observation error.

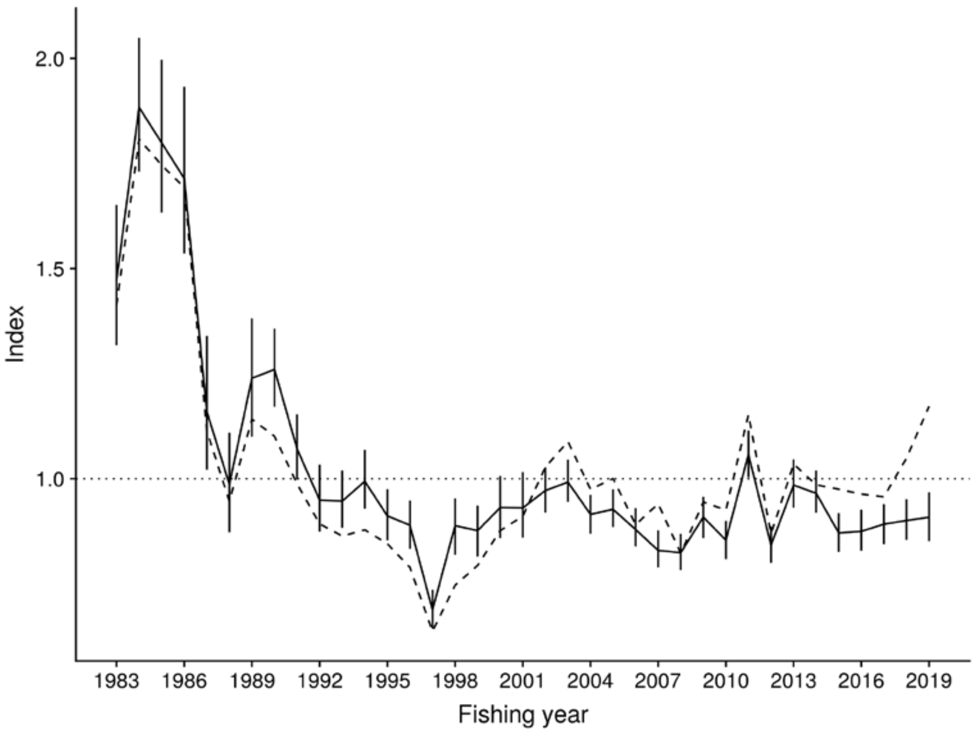


Figure 3: The standardised CPUE indices with 95% confidence intervals (solid line and vertical error bars) and unstandardised geometric CPUE (dashed line) for the combined CELR and the PCELR series.

There was ambiguity in the CELR data about what was recorded for estimated daily fishing duration: either incorrectly recorded as hours per diver, or correctly as total hours for all divers. For PAU 5A, fishing duration appeared to have been predominantly recorded as hours per diver. A model-based correction procedure was developed to detect and correct for misreporting, using a mixture model that determines the characteristics of each reporting type by fishing crew and assigns years to correct (reporting for all divers) or incorrect (by diver) reporting regimes with some probability. Only records with greater than 95% certainty of belonging to one or the other reporting type were retained for further analysis.

CPUE was defined as the log of daily catch-per-unit-effort. Variables in the model were fishing year, FIN (Fisher Identification Number), Statistical Area, dive condition, diver ID, and fine-scale statistical area. Variability in CPUE was mostly explained by differences among crews (FINs), with dive conditions also strongly affecting CPUE. The CPUE data showed initially high CPUE in the 1980s, followed by a rapid decline and subsequent increase in the late 1980s. A further decline in the early 1990s was evident, with relatively stable but fluctuating CPUE since 1992. In some circumstances, commercial CPUE may not be proportional to abundance because it is possible to maintain catch rates of pāua despite a declining biomass. This occurs because pāua tend to aggregate and divers move among areas to maximise their catch rates. Apparent stability in CPUE should therefore be interpreted with caution. The assumption of CPUE being proportional to biomass was investigated using the assessment model.

4.1.2 Relative abundance estimates from research diver surveys

Relative abundance of pāua in PAU 5A has previously been estimated from research diver surveys conducted in 1996, 2002, 2003, 2006, and 2008–2010. Not every stratum was surveyed in each year, and before 2005–06 surveys were conducted only in the area south of Dusky Sound.

Concerns about the reliability of this data as an estimate of relative abundance instigated several reviews in 2009 (Cordue 2009) and 2010 (Haist 2010). The reviews assessed i) the reliability of the research diver survey index as a proxy for abundance and ii) whether the Research Diver Survey Index (RDSI), when used in the pāua stock assessment models, results in model outputs that do not adequately reflect the status of the stocks. Both reviews suggest that outputs from pāua stock assessments using the RDSI should be treated with caution. Consequently, these data were not included in the assessment. For a summary of the conclusions from the reviews refer to the introductory PAU Working Group Report.

4.2 Stock assessment methods

The 2020 stock assessment for PAU 5A used an updated version of the length-based population dynamics model described by Breen et al (2003). The stock was last assessed using data up to the 2014 fishing year (Fu 2015a, b) and the most recent assessment uses data up to the 2018–2019 fishing year (Neubauer 2020b). Although the overall population-dynamics model remained unchanged, the most recent iteration of the PAU 5A stock assessment incorporates changes to the previous methodology (first introduced in the 2019 assessment of Pau 5D; Neubauer & Tremblay-Boyer 2019):

1. The base case model considered the entire area of PAU 5A, rather than conducting separate assessments for the PAU 5A northern and PAU 5A southern areas.
2. CPUE likelihood calculations reverted to predicting CPUE from beginning of year biomass since the previous change to mid-year predictions did not affect the assessment and caused potential for error and an increased computational burden.
3. A Bayesian statistical framework across all data inputs and assessments (MPD runs were not performed; all exploration was performed using full Markov chain Monte Carlo runs).
4. The assessment model framework was moved to the Bayesian statistical inference engine Stan (Stan Development Team 2018), including all data input models (the assessment model was previously coded in ADMB).
5. Catch sampling length-frequency (CSLF) data handling was modified to a model-based estimation of observation error with partitioning between observation and process error for CSLF and CPUE, and use of a multivariate normal model for centred-log-ratio-transformed mean CSLF and observation error.
6. The data weighting procedure was to use a scoring rule (log score) and associated divergence measure (Kullbach-Liebler divergence) to measure information loss and goodness of fit for CPUE and CSLF.
7. Growth and maturation were fit to data across all QMAs outside of the assessment model, and the resulting mean growth and estimate of proportions mature at age were supplied as an informed prior on growth to the model; no growth or maturation data were explicitly fitted in the model.

The model structure assumed a single-sex population residing in a single homogeneous area, with length classes from 70 mm to 170 mm in groups of 2 mm, although a spatial version of the assessment model (Neubauer, 2020a) was also tried. For the latter, the model assumed three areas, with the Southern area identical to the previously assessed Southern stock area, and the Northern areas splitting the previous Northern assessment area south of Milford Sound to account for growth differences to the north of Milford Sound.

Growth is length-based, without reference to age, mediated through a growth transition matrix that describes the probability of each length class to change at each time step. Pāua entered the partition following recruitment and were removed by natural mortality and fishing mortality.

The model simulates the population from 1965 to 2019. Catches were available for 1974–2019 although catches before 1995 must be estimated from the combined PAU 5 catch, and were assumed to increase linearly between 1965 and 1973 from 0 to the 1974 catch level. Catches included commercial, recreational, customary, and illegal catch, and all catches occurred within the same time step. For the spatial model, it was assumed that 80% of the non-commercial catch was taken from the southern area of PAU 5A, with the remainder being taken from the northern areas.

Recruitment was assumed to take place at the beginning of the annual cycle, and length at recruitment was defined by a uniform distribution with a range between 70 and 80 mm. Growth and natural mortalities were estimated within the model from informed prior distributions. The model estimated the commercial fishing selectivity, assumed to follow a logistic curve and to reach an asymptote. Dome-shaped selectivity curves were also investigated for the present assessment. The increase in Minimum Harvest Size since 2006 was modelled as a shift in fishing selectivity.

The commercial catch history estimates were made under assumptions about the split of the catch between sub-stocks of PAU 5, and between subareas within PAU 5A. The base case model run assumed that 40% of the catch in Statistical Area 030 was taken from PAU 5A between 1985 and 1996. Estimates made under alternative assumptions (a lower bound of 18% and an upper bound of 61%) were used in sensitivity trials. Commercial catch sampling length-frequency samples before 2002 (1992–1994, 1998, and 2001) were excluded from the base case, because the sample size is low and sampling coverage is dubious. The model was initiated with likelihood weights that were found to lead to subjectively appropriate fits to both CPUE and CSLF inputs in other areas (PAU 5D and PAU 5B) The RDSI and RDLF were excluded from all models, and the CPUE shape parameter was fixed at 1 assuming a linear relationship between CPUE and abundance except for one scenario assuming a hyper-stable CPUE-abundance relationship. The assessment proceeded in three stages (sets):

A first set of model runs explored:

- Including the FSU CPUE index or excluding it.
- Estimating a trend in catchability, and forcing hyper-stable CPUE.
- High and Low Statistical Area 030 catch scenarios prior to 1996.
- Lower recruitment variability.

The trend in catchability was implemented as a linear trend in log-space. Data weight parameters were set to values that produced reasonable fits in other assessments.

A variation of the first set of model runs explored running the same scenarios as described above, but using the spatial model described in Neubauer (2020a) for each of the three large scale reporting strata (Statistical Areas 030, 031, 032). Natural mortality and steepness were shared parameters, whereas recruitment was estimated independently for each region, and total (PAU 5A-wide) unfished recruitment was partitioned into each of the three regions using a composition vector that was estimated within the model using an informed prior based on relative catch levels.

After running the first set of models it was evident that models were using recruitment to adjust the biomass for increases in CPUE after an initial decline in the late 1980s and early 1990s. However, this period of CPUE increase coincides with a period of rapidly increasing efficiency (dive gear, operational aspects, weather forecasts) in all PAU fisheries around the country, which all show some degree of

CPUE increase during this period. The SFWG therefore decided to fix recruitment for the years until CSLF information became available (2000–01), and to instead use variable catchability by i) splitting catchability into reporting epochs (FSU, CELR and PCELR) and ii) estimating increase in catchability for each epoch.

In addition to fixing early recruitment, models using variable selectivity were trialled to account for spatially variable fishing patterns that are likely to drive some of the CPUE variation (rather than variation being recruitment driven): if fishers only fish a subset of available areas in any given year (due to weather or market constraints), variable (and potentially dome-shaped) selectivity would be expected given small scale variation in growth and fishing pressure. Both variable logistic selectivity (variable length at 50% selection), and fixed and variable dome-shaped selectivity (with variable right hand limb of the inverted quadratic curve used for the dome-shaped selectivity) were implemented. Models with variable dome-shaped selectivity did not converge and were therefore excluded.

Lastly, given doubts about accuracy in early FSU reporting, in conjunction with implausible scenarios from excluding FSU data altogether, the working group decided to trial estimating initial depletion in 1984 (and ignoring both catch and CPUE prior to 1984), as well as starting CPUE in 1984 instead of 1983 (reported CPUE was high from 1984, but lower in 1983), but maintaining the catch time-series from 1965. In summary, the second set of models were set up as follows:

- Including the FSU CPUE index, but starting CPUE in 1984, or estimating initial depletion in 1984 (starting catch and CPUE in 1984).
- Estimating a trend in catchability by CPUE reporting period (using separate initial q for FSU, CELR and PCELR).
- Baseline Statistical Area 030 catch scenarios prior to 1996.
- Fixed recruitment prior to CSLF data availability (estimated from three years prior to first year of CSLF data).
- Variable logistic selectivity and dome-shaped selectivity (fixed - variable dome-shape did not converge).

The robustness of models from the first two sets that were judged plausible (Baseline catch with FSU CPUE from 1984, with or without recruitment deviations for pre-CSLF period, with variable selectivity or not) was investigated by varying model weights. Three sets of weights were trialled in addition to weights used in sets 1 & 2: all sets down-weight CPUE by a factor of 2 relative to sets 1 & 2, and either doubled (0.2) or halved (0.05) CSLF weights.

The assessment calculates the following quantities from the marginal posterior distributions of various partitions of the biomass: the equilibrium (unfished) spawning stock biomass (SSB_0) assuming that recruitment is equal to the average recruitment, and the relative spawning and available biomass for 2018 (SSB_{2018} and $B^{Avail}_{2018}\mathrm{B}^{\mathrm{Avail}}_{\mathrm{Proj}}$) and for the projection ($Proj$) period ($\mathrm{SS}B_{Proj}$ and B^{Avail}_{proj}). This assessment also reports the following fishery indictors:

Relative SSB	Estimated spawning stock biomass in the final year relative to unfished spawning stock biomass
Relative B^{Avail}	Estimated available biomass in the final year relative to unfished available stock biomass
P(SSB_{2018} > 40% SSB_0)	Probability that the spawning stock biomass in 2018 was greater than 40% of the unfished spawning stock
P(SSB_{2018} > 20% SSB_0)	Probability that the spawning stock biomass in 2018 was greater than 20% of the unfished spawning stock (soft limit)
P(SSB_{Proj} > 40% SSB_0)	Probability that projected future spawning stock biomass will be greater than 40% of the unfished spawning stock given assumed future catches
P(SSB_{Proj} > 20% SSB_0)	Probability that projected future spawning stock biomass will be greater than 20% of the unfished spawning stock given assumed future catches
P(B_{Proj} > B_{2018})	Probability that projected future biomass (spawning stock or available biomass) is greater than estimated biomass for the 2018 fishing year given assumed future catches

4.3 Stock assessment results

The initial set of model runs produced three distinct outcomes: models that did not include FSU data suggested very little depletion since the start of the fishery (final stock status above 60% of SSB_0), whereas models with forced hyper-depletion in the CPUE index or estimated increase in catchability lead to higher depletion levels (final stock status near 40% of SSB_0).

The baseline model with FSU data included, as well as scenarios with low or high catch from Statistical Area 030 all produced intermediate status estimates, as did the model with reduced recruitment variability. The latter model stood out as a model that estimated both much faster growth as well as high M (M>0.1; with M<0.1 for all other runs).

Based on these runs the working group decided that model scenarios without FSU data most likely did not adequately capture biomass declines over the initial phase of the fishery, as the estimate of a stock near 75% of un-fished biomass in the early 2000s did not appear compatible with a voluntary 30% shelving of the quota in 2006. Given that models with estimated increase in q produced similar results to those with forced hyper-depletion, the latter were not pursued further.

Spatial model runs were able to partition the initial biomass decline and demographic variability into the three regions. The Northern region (north of Milford) had the lowest depletion level owing to sporadic fishing in the region, which has significantly slower growth than the other regions but a similar share of overall recruitment. Overall, aggregate values from the spatial model were nearly identical to the non-spatial model and the more parsimonious single-area model was therefore preferred by the working group.

All models in the second set of model runs produced similar outcomes, with the exception of the model with variable selectivity, which appeared to over-fit and produce implausible selectivity patterns. Starting CPUE in 1984 (ignoring the low 1983 year) produced very similar results to model runs that include the first year. It was nevertheless excluded from subsequent model runs given concerns about early CPUE reporting. Estimating initial depletion in 1984 invariably led to low estimated initial depletion (i.e., the mode of the posterior distribution for initial depletion near zero). This depletion level was judged implausible by the working group. As models with estimated initial depletion led to similar inferences about stock status and productivity as models with a longer catch time-series, these models were not explored further.

Estimated selectivity in the dome-shaped selectivity model was only slightly domed, with a slight increase in doming after 2006. The (invariable) left-hand limb of the curve was estimated near post-2006 selectivity for models with logistic selectivity. The model with variable logistic selectivity suggested very highly variable selectivity with selection of large individuals in early years to allow the model to fit a steep CPUE decline in the FSU years. However, this pattern was judged implausible by the working group, as it appeared that selectivity was taking the role of other, unknown process error and allowed the model to over-fit.

Models with no time-varying process error (i.e., no yearly variable selectivity or recruitment) prior to availability of CSLF data nevertheless provided reasonable fits to CPUE (which shows some high inter-annual variability).

Changing the weights for CSLF and CPUE data had comparatively little impact on the stock trajectory: Reducing CSLF weights generally led to a lower stock status, but all estimates remained near or above 40% or B_0. A reduction in CSLF weight also led to less extreme variation in estimated selectivity for the variable logistic selectivity model, but the selectivity still suggested selection of large individuals in the early years of the fishery, and a decrease in the fully selected size in more recent years, which is contrary to estimates from a model with a single shift in selectivity in 2006, which suggests a shift in the size-at-50% selection in 2006 in line with an increase in the MHS.

The difference from data weights was altogether small compared with differences introduced by estimating (or not) recruitment for pre-CSLF years. Models that included variable recruitment for all CPUE years as well as trends in q suggested a strong recent increase in q over the PCELR period, and a continued decline of the fishery to below 40% of B_0. However, this recent increase in catchability was judged less likely by the working group, especially since most of the significant innovations in the fishery (better boats, improved wetsuits and fins, and other gear) took place in the CELR period (1990s), and most likely not in the more recent PCELR period.

As a suitable base case, the working group selected a model with:

- CPUE starting in 1984, therefore removing the initial FSU record;
- estimated recruitment from 2001;
- separate catchability for three reporting periods.

The base case suggested a relatively slow but steady downward trend in spawning stock biomass since the 1990s (Figure 4), with a more recent downward trend that was attributed to estimates of recruitment being forced low to compensate for early estimated above-average recruitment (CPUE is slowly increasing most recently). The base case also indicated that the stock is currently above target spawning stock biomass with a high probability, with little to no probability that it is below the soft limit of 0.2 SSB_0. This inference was supported by the agreed sensitivity run, which included an estimated trend in catchability (Figure 4).

Projections from the base case model (Table 5) suggested little movement in spawning stock biomass over the coming years at current catch levels. The tested sensitivity led to lower recent stock status, but with a slight recent increase, providing a better fit to recent CPUE. In addition, projections from this model were slightly more optimistic about future stock trajectory, even at increased catch levels (Table 6).

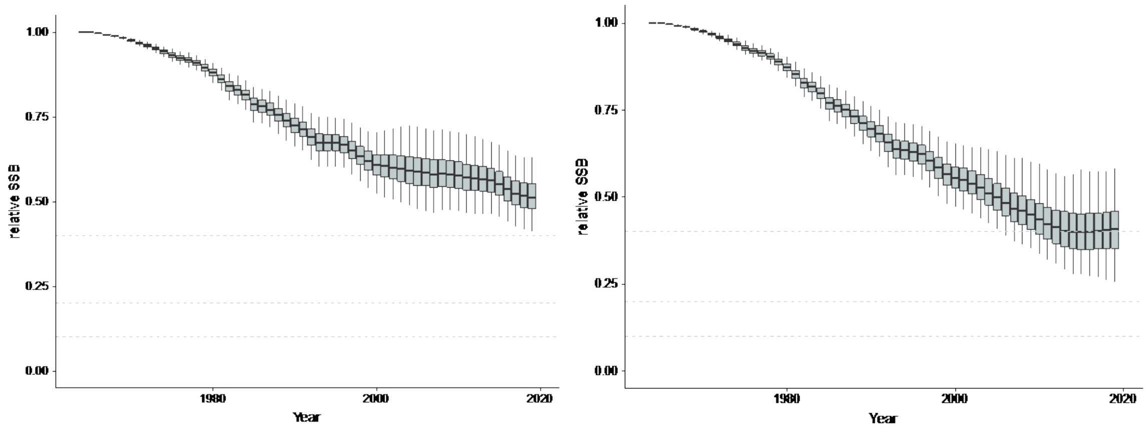


Figure 4: Posterior distributions of spawning stock biomass from the base case model, the sensitivity scenario with increasing catchability. The box shows the median of the posterior distribution (horizontal bar), the 25th and 75th percentiles (box), with the whiskers representing the 95% confidence range of the distribution.

Table 6: Projections for key fishery indicators from the base case model: probabilities of being above 40% and 20% of unfished spawning biomass (SSB) [P(SSB_{Proj} > 40% SSB_0) and P(SSB_{Proj} > 20% SSB_0)], the probability that SSB in the projection year is above current SSB, the posterior median relative to SSB, the posterior median relative available spawning biomass B^{Avail}_{Proj}, and the probability that the exploitation rate (U) in the projection year is above $U_{40\%\ SSB0}$, the exploitation rate that leads to 40% SSB_0. The total commercial catch (TCC) marked with * corresponds to current commercial catch under 30% shelving of the current TACC (149 t). Other TACC scenarios show 50% shelving (83.4 t), 10% shelving (125.1 t) and fishing at the current TACC. Simulation to equilibrium (assumed to have been reached after 50 projection years) are indicated with Eq. in the year column. [Continued on next page]

TACC (t)	Year	P(SSB_{Proj} > 40% SSB_0)	P(SSB_{Proj} > 20% SSB_0)	P(SSB_{Proj} > SSB_{2018})	Median rel. SSB_{Proj}	Median rel. B^{Avail}_{Proj}	P(U > $U_{40\%\ SSB0}$)
83.4	2019	0.99	1	0	0.52	0.41	0.6
	2020	0.98	1	0.12	0.52	0.4	0.59
	2021	0.98	1	0.39	0.52	0.4	0.58
	2022	0.98	1	0.46	0.52	0.4	0.57
	Eq.	0.85	0.99	0.63	0.59	0.46	0.59
104.3*	2019	0.99	1	0	0.52	0.41	0.6
	2020	0.98	1	0.12	0.52	0.4	0.59
	2021	0.98	1	0.27	0.51	0.39	0.58
	2022	0.96	1	0.34	0.51	0.39	0.57

Table 6 [Continued]

TACC (t)	Year	P(SSB_{Proj} > 40% SSB_0)	P(SSB_{Proj} > 20% SSB_0)	P(SSB_{Proj} > SSB_{2018})	Median rel. SSB_{Proj}	Median rel. B^{Avail}_{Proj}	P(U > $U_{40\% SSB0}$)
	Eq.	0.68	0.95	0.43	0.5	0.36	0.51
125.1	2019	0.99	1	0	0.52	0.41	0.6
	2020	0.98	1	0.12	0.52	0.4	0.59
	2021	0.97	1	0.19	0.51	0.39	0.57
	2022	0.95	1	0.25	0.5	0.37	0.56
	Eq.	0.48	0.87	0.24	0.41	0.25	0.42

4.5 Other factors

To run the stock assessment model a number of assumptions must be made, one of these being that CPUE is a reliable index of abundance. The literature on abalone fisheries suggests that this assumption is questionable and that CPUE is difficult to use in abalone stock assessments due to the serial depletion behaviour of fishers along with the aggregating behaviour of abalone. Serial depletion is when fishers consecutively fish-down beds of pāua but maintain their catch rates by moving to new unfished beds; thus CPUE stays high while the overall population biomass is actually decreasing. The aggregating behaviour of pāua results in the timely re-colonisation of areas that have been fished down, as the cryptic pāua that were unavailable at the first fishing event, move to and aggregate within the recently depleted area. Both serial depletion and aggregation behaviour cause CPUE to have a hyperstable relationship with abundance (i.e. abundance is decreasing at a faster rate than CPUE) thus potentially making CPUE a poor proxy for abundance. The strength of the effect that serial depletion and aggregating behaviour have on the relationship between CPUE and abundance in PAU 5A is difficult to determine. However, because fishing has been consistent in for a number of years and effort has been reasonably well spread, it could be assumed that CPUE is not as strongly influenced by these factors, relative to the early CPUE series.

The assumption of CPUE being a reliable index of abundance in PAU 5A can also be upset by exploitation of spatially segregated populations of differing productivity. This can conversely cause non-linearity and hyper-depletion in the CPUE-abundance relationship, making it difficult to accurately track changes in abundance by using changes in CPUE as a proxy.

Another source of uncertainty is the data. The commercial catch is unknown before 1974 and is estimated with uncertainty before 1995. Major differences may exist between the catches assumed in the model and what was actually taken. Non-commercial catch trends, including illegal catch, are also relatively poorly determined and could be substantially different from what was assumed.

The model treats the whole of the assessed area of PAU 5A as if it were a single stock with homogeneous biology, habitat and fishing pressure. The model assumes homogeneity in recruitment and natural mortality. Heterogeneity in growth can be a problem for this kind of model (Punt 2003). Nevertheless, the spatial-three area model showed nearly identical trends to the single area model, and variation in growth is most likely addressed to some extent by having a stochastic growth transition matrix based on increments observed in several different places; similarly the length frequency data are integrated across samples from many places. Nevertheless, length frequency data collected from the commercial catch may not represent the available biomass represented in the model with high precision.

The effect of these factors is likely to make model results optimistic. For instance, if some local stocks are fished very hard and others not fished, recruitment failure can result because of the depletion of spawners, as spawners must breed close to each other, and the dispersal of larvae is unknown and may be limited. Recruitment failure is a common observation in overseas abalone fisheries, and the current model does not account for such local processes that may decrease recruitment.

Another source of uncertainty is that fishing may cause spatial contraction of populations (Shepherd & Partington 1995), or that it may result in some populations becoming relatively unproductive after initial fishing (Gorfine & Dixon 2000). If this happens, the model will overestimate productivity in the population as a whole.

5. STATUS OF THE STOCKS

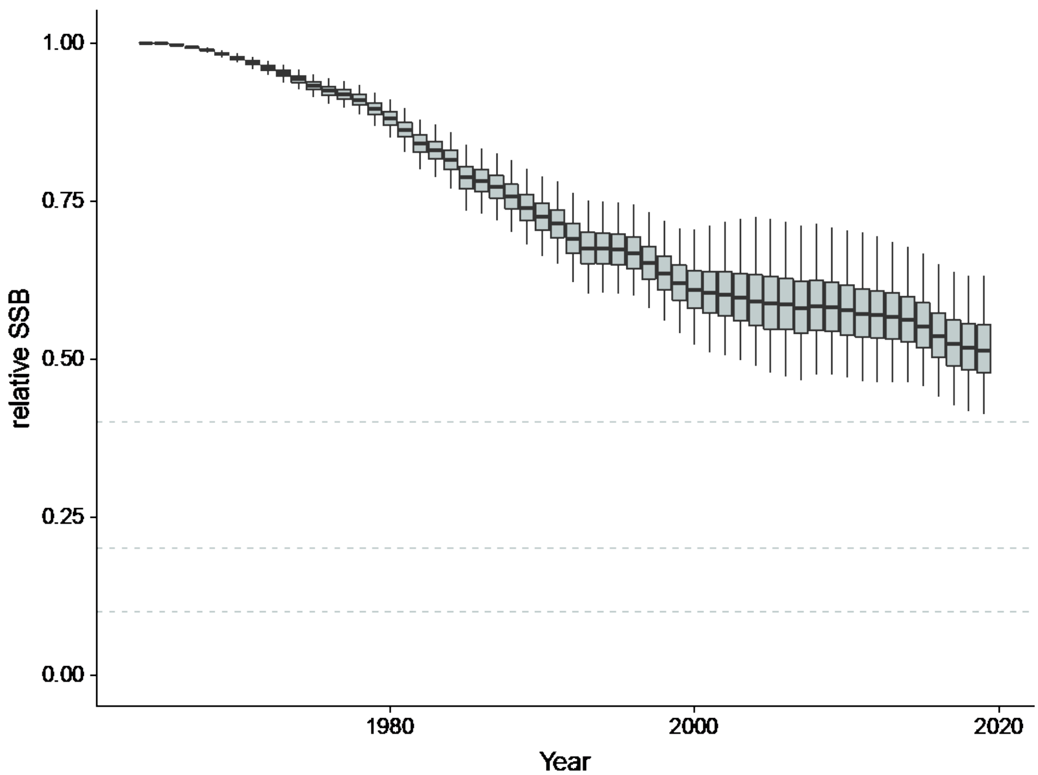
Stock Structure Assumptions

A genetic discontinuity between North Island and South Island pāua populations was found approximately around the area of Cook Strait (Will & Gemmell 2008).

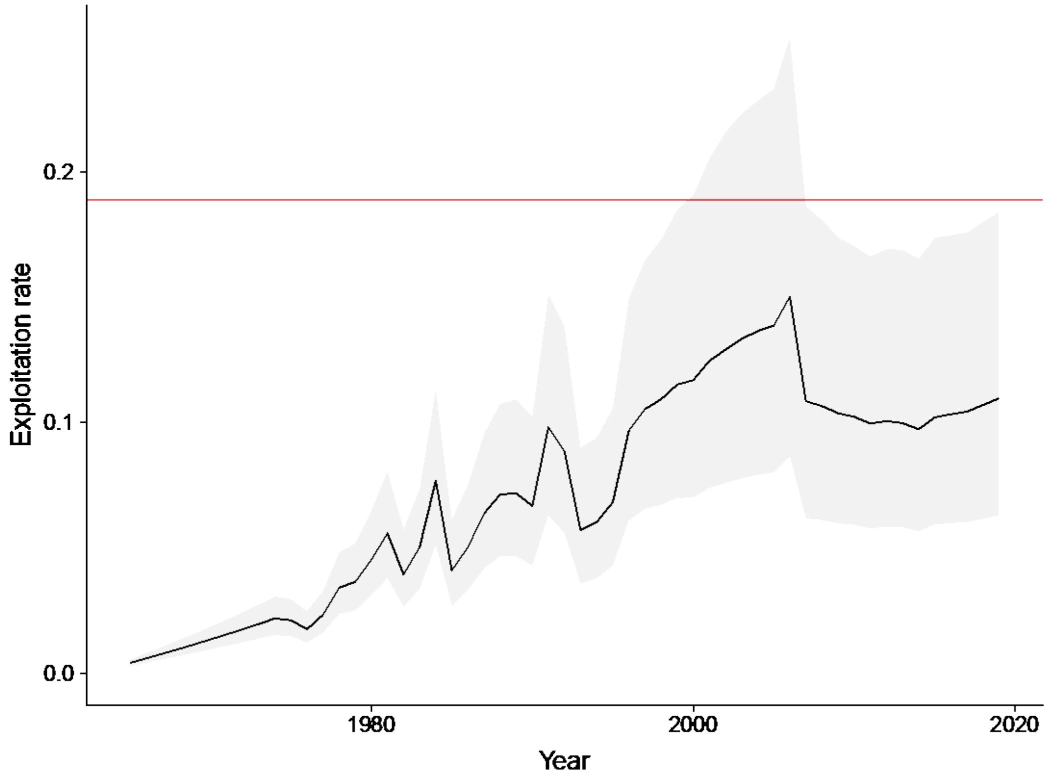
- **PAU 5A - *Haliotis iris***

Stock Status	
Year of Most Recent Assessment	2020
Assessment Runs Presented	Base case Sensitivity with linearly increasing catchability
Reference Points	Target: 40% B_0 (Default as per HSS) Soft Limit: 20% B_0 (Default as per HSS) Hard Limit: 10% B_0 (Default as per HSS) Overfishing threshold: $U_{40\%B0}$
Status in relation to Target	Base case: B_{2019} was estimated at 51% (41–63%) B_0 Sensitivity: B_{2019} was estimated at 40% (26–57%) B_0 For both cases combined, B_{2019} was Likely (> 60%) to be at or above the target
Status in relation to Limits	B_{2019} was Very Unlikely (< 10%) to be below both the soft and hard limits.
Status in relation to Overfishing	The fishing intensity in 2019 was Very Unlikely (< 10%) to be above the overfishing threshold.

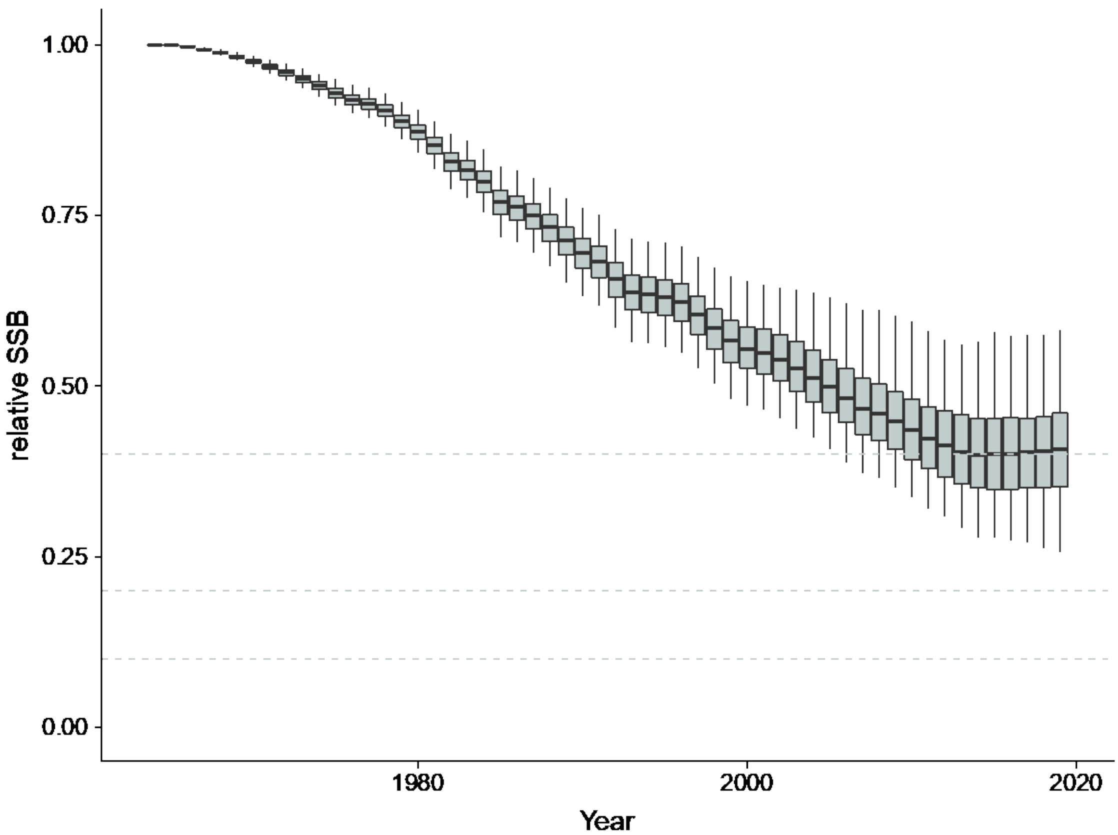
Historical Stock Status Trajectory and Current Status



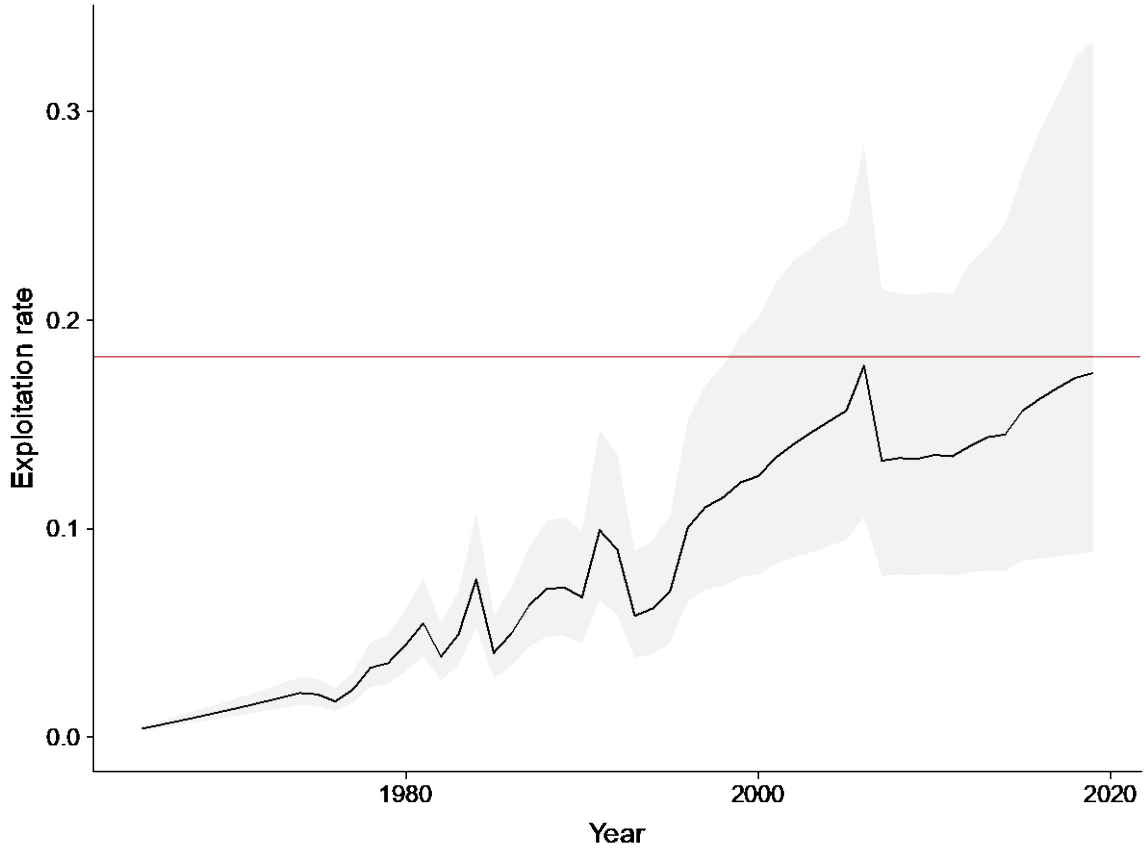
Posterior distributions from the base case model of spawning stock biomass as a percentage of *SSB_0*. The box shows the median of the posterior distribution (horizontal bar), the 25th and 75th percentiles (box), with the whiskers representing the 2.5th and 97.5th percentiles of the distribution. Dashed horizontal lines show target (40% of *SSB_0*), soft-limit (20% of *SSB_0*) and hard-limit (10% of *SSB_0*) reference points.



Posterior distributions from the base case model of exploitation rate (posterior median and 95% confidence interval) relative to the exploitation rate that leads to a relative spawning stock biomass of 40% of *SSB_0*.



Posterior distributions from the main sensitivity (increasing catchability) model of spawning stock biomass as a percentage of *SSB_0*. The box shows the median of the posterior distribution (horizontal bar), the 25th and 75th percentiles (box), with the whiskers representing the 2.5th and 97.5th percentiles of the distribution. Dashed horizontal lines show target (40% of *SSB_0*) soft-limit (20% of *SSB_0*) and hard-limit (10% of *SSB_0*) reference points.



Posterior distributions from the main sensitivity (increasing catchability) of exploitation rate (posterior median and 95% confidence interval) relative to the exploitation rate that leads to a relative spawning stock biomass of 40% of *SSB_0*.

Fishery and Stock Trends	
Recent Trend in Biomass or Proxy	For the base case, spawning stock biomass declined steeply from the early years up to the early 2000s, with a slow decline since. The more recent trend (since 2015) suggests that biomass remained above 40% SSB_0 but trending slightly downward. The latter conflicts with the CPUE index for the most recent years. The decline in the main sensitivity model is more gradual until about 2015, with a slight increase since 2015 from near 40% SSB_0. The latter trend is more compatible with recent (standardised) CPUE.
Recent Trend in Fishing Intensity or Proxy	For both the base case and the main sensitivity, the exploitation rate reached a peak near 2006, at which point ACE shelving reduced the exploitation rates significantly. For the base case, the exploitation rate remained well below the exploitation rate that leads to a relative spawning stock biomass of 40% SSB_0. In the main sensitivity, the recent exploitation rate has trended upwards in recent years towards the exploitation rate that leads to a relative spawning stock biomass of 40% SSB_0.
Other Abundance Indices	-
Trends in Other Relevant Indicators or Variables	-

Projections and Prognosis	
Stock Projections or Prognosis	At current levels of catch spawning stock biomass is projected to remain nearly unchanged at 51% B_0 after 3 years, with an equilibrium value of 50% B_0. If shelving is reduced to 10%, spawning stock biomass is projected to decline to 50% B_0 over 3 years, and to 41% B_0 in the long term
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	Unlikely (< 40%) at current catch levels Unlikely (< 40%) if shelving reduced by 10% About as Likely as Not (40–60%) if shelving reduced by 20%

Assessment Methodology and Evaluation		
Assessment Type	Level 1 - Full Quantitative Stock Assessment	
Assessment Method	Length-based Bayesian model	
Assessment Dates	Latest assessment: 2020	Next assessment: 2025
Overall assessment quality rank	1 – High Quality	
Main data inputs (rank)	- Catch history	1 – High Quality for commercial catch 2 – Mixed or Medium Quality for customary catch 1. No data for recreational or illegal catch
	- CPUE indices early series	2 – Medium or Mixed Quality: not believed to be fully representative of the entire QMA
	- CPUE indices later series	1 – High Quality
	- Commercial sampling length frequencies	2 – Medium or Mixed Quality: not believed to be fully representative of the entire QMA
	- Tag recapture data (for growth estimation)	1 – High Quality
	- Maturity at length data	1 – High Quality
Data not used (rank)	- Research Dive Survey Indices - Research Dive Length Frequencies	3 – Low Quality: not believed to index the stock 3 – Low Quality: not believed to be representative of the entire QMA
Changes to Model Structure and Assumptions	- The base case model was implemented as a single area model rather than the separate PAU 5A northern and PAU 5A southern models of previous years. - A three-area spatial model was also developed to corroborate findings from the single area model. - MPD runs were not performed; all exploration was performed using full Markov Chain Monte Carlo runs. - The assessment model framework was moved to the Bayesian statistical inference engine Stan (Stan Development Team 2018), including all data input models (the assessment model was previously coded in ADMB).	

	- A multivariate normal model was used for centred-log-ratio-transformed mean CSLF and observation error. - The data weighting procedure was based on a scoring rule (log score) and associated divergence measure (Kullbach-Liebler divergence) to measure information loss and goodness of fit for CPUE and CSLF. - Growth and maturation were fit to data across all QMAs outside of the assessment model, and the resulting mean growth and estimate of proportions mature at age were supplied as an informed prior on growth to the model; no growth or maturation data were explicitly fitted in the model.
Major Sources of Uncertainty	- CPUE may not be a reliable index of abundance. - Any effect of voluntary increases in MHS may not have been adequately captured by the model, which could therefore be underestimating the spawning biomass in recent years.

Qualifying Comments
-

Fishery Interactions
-

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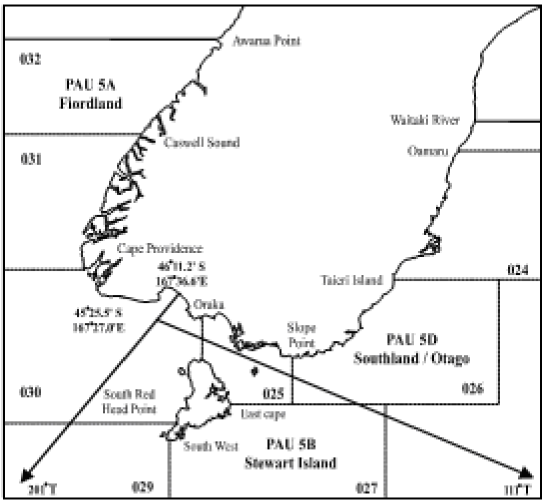
PĀUA (PAU 5B) - Stewart Island

(*Haliotis iris*)
Pāua



1. FISHERY SUMMARY

Before 1995, PAU 5B was part of the PAU 5 QMA, which was introduced into the QMS in 1986 with a TACC of 445 t. As a result of appeals to the Quota Appeal Authority, the TACC increased to 492 t in the 1991–92 fishing year; PAU 5 was then the largest pāua QMA by number of quota holders and TACC. Concerns about the status of the PAU 5 stock led to a voluntary 10% reduction in the TACC in 1994–95. On 1 October 1995, PAU 5 was divided into three QMAs (PAU 5A, PAU 5B, and PAU 5D; see the figure above) and the TACC was divided equally among them; the PAU 5B TACC was set at 148.98 t.

On 1 October 1999 a TAC of 155.98 t was set for PAU 5B, comprising a TACC of 143.98 t (a 5 t reduction) and customary and recreational allowances of 6 t each. The TAC and TACC were subsequently reduced twice, and TAC was set at 105 t in 2002–2018, with a TACC of 90 t, customary and recreational allowances at 6 t each and an allowance of 3 t for other mortality. In 2018 the TACC was increased to 107 t, and the customary allowance to 7 t, bringing the TAC to 123 t but an injunction has been filed (Table 1).

Table 1: Total allowable catches (TAC, t) allowances for customary fishing, recreational fishing, and other sources of mortality (t) and Total Allowable Commercial Catches (TACC, t) declared for PAU 5 and PAU 5B since introduction into the QMS.

Year	TAC	Customary	Recreational	Other mortality	TACC
1986–1991*	-	-	-	-	445
1991–1994*	-	-	-	-	492
1994–1995*	-	-	-	-	442.8
1995–1999	-	-	-	-	148.98
1999–2000	155.9	6	6	-	143.98
2000–2002	124.87	6	6	-	112.187
2002–Present	105	6	6	3	90

*PAU 5 TACC figures

1.1 Commercial fishery

The fishing year runs from 1 October to 30 September.

Concerns about the status of the stock led to the commercial fishers agreeing to voluntarily reduce their Annual Catch Entitlement (ACE) by 25 t for the 1999/00 fishing year. This shelving continued for the 2000/01and 2001/02 fishing years at a level of 22 t, but was discontinued at the beginning of the 2002/03 fishing year (Table 2).

On 1 October 2001 it became mandatory to report catch and effort on Pāua Catch Effort Landing Returns (PCELRs) using fine-scale reporting areas that had been developed by the New Zealand Pāua Management Company for their voluntary logbook programme (Figure 1).

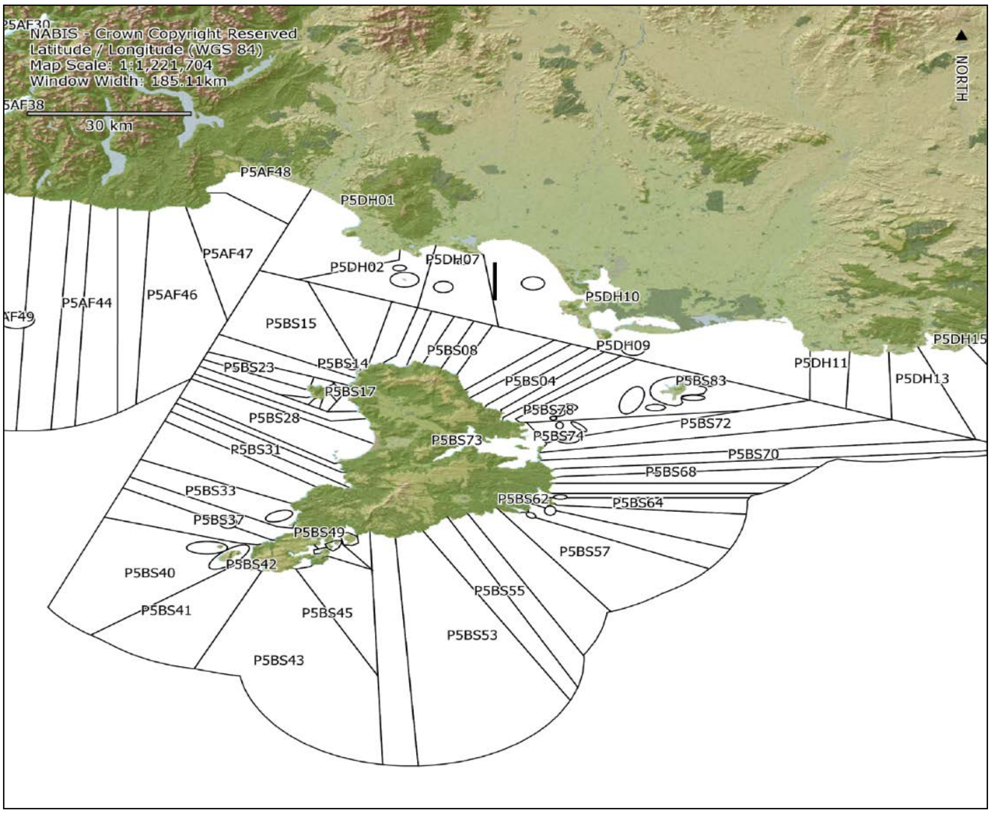


Figure 1: Map of fine scale statistical reporting areas for PAU 5B.

PAU 5B commercial landings have been close to the TACC in most fishing years since 1995, with the exception of the fishing years 1999–00, 2000–01, and 2001–02, when the TACC was not reached (Table 2 and Figure 2). Landings for PAU 5 prior to 1995 are reported in the introductory PAU Working Group Report.

Table 2: TACC and reported commercial landings (t) of pāua in PAU 5B, 1995–96 to present, from QMR and MHR returns. [Continued next page]

Year	Landings	TACC
1995–96	144.66	148.98
1996–97	142.36	148.98
1997–98	145.34	148.98
1998–99	148.55	148.98
1999–00	118.07	143.98
2000–01	89.92	112.19
2001–02	89.96	112.19
2002–03	89.86	90.00
2003–04	90.00	90.00
2004–05	89.97	90.00
2005–06	90.47	90.00
2006–07	89.16	90.00
2007–08	90.21	90.00
2008–09	90.00	90.00
2009–10	90.23	90.00
2010–11	89.67	90.00
2011–12	89.59	90.00
2012–13	90.58	90.00
2013–14	88.84	90.00
2014–15	89.45	90.00
2015–16	88.39	90.00

Table 2 [Continued]

Year	Landings	TACC
2016–17	92.99	90.00
2017–18	89.33	90.00
2018–19	89.03	90.00

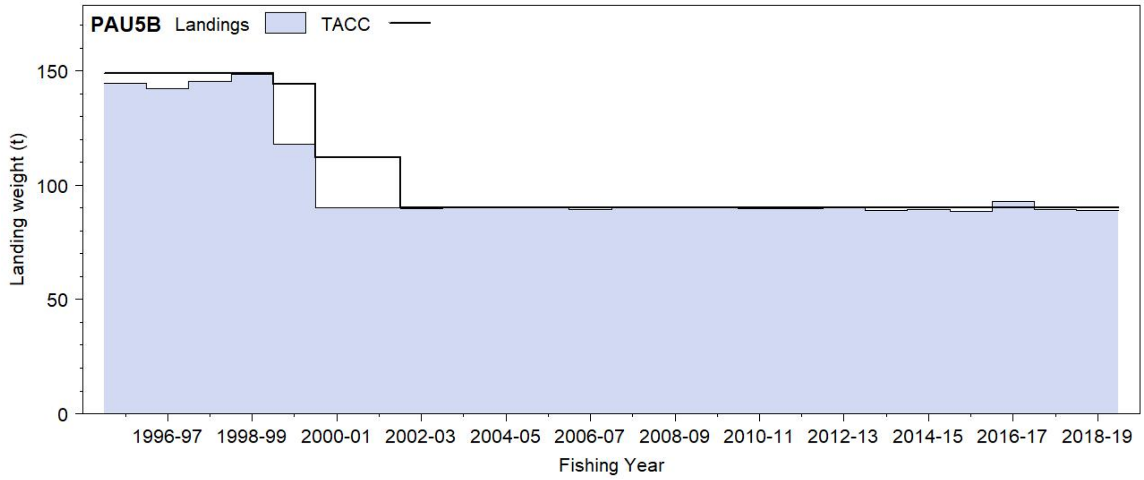


Figure 2: Reported commercial landings and TACC for PAU 5B from 1995–96 to present. For reported commercial landings in PAU 5 before 1995–96 refer to figure 1 and table 1 in the introductory PAU Plenary Report.

1.2 Recreational fisheries

The 'National Panel Survey of Marine Recreational Fishers 2011–12: Harvest Estimates' estimated that the recreational harvest for PAU 5B was 0.82 t with a CV of 50%. For the 2017 assessment model, the SFWG agreed to assume that the recreational catch rose linearly from 1 t in 1974 to 5 t in 2006, and remained at 5 t between 2007 and 2017. The National Panel Survey was repeated in the 2017–18 fishing year (Wynne-Jones et al 2019). The estimated recreational catch for that year was 9.85 tonnes. For further information on recreational fisheries refer to the introductory PAU Plenary Report.

1.3 Customary fisheries

Estimates of customary catch for PAU 5B are shown in Table 3. These numbers are likely to be an underestimate of customary harvest as only the catch in numbers are reported in the table.

Table 3: Fisheries New Zealand records of customary harvest of pāua (reported in numbers) of pāua in PAU 5B between 2000–01 and 2018–19. – no data.

Fishing year	Approved	Harvested
2000–01	50	50
2001–02	610	590
2002–03	–	–
2003–04	–	–
2004–05	–	–
2005–06	140	90
2006–07	485	483
2007–08	2 685	2 684
2008–09	3 520	3 444
2009–10	2 680	2 043
2010–11	2 053	1 978
2011–12	495	495
2012–13	1 875	1 828
2013–14	130	130
2014–15	–	–
2015–16	2 195	2 003
2016–17	75	75
2017–18	2 245	2 245
2018–19	1 405	1 337

For the 2017 assessment model the SFWG agreed to assume that customary catch was equal to 1 t from 1974–2017. Reported customary catch in 2018–19 was 1337 kg.

For further information on customary fisheries refer to the introductory PAU Plenary Report.

1.4 Illegal catch

There is qualitative data to suggest significant illegal, unreported, unregulated (IUU) activity in this Fishery. Illegal catch was estimated by the Ministry of Fisheries to be 15 t, but "Compliance express extreme reservations about the accuracy of this figure." The SFWG agreed to assume for the 2013 assessment that illegal catch was zero before 1986, then rose linearly from 1 t in 1986 to 5 t in 2006, and remained constant at 5 t between 2007 and 2013. For further information on illegal catch refer to the introductory PAU Working Group Report.

1.5 Other sources of mortality

For further information on other sources of mortality refer to the introductory PAU Plenary Report.

2. BIOLOGY

For further information on pāua biology refer to the introductory PAU Plenary Report. A summary of biological parameters used in the PAU 5B assessment is presented in Table 4.

3. STOCKS AND AREAS

For further information on stocks and areas refer to the introductory PAU Plenary Report.

Table 4: Estimates of biological parameters (*H. iris*).

		Estimate	Source
1. Natural mortality (M)		0.10 (CV 0.10)	Assumed prior probability distribution
2. Weight = a(length)^b (Weight in g, length in mm shell length).			
		All	
	a	b	
	2.99 x 10^{-5}	3.303	Schiel & Breen (1991)
3. Size at maturity (shell length)			
		50% maturity at 91 mm	Naylor (NIWA unpub. data)
		95% maturity at 133 mm	Naylor (NIWA unpub. data)
4. Growth parameters (both sexes combined)			
Growth at 75 mm		Growth at 120 mm	Median (5–95% range) of posterior distributions estimated by the assessment model
26.1 mm (24.8 to 27.2)		6.9 mm (6.5–7.3)	

4. STOCK ASSESSMENT

The stock assessment was done with a length-based Bayesian estimation model, with parameter point estimates based on the mode of the joint posterior distribution and uncertainty estimated from marginal posterior distributions generated from Markov chain-Monte Carlo simulations. The most recent stock assessment was conducted in 2017 for the fishing year ended 30 September 2017. A base case model (0.1) was chosen from the assessment. The SFWG also suggested several sensitivity runs; model 0.4 which assumed an alternate catch history and model 0.6 where a time varying catchability was estimated.

4.1 Estimates of fishery parameters and abundance

Parameters estimated in the assessment model and their Bayesian prior distributions are summarized in Table 5.

Table 5: A summary of estimated model parameters, lower bound, upper bound, type of prior, (U, uniform; N, normal; LN = lognormal), mean and CV of the prior.

Parameter	Phase	Prior	μ	CV	Lower	Upper
$\ln(R_0)$	1	U	–	–	5	50
M (natural mortality)	3	U	–	–	0.01	0.5
g_1(Mean growth at 75 mm)	2	U	–	–	0.01	150
$g2$(Mean growth at 120 mm)	2	U	–	–	0.01	150
g_{50}	2	U	–	–	0.01	150
$g_{50\text{-}95\%}$	2	U	–	–	0.01	150
g_{max}	1	U	–	–	0.01	50
α	2	U	–	–	0.01	10
β	2	U	–	–	0.01	10
Ln(q^I) (catchability coefficient of CPUE)	1	U	–	–	-30	0
Ln(q^I) (catchability coefficient of PCPUE)	1	U	–	–	-30	0
L_{50} (Length at 50% maturity)	1	U	–	–	70	145
$L_{95\text{-}50}$(Length between 50% and 95% maturity)	1	U	–	–	1	50
D_{50}(Length at 50% selectivity for the commercial catch)	2	U	–	–	70	145
$D_{95\text{-}50}$(Length between 50% and 95% selectivity for the commercial catch)	2	U	–	–	0.01	50
D_s	1	U	–	–	0.01	10
ϵ (Recruitment deviations)	1	N	0	0.4	-2.3	2.3

The observational data were:

1. A 1990–2001 standardised CPUE series based on CELR data.
2. A 2002–2017 standardised CPUE series based on PCELR data.
3. A commercial catch sampling length frequency series for 1998, 2002–04, 07, 2009–2012.
4. Tag-recapture length increment data.
5. Maturity at length data

4.1.1 Relative abundance estimates from standardised CPUE analyses

The 2017 stock assessment used two sets of standardised CPUE indices: one based on CELR data covering 1990–2001, and another based on PCELR data covering 2002–2017. For both series, standardised CPUE analyses were carried out using Generalised Linear Models (GLMs). A stepwise procedure was used to select predictor variables, with variables entering the model in the order that gave the maximum decrease in the residual deviance. Predictor variables were accepted in the model only if they explained at least 1% of the deviance.

For both the CELR and PCELR data, the Fisher Identification Number (FIN) was used in the standardisations instead of vessel, because the FIN is associated with a permit holder who may employ a suite of grouped vessels, which implies that there could be linkage in the catch rates among vessels operated under a single FIN.

For the CELR data (1990-2001) there is ambiguity in what is recorded for estimated daily fishing duration (total fishing duration for all divers), and it has not been used in past standardisations as a measure of effort; instead the number of divers has been used. However, there is evidence that the fishing duration for a diver changes over time, and because of this criteria were used to identify records for which the recorded fishing duration should predominantly be recorded correctly. The criteria used to subset the data were: (i) just one diver or (ii) fishing duration ≥ 8 hours and number of divers ≥ 2. For the other records the recorded fishing duration was multiplied by the number of diver. The data set consisting of predominantly correct records for the recorded fishing duration, and others with the recorded fishing duration scaled up by the number of divers was used for the CELR standardisation using estimated daily catch and effort as estimated fishing duration.

For the PCELR data (2002–2017) the unit of catch was diver catch, with effort as diver duration.

FIN codes were used to select a core group of fishers from the CELR data, with the requirement that there be a minimum of 7 records per year for a minimum of 2 years to qualify for the core fisher group. This retained 84% of the catch over 1990–2001. For the PCELR data the FIN was also used to select a core group of fishers, with the requirement that there be a minimum of 20 records per year for a minimum of 3 years. This retained 87% of the catch over 2002–2017.

For the CELR data, year was forced into the model and other predictor variables offered to the model were FIN, Statistical Area (025, 027, 029, 030), month and fishing duration (as a cubic polynomial),. For the PCELR data, fishing year was forced into the model and variables offered to the model were month, diver key, FIN statistical area, diver duration (third degree polynomial), and diving conditions.

The standardised CPUE from the CELR data shows an increase from 1990 to 1991 followed by a steady decline through to 2001 at which point it is 49% of its initial 1990 level (Figure 3-top). The standardised CPUE from the PCELR data shows a 74% increase from 2002 to 2014 then a slight decline from 2014 to 2017. This 13% decline between 2014 and 2017 is not unexpected and is most likely due to the commercial fishers voluntarily increasing the minimum harvest size (Figure 3-bottom).

4.1.2 Relative abundance estimates from research diver surveys

The relative abundance of pāua in PAU 5B has also been estimated from a number of independent research diver surveys (RDSI) undertaken in various years between 1993 and 2007. The survey strata included Ruggedy, Waituna, Codfish, Pegasus, Lords, and East Cape. These data were included in the assessment although there is concern that the data are not a reliable index of abundance.

Concerns about the ability of the data collected in the independent Research Dive surveys to reflect relative abundance instigated several reviews in 2009 (Cordue 2009) and 2010 (Haist 2010). The reviews assessed the reliability of the research diver survey index as an index of abundance and whether the RDSI, when used in the pāua stock assessment models, results in model outputs that adequately reflect the status of the stocks. Both reviews suggested that outputs from pāua stock assessments using the RDSI should be treated with caution however this data was included in the 2017 assessment based on recommendations arising from the pāua stock assessment review workshop (Butterworth et al 2015).

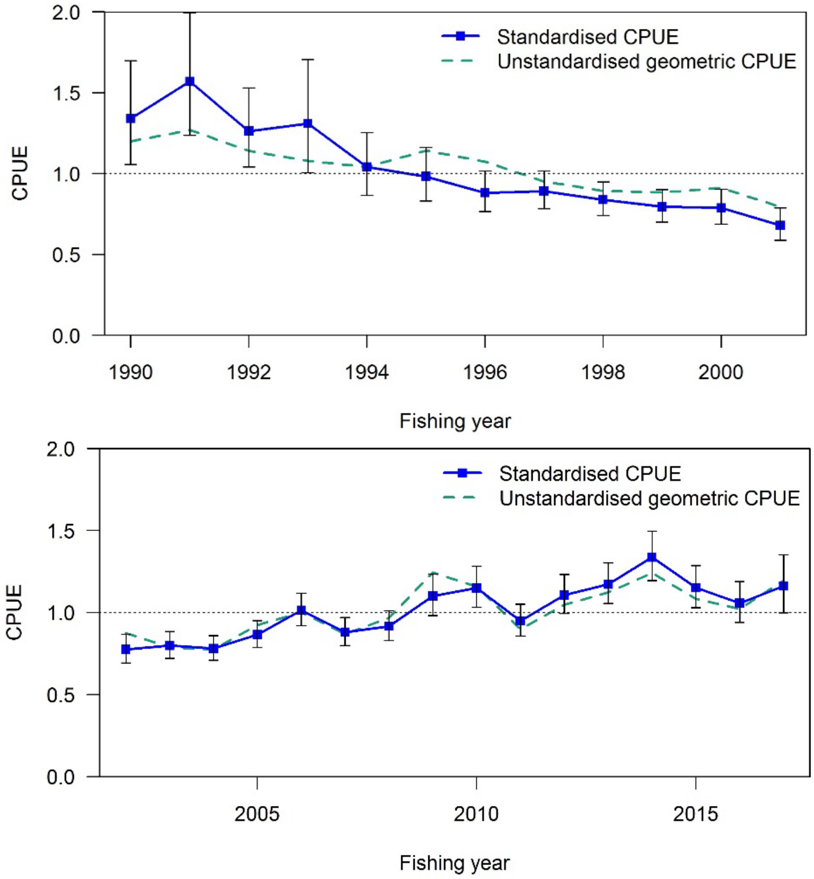


Figure 3: The standardised CPUE indices with 95% confidence intervals for the CELR series covering 1990–2001 (blue line for top-figure). The standardised CPUE indices with 95% confidence intervals for the PCELR series covering 2002–2017 (blue line for bottom-figure). For both indices the unstandardised geometric CPUE is calculated as catch divided by fishing duration.

4.2 Stock assessment methods

The 2017 PAU 5B stock assessment used the same length-based model as the 2017 PAU 5D assessment (Marsh & Fu 2017). The model was described by Breen et al (2003). PAU 5B was last assessed in 2013 (Fu 2014 and Fu et al 2014a).

The model structure assumed a single sex population residing in a single homogeneous area, with length classes from 70 mm to 170 mm in 2 mm bins. Growth is length-based, without reference to age, mediated through a growth transition matrix that describes the probability of transitions among length class at each time step. Pāua enter the model following recruitment and are removed by natural mortality and fishing mortality.

The model simulates the population from 1965 to 2017. Catches were available for 1974–2017 although catches before 1995 must be estimated from the combined PAU 5 catch. Catches were assumed to increase linearly between 1965 and 1973 from 0 to the 1974 catch level. Catches included commercial, recreational, customary, and illegal catch, and all catches occurred within the same time step.

Recruitment was assumed to take place at the beginning of the annual cycle, and length at recruitment was defined by a uniform distribution with a range between 70 and 80 mm. No explicit stock-recruitment relationship was modelled in previous assessments; however, the Shellfish Working Group agreed to use a Beverton-Holt stock-recruitment relationship with steepness (h) of 0.75 for this assessment.

Maturity is not required in the population partition but is necessary for estimating spawning biomass. The model estimated proportions mature from length-at-maturity data. Growth and natural mortalities were also estimated within the model. The model estimated the commercial fishing selectivity, assumed to follow a logistic curve and asymptote at 1. The increase in Minimum Harvest Size between 2006 and 2017 was modelled as an annual shift in fishing selectivity.

The assessment was conducted in several steps. First, the model was fitted to the data with parameters estimated at the mode of their joint posterior distribution (MPD). Next, from the resulting fit, Markov chain-Monte Carlo (MCMC) simulations were made to obtain a large set of samples from the joint posterior distribution. From this set of samples, forward projections were made and an agreed set of biological indicators obtained. Model sensitivity was explored by comparing MPD fits made under alternative model assumptions.

The base case incorporated a number of changes since the last assessment of PAU 5B in 2013. First, a more flexible functional form (inverse logistic) was used to describe the variance associated with the mean growth increment at length. Second, the predicted CPUE is now calculated after 50% of the fishing and natural mortality have occurred (previously the CPUE indices were fitted to the vulnerable biomass calculated after 50% of the catch was taken). This is considered to be appropriate if fishing occurs throughout a year (Schnute 1985). The change was recommended by the pāua review workshop held in Wellington in March 2015 (Butterworth et al. 2015). Accordingly, mid-season numbers (and biomass) was calculated after half of the natural mortality and half of the fishing mortality was applied.

The third change was made to the likelihood function, fitting the tag-recapture observations so that weights could be assigned to individual data sets. This also followed the pāua review workshop's recommendation that "the tagging data should be weighted by the relative contribution of average yield from the different areas so that the estimates could better reflect the growth rates from the more productive areas" (Butterworth et al 2015). Two smaller changes were added in this iteration of the assessment model, including: 1) adding a lag between recruitment and spawning for models where the partition was started at > 2 mm; and 2) adding a time varying parameter on the catchability coefficient of the CPUE observations.

The base case model (0.1) and the six sensitivities (0.1all and 0.2–0.6) were considered (Table 6): two separate CPUE series (0.2), excluding research diver observations (0.3), alternative catch history (0.4), modelling the partition at 2 mm (0.5), and estimating a time varying catchability (0.6). MCMCs were carried out for the base case and model runs 0.4 and 0.6.

Table 6: Summary descriptions of base case (0.1) and sensitivity model runs.

Model	Description
0.1	inverse logistic growth model, tag-recapture weighted, CSLF data up to 2016, M prior Uniform, tag data > 70 mm, RDLF and RDSI included, Combined CPUE series, Catch history assumption 3
0.1 all	The same as model 0.1 with CSLF data up to and including the 2017 fishing year.
0.2	Model 0.1 with split CPUE series, one for the CELR and another for the PCELR
0.3	Model 0.1 but with the RDLF and RDSI data excluded
0.4	Model 0.1 but with catch history assumption 1
0.5	Model 0.1 but start modelling at 2 mm instead of 70 mm
0.6	Model 0.1 but with a time varying catchability coefficient, with an estimated drift parameter ~ Uniform(-0.05, 0.05)

The assessment calculated the following quantities from their posterior distributions: the equilibrium spawning stock biomass with recruitment equal to the average recruitment from the period for which recruitment deviation were estimated (B_0,), the mid-season spawning and recruited biomass for 2013 (B_{2013} and $B^r_{proj2013}$) and for the projection period (B_{proj} and B^r_{proj}). This assessment also reported the following fishery indictors:

- $B\%B_0$ Current or projected spawning biomass as a percentage of B_0
- $B\%B_{msy}$ Current or projected spawning biomass as a percentage of B_{msy}
- $\Pr(B_{proj} > B_{msy})$ Probability that projected spawning biomass is greater than B_{msy}
- $\Pr(B_{proj} > B_{2012})$ Probability that projected spawning biomass is greater than $B_{current}$
- $B\%B_0^r$ Current or projected recruited biomass as a percentage of B_0^r
- $B\%B_{msy}^r$ Current or projected recruited biomass as a percentage of B_{msy}^r
- $\Pr(B_{proj} > B_{msy}^r)$ Probability that projected recruit-sized biomass is greater than B_{msy}^r
- $\Pr(B_{proj} > B_{2012}^r)$ Probability that projected recruit-sized biomass is greater than B_{2012}^r
- $\Pr(B_{proj} > 40\%B_0)$ Probability that projected spawning biomass is greater than 40% B_0
- $\Pr(B_{proj} < 20\%B_0)$ Probability that projected spawning biomass is less than 20% B_0
- $\Pr(B_{proj} < 10\%B_0)$ Probability that projected spawning biomass is less than 10% B_0
- $\Pr(U_{proj} > U_{40\%B0})$ Probability that projected exploitation rate is greater than $U_{40\%B0}$

4.3 Stock assessment results

The base case model (0.1) estimated that the unfished spawning stock biomass (B_0) was about 3948 t (3630–4271 t) (Figure 4), and the spawning stock population in 2017 (B_{2017}) was about 47% (39–58%) of B_0 (Table 7). The base case indicated that spawning biomass increased rapidly after 2002 when the stock was at its lowest level.

Three-year projections (2018–2020) were run for two alternative recruitment assumptions, with the period of recruitment sampled from the past 10 years of estimates and from the past 5 years of estimates (explored due to recent lower-than-average recruitment), and with four different future harvest levels based on changes to the total allowable catch (TACC), with the TACC increasing by 5% (94.5 t), 10% (99 t), 15% (103.5 t) and 20% (108 t) (Tables 8–11). The base case model suggested that the current stock status was very unlikely to fall below the target of 40% B_0. The projections suggested that with an increase of 20% of the current TACC, future biomass was likely to remain constant over the next 3 years. The conclusion was similar across all sensitivity runs.

The MCMC simulation started at the MPD parameter values and the traces show good mixing. MCMC chains starting at either higher or lower parameter values also converged after the initial burn-in phase. The base case model estimated an *M* of 0.10 with a 90% credible interval between 0.08 and 0.12. The midpoint of the commercial fishery selectivity (pre-2006), where selectivity is 50% of the maximum, was estimated to be about 125 mm and the selectivity ogive was very steep. The model estimated an annual shift of about 1.9 mm in selectivity, with a total increase of about 10 mm between 2006 and 2011.

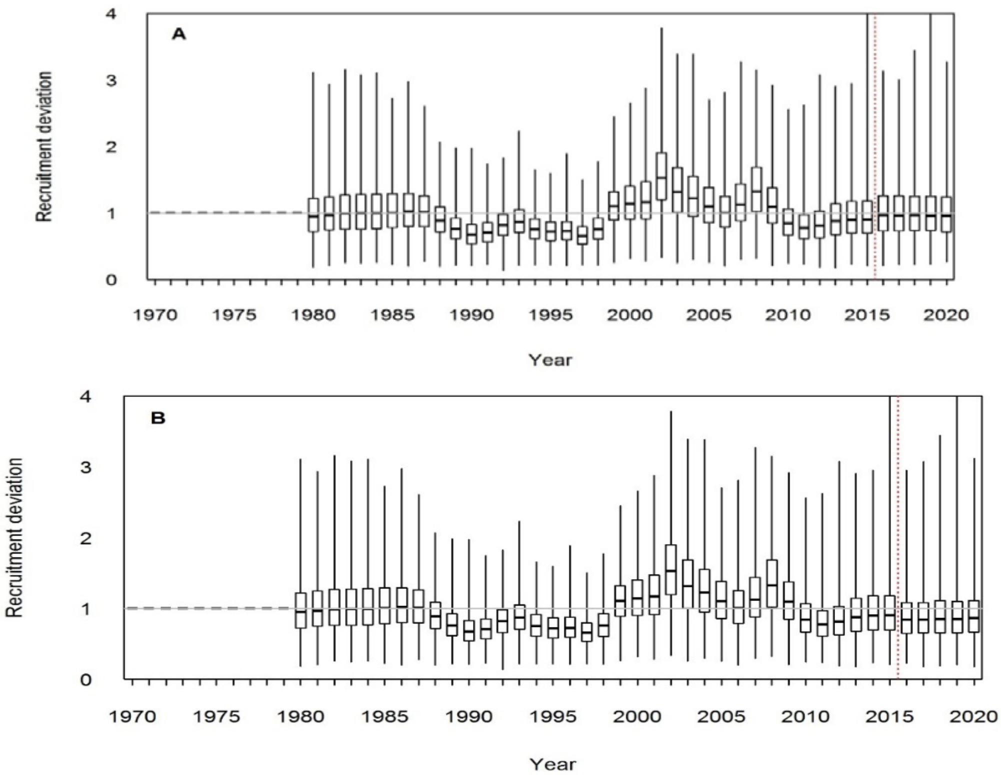


Figure 4: Recruitment deviations around the stock recruitment relationship estimated and forecasted for model 0.1. The red line is the time up to where recruitment deviations were resampled from. The top figure (A) is when we resample from the last 10 years. The bottom figure (B) is when we resample from the last 5 years.

The estimated recruitment deviations showed a period of relatively low recruitment through the 1990s to the early 2000s. From the early 2000s to 2010 recruitment was above the average however, from 2011 until 2015 recruitment has been lower than the long-term average. (Figure 5). Exploitation rates peaked around 2002, but have decreased since then. The base case estimated exploitation rate in 2017 to be about 0.09 (0.07–0.11) (Table 7).

Table 7: Summary of the marginal posterior distributions from the MCMC chain from the base case (Model 0.1), and the sensitivity trials (models 0.4 and 0.6). The columns show the median, the 5th and 95th percentiles values observed in the 1000 samples. Biomass is in tonnes.

	MCMC 0.1	**MCMC 0.4**	**MCMC 0.6**
B_0	3948 (3630–4271)	4470 (4112–4841)	3947 (3608–4287)
B_{2017}	1873 (1513–2360)	2144 (1750–2686)	1711 (1223–2410)
B_{2017} %B_0	47 (39–58)	48 (40–59)	44 (32–59)
rB_0	3553 (3221–3876)	4029 (3655–4400)	3569 (3223–3882)
rB_{2017}	1524 (1230–1906)	1755 (1435–2178)	1374 (964–1970)
rB_{2017}/rB_0	0.43 (0.35–0.53)	0.44 (0.36–0.53)	0.39 (0.27–0.54)
$U_{40\%B0}$	16 (13–23)	13 (10–17)	6 (5–9)
U_{msy}	33 (24–53)	33 (24–53)	30 (21–51)
U_{2017}	9 (7–11)	8 (6–9)	10 (7–14)

4.4 Other factors

The assessment used CPUE as an index of abundance. The assumption that CPUE indexes abundance is questionable. The literature on abalone fisheries suggests that CPUE is problematic for stock assessments because of serial depletion. This can happen when fishers deplete unfished or lightly fished beds and maintain their catch rates by moving to new areas. Thus CPUE stays high while the biomass is actually decreasing. For PAU 5B, the model estimate of stock status was strongly driven by the trend in the recent CPUE indices. It is unknown to what extent the CPUE series tracks stock abundance. The SFWG believed that the increasing trend in recent CPUE series are credible, corroborating anecdotal evidence from the commercial divers in PAU 5B that the stock has been in good shape in recent years.

Natural mortality is an important productivity parameter. It is often difficult to estimate *M* reliably within a stock assessment model and the estimate is strongly influenced by the assumed prior. For the pāua assessment, the choice of prior has been based on current belief on the plausible range of the natural mortality for pāua, and therefore it is reasonable to incorporate available evidence to inform the estimation of *M*. The sensitivity of model results to the assumptions on *M* could be assessed through the use of alternative priors.
Another source of uncertainty is the data. The commercial catch is unknown before 1974 and is estimated with uncertainty before 1995. Major differences may exist between the catches we assume and what was actually taken. In addition, non-commercial catch estimates are poorly determined and could be substantially different from what was assumed, although generally non-commercial catches appear to be relatively small compared with commercial catch. The estimate of illegal catch in particular is uncertain.

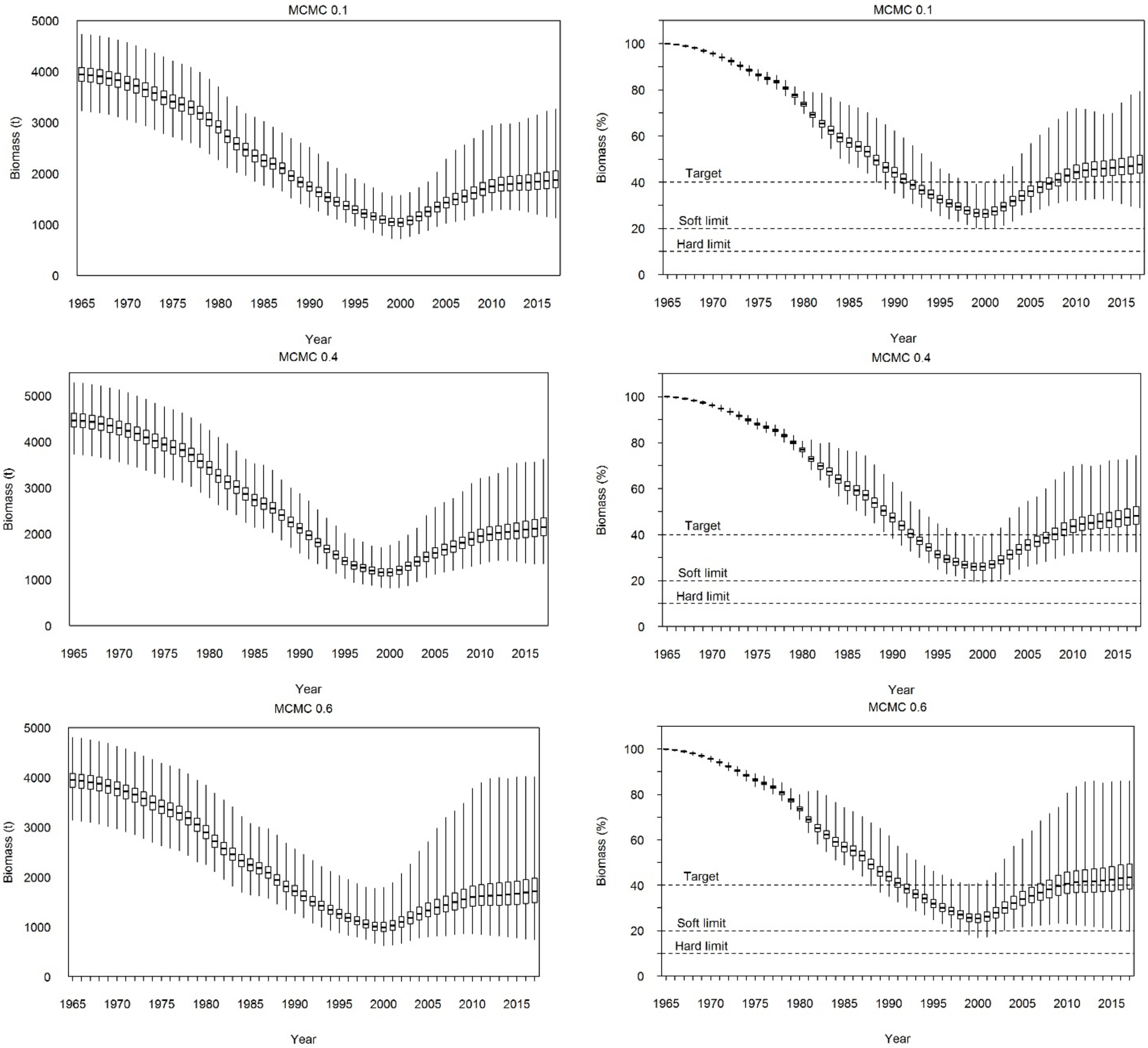


Figure 5: Posterior distributions of spawning stock biomass and spawning stock biomass as a percentage of the unfished level from MCMC for models 0.1, 0.4 and 06. The box shows the median of the posterior distribution (horizontal bar), the 25th and 75th percentiles (box), with the whiskers representing the full range of the distribution.

Table 8: Projected quantities for the Base model with an assumed 5% TACC increase and recruitment based on the past 10 years.

	2018	2019	2020
Bt	1898 (1460–2528)	1916 (1451–2594)	1936 (1439–2655)
%B0	0.48 (0.38–0.63)	0.49 (0.38–0.64)	0.49 (0.37–0.65)
rBt	1536 (1176–2031)	1550 (1176–2077)	1569 (1177–2124)
%rB0	0.43 (0.34–0.56)	0.44 (0.34–0.58)	0.44 (0.34–0.59)
Pr (>*Bcurrent*)	0.65	0.69	0.71
Pr (>40%B_0)	0.93	0.93	0.93
Pr (<20% B_0)	0	0	0
Pr (<10% B_0)	0	0	0
Pr (>*rBcurrent*)	0.61	0.64	0.69
Pr (U>U40% B_0)	0	0	0.01

Table 9: Projected quantities for the Base model with an assumed 20% TACC increase and recruitment based on the past 10 years.

	2018	2019	2020
Bt	1892 (1453–2521)	1896 (1431–2574)	1904 (1407–2624)
% B_0	0.48 (0.38–0.62)	0.48 (0.37–0.63)	0.48 (0.37–0.64)
rBt	1529 (1169–2024)	1530 (1156–2057)	1537 (1144–2092)
%rB_0	0.43 (0.34–0.56)	0.43 (0.33–0.57)	0.43 (0.33–0.58)
Pr (>*Bcurrent*)	0.58	0.59	0.59
Pr (>40% B_0)	0.93	0.92	0.91
Pr (<20% B_0)	0	0	0
Pr (<10% B_0)	0	0	0
Pr (>*rBcurrent*)	0.53	0.51	0.53
Pr (U>U40% B_0)	0.02	0.02	0.03

Table 10: Projected quantities for the Base model with an assumed 5% TACC increase and recruitment based on the past 5 years.

	2018	2019	2020
Bt	1876 (1434–2530)	1879 (1406–2571)	1876 (1373–2646)
% B_0	0.48 (0.37–0.62)	0.48 (0.37–0.64)	0.48 (0.36–0.65)
rBt	1536 (1175–2032)	1545 (1167–2073)	1551 (1154–2119)
%rB_0	0.43 (0.34–0.56)	0.44 (0.34–0.58)	0.44 (0.33–0.59)
Pr (>*Bcurrent*)	0.47	0.49	0.48
Pr (>40% B_0)	0.92	0.9	0.88
Pr (<20% B_0)	0	0	0
Pr (<10% B_0)	0	0	0
Pr (>*rBcurrent*)	0.6	0.6	0.59
Pr (U>U40% B_0)	0	0	0.01

Table 11: Projected quantities for the Base model with an assumed 20% TACC increase and recruitment based on the past 5 years.

	2018	2019	2020
Bt	1869 (1427–2523)	1859 (1386–2551)	1844 (1341–2614)
% B_0	0.47 (0.37–0.62)	0.47 (0.36–0.63)	0.47 (0.35–0.65)
rBt	1529 (1168–2025)	1525 (1147–2053)	1519 (1121–2087)
%rB_0	0.43 (0.34–0.56)	0.43 (0.33–0.57)	0.43 (0.32–0.58)
Pr (>*Bcurrent*)	0.41	0.39	0.37
Pr (>40% B_0)	0.91	0.89	0.85
Pr (<20% B_0)	0	0	0
Pr (<10% B_0)	0	0	0
Pr (>*rBcurrent*)	0.52	0.48	0.44
Pr (U>U40% B_0)	0.02	0.02	0.03

The model treats the whole of the assessed area of PAU 5B as if it were a single stock with homogeneous biology, habitat and fishing pressures. The model assumes homogeneity in recruitment and natural mortality, and assumes that growth has the same mean and variance throughout. Heterogeneity in growth can be a problem for this kind of model (Punt 2003). Variation in growth is addressed to some extent by having a stochastic growth transition matrix based on increments observed in several different places; similarly the length frequency data are integrated across samples from many places.

The effect of these factors is likely to make model results optimistic. For instance, if some local stocks are fished very hard and others not fished, recruitment failure can result because of the localized depletion of spawners. Spawners must be close to each other to breed and the dispersal of larvae is unknown and may be limited. Recruitment failure is a common observation in overseas abalone fisheries, so local processes may decrease recruitment, an effect that the current model cannot account for.

Another source of uncertainty is that fishing may cause spatial contraction of populations (Shepherd & Partington 1995), or that some populations become relatively unproductive after initial fishing (Gorfine & Dixon 2000). If this happens, the model will overestimate productivity in the population as a whole. Past recruitments estimated by the model might instead have been the result of serial depletion.

4.5 Future research considerations

- Continue to develop fisheries-independent survey methodologies that are representative of the PAU 5B area;
- Further investigate *q*-drift to determine how to quantify it and its implications for assessment outcomes;
- Ensure models are robust to assumptions about, or estimates of, natural mortality and stock-recruitment parameters;
- Review the commercial catch sampling programme in light of the increasing trend of live or frozen-in-shell exports.

5. STATUS OF THE STOCK

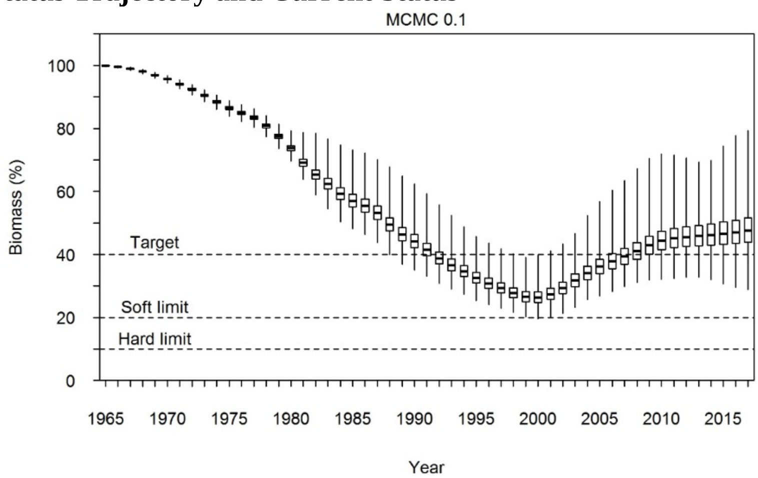
Stock Structure Assumptions

PAU 5B is assumed to be a homogenous stock for purposes of the stock assessment.

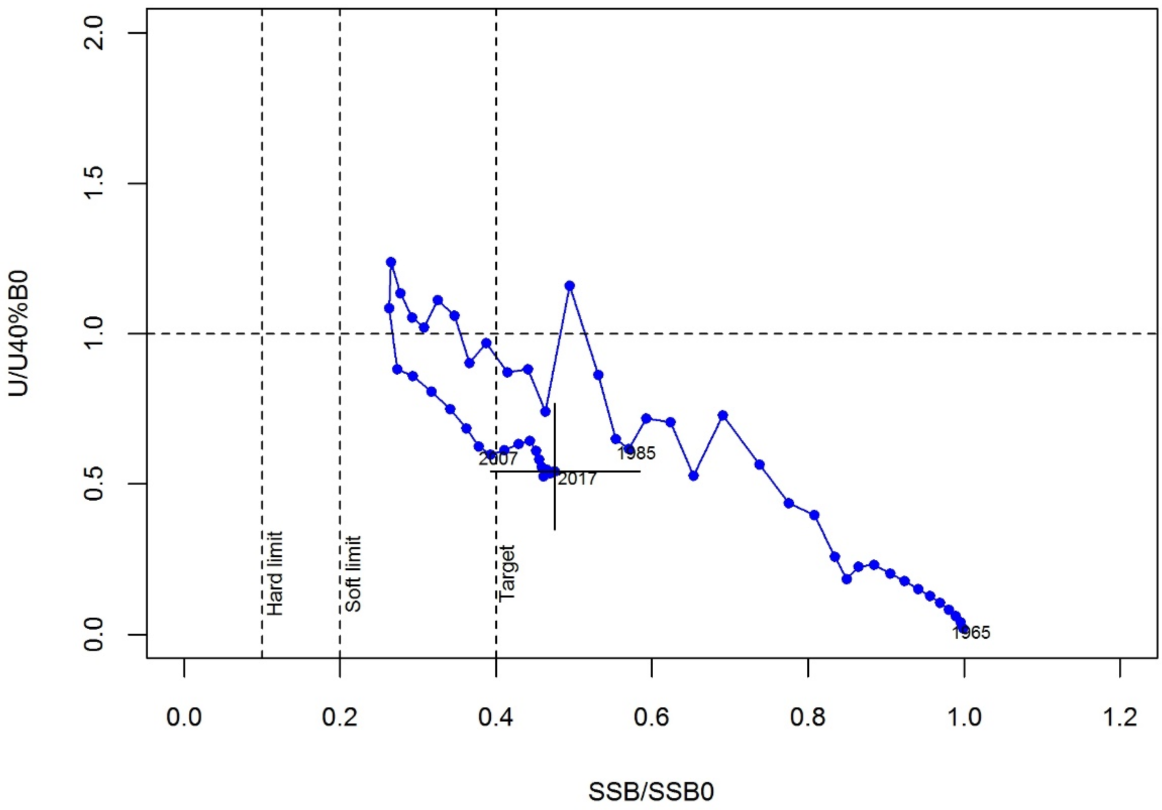
- **PAU 5B - *Haliotis iris***

Stock Status	
Year of Most Recent Assessment	2018
Assessment Runs Presented	MCMC 0.1 (base case)
Reference Points	Target: 40% B_0 (Default as per HSS) Soft Limit: 20% B_0 (Default as per HSS) Hard Limit: 10% B_0 (Default as per HSS) Overfishing threshold: $U_{40\%B0}$
Status in relation to Target	B_{2017} was estimated to be 47% B_0 for the base case; Likely (> 60%) to be at or above the target
Status in relation to Limits	Very Unlikely (< 10%) to be below the soft and hard limits
Status in Relation to Overfishing	Overfishing is Very Unlikely (< 10%) to be occurring

Historical Stock Status Trajectory and Current Status



Posterior distributions of spawning stock biomass as a percentage of the unfished level from MCMC 0.1. The box shows the median of the posterior distribution (horizontal bar), the 25th and 75th percentiles (box), with the whiskers representing the full range of the distribution.



Trajectory of exploitation rate as a ratio $U_{40\%B0}$ and spawning stock biomass as a ratio of B_0 from the start of assessment period 1965 to 2017 for MCMC 0.1 (base case). The vertical lines at 10%, 20% and 40% B_0 represent the hard limit, the soft limit, and the target respectively. $U_{40\%B0}$ is the exploitation rate at which the spawning stock biomass would stabilise at 40% B_0 over the long term. Each point on trajectory represents the estimated annual stock status: the value on x axis is the mid-season spawning stock biomass (as a ratio of B_0) and the value on the y axis is the corresponding exploitation rate (as a ratio $U_{40\%B0}$) for that year. The estimates are based on MCMC medians and the 2017 90% CI is shown by the crossed line.

Fishery and Stock Trends	
Recent Trend in Biomass or Proxy	Biomass decreased to its lowest level in 2002 but has increased since then.
Recent Trend in Fishing Intensity or Proxy	Exploitation rate peaked in late 1990s and has since declined.
Other Abundance Indices	Standardised CPUE generally declined until the early 2000s, but has shown an overall increase since then.
Trends in Other Relevant Indicators or Variables	Estimated recruitment was relatively low through the 1990s to the early 2000s, increased from 2002 until 2010 and has since fallen below the long term average.

Projections and Prognosis	
Stock Projections or Prognosis	At the current catch level biomass is expected to remain at or above the target over the next 3 years.
Probability of Current Catch or TACC causing Biomass to remain below or to decline below Limits	Results from all models suggest it is Very Unlikely (< 10%) that current catch or TACC will cause a decline below the limits.
Probability of Current Catch or TACC to cause Overfishing to continue or to commence	Very Unlikely (< 10%)

Assessment Methodology and Evaluation		
Assessment Type	Full Quantitative Stock Assessment	
Assessment Method	Length-based Bayesian model	
Assessment Dates	Latest: 2018	Next: 2021
Overall assessment quality (rank)	1 – High Quality	
Main data inputs (rank)	- Catch history	1 – High Quality for commercial catch 2 – Medium or Mixed Quality for recreational, customary and illegal as catch histories are not believed to be fully representative of the QMA
	- CPUE indices early series	2 – Medium or Mixed Quality: not believed to be fully representative of the whole QMA
	- CPUE indices later series	1 – High Quality
	- Commercial sampling length frequencies	2 – Medium or Mixed Quality: not believed to be fully representative of the whole QMA
	- Tag recapture data (for growth estimation)	1 – High Quality
	- Maturity at length data	1 – High Quality
	- Research Dive Survey Indices	2 – Medium or Mixed Quality: uncertain whether it indexes the stock
Data not used (rank)	- Research Dive Length Frequencies	2 – Medium or Mixed Quality: not believed to be representative of the entire QMA
Changes to Model Structure and Assumptions	New model	
Major Sources of Uncertainty	- *M* may not be estimated accurately. - CPUE may not be a reliable index of abundance and it is unclear whether catchability has changed over time. - The model treats the whole of the assessed area of PAU 5B as if it were a single stock with homogeneous biology, habitat and fishing pressure. - Any effect of voluntary increases in MHS from 125 mm to 137 mm between 2006 and 2017 may not have been adequately captured by the model, which could therefore be underestimating the spawning biomass in recent years.	

Qualifying Comments:
-

Fishery Interactions
-

6. FOR FURTHER INFORMATION

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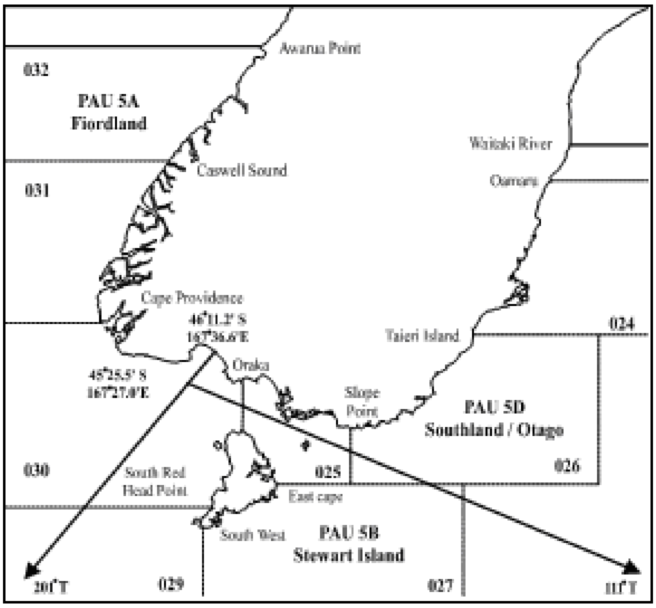
PĀUA (PAU 5D) - Southland / Otago

(*Haliotis iris*)
Pāua



1. FISHERY SUMMARY

Before 1995, PAU 5D was part of the PAU 5 QMA, which was introduced into the QMS in 1986 with a TACC of 445 t. As a result of appeals to the Quota Appeal Authority, the TACC increased to 492 t for the 1991–92 fishing year; PAU 5 was then the largest QMA by number of quota holders and TACC. Concerns about the status of the PAU 5 stock led to a voluntary 10% reduction in the TACC in 1994–95. On 1 October 1995, PAU 5 was divided into three QMAs (PAU 5A, PAU 5B, and PAU 5D; see figure above) and the TACC was divided equally among them; the PAU 5D quota was set at 148.98 t.

On 1 October 2002 a TAC of 159 t was set for PAU 5D, comprising a TACC of 114 t, customary and recreational allowances of 3 t and 22 t respectively, and an allowance of 20 t for other mortality. The TAC and TACC have been changed since then, but customary, recreational and other mortality allowances have remained unchanged (Table 1).

Table 1: Total allowable catches (TAC, t) allowances for customary fishing, recreational fishing, and other sources of mortality (t) and Total Allowable Commercial Catches (TACC, t) declared for PAU 5 and PAU 5D since introduction to the QMS.

Year	TAC	Customary	Recreational	Other mortality	TACC
1986–1991*	-	-	-	-	445
1991–1994*	-	-	-	-	492
1994–1995*	-	-	-	-	442.8
1995–2002	-	-	-	-	148.98
2002–2003	159	3	22	20	114
2003–present	134	3	22	20	89

*PAU 5 TACC figures

1.1 Commercial fishery

The fishing year runs from 1 October to 30 September. On 1 October 2001, it became mandatory to report catch and effort on Paua Catch Effort Landing Return (PCELR) forms using fine-scale reporting areas that had been developed by the New Zealand Pāua Management Company for their voluntary logbook programme (Figure 1). Since 2010, the commercial industry has adopted some voluntary management initiatives which include raising the minimum harvest size for commercial fishers over specific statistical reporting areas. The industry has also voluntarily closed, to commercial harvesting, specific areas that are of high importance to recreational pāua fishers. In recent years commercial fishers have been voluntarily shelving a percentage of their Annual Catch Entitlement (ACE), which is reflected by the annual catch landings falling below the TACC (Figure 2, Table 2).

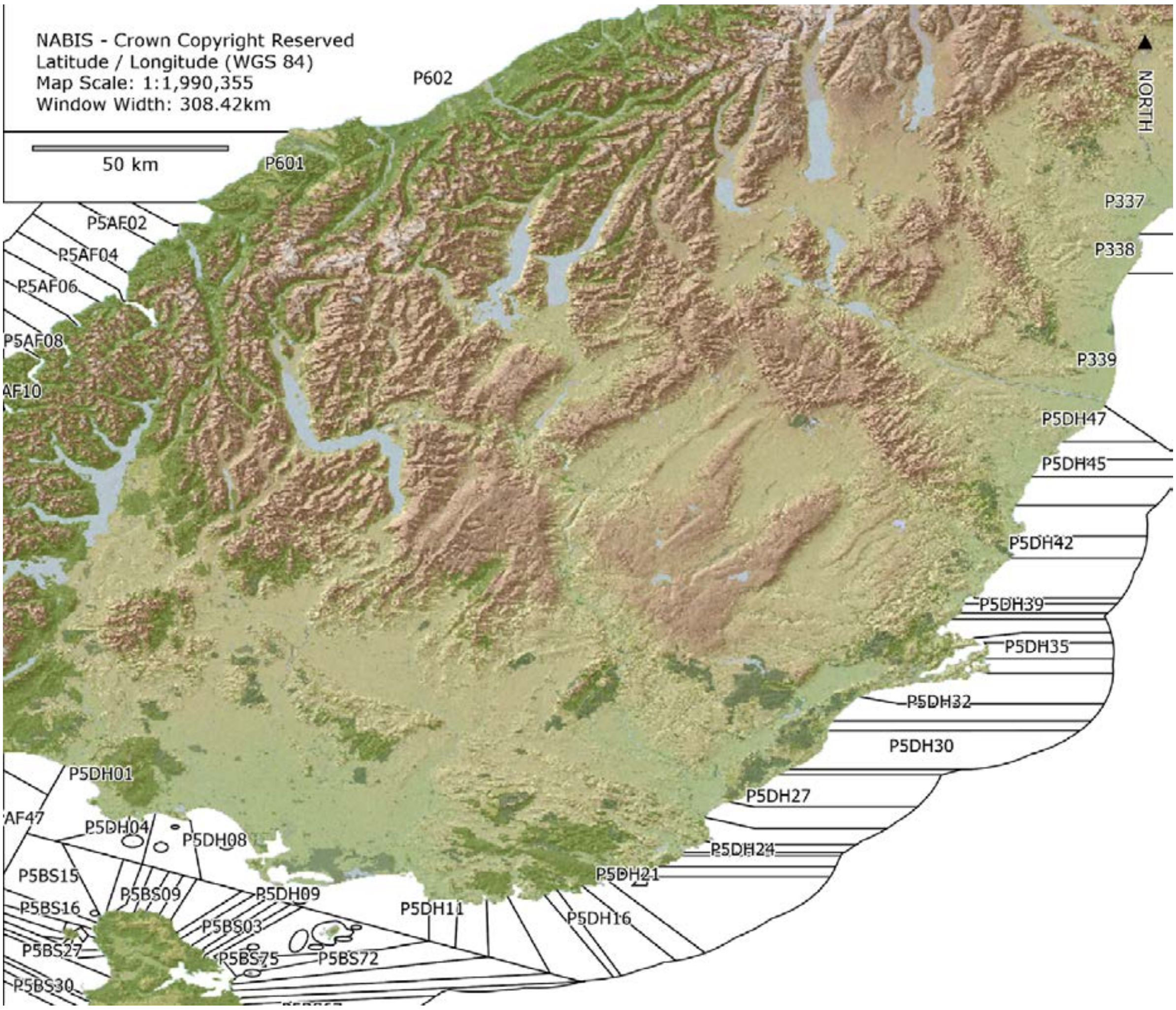


Figure 1: Map of fine scale statistical reporting areas for PAU 5D.

Commercial landings for PAU 5D are shown in Table 2 and Figure 2. Commercial landings for PAU 5 are reported in the introductory PAU Working Group Report.

Table 2: TACC and reported landings (t) of pāua in PAU 5D from 1995–96 to the present. [Continued next page]

Year	Landings	TACC
1995–96	167.42	148.98
1996–97	146.6	148.98
1997–98	146.99	148.98
1998–99	148.78	148.98
1999–00	147.66	148.98
2000–01	149.00	148.98
2001–02	148.74	148.98
2002–03	111.69	114.00
2003–04	88.02	89.00
2004–05	88.82	89.00
2005–06	88.93	89.00
2007–08	88.98	89.00
2006–07	88.97	89.00
2008–09	88.77	89.00
2009–10	89.45	89.00
2010–11	88.70	89.00
2011–12	89.23	89.00
2012–13	87.91	89.00
2013–14	84.59	89.00
2014–15	71.87	89.00

Table 2 [Continued]

Year	Landings	TACC
2015–16	65.95	89.00
2016–17	63.12	89.00
2017–18	62.48	89.00
2018–19	55.55	89.00

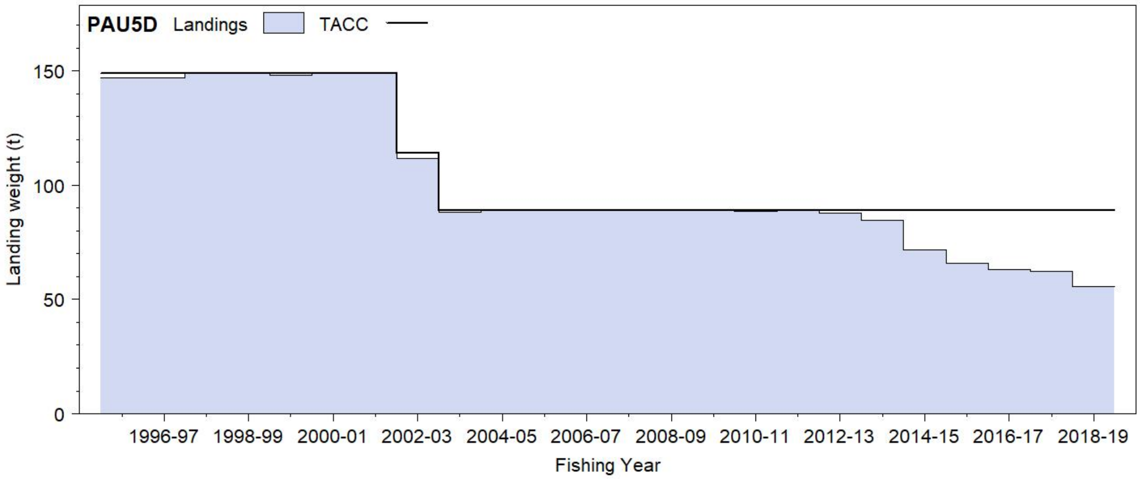


Figure 2: Reported commercial landings and TACC for PAU 5D from 1995–96 to present. For reported commercial landings in PAU 5 prior to 1995–96 refer to Figure 1 and Table 1 of the introductory PAU Working Group Report.

1.2 Recreational fisheries

For the purpose of the stock assessment model, the SFWG agreed to assume that the recreational catch in 1974 was 2 t and that it increased linearly to 10 t by 2005, where it has remained unchanged to date. For further information on recreational fisheries refer to the introductory PAU Working Group Report.

1.3 Customary fisheries

Estimates of customary catch for PAU 5D are shown in Table 3. These numbers are likely to be an underestimate of customary harvest as only the catch in numbers are reported in the table.

Table 3: Fisheries New Zealand records of customary harvest of pāua (reported in numbers) of pāua in PAU 5D between 2000-01 and 2018-19. – no data.

Fishing year	Approved	Harvested
2000–01	665	417
2001–02	5 530	3 553
2002–03	2 435	1 351
2003–04	–	–
2004–05	–	–
2005–06	1 560	1 560
2006–07	2 845	2 126
2007–08	5 600	5 327
2008–09	6 646	6 094
2009–10	4 840	4 150
2010–11	15 806	15 291
2011–12	7 935	7 835
2012–13	10 254	8 782
2013–14	5 720	5 358
2014–15	–	–
2015–16	15 922	13 110
2016–17	3 676	3 576
2017–18	3 588	3 310
2018–19	950	894

For the purpose of the stock assessment model, the SFWG agreed to assume that, for PAU 5D, the customary catch has been constant at 2 t from 1974 to the current stock assessment. The reported customary catch in 2018–19 was 894 kg. For further information on customary fisheries refer to the introductory PAU Working Group Report.

1.4 Illegal catch
For the purpose of the stock assessment model, the SFWG agreed to assume that, for PAU 5D, illegal catches have been constant at 10 t from 1974 to the current stock assessment. For further information on illegal catch refer to the introductory PAU Working Group Report.

1.5 Other sources of mortality
For further information on other sources of mortality refer to the introductory PAU Working Group Report.

2. BIOLOGY

For further information on pāua biology refer to the introductory PAU Working Group Report. A summary of biological parameters used in the PAU 5D assessment is presented in Table 4.

3. STOCKS AND AREAS

For further information on stocks and areas refer to the introductory PAU Working Group Report.

Table 4: Estimates of biological parameters (*H. iris*).

		Estimate	Source
1. Natural mortality (*M*)			
		0.15(0.12-0.19)	Median (5–95% range) of posterior estimated by the base case model
2. Weight = a(length)^b (Weight in g, length in mm shell length)			
All	a	b	
	2.99 x 10^{-5}	3.303	Schiel & Breen (1991)
3. Size at maturity (shell length)			
		50% maturity at 91 mm (89–93)	Median (5–95% range) estimated outside of the assessment
		95% maturity at 103 mm (103–105)	Median (5–95% range) estimated outside of the assessment
4. Estimated annual growth increments (both sexes combined)			
	16.65 (15.96–24.29)	4.57 (3.27–6.40)	

4. STOCK ASSESSMENT

The stock assessment was implemented as a length-based Bayesian estimation model, with uncertainty of model estimates investigated using the marginal posterior distributions generated from Markov chain-Monte Carlo simulations. The most recent stock assessment was conducted for the fishing year ended 30 September 2018. A base case model (0.0 - referred to as the reference model henceforth) was chosen from the assessment. Data weighting had the strongest impact on assessment outcomes, and a range of scenarios with varying weights for CPUE and commercial length-frequency data were explored. QMA specific growth patterns remain highly uncertain due to high spatial variability in growth and relatively low spatial coverage of the tag-recapture programme to estimate pāua growth. This uncertainty translates into uncertainty about stock status and stock trajectories.

4.1 Estimates of fishery parameters and abundance indices
Parameters estimated in the assessment model and their assumed Bayesian priors are summarized in Table 5.

Table 5: A summary of estimated model parameters, lower bound, upper bound, type of prior, (U, uniform; N, normal; LN = lognormal; Beta = beta distribution), mean and CV of the prior.

Parameter	Prior	μ	sd	Bounds	
				Lower	Upper
ln(*R0*)	LN	exp(13.5)	0.5	10	20
D_{50}(Length at 50% selectivity for the commercial catch)	LN	123	0.05	100	145
$D_{95\text{-}50}$(Length between 50% and 95% selectivity the commercial catch)	LN	5	0.5	0.01	50
Steepness (h)	Beta				
ϵ (Recruitment deviations)	LN	0	2	0	-

The observational data were:

1. A standardised CPUE series covering 1989–2018 based on combined CELR and PCELR data.
2. A commercial catch sampling length frequency series for 1991–93, 1997, 1999–2016
3. Tag-recapture length increment data.
4. Maturity at length data

4.1.1 Relative abundance estimates from standardised CPUE analyses

The 2019 stock assessment used a combined series of standardised CPUE indices that included both CELR data covering 1990–2001, and PCELR data covering 2002–2018. CPUE standardisation was carried out using a Bayesian Generalised Linear Mixed Model (GLMM) which partitioned variation among fixed (research strata) and random variables, and between fine-scale reporting (PCELR) and larger scale variables (CELR). The variation explained by fine-scale variables (e.g. fine scale statistical areas or divers) in PCELR data was considered unexplained in the CELR portion of the model and therefore added to observation error.

For the CELR data, there was ambiguity in what was recorded for estimated daily fishing duration: either incorrectly recorded as hours per diver, or correctly as total hours for all divers. For PAU 5D, fishing duration appeared to have been predominantly recorded as hours per diver. A model-based correction procedure was developed to detect and correct for misreporting, using a mixture model that determines the characteristics of each reporting type by fishing crew and assigns years to correct (reporting for all divers) or incorrect (by diver) reporting regimes with some probability. Only records with greater than 95% certainty of belonging to one or the other reporting type were retained for further analysis.

CPUE was defined as the log of daily catch-per-unit-effort. Variables in the model were fishing year, FIN (Fisher Identification Number), Statistical Area (024, 026), dive condition, diver ID, and fine-scale statistical area. Variability in CPUE was mostly explained by differences among divers and crews (FINs), with dive conditions strongly affecting CPUE. The CPUE data showed a slight decline in the 1990s followed by a strong downturn in CPUE in the early 2000s, followed by a strong recovery of CPUE to levels above those seen in the early 1990s (Figure 3). However, CPUE subsequently declined to below-average levels, where it has remained relatively stationary since 2013. In some circumstances, commercial CPUE may not be proportional to abundance because it is possible to maintain catch rates of pāua despite a declining biomass. This occurs because pāua tend to aggregate and divers move among areas to maximise their catch rates. Apparent stability in CPUE should therefore be interpreted with caution. The assumption of CPUE being proportional to biomass was investigated using the assessment model.

4.1.2 Relative abundance estimates from research diver surveys

The relative abundance of pāua in PAU 5D has also been estimated from a number of independent research diver surveys (RDSI) undertaken in various years between 1994 and 2004. The survey strata (Catlins East and Catlins West) cover the areas that produced about 25% of the recent catches in PAU 5D. This data was not included in the assessment because there is concern that the data is not a reliable enough index of abundance and the data is not representative of the entire PAU 5D QMA.

Concerns about the ability of the data collected in the independent Research Dive surveys to reflect relative abundance instigated reviews in 2009 (Cordue 2009) and 2010 (Haist 2010). The reviews assessed the reliability of the research diver survey index as a proxy for abundance and whether the RDSI, when used in the pāua stock assessment models, results in model outputs that adequately reflect the status of the stocks. Both reviews suggested that outputs from pāua stock assessments using the

RDSI should be treated with caution. For a summary of the review's conclusions refer to the introductory PAU Working Group Report.

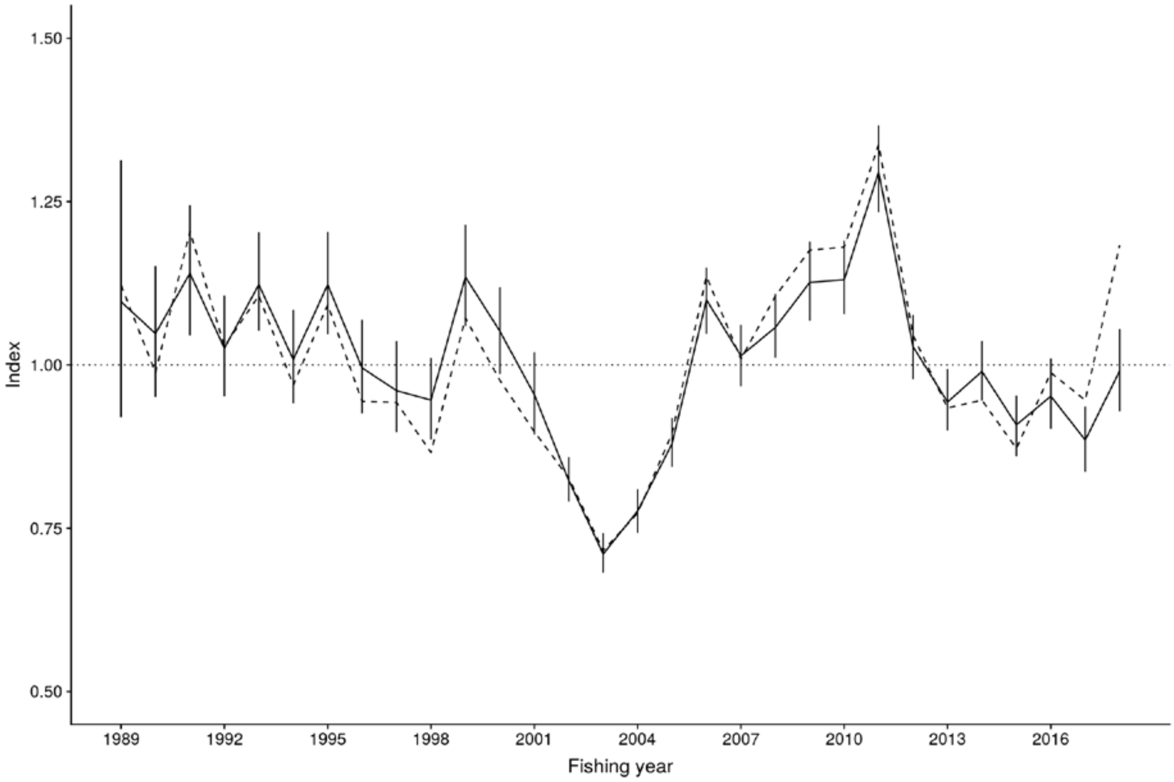


Figure 3: The standardised CPUE indices with 95% confidence intervals (solid line and vertical error bars) and unstandardized geometric CPUE (dashed line) for the combined CELR and the PCELR series.

4.2 Stock assessment methods

The 2019 PAU 5D stock assessment used the length-based population dynamics model first described by Breen et al (2003). PAU 5D was last assessed using data up to the 2015–2016 fishing year (Marsh & Fu 2017), and the most recent assessment uses data up to the 2017–2018 fishing year (Neubauer & Tremblay-Boyer 2019). Although the overall population-dynamics model remained unchanged, the most recent iteration of the PAU 5D stock assessment incorporates a number of changes to the previous methodology:

1. CPUE likelihood calculations reverted to predicting CPUE from beginning of year biomass since the previous change to mid-year predictions did not affect the assessment and caused potential for error and an increased computational burden.
2. A Bayesian statistical framework across all data inputs and assessments (MPD runs were not performed; all exploration was performed using full Markov Chain Monte Carlo runs).
3. The assessment model framework was moved to the Bayesian statistical inference engine Stan (Stan Development Team 2018), including all data input models (the assessment model was previously coded in ADMB).
4. Catch sampling length-frequency (CSLF) data handling was modified to a model-based estimation of observation error with partitioning between observation and process error for CSLF and CPUE, and use of a multivariate normal model for centred-log-ratio-transformed mean CSLF and observation error.
5. The data weighting procedure was to use a scoring rule (log score) and associated divergence measure (Kullbach-Liebler divergence) to measure information loss and goodness of fit for CPUE and CSLF.
6. Growth and maturation were fit to data across all QMAs outside of the assessment model, and the resulting mean growth and estimate of proportions mature at age were supplied as an informed prior on growth to the model; no growth or maturation data were explicitly fitted in the model.

The model structure assumed a single sex population residing in a single homogeneous area, with length classes from 70 mm to 170 mm, in groups of 2 mm. Growth is length-based, without reference to age, mediated through a growth transition matrix that describes the probability of each length class changing in each year. Pāua entered the partition following recruitment and were removed by natural mortality and fishing mortality.

The model simulates the population from 1965 to 2018. Catches were available for 1974–2018 although catches before 1995 must be estimated from the combined PAU 5 catch, and were assumed to increase linearly between 1965 and 1973 from 0 to the 1974 catch level. Catches included commercial, recreational, customary, and illegal catch, and all catches occurred within the same time step.

Recruitment was assumed to take place at the beginning of the annual cycle, and length at recruitment was defined by a uniform distribution with a range between 70 and 80 mm. The stock-recruitment relationship is unknown for pāua. However, the Shellfish Working Group agreed to use a Beverton-Holt stock-recruitment relationship, with steepness (*h*) estimated for this assessment.

Growth, maturation and natural mortality were also estimated within the model, although no fitting to raw data was performed, and all inputs were provided as priors with mean and observation error. The model estimated the commercial fishing selectivity, which was assumed to follow a logistic curve and to reach an asymptote.

The assessment proceeded iteratively by first replacing the previous growth formulation (i.e. fitting to growth data from PAU 5D only within the model) with an informed prior on mean growth and growth variability. Previous assessments noted that growth collected from a limited number of sites may not represent mean growth and true growth variability across the QMA. It was noted in the current assessment that PAU 5D growth data was almost exclusively from sites with very fast growth, and that alternative assumptions about growth lead to radically different estimates of stock status. To reflect uncertainty about true growth, a prior formulated from a South Island-wide meta-analysis was used in the model.

Providing less information about growth to the model meant that more weight was placed on CPUE and CSLF data, and it was found that data weights were now the most influential uncertainty in the model. Previous methods to weight datasets give more weight to CPUE data by default because CPUE has a more direct link to abundance than CSLF data, and one can argue a lower potential for process error. However, for pāua in particular, CPUE is often seen as a risky index of abundance (see qualifications below). The current assessment therefore does not favour either dataset *a priori*, but rather attempts to explore scenarios where either dataset has high weight relative to the other. To more accurately quantify model fit and information loss from each data source, a new procedure was developed based on the log scoring rule (a scoring rule quantifies the predictive quality of a model). The log score provides a base to weight datasets (i.e. to penalise deviation from any dataset) and to measure information loss from data (e.g. the estimated CPUE and observation error) to model quantities. Models with various divergence penalty configurations for CPUE and CSLF were introduced and the resulting model fit and divergence between model and input were noted until a set of models with satisfactory fits and deviations was found.

The reference model (model 0) excluded the RDSI and RDLF data, fitted the combined CPUE series and the mean CSLF and observation error, estimated process error for CPUE and CSLF, updated growth estimates within the model, and estimated *M* and steepness within the model. The data weights in this model led to slightly increased information loss from CSLF data relative to CPUE data, with satisfactory fits to both datasets.

The sensitivity trials carried out used lower weight for the CPUE indices and a more restrictive prior for *M* as opposed to the base-case.

The assessment calculates the following quantities from the marginal posterior distributions of various partitions of the biomass: the equilibrium (unfished) spawning stock biomass (SSB_0) assuming that recruitment is equal to the average recruitment, and the relative spawning and available biomass for

2018 (SSB_{2018} and B_{2018}^{Avail}) and for the projection ($Proj$) period (SSB_{Proj} and B_{proj}^{Avail}. This assessment also reports the following fishery indictors:

Relative *SSB*	Estimated spawning stock biomass in the final year relative to unfished spawning stock biomass
Relative B^{Avail}	Estimated available biomass in the final year relative to unfished available stock biomass
P(SSB_{2018} > 40% SSB_0)	Probability that the spawning stock biomass in 2018 was greater than 40% of the unfished spawning stock
P(SSB_{2018} > 20% SSB_0)	Probability that the spawning stock biomass in 2018 was greater than 20% of the unfished spawning stock (soft limit)
P(SSB_{Proj} > 40% SSB_0)	Probability that projected future spawning stock biomass will be greater than 40% of the unfished spawning stock given assumed future catches
P(SSB_{Proj} > 20% SSB_0)	Probability that projected future spawning stock biomass will be greater than 20% of the unfished spawning stock given assumed future catches
P(B_{Proj} > B_{2018})	Probability that projected future biomass (spawning stock or available biomass) is greater than estimated biomass for the 2018 fishing year given assumed future catches

4.3 Stock assessment results

The base case model suggested a relatively flat trend in spawning stock biomass over the past seven years, following a slow downwards trend from 2005 to 2011 (Figure 4). The base case also indicated a high probability that the stock is currently near the target spawning stock biomass (Table 6), with little to no probability that it is below the soft limit of 20% *SSB*. This inference was supported by all sensitivity runs (Table 6). Nevertheless, relative available biomass was markedly lower than the spawning stock biomass, meaning that a considerable part of the spawning biomass was below the minimum harvest size, and is therefore not accessible to the fishery.
Projections suggested relatively stable SSB for scenarios of current catch and 10% or 20% increased or decreased catch (Table 7). For all catch scenarios, available biomass was projected to slowly increase, although this increase is somewhat uncertain (there was a 60% likelihood of an increase in three years over current available biomass at current catch).

Two sensitivity scenarios were agreed as the main sensitivity scenarios that bracketed estimated stock status in the base-case run. The first scenario was the base case with a more restrictive prior for *M* (log-normal SD of 0.1 instead of 0.2) which forced *M* to a lower point in the assessment; it also led to lower recent stock status, all else being equal (Table 6; Figure 4). Nevertheless, this scenario also suggested a recent upturn in the fishery with increasing available biomass, despite a lower stock status estimate. This model run suggested a potentially stronger impact from recent shelving measures than the base case. Projections from this scenario largely agreed with those from the base-case.

Table 6: Model runs for the stock assessment of pāua in management area PAU 5D. Posterior quantities for data fits in terms of the Kullback-Leibler divergence (KLD) for catch-per-unit-effort (CPUE) and catch sampling length frequency (CSLF), stock status (relative spawning stock biomass), relative available biomass and probability of the stock status being above the soft limit (P(SSBproj > 20% SSB0). Numbers are posterior medians, with the 0.025 and 0.975 posterior quantiles in parentheses.

Run	KLD CPUE	KLD CSLF	Stock status	Available	P(SSB_{proj} > 20% SSB_0)
Base	0.67 (0.53;0.82)	0.73 (0.66;0.84)	0.40 (0.25;0.65)	0.25 (0.17;0.39)	1.00
Constrain M	0.68 (0.53;0.92)	0.74 (0.66;0.84)	0.36 (0.24;0.56)	0.23 (0.16;0.35)	1.00
Lower CPUE weight	0.84 (0.70;1.05)	0.73 (0.65;0.83)	0.44 (0.28;0.71)	0.29 (0.19;0.46)	1.00

The second main sensitivity scenario did not up-weight the CPUE and, therefore, only down-weighted CSLF data. This sensitivity scenario resulted in declining recent spawning stock biomass trends (Figure 4), despite resulting in slightly higher estimates for current stock status (Table 6). The declining trend continued for projections in this scenario regardless of the applied catch. For both main sensitivity scenarios, the probability of stock status being at or falling below the soft limit was close to zero over the timeframe of projections.

For a number of reasons (outlined below) reference points based on deterministic MSY or B_{MSY} are not currently used for managing pāua stocks and were therefore not calculated.

There are several reasons why deterministic B_{MSY} is not considered a suitable target for management of the pāua fishery. First, it assumes a harvest strategy that is unrealistic in that it involves perfect knowledge of catch and biology and perfect stock assessments (because current biomass must be known exactly in order to calculate target catch), a constant-exploitation management strategy with annual changes in TACC (which are unlikely to happen in New Zealand and not desirable for most stakeholders), and perfect management implementation of the TACC and catch splits with no under- or over-runs. Second, it assumes perfect knowledge of the stock-recruit relationship, which is actually very poorly known. Third, deterministic MSY is commonly much higher than realised catch for pāua stocks (e.g. Marsh & Fu 2017) and deterministic B_{MSY} is estimated at biomass levels corresponding to very low available biomass levels. Management based on deterministic MSY-based reference points would likely lead to biomass occasionally falling below 20% B_0, the default soft limit according to the Harvest Strategy Standard. Thus, the actual target needs to be above this theoretical deterministic biomass, but the extent to which it needs to be above has not been determined.

In the meantime, an interim target of 40% B_0 is used as a proxy for a more realistic interpretation of B_{MSY}.

Table 7: Projections for key fishery indicators from the base case model: probabilities of being above 40% and 20% of unfished spawning biomass (*SSB*) [P(SSB_{Proj} > 40% SSB_0) and P(SSB_{Proj} > 20% SSB_0)], the probability that *SSB* in the projection year is above current *SSB*, the posterior median relative to *SSB*, the posterior median relative available spawning biomass B^{Avail}_{Proj}, and the probability that the exploitation rate (*U*) in the projection year is above $U_{40\%\ SSB0}$, the exploitation rate that leads to 40% SSB_0. The total commercial catch (TCC) marked with * corresponds to current commercial catch under 35% shelving of the current TACC (89 t). Other TACC scenarios show 50% shelving (44.5 t), 20% shelving (71.2 t) and fishing at the current TACC. Simulation to equilibrium (assumed to have been reached after 50 projection years) are indicated with Eq. in the year column.

TACC (t)	Year	P(SSB_{Proj} > 40% SSB_0)	P(SSB_{Proj} > 20% SSB_0)	P(SSB_{Proj} > SSB_{2018})	Median rel. SSB_{Proj}	Median rel. B^{Avail}_{Proj}	P(U > $U_{40\%\ SSB0}$)
44.5	2018	0.52	1	0	0.41	0.46	0.46
	2019	0.51	1	0.39	0.42	0.48	0.31
	2020	0.52	1	0.45	0.43	0.5	0.26
	2021	0.53	0.99	0.49	0.44	0.52	0.23
	Eq.	0.63	0.87	0.61	0.52	0.53	0.24
57.85	2018	0.52	1	0	0.41	0.46	0.46
	2019	0.51	1	0.39	0.42	0.48	0.44
	2020	0.5	0.99	0.42	0.42	0.5	0.42
	2021	0.5	0.98	0.44	0.42	0.51	0.4
	Eq.	0.53	0.81	0.52	0.47	0.48	0.4
71.2	2018	0.52	1	0	0.41	0.46	0.46
	2019	0.51	1	0.39	0.42	0.48	0.54
	2020	0.48	0.99	0.39	0.41	0.49	0.53
	2021	0.46	0.96	0.41	0.41	0.5	0.53
	Eq.	0.46	0.75	0.44	0.42	0.42	0.57
89	2018	0.52	1	0	0.41	0.46	0.46
	2019	0.51	1	0.39	0.42	0.48	0.64
	2020	0.45	0.99	0.36	0.4	0.48	0.66
	2021	0.42	0.94	0.37	0.4	0.48	0.68
	Eq.	0.37	0.68	0.34	0.36	0.37	0.73

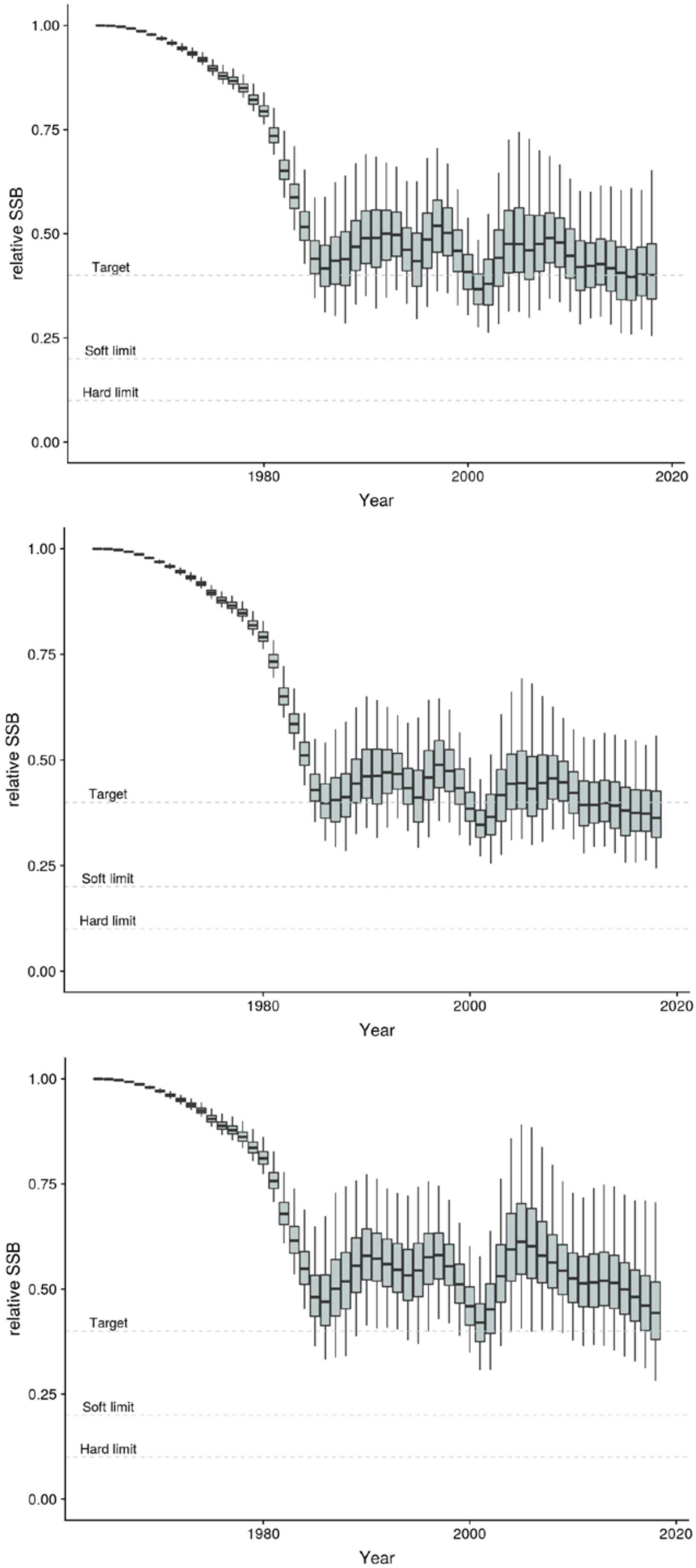


Figure 4: Posterior distributions of spawning stock biomass from the base case model, the sensitivity scenario with a more constrained prior on natural mortality (M), and the sensitivity scenario with lower weight on CPUE. The box shows the median of the posterior distribution (horizontal bar), the 25th and 75th percentiles (box), with the whiskers representing the 95% confidence range of the distribution.

4.4 Other factors

To run the stock assessment model a number of assumptions must be made, one of these being that CPUE is a reliable index of abundance. The literature on abalone fisheries suggests that this assumption is questionable and that CPUE is difficult to use in abalone stock assessments due to the serial depletion behaviour of fishers along with the aggregating behaviour of abalone. Serial depletion is when fishers consecutively fish-down beds of pāua but maintain their catch rates by moving to new unfished beds; thus CPUE stays high while the overall population biomass is actually decreasing. The aggregating behaviour of pāua results in the timely re-colonisation of areas that have been fished down, as the cryptic pāua, that were unavailable at the first fishing event, move to and aggregate within the recently depleted area. Both serial depletion and aggregation behaviour cause CPUE to have a hyperstable relationship with abundance (i.e. abundance is decreasing at a faster rate than CPUE) thus making CPUE a poor proxy for abundance. The strength of the effect that serial depletion and aggregating behaviour have on the relationship between CPUE and abundance in PAU 5D is difficult to determine. However, because fishing has been consistent in PAU 5D for a number of years and effort has been reasonably well spread, it could be assumed that CPUE is not as strongly influenced by these factors, relative to the early CPUE series.

The assumption of CPUE being a reliable index of abundance in PAU 5D can also be upset by exploitation of spatially segregated populations of differing productivity. This can conversely cause non-linearity and hyper-depletion in the CPUE-abundance relationship, making it difficult to track changes in abundance by using changes in CPUE as a proxy.

Another source of uncertainty is the data. The commercial catch is unknown before 1974 and is estimated with uncertainty before 1995. Major differences may exist between the catches we assume and what was actually taken. Non-commercial catch estimates, including illegal catch, are also poorly determined and could be substantially different from what was assumed.

The model treats the whole of the assessed area of PAU 5D as if it were a single stock with homogeneous biology, habitat and fishing pressure. The model assumes homogeneity in recruitment and natural mortality.

Heterogeneity in growth can be a problem for this kind of model (Punt 2003). Variation in growth is addressed to some extent by having a stochastic growth transition matrix based on increments observed in several different places; similarly the length frequency data are integrated across samples from many places. Thus, length frequency data collected from the commercial catch may not represent the available biomass represented in the model with high precision.

The effect of these factors is likely to make model results optimistic. For instance, if some local stocks are fished very hard and others not fished, recruitment failure can result because of the depletion of spawners, as spawners must breed close to each other, and the dispersal of larvae is unknown and may be limited. Recruitment failure is a common observation in overseas abalone fisheries, so local processes may decrease recruitment, an effect that the current model does not account for.

Another source of uncertainty is that fishing may cause spatial contraction of populations (Shepherd & Partington 1995), or that it may result in some populations becoming relatively unproductive after initial fishing (Gorfine & Dixon 2000). If this happens, the model will overestimate productivity in the population as a whole. Past recruitments estimated by the model might instead have been the result of serial depletion.

5. FUTURE RESEARCH CONSIDERATIONS

- Revisit PAU 5 catch reconstructions.
- Examine the effects of removing historical catches from areas that are now closed.
- Re-examine the diver surveys and length frequencies to determine their utility.
- Further investigate method for representing potential increases in catchability over time; e.g. a linear trend.

- Consider the need for more tagging in certain areas to fill gaps in growth data; e.g. Colac Bay and Moeraki.
- Further investigate data weighting procedures for pāua stocks. The prior on R_0 previously used in the PAU 5D assessment implied a prior on stock status that may have biased assessments of pāua stock status high. Check this further and determine whether it may also be an issue for other pāua stocks.

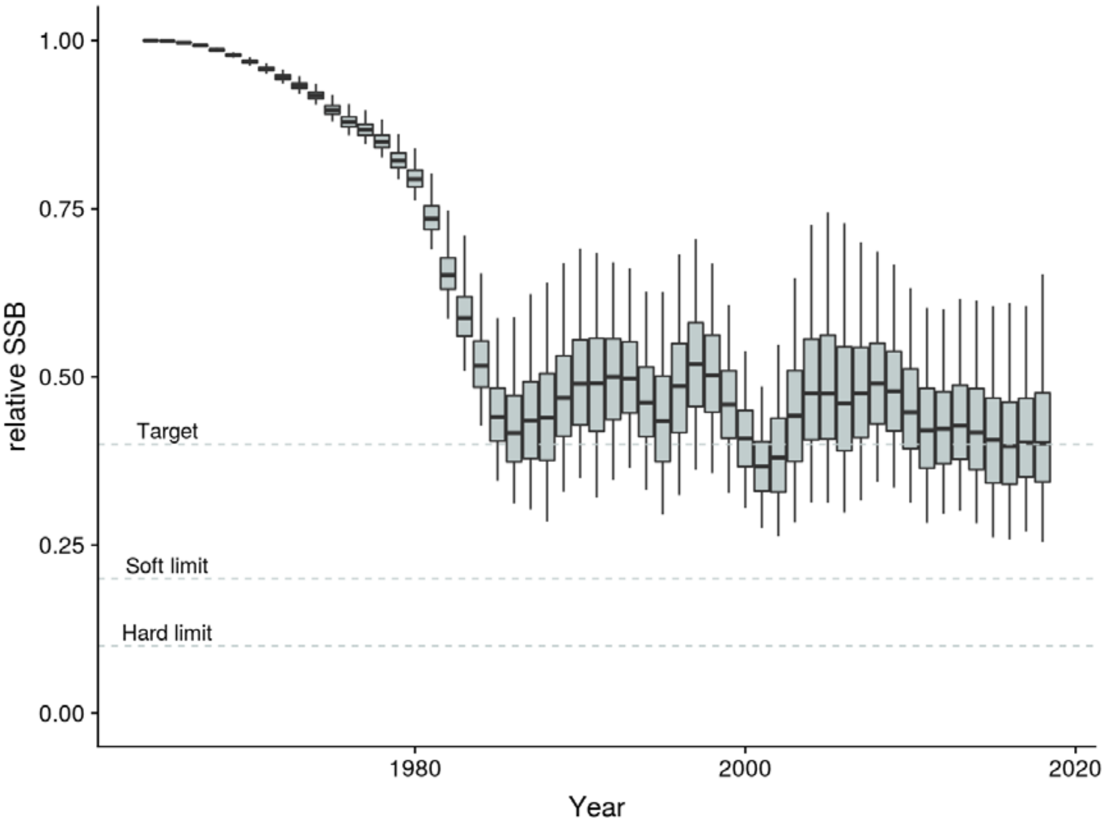
6. STATUS OF THE STOCK

Stock Structure Assumptions
PAU 5D is assumed in the model to be a discrete and homogenous stock

- **PAU 5D - *Haliotis iris***

Stock Status	
Year of Most Recent Assessment	2019
Assessment Runs Presented	Reference case MCMC
Reference Points	Interim Target: 40% B_0 Soft Limit: 20% B_0 Hard Limit: 10% B_0 Overfishing threshold: $U_{40\%B0}$
Status in relation to Target	B_{2018} was estimated to be 42% B_0. About as Likely as Not (40–60%) to be at or above the target
Status in relation to Limits	Very Unlikely (< 10%) to be below the soft limit and Very Unlikely (< 10%) to be below the hard limit.
Status in Relation to Overfishing	Overfishing is About as Likely as Not (40–60%) to be occurring

Historical Stock Status Trajectory and Current Status



Posterior distributions of spawning stock biomass from the base case model. The box shows the median of the posterior distribution (horizontal bar), the 25th and 75th percentiles (box), with the whiskers representing the 95% confidence range of the distribution.

Fishery and Stock Trends	
Recent Trend in Biomass or Proxy	Biomass decreased up to about 1984 and has been fluctuating moderately around the target subsequently.
Recent Trend in Fishing Mortality or Proxy	Exploitation rate peaked in 2002 and has since declined.
Other Abundance Indices	Standardised CPUE generally declined until the early 2000s, recovered in the mid-2000s, and gradually decreased to a recent stable but below average level.
Trends in Other Relevant Indicators or Variables	Recruitment appears to pulse in approximately five year intervals, with two larger than average pulses in the mid-1990s and 2000. Increases in pāua areas closed to commercial fishing and voluntary increases in MHS both create buffers to fishing.

Projections and Prognosis	
Stock Projections or Prognosis	At the current catch level biomass is About as Likely as Not (40–60%) to remain at current levels. Under the current TACC, biomass is likely to decline in the short term.
Probability of Current Catch or TACC causing Biomass to remain below or to decline below Limits	Results from all model assessment runs presented suggest it is Very Unlikely (< 10%) that current levels of catch will cause a decline below the soft or hard limits.
Probability of Current Catch or TACC causing Overfishing to continue or to commence	About as Likely as Not (40–60%) for current catch; Very Likely (> 90%) for current TACC

Assessment Methodology and Evaluation		
Assessment Type	1- Full Quantitative Stock Assessment	
Assessment Method	Length based Bayesian model	
Assessment Dates	Latest: 2019	Next: 2022
Overall assessment quality (rank)	1 – High Quality	
Main data inputs (rank)	- Catch History	2 – Medium or Mixed Quality: not believed to be fully representative of catch in the QMA
	- CPUE Indices early series	2 – Medium or Mixed Quality: not believed to be fully representative of CPUE in the QMA
	- CPUE Indices later series	1– High Quality
	- Commercial sampling length frequencies	1 – High Quality
	- Tag recapture data	2 – Medium or Mixed Quality: not believed to be representative of the whole QMA
	- Maturity at length data	1 – High Quality
Data not used (rank)	- Research Dive survey indices	3 – Low Quality: not believed to be a reliable indicator of abundance in the whole QMA
	- Research Dive length frequencies	3 – Low Quality: not believed to be a reliable indicator of length frequency in the whole QMA
Changes to Model Structure and Assumptions	- Both CPUE series combined to form a single index - Calculations for the CPUE likelihood were reverted to predicting CPUE from beginning of year biomass since the previous change to mid-year predictions did not affect the assessment and caused potential for error and increased computational burden.	

	- A Bayesian statistical framework across all data inputs and assessments (i.e. MPD runs were not performed, all exploration was performed using full Markov Chain Monte Carlo). - The assessment model framework was moved to the Bayesian statistical inference engine Stan (Stan Development Team 2018), including all data input models (the assessment model was previously coded in ADMB). - Changed CSLF data handling to model-based estimation of observation error and partitioning between observation and process error for CSLF and CPUE, with use of a multivariate normal model for centred-log-ratio-transformed mean CSLF and observation error. - Changed data weighting procedure to use scoring rule (log score) and associated divergence measure (Kullbach-Liebler divergence) to measure information loss and goodness of fit for CPUE and CSLF. - Growth and maturation were fit to data across all QMAs outside of the assessment model, and the resulting mean growth and estimate of proportions mature at age were supplied as an informed prior on growth to the model; no growth or maturation data was explicitly fitted in the model.
Major Sources of Uncertainty	- Growth data were limited and may not be representative of growth within the entire QMA. This was mitigated by formulating a weakly informative prior about growth based on meta-analysis for all South Island pāua stocks. - Assuming CPUE is a reliable index of abundance for pāua - Sensitivity of the model to data weighting assumptions - Potential increases in q

Qualifying Comments
Uncertainties in the input data and model structure necessitate caution in the interpretation of the assessed status of the stock. However, the high MHS relative to length-at-maturity (along with closed areas) means that a relatively large proportion of the spawning stock is not available to the fishery and provides a buffer from the effects of fishing for the stock.

Fishery Interactions
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6. FOR FURTHER INFORMATION

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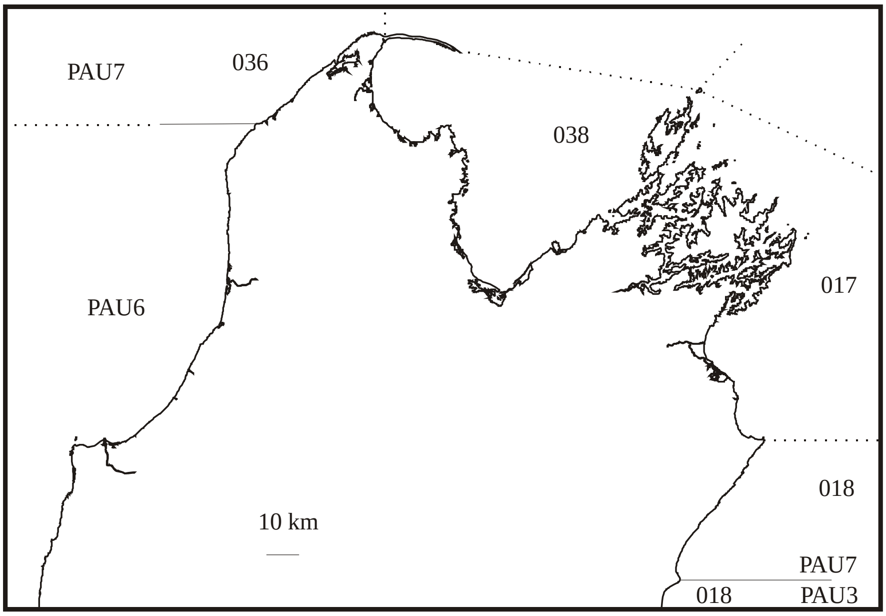
PĀUA (PAU 7) – Marlborough

(Haliotis iris)
Pāua



1. FISHERY SUMMARY

PAU 7 was introduced into the Quota Management System in 1986–87 with a TACC of 250 t. As a result of appeals to the Quota Appeal Authority the TACC increased to 267.48 t by 1989. On 1st October 2001 a TAC of 273.73 t was set with a TACC of 240.73 t, customary and recreational allowances of 15 t each and an allowance of 3 t for other mortality. On 1 October 2002 the TAC was reduced to 220.24 t and the TACC was set at 187.24 t; no changes were made to the customary, recreational or other mortality allowances. In 2016 the TACC was further reduced to 93.62 t, and the allowance for other mortality was increased to 10 t, setting the TAC to 133.62 (Table 1).

Table 1: Total allowable catches (TAC, t) allowances for customary fishing, recreational fishing, and other sources of mortality (t) and Total Allowable Commercial Catches (TACC, t) declared for PAU 7 since introduction into the QMS.

Year	TAC	Customary	Recreational	Other mortality	TACC
1986–89	–	–	–	–	250.00
1989–01	–	–	–	–	267.48
2001–02	273.73	15	15	3	240.73
2002–16	220.24	15	15	3	187.24
2016–Present	133.62	15	15	10	93.62

1.1 Commercial fisheries

The fishing year runs from 1 October to 30 September. In 2000–01 concerns about the status of the PAU 7 fishery led to a decision by the commercial sector to voluntarily shelve 20% of the TACC for that fishing year. From the 2003–04 to the 2006–07 fishing years the industry proposed to shelve 15% of the TACC. In the 2012–13 and 2013–14, the industry shelved 20% of the 187.24 t TACC. In 2014–15, PAU 7 stakeholders again agreed to voluntarily shelve 30%. However some only shelved 20% and some shelved 30%; an average of 28% was shelved overall. In October 2016 the TACC was reduced by 50%. Almost immediately following this as a result of the Kaikōura earthquake of November 2016 the southern area of the fishery was closed under emergency provisions, this was later replaced by an official S11 closure. This area historically accounted for approximately 10% of the total PAU 7 catch. From 1 October 2017 the TAC was reduced a further 10%, but this decision was set aside by agreement following a court injunction so the TAC is still set at 133.63 t for PAU7. However, PAU 7 stakeholders have agreed to a 10% shelving which they have maintained to date. The customary and recreational allowances are still set at 15 t.

On 1 October 2001 it became mandatory to report catch and effort on PCELRs using fine-scale reporting areas (Figure 1) that had been developed by the New Zealand Pāua Management Company for their voluntary logbook programme. Reported landings and TACCs for PAU 7 are shown in Table 2 and Figure 2.

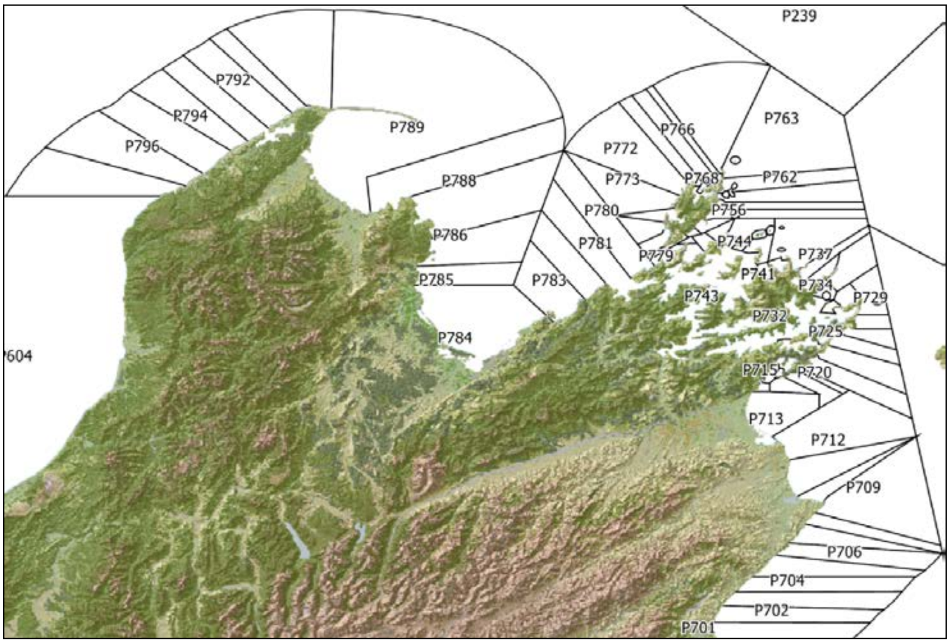


Figure 1: Map of fine scale statistical reporting areas for PAU 7.

Table 2: Reported landings and TACC in PAU 7 from 1983–84 to the present. The last column shows the TACC after shelving has been accounted for.

Year	Landings (kg)	TACC (t)	Shelving	Year	Landings (t)	TACC (t)	Shelving
1974–75	197 910	-	-	1996–97	267 594	267.48	267.48
1975–76	141 880	-	-	1997–98	266 655	267.48	267.48
1976–77	242 730	-	-	1998–99	265 050	267.48	267.48
1977–78	201 170	-	-	1999–00	264 642	267.48	267.48
1978–79	304 570	-	-	2000–01	215 920	267.48	*213.98
1979–80	223 430	-	-	2001–02	187 152	240.73	240.73
1980–81	490 000	-	-	2002–03	187 222	187.24	187.24
1981–82	370 000	-	-	2003–04	159 551	187.24	*159.15
1982–83	400 000	-	-	2004–05	166 940	187.24	*159.15
1983–84	330 000	-	-	2005–06	183 363	187.24	*159.15
1984–85	230 000	-	-	2006–07	176 052	187.24	*159.15
1985–86	236 090	-	-	2007–08	186 845	187.24	187.24
1986–87	242 180	250		2008–09	186 846	187.24	187.24
1987–88	255 944	250		2009–10	187 022	187.24	187.24
1988–89	246 029	250		2010–11	187 240	187.24	187.24
1989–90	267 052	267.48		2011–12	186 980	187.24	187.24
1990–91	273 253	267.48		2012–13	149 755	187.24	*149.80
1991–92	268 309	267.48	267.48	2013–14	145 523	187.24	*149.80
1992–93	264 802	267.48	267.48	2014–15	133 584	187.24	*134.80
1993–94	255 472	267.48	267.48	2015–16	138 790	187.24	187.24
1994–95	247.108	267.48	267.48	2016–17	93.610	93.620	93.620
1995–96	268 742	267.48	267.48	2017–18	81.880	93.620	*84.26
				2018-19	79.697	93.620	*84.26

* Voluntary shelving

1.2 Recreational fisheries

A nationwide panel survey of over 7000 marine fishers who reported their fishing activity over the fishing year from 1 October 2011 to 30 September 2012 was conducted by The National Research Bureau Ltd in close consultation with Marine Amateur Fishing Working Group (Wynne-Jones et al 2014). The survey is based on an improved survey method developed to address issues and to reduce bias encountered in past surveys. The survey estimated that about 50 534 pāua, or 14.13 t (CV of 34%) were harvested by recreational fishers in PAU 7 for 2011–12. For this assessment, the SFWG agreed to assume that recreational catch was 5 t in 1974 and that it increased linearly to 15 t in 2000 and then remained at 15 t subsequently. In 2017–18, the National Panel Survey was repeated and the estimated recreational catch was 3.02 t (CV of 36%) (Wynne-Jones et al 2019). For further information on recreational fisheries refer to the introductory PAU Working Group Report.

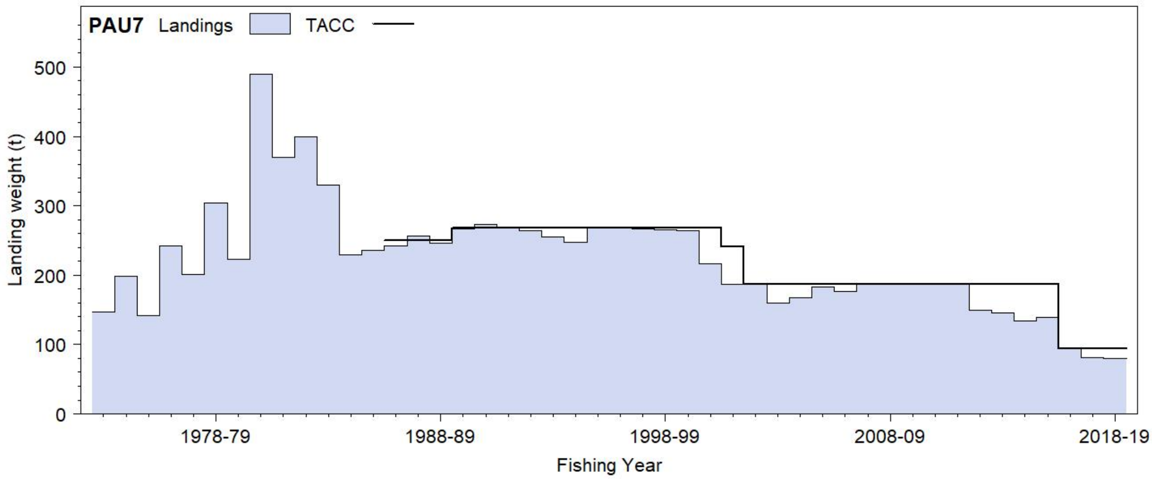


Figure 2: Reported commercial landings and TACC for PAU 7 from 1986–87 to present.

1.3 Customary fisheries

Customary catch was incorporated into the PAU 7 TAC in 2002 as an allowance of 15 t. Estimates of customary catch for PAU 7 are shown in Table 3. These numbers are likely to be an underestimate of customary harvest as only the catch in kilograms and numbers are reported in the table.

Table 3: Fisheries New Zealand records of customary harvest of pāua (reported as weight (kg) and numbers) of pāua in PAU 7 between 2007-08 and 2011-12. No reports since. – no data.

	Weight (kg)		Numbers	
Fishing year	**Approved**	**Harvested**	**Approved**	**Harvested**
2007–08	–	–	1 110	808
2008–09	–	–	1 270	1 014
2009–10	–	–	1 085	936
2010–11	–	–	60	31
2011–12	–	–	20	20

Records of customary catch taken under the South Island Regulations show that about 20 to 1014 pāua were reported to have been collected each year from 2007–08 to 2011–12, with an average of 449 pieces each year. Those numbers were substantially lower than the annual allowances. There has not been any reports since.

For the 2015 stock assessment, the Working Group agreed to assume that customary catch was 4 t in 1974, increasing linearly to 5 t between 1974 and 2000 and then remaining at 5 t subsequently.

For further information on customary fisheries refer to the introductory PAU Plenary chapter.

1.4 Illegal catch

There are no estimates of illegal catch for PAU 7.

For the 2015 stock assessment, the Working Group agreed to assume that illegal catch was 1 t in 1974 and that it increased linearly to 15 t between 1974 and 2000, remaining at 15 t from 2000 to 2005, then decreasing linearly to 7.5 t in 2008, and then remaining at 7.5 subsequently.

For further information on illegal catch refer to the introductory PAU Plenary chapter.

1.5 Other sources of mortality

The Working Group agreed that handling mortality would not be factored into the model. For further information on other sources of mortality refer to the introductory PAU Plenary chapter**.**

On November 16th 2016 a 7.8 magnitude earthquake hit the upper east coast of the South Island, uplifting areas of the coast by as much as 4 m. In the PAU 7 fishery, pāua statistical areas P701 to P710 were impacted to varying degrees by the earthquake. The earthquake caused direct mortality of a large number of juvenile and adult pāua that became exposed to the terrestrial environment with no means of being able to return to the water. More indirect mortality is also expected from the earthquake due to an immediate loss of pre-earthquake pāua habitat that now lies above the new post-earthquake high tide mark.

Impacts of the seabed uplift on pāua populations in PAU 7 will only become clear in the longer term. The immediate loss of area to the fishery, assumed to be good habitat for pāua, is only part of the impact that the seabed uplift associated with the earthquake will have on pāua populations. Juvenile pāua recruit in shallow water, and so the loss of juvenile habitat will have been higher than the loss of adult habitat. This will impact on the number of juvenile pāua growing into the fishery over the coming years. This impact will be difficult to quantify directly, but may affect pāua populations and fisheries over a span of multiple years.

2. BIOLOGY

For further information on pāua biology refer to the introductory PAU Plenary chapter. A summary of biological parameters used in the PAU 7 stock assessment is presented in Table 4.

Table 4: Estimates of biological parameters (*H. iris*).

Fishstock		**Estimate**	**Source**
1. Natural mortality (*M*)			
All		0.02–0.25	Sainsbury (1982)
PAU 7	0.11 (0.10–0.13)	Median (5%–95% CI)	estimated from the base case assessment model
2. Weight = a (length)^b (weight in g, shell length in mm)			
	a = 2.59E–08	b = 3.322	Schiel & Breen (1991)
3. Size at maturity (shell length)			
50% mature	92 mm (91.3–92.7)	Median (5%–95% CI)	estimated by the assessment model
length at 95% mature - 50% mature	8.7 (9.6–13.4) mm	Median (5%–95% CI)	estimated by the assessment model
4. Exponential growth parameters (both sexes combined)			
l^g_{50}	104 mm (98.5–107.1)	Median (5%–95% CI)	estimated by the assessment model: length of animal at 50% maximum growth increment
$l^g_{95\text{-}50}$	30.9 mm (25.9–37.4)	Median (5%–95% CI)	estimated by the model: length of animal between at 50% and 95% maximum growth increment.
$\Delta_{\max}$	30 mm (26.3–36.1)	Median (5%–95% CI)	estimated by the model: maximum growth increment

3. STOCKS AND AREAS

For further information on stocks and areas refer to the introductory PAU Plenary chapter.

4. STOCK ASSESSMENT

The stock assessment is implemented as a length-based Bayesian estimation model, with point estimates of parameters based on the mode of the joint posterior distribution, and uncertainty of model estimates investigated using the marginal posterior distributions generated from Markov chain-Monte Carlo simulations. The 2015 assessment was restricted to Statistical Areas 017 and 038, which includes approximately 85–95% of the catch over the past 10 years**.**

4.1 Estimates of fishery parameters and abundance indices

Parameters estimated in the assessment model and their assumed Bayesian priors are summarised in Table 5.

4.1.1 Relative abundance estimates from standardised CPUE analyses

The 2015 stock assessment used two sets of standardised CPUE indices: one based on CELR data covering 1990–2001, and another based on PCELR data covering 2002–2015. For both series, standardised CPUE analyses were carried out using Generalised Linear Models (GLMs). A stepwise procedure was used to select predictor variables, with variables entering the model in the order that gave the maximum decrease in the residual deviance. Predictor variables were accepted in the model only if they explained at least 1% of the deviance.

For both the CELR and PCELR data, the Fisher Identification Number (FIN) was used in the standardisations instead of vessel, because the FIN is associated with a permit holder who may employ a suite of grouped vessels, which implies that there could be linkage in the catch rates among vessels operated under a single FIN. FIN codes were used to select a core group of fishers from the CELR data, with the requirement to qualify for the core fisher group that there be a minimum of 15 records per year for a minimum of 3years. For the PCELR data the FIN was also used to select a core group of fishers, with the requirement that there be a minimum of 20 records per year for a minimum of 8 years. For both periods, over 80% of catches were retained.

Table 5: A summary of estimated model parameters, lower bound, upper bound, type of prior, (*U*, uniform; *N*, normal; *LN* = lognormal), mean and CV of the prior.

Parameter	Definition	Phase	Prior	μ	CV	Lower	Upper
ln(*R0*)	Natural log of base recruitment	1	U	–	–	5	50
M	Instantaneous rate of natural mortality	3	LN	0.1	0.1	0.01	0.5
Δ_{max}	Maximum growth increment	2	U	–	–	1	50
l^g_{50}	length at 50% maximum growth	2	U	–	–	0.01	150
l^g_{95-50}	length between 50% and 95% maximum growth	2	U	–	–	0.01	150
α	parameter that defines the variance of growth increment	2	U	–	–	0.001	5
β	parameter that defines the variance of growth increment		U	–	–	0.001	5
$Ln(q^I)$	Catchability coefficient of CPUE	1	U	–	–	-30	0
$Ln(q^J)$	Catchability coefficient of PCPUE	1	U	–	–	-30	0
L_{50}	Length at which maturity is 50%	1	U	–	–	70	145
L_{95-50}	Interval between L50 and L95	1	U	–	–	1	50
T_{50}	Length at which Fighting Bay length frequency selectivity is 50%	2	U	–	–	70	125
T_{95-50}	Difference between T50 and T95	2	U	–	–	0.001	50
D_{50}	Length at which commercial diver selectivity is 50%	2	U	–	–	70	145
D_{95-50}	Difference between D_{50} and D_{95}	2	U	–	–	0.01	50
ε	Vector of annual recruitment deviations from 1977 to 2013	1	N	0	0.4	-2.3	2.3
D_s	Change in commercial diver selectivity for one unit of change of MHS	1	U	–	–	0.01	10

The observational data were:

1. A standardised CPUE series covering 1983–2001 based on FSU/CELR data.
2. A standardised CPUE series covering 2002–2015 based on PCELR data.
3. A length frequency dataset from the Fighting Bay fish-down experiment (FBLF).
4. A commercial catch sampling length frequency series (CSLF).
5. Tag-recapture length increment data.
6. Maturity at length data

For the CELR data there is ambiguity in what is recorded for estimated daily fishing duration: either incorrectly recorded as hours *per diver*, or correctly as total hours *for all* divers. For PAU 7, fishing duration appeared to have been predominantly recorded as hours per diver. The standardisation was therefore restricted to records where fishing duration ≤ 10 hours. This subset of data was used for the CELR standardisation using estimated daily catch, and effort as fishing duration.

For the PCELR data the unit of catch was diver catch, with effort as diver duration.

For the CELR data, year was forced into the model and other predictor variables offered to the model were FIN and fishing duration (as a cubic polynomial). For the PCELR data, fishing year was forced into the model and variables offered to the model were month, diver key, FIN statistical area, diver duration (third degree polynomial), and diving conditions.

The standardised CELR index shows a decline from the early 1990s to 2001. The standardised PCELR index shows an increase from 2002 to 2008 with an overall slow decline since then (Figure 3).

4.1.2 Relative abundance estimates from research diver surveys

The relative abundance of pāua in PAU 7 was also estimated from a number of independent research diver surveys (RDSI) undertaken in various years between 1992 and 2005. Concerns about the reliability of these data to estimate relative abundance instigated reviews in 2009 (Cordue 2009) and 2010 (Haist 2010). The reviews assessed i) the reliability of the research diver survey index as a proxy for abundance and ii) whether the RDSI, when used in the pāua stock assessment models, results in model outputs that adequately reflect the status of the stocks. Both reviews suggested that outputs from pāua stock assessments using the RDSI should be treated with caution. For a summary of the conclusions from the reviews refer to the introductory PAU Plenary chapter.

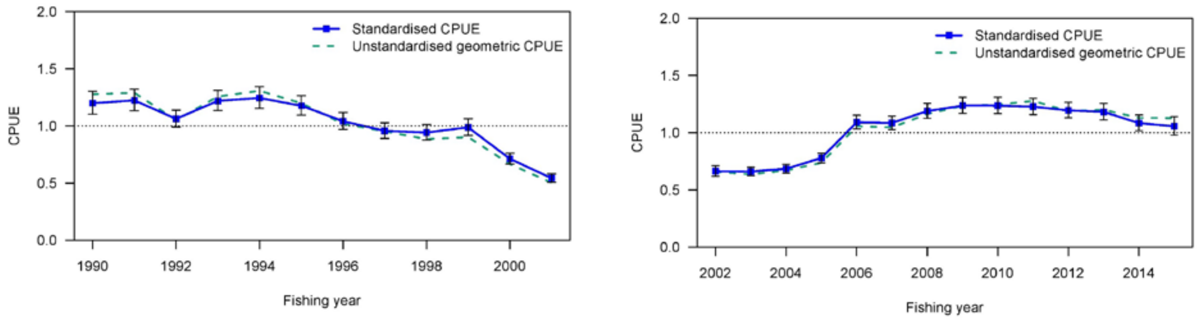


Figure 3: The standardised CPUE indices with 95% confidence intervals for the early CELR series (left) and the recent PCELR series (right).

4.2 Stock assessment methods

The 2015 PAU 7 stock assessment used the length-based model first used in 1999 for PAU 5B (Breen et al 2000) and revised for subsequent assessments in PAU 7 (Breen et al 2001, Breen & Kim 2003, 2005, McKenzie & Smith 2009b, Fu 2012). The model was described in Breen et al (2003). The assessment also addressed a number of recommendations made by the pāua review workshop held in Wellington in March 2015 (Butterworth et al 2015)

The model structure assumes a single sex population residing in a single homogeneous area, with length classes from 70 mm to 170 mm, in groups of 2 mm. Growth is length-based, without reference to age, mediated through a growth transition matrix that describes the probability of each length class changing at each time step. Pāua enter the partition following recruitment and are removed by natural mortality and fishing mortality. The assessment addresses only Areas 017 and 038 within PAU 7. These areas have supported over 90% of the catch until recently, and all of the available data originate from these two areas, but the relationship between this subset of PAU 7 and the remainder of PAU 7 is uncertain.

The model simulates the population dynamics from 1965 to 2015. Catches were available for 1974–2015, and were assumed to increase linearly between 1965 and 1973 from 0 to the 1974 catch level. Catches included commercial, recreational, customary, and illegal catch, and all catches occurred within the same time step.

Recruitment was assumed to take place at the beginning of the annual cycle, and length at recruitment was defined by a uniform distribution with a range between 70 and 80 mm. The stock-recruitment relationship is unknown for pāua. A relationship may exist on small scales, but not be apparent when large-scale data are modelled (Breen et al 2003). No explicit stock-recruitment relationship was modelled in previous assessments; however, the SFWG agreed to use a Beverton-Holt stock-recruitment relationship with steepness (h) of 0.75 for this assessment.

Maturity is not required in the population partition. The model estimated proportions mature with the inclusion of length-at-maturity data. Growth and natural mortalities were also estimated within the model.

The models used two selectivities: the commercial fishing selectivity and the Fighting Bay catch sample selectivity, both assumed to follow a logistic curve and to reach an asymptote.

The assessment was conducted in several steps. First, the model was fitted to the data with arbitrary weights on the various data sets. The weights were then iteratively adjusted to produce balanced residuals among the datasets where the standardised deviation of the normalised residuals was close to one for each dataset. The fit obtained is the mode of the joint posterior distribution of parameters (MPD). Next, from the resulting fit, Markov chain-Monte Carlo (MCMC) simulations were made to obtain a large set of samples from the joint posterior distribution. From this set of samples, forward projections were made with a set of agreed indicators obtained. Sensitivity trials were explored by comparing MPD fits made with alternative model assumptions.

A base case model (1.0) was chosen by the Shellfish Working Group for the assessment: The base case model is configured such that (a) predicted CPUE is calculated after half of the natural and fishing mortality has occurred; (b) Francis (2011) method was used to determine the weight of CSLF and CPUE; (c) growth was estimated using the inverse-logistic model; (d) tag-recapture observations from the Staircase were excluded; (e) tag-recapture observations were weighted by the catch in each area; (f) the CPUE shape parameter was fixed at 1 assuming a linear relationship between CPUE and abundance. The base case used a lognormal prior on M, with μ_M= 0.1 and σ_M= 0.1. The choice of CV was arbitrary, but generally chosen to be very informative to prevent obtaining unrealistic estimates. A sensitivity run (MCMC 1.4) used a prior (μ_M = 0.15 and σ_M = 0.25) developed from posterior estimates of M from assessments of PAU 5A and PAU 5B, based on the recommendation from the pāua review workshop (Butterworth et al 2015).

The SFWG also suggested the following sensitivity runs: using a smaller CV of 0.05 (model 1.1), or a larger CV of 0.12 (1.2); estimating the CPUE shape parameter assuming a uniform prior bounded between 0.5 and 1.5 (1.3), or fixing it at the lower (1.3a) and upper value (1.3b) respectively; using an alternative prior when estimating natural mortality; including tag-recapture observations from the Staircase (1.5). The base case and sensitivities are summarised in Table 6.

Table 6: Summary descriptions of base case and sensitivity model runs.

Model	Description
1.0	base case, Francis (2011) weighting, inverse logistic, excluded Staircase growth, growth data weighted
1.1	1.0, CV for CPUE2 = 0.5
1.2	1.0, CV for CPUE2 = 1.2
1.3	1.0, estimated CPUE shape parameter with a uniform prior [0.5,1.5]
1.3a	1.0, CPUE shape parameter = 0.5
1.3b	1.0, CPUE shape parameter = 1.5
1.4	1.0, M estimated with a prior developed using information from PAU 5A and PAU 5B.
1.5	1.0, included Staircase growth

The assessment calculates the following quantities from their posterior distributions: the equilibrium spawning stock biomass assuming that recruitment is equal to the average recruitment from the period for which recruitment deviation were estimated (B_0,), the mid-season spawning and recruited biomass for 2015 (B_{2015} and B^r_{2015}) and for the projection period (B_{proj} and B^r_{proj}). This assessment also reports the following fishery indictors:

$B\%B_0$	Current or projected spawning biomass as a percentage of B_0
$B\%B_{msy}$	Current or projected spawning biomass as a percentage of B_{msy}
$\Pr(B_{proj} > B_{msy})$	Probability that projected spawning biomass is greater than B_{msy}
$\Pr(B_{proj} > B_{2015})$	Probability that projected spawning biomass is greater than $B_{current}$
$B\%B^r_0$	Current or projected recruited biomass as a percentage of B^r_0
$B\%B^r_{msy}$	Current or projected recruited biomass as a percentage of B^r_{msy}
$\Pr(B^r_{proj} > B^r_{msy})$	Probability that projected recruit-sized biomass is greater than B^r_{msy}
$\Pr(B^r_{proj} > B^r_{2015})$	Probability that projected recruit-sized biomass is greater than B^r_{2015}
$\Pr(B_{proj} > 40\%B_0)$	Probability that projected spawning biomass is greater than 40% B_0
$\Pr(B_{proj} < 20\%B_0)$	Probability that projected spawning biomass is less than 20% B_0
$\Pr(B_{proj} < 10\%B_0)$	Probability that projected spawning biomass is less than 10% B_0
$\Pr(U_{proj} > U_{40\%B0})$	Probability that projected exploitation rate is greater than $U_{40\%B0}$

Forward projections (2016–2018) were made for the base case with a number of alternative future catch scenarios. Future recruitment deviations were resampled from model estimates either from 2002–2011 (a period with both high and low recruitment), or from 2010–2011 (a period with low recruitment). The total catch used in the projections was 142 717 kg (28% TACC reduction), 131 515 (35% TACC reduction), 123 514 kg (40% shelving), 107 511 kg (50% shelving) and 91 510 kg (60% TACC), and 27 500 kg (100% TACC reduction).

4.2.1 Stock assessment results

Current estimates from the base case suggested that spawning stock population in 2015 ($B_{current}$) was about 18% (16–21%) of the unfished level (B_0), or 69% (16–21%) of B_{msy} (Figure 4, Table 7). Estimated recent recruitment has been below average (recruitment in 2010 and 2011 was the lowest after 2002). The estimated exploitation rate has declined since 2003, and was further reduced after 2012. The exploitation rate in 2015 was estimated to be 0.46 (0.40–0.52).

The model projection made for three years using recruitment re-sampled from a period with both high and low recruitment (2002–2011), suggested that the spawning stock abundance will increase to 22% (16–29%) of B_0 in 2018 if the future catch remains at the current level (corresponding to a 28% TACC shelving), or 24% (18–31%) of B_0 if the future catch is reduced to 50% of the TACC (Figure 5). The projections using recruitment re-sampled from the recent period with low recruitment (2010–2011), suggested that the spawning stock abundance will only increase to 19% (14–25%) of B_0 in 2018 if the future catch remains at the current level, or 21% (16–27%) of B_0 with a 50% TACC reduction (Figure 6). It was extremely unlikely that the stock status will be above the target (40% B_0) in the short term.

The base case model matched very closely with the early CPUE and predicted CPUE indices were all well within the confidence bounds of the observed values. Predicted CPUE declined more than observed values between 2009 and 2013. However, the overall change in relative abundance between 2002 and 2015 is similar between the predicted and observed values. The standardised residuals show no apparent departure from the model's assumption of normality. Commercial catch length frequencies were well fitted for most years. The mean length of CSLF has increased since 2003, and has remained reasonably stable since 2007, except in 2014. The average fish size in the catch in recent years has been well below those in the early 1990s. The standardised residuals of the fits to CSLF revealed that in general the model predicted a slightly narrower distribution than what was observed in the catch. This might be because the fishery has been fished down to a low level and the chance of sampling pāua of large sizes has reduced. Estimated logistic selectivity was very close to knife-edge around the MLS, with a small increase in 2015. Fits to growth increment and maturity data appeared adequate. The relative weight assigned to tag-recapture observations from Perano and Rununder was about three times more than those from Northern Faces, and as a result, estimated mean growth was higher than if equal weights were assumed. The Fighting Bay length frequency fitted well, suggesting this length distribution was consistent with the estimated growth rates in the model.

Table 7: Summary of the marginal posterior distributions from the MCMC chain from the base case (1.0) and sensitivities. The columns show the medians and the 5th and 95th percentiles. Biomass is in tonnes.

	MCMC 1.0	MCMC 1.1	MCMC 1.2	MCMC 1.3	MCMC 1.4
B_0	4291 (3980–4584)	4296 (3963–4600)	4296 (3968–4610)	4322 (4011–4632)	3784 (3185–4359)
B_{msy}	1133 (1056–1209)	1133 (1051–1212)	1137 (1053–1216)	1137 (1060–1216)	1019 (913–1153)
$B_{current}$	780 (689–888)	763 (689–855)	786 (683–919)	804 (701–938)	821 (723–937)
$B_{current}/B_0$	0.18 (0.16–0.21)	0.18 (0.15–0.21)	0.18 (0.16–0.22)	0.19 (0.16–0.22)	0.22 (0.17–0.28)
$B_{current}/B_{msy}$	0.69 (0.59–0.81)	0.68 (0.58–0.79)	0.69 (0.59–0.83)	0.71 (0.6–0.85)	0.81 (0.65–0.98)
B_{msy}/B_0	0.26 (0.26–0.27)	0.26 (0.26–0.27)	0.26 (0.26–0.27)	0.26 (0.26–0.27)	0.27 (0.26–0.29)
rB_0	3532 (3185–3842)	3543 (3184–3876)	3538 (3179–3872)	3544 (3210–3876)	3019 (2395–3605)
rB_{msy}	544 (438–638)	546 (443–648)	547 (439–649)	539 (442–643)	414 (279–571)
rBcurrent	300 (260–349)	297 (265–336)	302 (251–364)	314 (265–382)	306 (266–351)
$rB_{current}/rB_0$	0.09 (0.07–0.1)	0.08 (0.07–0.1)	0.09 (0.07–0.11)	0.09 (0.07–0.11)	0.1 (0.08–0.13)
$rB_{current}/rB_{msy}$	0.55 (0.43–0.74)	0.55 (0.43–0.71)	0.55 (0.42–0.76)	0.59 (0.44–0.79)	0.74 (0.51–1.15)
rB_{msy}/rB_0	0.15 (0.14–0.17)	0.15 (0.14–0.17)	0.15 (0.14–0.17)	0.15 (0.14–0.17)	0.14 (0.11–0.16)
MSY	207 (202–214)	207 (201–213)	208 (202–215)	207 (201–214)	217 (206–234)
U_{msy}	0.37 (0.31–0.47)	0.37 (0.3–0.46)	0.37 (0.31–0.47)	0.37 (0.31–0.47)	0.51 (0.35–0.79)
$U_{\%40B0}$	0.19 (0.16–0.23)	0.18 (0.16–0.22)	0.19 (0.16–0.23)	0.19 (0.16–0.22)	0.25 (0.18–0.4)
$U_{current}$	0.46 (0.4–0.52)	0.46 (0.41–0.5)	0.46 (0.38–0.54)	0.44 (0.36–0.51)	0.46 (0.41–0.52)

Table 8: Summary of key indicators for projected biomass in 2018 from the projection for the base case MCMC with 28%, 35%, 40%, 50%, 60%, and 100% TACC reduction. The columns show the medians and the 5th and 95th percentiles. Biomass is in tonnes.

	28% reduction	35% reduction	40% reduction	50% reduction	60% reduction	100% reduction
B_{2018}	943 (711–1227)	971 (739–1255)	990 (759–1274)	1030 (799–1314)	1068 (8381353)	1225 (996–1508)
B_{2018}/B_0	0.22 (0.16–0.29)	0.23 (0.17–0.30)	0.23 (0.17–0.30)	0.24 (0.18–0.31)	0.25 (0.19–0.32)	0.29 (0.23–0.36)
B_{2018}/B_{msy}	0.83 (0.61–1.11)	0.86 (0.64–1.13)	0.88 (0.65–1.15)	0.91 (0.69–1.18)	0.95 (0.72–1.22)	1.08 (0.86–1.36)
Pr (B_{2018}>Bmsy)	0.10	0.14	0.17	0.24	0.3268	0.7546
Pr (B_{2018}>B_{2015})	0.94	0.97	0.98	0.99	0.9972	1
Pr (B_{2018}>40%B0)	0.00	0.00	0.00	0.00	0.0002	0.003
Pr (B_{2018}<20%B0)	0.26	0.19	0.15	0.09	0.05	0.0026
Pr (B_{2018}<10%B0)	0.00	0.00	0.00	0.00	0	0

Changes in stock size in response to fishing pressure over time are shown in Figure 7. This was done by plotting the annual spawning biomass and exploitation rate as a ratio of a reference value from 1965 to 2015. Each point on the trajectory represents the estimated annual stock status: the value on the x axis is the mid-season spawning stock biomass as a ratio of B_0, the value on the y axis is the corresponding exploitation rate as a ratio of $U_{40\%B0}$ for that year. The trajectory started in 1965 when the SSB is close to B_0 and the exploitation rate is close to 0. The model indicated an early phase of the fishery where the exploitation rates were below $U_{40\%B0}$ and the SSBs were above 40% B_0 and a development phase where the exploitation rates increased and the SSBs decreased in relation to the target. The current exploitation rate is about twice of $U_{40\%B0}$ and the current spawning stock biomass is just below 20% B_0.

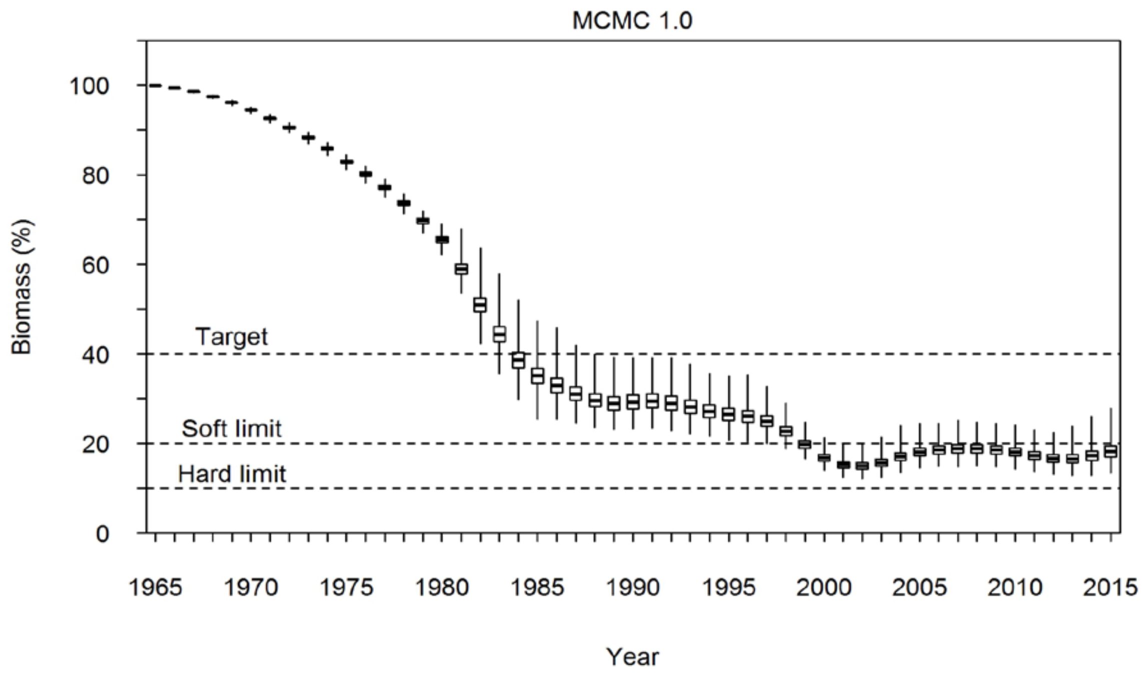


Figure 4: Posterior distribution of spawning stock biomass as a percentage of virgin level from MCMC 1.0. The box shows the median of the posterior distribution (horizontal bar), the 25th and 75th percentiles (box), with the whiskers representing the full range of the distribution.

4.3 Other factors

The stock assessment model assumed homogeneity in recruitment, and that natural mortality does not vary by size or year, and that growth has the same mean and variance throughout the entire area. However, it is known that pāua fisheries are spatially variable and that apparent growth and maturity in pāua populations can vary over very short distances. Variation in growth is addressed to some extent by having a stochastic growth transition matrix based on tagging data collected from a range of different locations. Similarly, the length frequency data are integrated across samples from many places. The effect of this integration across local areas is likely to make model results optimistic.

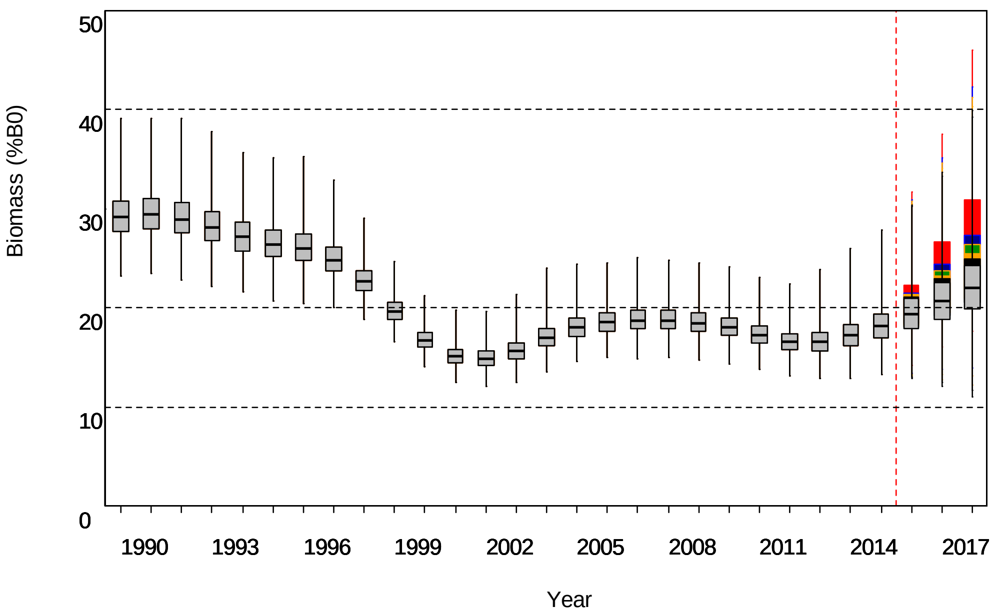


Figure 5: Posterior distributions of projected spawning stock biomass 2016–2018 for the base case (MCMC 1.0) with future recruitment resampled from model estimates 2002–2011 under six catch scenarios: 28% TACC reduction (gray), 35% TACC reduction (black), 40% TACC reduction (orange), 50% TACC reduction (green), 60% TACC reduction (blue), and 100% TACC reduction shelving (red). The box shows the median of the posterior distribution (horizontal bar), the 25th and 75th percentiles (box), with the whiskers representing the full range of the distribution.

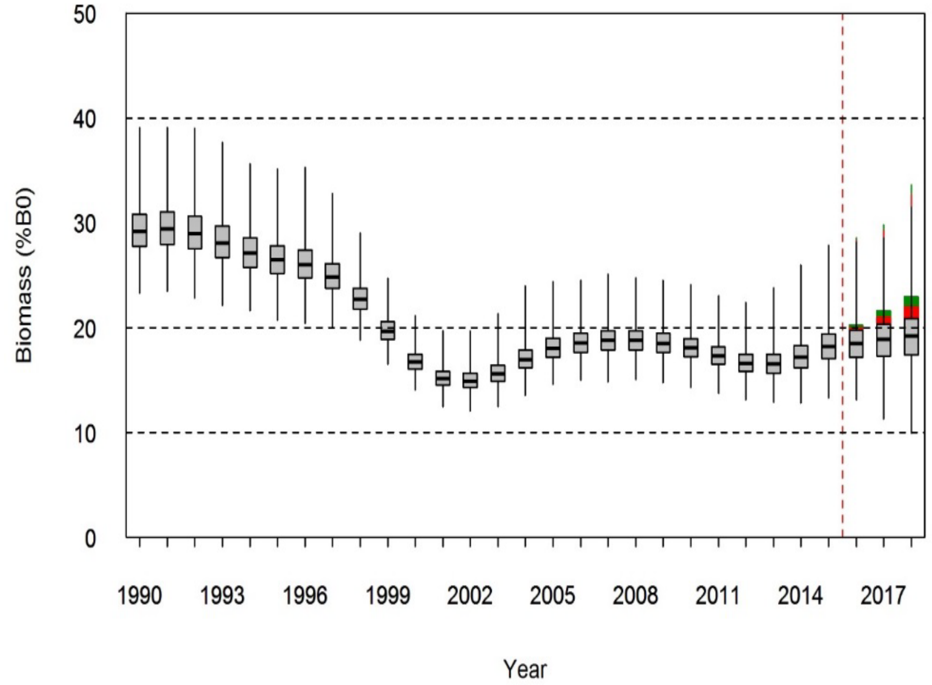


Figure 6: Posterior distributions of projected spawning stock biomass 2016–2018 for the base case (MCMC 1.0) with future recruitment resampled from model estimates 2010–2011 under three catch scenarios: 28% TACC reduction (gray), 40% TACC reduction (red), 50% TACC reduction (green), 60%. The box shows the median of the posterior distribution (horizontal bar), the 25th and 75th percentiles (box), with the whiskers representing the full range of the distribution.

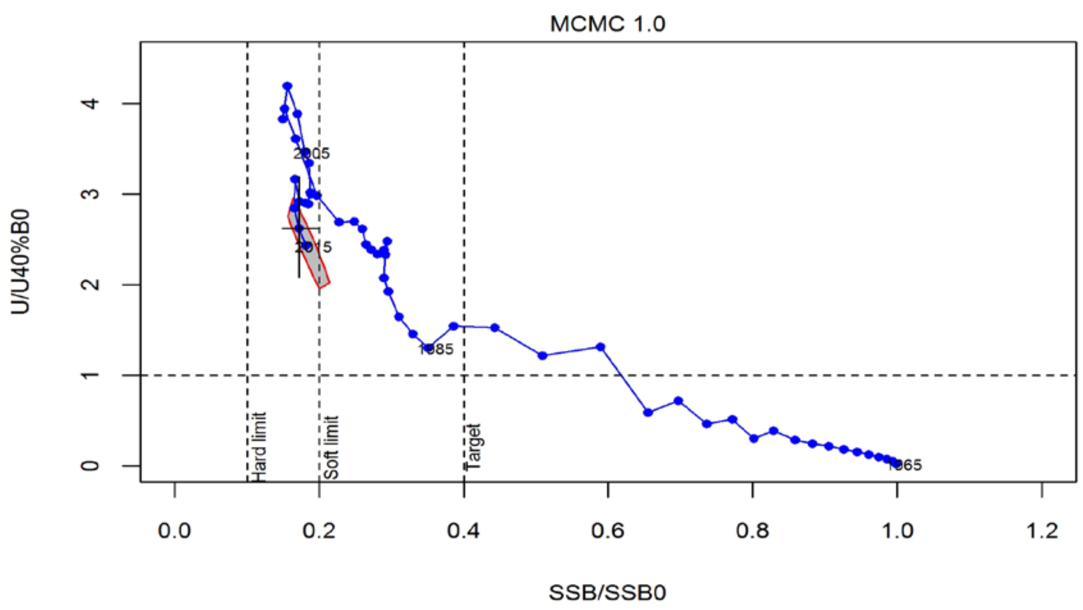


Figure 7: Trajectory of exploitation rate as a ratio of $U_{\%40B0}$ and spawning stock biomass as a ratio of B_0, from the start of assessment period 1965 to 2015 for MCMC 1.0 (base case). The vertical lines at 10%, 20% and 40% B_0 represent the soft limit, the hard limit, and the target. Estimates are based on MCMC median and the 2015 90% marginal CI is shown by the cross line, and joint CI is shown by the grey area.

For instance, if some local stocks are fished very hard and others not fished, local recruitment failure can result due to the limited dispersal range of this species. Recruitment failure is a common observation in overseas abalone fisheries. Fishing may also cause spatial contraction of populations (e.g., Shepherd & Partington 1995), and some populations appear to become relatively unproductive after initial fishing (Gorfine & Dixon 2000). If this happens, the assessment will overestimate productivity in the population as a whole. It is also possible that good recruitments estimated by the model might have been the result of serial depletion.

CPUE provides information on changes in relative abundance. However, CPUE is generally considered to be a poor index of stock abundance for pāua, due to divers' ability to maintain catch rates by moving from area to area despite a decreasing biomass (hyperstability). Breen & Kim (2003) argued that standardised CPUE might be able to relate to the changes of abundance in a fully exploited fishery such as PAU 7, and a large decline in the CPUE is most likely to reflect a decline in the fishery. Analysis of CPUE currently relies on Pāua Catch Effort Landing Return (PCELR) forms, which record daily fishing time and catch per diver on a relatively large spatial scale. These data will likely remain the basis for stock assessments and formal management in the medium term.

Since October 2010, a dive-logger data collection program has been initiated to achieve fine-scale monitoring of pāua fisheries (Neubauer et al 2014, Neubauer & Abraham 2014). The use of the data loggers by pāua divers and ACE holders has been steadily increasing over the last three years. Using fishing data logged at fine spatial and temporal scales can substantially improve effort calculations and the resulting CPUE indices and allow complex metrics such as spatial CPUE to be developed (Neubauer & Abraham 2014). Data from the loggers have been analysed to provide comprehensive descriptions of the spatial extent of the fisheries and insight on relationships between diver behavior, CPUE, and changes in abundance on various spatial and temporal scale (Neubauer et al 2014, Neubauer & Abraham 2014, Neubauer 2015). However the data-loggers can potentially change how the divers operate such that they may become more effective in their fishing operations (the divers become capable of avoiding areas that have been heavily fished or that have relatively low CPUE without them having to go there to discover this), therefore changing the meaning of diver CPUE (Butterworth 2015).

Commercial catch length frequencies provide information on changes in population structure under fishing pressure. However, if serial depletion has occurred and fishers have moved from area to area, samples from the commercial catch may not correctly represent the population of the entire stock. For PAU 7, there has been a long time-series of commercial catch sampling and the spatial coverage of the available samples is generally considered to be adequate throughout the years.

4.4 Future research needs

- Increased tagging to obtain better fine scale growth information.
- Consider including more of the east coast in the assessment, noting that this would need to be considered as a separate fishery due to differences in size limits.
- Examine the possibility of spatial patterns in length and growth.

5. STATUS OF THE STOCKS

Stock Structure Assumptions

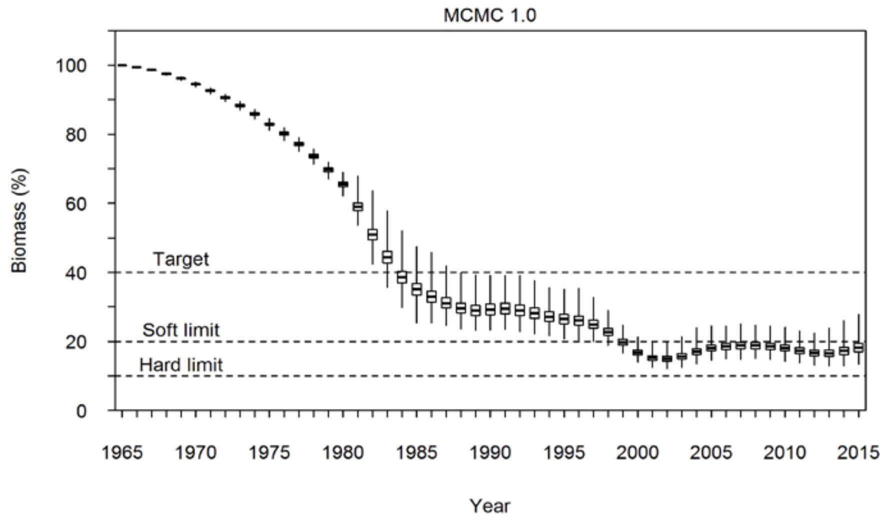
The 2015 assessment was conducted for Statistical Areas 017 and 038 only, but these include most (more than 90%) of the recent catch.

- **PAU 7-** *Haliotis iris*

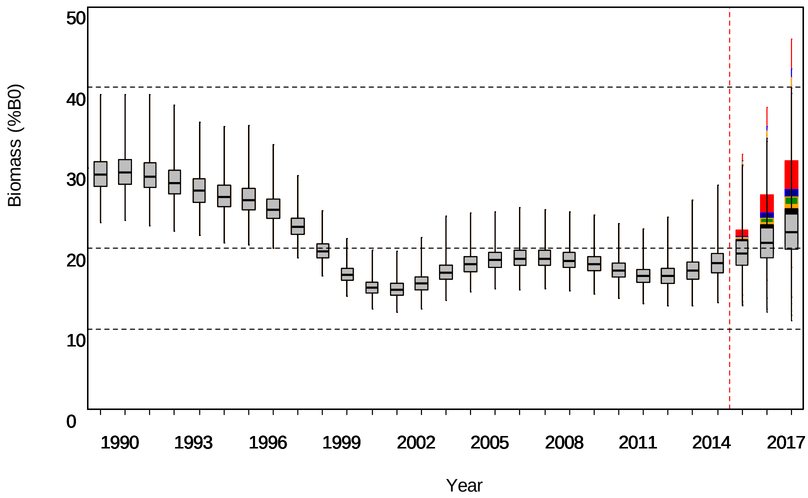
Stock Status	
Year of Most Recent Assessment	2015
Assessment Runs Presented	Base case MCMC
Reference Points	Interim Target: 40% B_0 Soft Limit: 20% B_0 Hard Limit: 10% B_0 Overfishing threshold: $U_{40\%B0}$
Status in relation to Target	Spawning stock biomass was estimated to be 18% B_0 and is Very Unlikely (< 10%) to be at or above the target

Status in relation to Limits	Spawning stock biomass was estimated to be 18% B_0, and is About as Likely as Not (40–60%) to be below the soft limit and Unlikely (< 40%) to be below the hard limit
Status in relation to Overfishing	In 2014–15 the fishing intensity was Very Likely (> 90%) to be above the overfishing threshold

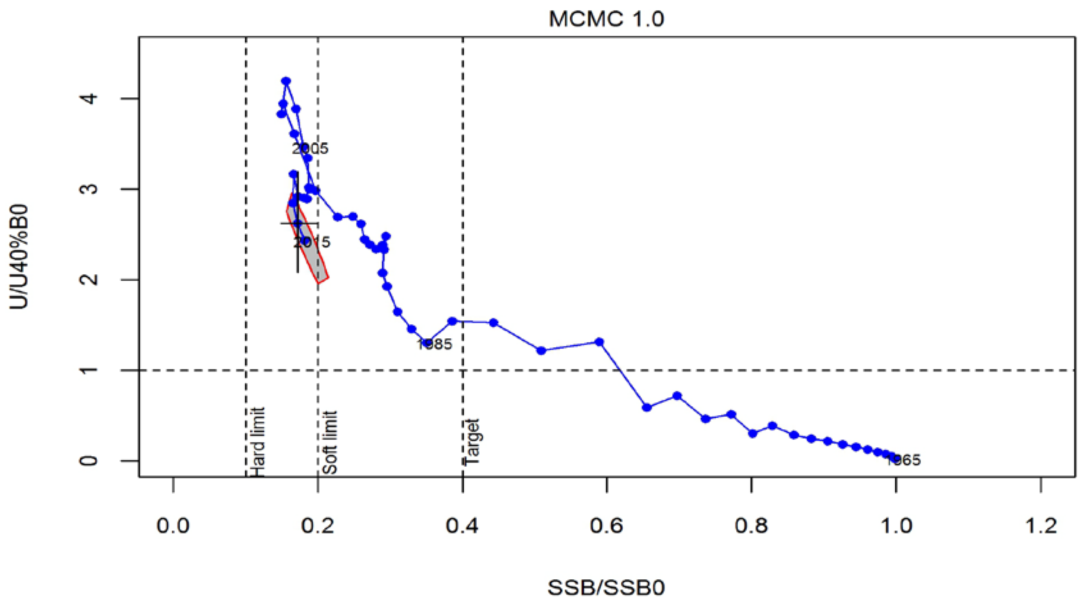
Historical Stock Status Trajectory and Current Status



Posterior distribution of spawning stock biomass as a percentage of virgin level from MCMC 1.0. The box shows the median of the posterior distribution (horizontal bar), the 25th and 75th percentiles (box), with the whiskers representing the full range of the distribution.



Posterior distributions of projected spawning stock biomass 2016–2018 for the base case (MCMC 1.0) with future recruitment resampled from model estimates 2002–2011 under six catch scenarios: 28% TACC reduction (gray), 35% TACC reduction (black), 40% TACC reduction (orange), 50% TACC reduction (green), 60% TACC reduction (blue), and 100% TACC reduction shelving (red). The box shows the median of the posterior distribution (horizontal bar), the 25th and 75th percentiles (box), with the whiskers representing the full range of the distribution.



Trajectory of exploitation rate as a ratio of $U_{\%40B0}$ and spawning stock biomass as a ratio of B_0, from the start of assessment period 1965 to 2015 for MCMC 1.0 (base case). The vertical lines at 10%, 20% and 40% B_0 represent the soft limit, the hard limit, and the target. Estimates are based on MCMC median and the 2015 90% marginal CI is shown by the cross line, and joint CI is shown by the grey area.

Fishery and Stock Trends	
Recent Trend in Biomass or Proxy	Biomass reached its lowest point in 2002–03. It has since fluctuated at or just below the soft limit.
Recent Trend in Fishing Intensity or Proxy	Fishing intensity peaked in 2003 but has subsequently declined.
Other Abundance Indices	-
Trends in Other Relevant Indicators or Variables	-
Projections and Prognosis	
Stock Projections or Prognosis	Three year projections indicate that spawning biomass will increase slightly, to varying degrees, under different levels of catch when future recruitment is resampled from 2002–2011 but it is Very Unlikely (< 10%) to be at or above the target by this time.
Probability of Current Catch or TACC causing Biomass to remain below or to decline below Limits	Soft Limit: About as Likely as Not (40–60%) Hard Limit: Unlikely (< 40%)
Probability of Current Catch or TACC causing Overfishing to continue or commence	Very Likely (> 90%)

Assessment Methodology & Evaluation		
Assessment Type	Full quantitative stock assessment	
Assessment Method	Length based Bayesian model	
Assessment Dates	Latest assessment: 2015	Next assessment: 2018
Overall assessment quality rank	1 – High Quality	

Qualifying Comments
-

Fishery Interactions
-

6. FOR FURTHER INFORMATION

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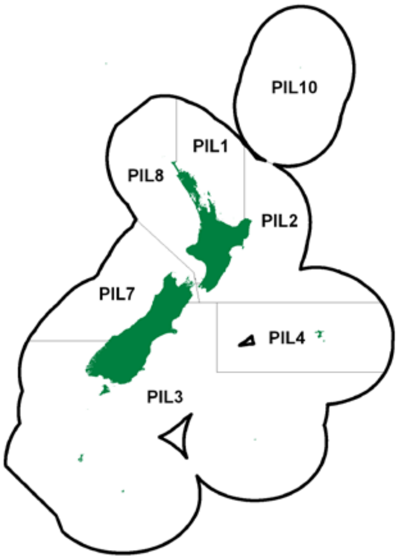
PILCHARD (PIL)

(*Sardinops sagax*)
Mohimohi



1. FISHERY SUMMARY

Pilchards were introduced into the QMS in October 2002 with allowances, TACCs and TACs as shown in Table 1.

Table 1: Recreational and Customary non-commercial allowances, TACCs and TACs by Fishstock.

Fishstock	Recreational Allowance	Customary Non-commercial Allowance	TACC	TAC
PIL 1	20	10	2 000	2 030
PIL 2	10	5	200	215
PIL 3	5	2	60	67
PIL 4	3	2	10	15
PIL 7	10	5	150	165
PIL 8	10	5	65	80
PIL 10	0	0	0	0

1.1 Commercial fisheries

Pilchards occur around most of New Zealand, however, commercial fisheries have only developed in north-eastern waters (east Northland to Bay of Plenty), and in Tasman Bay and Marlborough Sounds at the north of the South Island. Historical estimated and recent reported pilchard landings and TACCs are shown in Tables 2, 3, and 4, while Figure 1 shows the historical and recent landings and TACC values for the main pilchard stocks.

The first recorded commercial landings of pilchards were in 1931 (Table 2), but a minor fishery existed before this. Informal sales, mainly as bait, or as food for zoos and public aquariums, were unreported. A fishery for pilchards developed in the Marlborough Sounds in 1939 and operated through the war years providing canned fish for the armed forces. Landings reached over 400 t in 1942, but the fishery was unsuccessful for a variety of reasons and ceased in 1950. Between 1950 and 1990 landings were generally less than 20 t, intermittently reaching 70–80 t.

From 1990–91 the northeastern fishery was developed by vessels using both lampara nets and purse seines (Table 4). Lampara netting was the main method in the first couple of years, and continued at a low level through the 1990s. From 1993–94 onwards, purse seining became the dominant method. A diminishing catch (less than 10 t annually) was caught by beach seine. Almost all the pilchard catch (particularly in the northeastern fishery) is targeted. A small catch (less than 10 t annually), has been recorded as a bycatch of jack mackerel targeting.

Table 2: Reported landings (t) for the main QMAs from 1931 to 1990.

Year	PIL 1	PIL 2	PIL 3	PIL 4	Year	PIL 1	PIL 2	PIL 3	PIL 4
1931–32	5	0	0	0	1957	2	0	0	0
1932–33	4	0	0	0	1958	8	0	0	0
1933–34	2	0	0	0	1959	3	2	0	0
1934–35	0	0	0	0	1960	3	3	0	0
1935–36	0	0	0	0	1961	0	8	0	0
1936–37	0	0	0	0	1962	0	1	0	0
1937–38	0	0	0	0	1963	0	0	0	0
1938–39	0	0	0	0	1964	0	0	0	0
1939–40	0	5	0	0	1965	2	0	0	0
1940–41	3	41	0	0	1966	3	0	0	0
1941–42	15	73	0	0	1967	8	0	0	0
1942–43	0	69	0	0	1968	8	2	0	0
1943–44	0	9	0	0	1969	3	4	0	0
1944	0	0	0	0	1970	1	0	1	0
1945	0	0	0	0	1971	1	0	0	0
1946	0	0	0	0	1972	0	0	8	0
1947	0	0	0	0	1973	0	67	0	0
1948	0	0	0	0	1974	18	1	0	0
1949	0	0	0	0	1975	2	0	0	0
1950	0	0	0	0	1976	6	0	0	0
1951	0	0	0	0	1977	20	0	0	0
1952	0	0	0	0	1978	5	0	0	0
1953	0	0	0	0	1979	1	0	2	0
1954	0	0	0	0	1980	1	16	0	0
1955	0	0	0	0	1981	0	8	0	0
1956	4	0	0	0	1982	0	16	0	0

Year	PIL 7	PIL8	Year	PIL 7	PIL8
1931–32	0	0	1957	0	0
1932–33	0	0	1958	0	0
1933–34	0	0	1959	2	0
1934–35	0	0	1960	3	0
1935–36	0	0	1961	8	0
1936–37	0	0	1962	1	0
1937–38	0	0	1963	0	0
1938–39	0	0	1964	0	0
1939–40	5	0	1965	1	0
1940–41	49	0	1966	0	0
1941–42	79	0	1967	0	1
1942–43	69	0	1968	0	0
1943–44	9	0	1969	7	0
1944	217	0	1970	81	0
1945	74	0	1971	0	0
1946	61	0	1972	0	0
1947	5	0	1973	3	0
1948	46	0	1974	0	0
1949	11	0	1975	0	0
1950	0	0	1976	0	0
1951	0	0	1977	0	0
1952	9	0	1978	0	0
1953	0	0	1979	0	0
1954	0	0	1980	24	0
1955	0	0	1981	8	0
1956	0	0	1982	16	0

Notes:
1. The 1931–1943 years are April–March but from 1944 onwards are calendar years.
2. Data up to 1985 are from fishing returns: Data from 1986 to 1990 are from Quota Management Reports.
3. Data for the period 1931 to 1982 are based on reported landings by harbour and are likely to be underestimated as a result of under-reporting and discarding practices. Data includes both foreign and domestic landings.

Total annual landings increased steadily from 1990 as the fishery developed in northeastern waters, reaching over 1200 t in 1999–00, and almost 1500 t in 2000–01. Total commercial landings declined consistently after 2003–04, largely influenced by catches from PIL 1, and since 2010–11 have been between 221 and 624t. Landings in PIL 1 have been below the TACC since this stock was introduced to the QMS in 2002, declining to an average of 230 t in 2013-14 to 2017-18. Landings in PIL 8 have fluctuated between 12 t and 162 t since this stock was introduced to the QMS. The sudden increase in catches in PIL 8 from 2000–2001 to 2005–06 was thought to be in part the result of previously unreported catches now being reported due to the species being introduced to the QMS. After 2006 landings in PIL 8 exceeded the TACC in 2007-08, 2013-14 and 2017-18, with landings in 2017-18 exceeding the TACC by 97 t.

Table 3: Reported total New Zealand landings (t) of pilchard from 1931 to 1990.

Year	Landings	Year	Landings	Year	Landings	Year	Landings	Year	Landings	Year	Landings
1931	5	1941	168	1951	0	1961	17	1971	1	1981	17
1932	4	1942	418	1952	9	1962	2	1972	8	1982	32
1933	2	1943	219	1953	0	1963	0	1973	70	1983	-
1934	0	1944	218	1954	0	1964	1	1974	19	1984	-
1935	0	1945	74	1955	0	1965	3	1975	2	1975	49
1936	0	1946	61	1956	4	1966	3	1976	6	1986	29
1937	0	1947	5	1957	2	1967	9	1977	20	1987	70
1938	0	1948	46	1958	8	1968	10	1978	6	1988	6
1939	10	1949	11	1959	7	1969	15	1979	4	1989	1
1940	93	1950	0	1960	8	1970	83	1980	41	1990	2

Source: Annual reports on fisheries and subsequent MAF data.

A 2000 t annual Commercial Catch Limit (CCL) was introduced for FMA 1 from 01 October 2000. The CCL was subject to a logbook programme, a catch spreading arrangement and the avoidance of areas of particular importance to non-commercial fishers. The CCL was superseded when the PIL 1 stock was introduced to the QMS with a TACC of 2000 t on 1st October 2002.

Table 4: Reported landings (t) of pilchard by Fishstock from 1990–91 to 2016–17.

QMA	PIL 1		PIL 2		PIL 3		PIL 7		PIL 8		Total
	Landings	TACC	Landings	TACC	Landings	TACC	Landings	TACC	Landings	TACC	Landings
1990–91	15	-	0	-	0	-	9	-	< 1	-	25
1991–92	59	-	0	-	0	-	< 1	-	0	-	59
1992–93	163	-	2	-	0	-	0	-	0	-	164
1993–94	258	-	0	-	0	-	0	-	1	-	259
1994–95	317	-	0	-	0	-	< 1	-	< 1	-	317
1995–96	168	-	< 1	-	0	-	2	-	0	-	170
1996–97	419	-	0	-	0	-	2	-	< 1	-	421
1997–98	440	-	0	-	0	-	1	-	0	-	447
1998–99	785	-	0	-	< 1	-	2	-	1	-	788
1999–00	1 227	-	0	-	0	-	4	-	< 1	-	1 231
2000–01	1 290	-	0	-	0	-	12	-	188	-	1 491
2001–02	574	-	0	-	0	-	93	-	129	-	796
2002–03	792	2 000	0	200	0	60	8	150	153	65	953
2003–04	1 284	2 000	0	200	< 1	60	1	150	34	65	1 320
2004–05	853	2 000	0	200	< 1	60	< 1	150	106	65	959
2005–06	892	2 000	< 1	200	< 1	60	2	150	116	65	1 010
2006–07	808	2 000	0	200	0	60	11	150	45	65	864
2007–08	635	2 000	0	200	0	60	10	150	71	65	716
2008–09	644	2 000	< 1	200	0	60	3	150	23	65	670
2009–10	599	2 000	0	200	4	60	10	150	54	65	667
2010–11	319	2 000	< 1	200	<1	60	2	150	12	65	333
2011–12	178	2 000	0	200	< 1	60	< 1	150	42	65	221
2012–13	332	2 000	<1	200	0	60	2	150	58	65	391
2013–14	255	2 000	<1	200	<1	60	13	150	97	65	365
2014–15	210	2 000	<1	200	<1	60	6	150	19	65	235
2015–16	261	2 000	0	200	0	60	19	150	44	65	324
2016–17	226	2 000	0	200	0	60	21	150	37	65	284
2017–18	229	2 000	<1	200	0	60	233	150	162	65	624
2018–19	203	2 000	<1	200	0	60	78	150	63	65	343

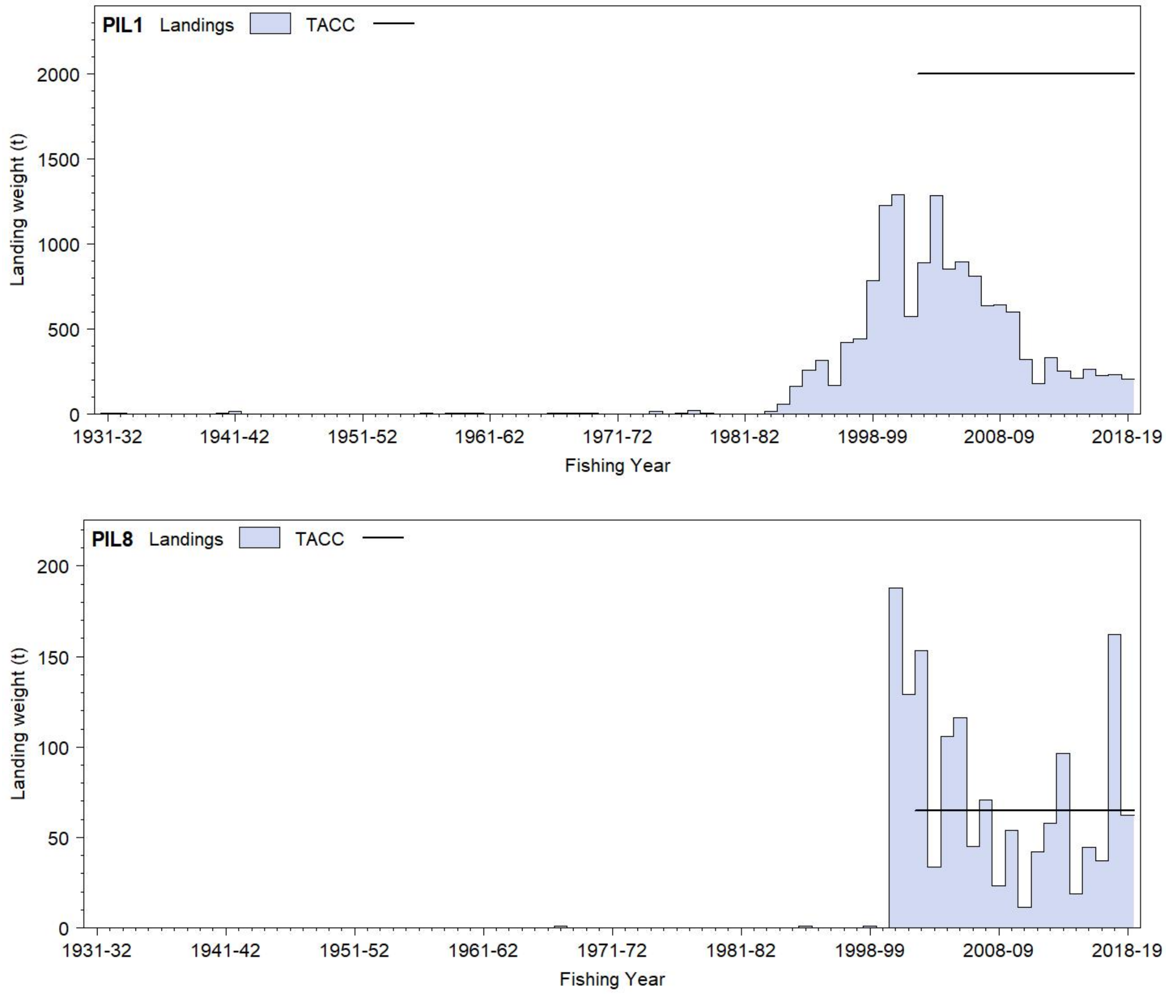


Figure 1: Reported commercial landings and TACC for the two main PIL stocks. PIL 1 (Auckland East), and PIL 8 (Central Egmont, Auckland West).

1.2 Recreational fisheries

Recreational fishers seldom target pilchards, except for bait. However bait is generally bought in commercially frozen packs (the main product of the commercial fishery). Pilchard may be caught accidentally in small mesh nets that are set or dragged to catch mullet, or on small hooks fished from wharves.

A National Panel Survey of recreational fishers was conducted for the first time throughout 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 (Wynne-Jones et al 2014). The panel members were contacted regularly about their fishing activities and harvest information collected in standardised phone interviews. The national panel survey was repeated during the 2017–18 fishing year using very similar methods to produce directly comparable results (Wynne-Jones et al 2019). Recreational catch estimates from the two national panel surveys are given in Table 5. Note that national panel survey estimates do not include recreational harvest taken under s111 general approvals.

Table 5: Recreational harvest estimates for pilchard stocks (Wynne-Jones et al 2014). Mean fish weights were not available from boat ramp surveys to convert these catches to tonnes. [Continued on next page]

Stock	Year	Method	Number of fish	Total weight (t)	CV
PIL 1	2011/12	Panel survey	12 827	-	0.47
	2017/18	Panel survey	14 962		0.46
PIL 2	2011/12	Panel survey	1 022	-	0.83
	2017/18	Panel survey	2 875		0.63

Table 5 [Continued]

Stock	Year	Method	Number of fish	Total weight (t)	CV
PIL 3	2011/12	Panel survey	9 144	-	0.99
	2017/18	Panel survey	4 407		1.00
PIL 7	2011/12	Panel survey	101	-	1.05
	2017/18	Panel survey	10 346		0.74
PIL 8	2011/12	Panel survey	137	-	1.01
	2017/18	Panel survey	27 864		0.91

1.3 Customary non-commercial catch

Pilchards were known by the early Maori as mohimohi, and could have been taken in fine mesh nets, but there are very few accounts of pilchard capture and use. An estimate of the current customary non-commercial catch is not available.

1.4 Illegal catch

There is no known illegal catch of pilchards.

1.5 Other sources of mortality

Some accidental captures by vessels purse seining for jack mackerel or kahawai may be discarded if no market is available. Pilchard mortality is known to be high in some places as a result of scale loss resulting from net contact.

2. BIOLOGY

The taxonomy of *Sardinops* is complex. The New Zealand pilchard was previously identified as *Sardinops neopilchardus*, but there is now considered to be a single species, *S. sagax*, with several regional subspecies or populations.

Pilchard are generally found inshore, particularly in gulfs, bays, and harbours. They display seasonal changes in abundance (e.g. locally abundant in Wellington Harbour during spring), reflecting schooling and dispersal behaviour, localised movement, and actual changes in population size. The geographical extent of their movements in New Zealand is unknown.

Their vertical distribution in the water column varies, but on the inner shelf they move between the surface and the seafloor. Pilchards form compact schools (known as ‘meatballs’), particularly during summer, and these are heavily preyed upon by larger fishes, seabirds, and marine mammals and are thought to form an important part of the diet for many species. There have been no biological studies that are directly relevant to the recognition of separate stocks.

Spawning is recorded from many coastal regions over the shelf during spring and summer. The pelagic eggs are at times extremely abundant. Otolith readings suggest that pilchard are relatively fast growing and short-lived. They reach a maximum length of about 25 cm, and perhaps 9 years, but the main size range is of 10–20 cm fish, 2 to 6 years old. Maturity is probably at age 2.

A study on the feeding of Northland pilchards found that phytoplankton was probably the dominant food, but organic detritus was also important, and small zooplankton - mainly copepods - were taken and at times were the main component. Feeding by females diminished during the spawning season. Although they generally comprise single-species schools, pilchards associate with other small pelagic fishes, particularly anchovy. In northern waters they also occur with juvenile jack mackerel, and in southern waters with sprats.

During the 1990s pilchard populations were severely impacted by natural mass mortalities, generally attributed to a herpes virus. The first outbreak occurred in Australia and New Zealand in 1995 and Australia experienced another outbreak in 1998.

Biological parameters relevant to stock assessment are shown in Table 6.

Table 6: Estimates of biological parameters.

Fishstock		Estimate	Source
1. Natural mortality (*M*)			
PIL 1		*M* = 0.66	NIWA, unpublished estimate[1]
PIL 1		*M* = 0.46	NIWA, unpublished estimate[2]
2. Weight = a (length)^b			
	Both sexes combined		
PIL 1	a = 2.2	b = 3.3	Paul et al (2001)[3]
PIL 7	a = 3.7	b = 3.3	Baker (1972)[4]

Notes:
1. Hoenig's rule-of-thumb estimate, maximum age = 7 years.
2. Hoenig's rule-of-thumb estimate, maximum age = 10 years.
3. Fork length in mm, weight in g, n = 493.
4. Standard length in mm, weight in g, n = 660.

3. STOCKS AND AREAS

No biological information is available on which to make an assessment on whether separate pilchard biological stocks exist in New Zealand (in Australia there is evidence of small differences between some populations off the southwest coast).

Pilchard and anchovy are often caught together. Pilchard fishstock boundaries are fully aligned with those for anchovy.

4. STOCK ASSESSMENT

There have been no stock assessments of New Zealand pilchard.

4.1 Estimates of fishery parameters and abundance

No fishery parameters are available.

4.2 Biomass estimates

No estimates of biomass are available.

4.3 Yield estimates and projections

(i) Northeast North Island (PIL 1)

MCY has been estimated using the equation $MCY = cY_{AV}$ (Method 4). The most appropriate Y_{AV} was considered the average of landings for the three years 1998–99 to 2000–01. Although a brief period, three years represents at least half the exploited life span for this species. The mean of these landings is 1101 t. With provisional values of *M* about 0.4 or 0.6, the value of c becomes 0.6 (i.e. high natural variability).

1998–99 to 2000–01

$MCY = 0.6 \times 1101$ t

$= 661$ t (rounded to 660 t)

However, the *MCY* approach is considered to be of limited value for pilchards, because this fishery has been developing rapidly, was historically infrequently targeted, and since 2000 has been subject to a CCL and more recently a TACC. The level of risk to the stock by harvesting the northeast North Island population at the estimated *MCY* value cannot be determined.

(ii) Tasman Bay/Marlborough Sounds (PIL 7)

MCY cannot be estimated for this region because the fishery has been largely unexploited since the 1940s, and no appropriate biological parameters exist.

(iii) Other regions

MCY cannot be estimated because of insufficient information, and absence of fisheries. Current biomass cannot be estimated, so *CAY* cannot be determined.

4.4 Other factors

It is likely that pilchard, although not strongly migratory, will vary considerably in their regional abundance over time. The larger vessels in the fleet that targets them are capable of travelling moderate distances to the best grounds. Thus, while the resource may have a relatively localised distribution, the catching sector of the fishery does not. Should the pilchard fishery develop again after its recent decline it is likely to become one component of a set of fisheries for small pelagic species (anchovy, sprats, and small jack mackerels). Mixed catches will be inevitable.

Pilchard is abundant in some New Zealand regions. However, it is unlikely that the biomass is comparable to the very large stocks of pilchard (sardine) in some world oceans where strong upwelling promotes high productivity. It is more likely that the New Zealand pilchard comprises abundant but localised coastal populations, comparable to those of southern Australia. They appear to be adaptable feeders, able to utilise food items from organic detritus through phytoplankton to zooplankton. East Northland is a region where under neutral to El Niño conditions moderately productive upwelling predominates but, in La Niña years, downwelling and oceanic water incursion will limit recruitment and may affect adult condition and survival.

In those regions of the world where small pelagic fishes are particularly abundant and have been well studied, there is often a reciprocal relationship between the stock size of pilchard and anchovy, as well as great variability in their overall abundance. Many pilchard/anchovy fisheries have undergone boom-and-bust cycles. In both Australia and New Zealand, pilchard have been affected by mass mortality events, the two in Australia are estimated to have each killed over 70% of the adult fish. The mortality rate of the 1995 event in New Zealand is not known, but was high. In combination, these features of the pilchard's biology suggest that the yield from the New Zealand stock will be variable, both short-term (annual) and long-term (decadal).

5. STATUS OF THE STOCKS

MCY estimates for PIL are unreliable. It is not known if the current catches or TACCs are sustainable.

Yield estimates, TACCs and reported landings by Fishstock are summarised in Table 7.

Table 7: Summary of yield estimates (t), TACCs (t), and reported landings (t) of pilchards for the most recent fishing year.

Fishstock		FMA	*MCY* Estimates	2017–18 Actual TACC	2017–18 Reported Landings
PIL 1	Auckland (East)	1	660	2 000	229
PIL 2	Central (East)	2	–	200	0
PIL 3	South-east (Coast)/Southland & Sub-Antarctic	3, 5 & 6	–	60	0
PIL 4	South-east (Chatham)	4	–	10	0
PIL 7	Challenger	7	–	150	233
PIL 8	Central (West)/Auckland (West)	8, 9	–	65	162
PIL 10	Kermadec	10	–	0	0

6. FOR FURTHER INFORMATION

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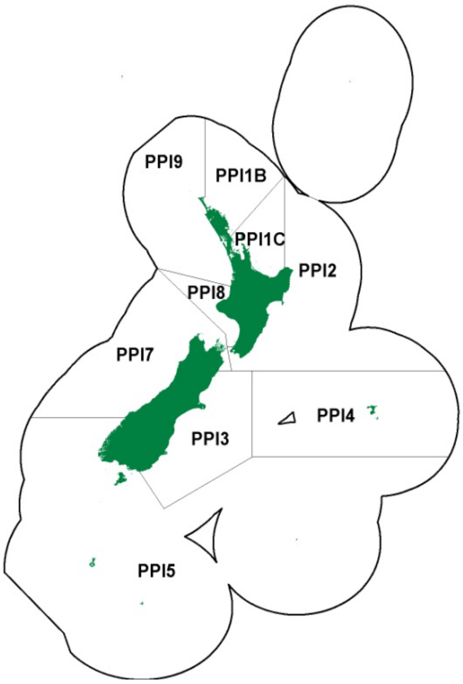
PIPI (PPI)

(*Paphies australis*)
Pipi



1. SUMMARY

Pipi are important shellfish both commercially and for non-commercial fishers. PPI 1A (which is located in Whangarei harbour) was introduced into the Quota Management System (QMS) on 1 October 2004; the other PPI stocks listed in Table 1 were introduced in October 2005. The total TAC introduced to the QMS was 713 t. This consisted of a 204 t TACC, an allocation of 242 t for both the recreational and customary allowances, and a 25 t allowance for other sources of mortality (Table 1). No changes have occurred to the TAC since. The fishing year is from 1 October to 30 September.

Table 1: Current Total allowable catches (TAC, t) allowances for customary fishing, recreational fishing, and other sources of mortality (t) and Total Allowable Commercial Catches (TACC, t) for pipi.

Fishstock	TAC	Customary	Recreational	Other sources of mortality	TACC
PPI 1A	250	25	25	0	200
PPI 1B	160	76	76	8	0
PPI 1C	243	115	115	10	3
PPI 2	7	3	3	1	0
PPI 3	19	9	9	1	0
PPI 4	3	1	1	1	0
PPI 5	3	1	1	1	0
PPI 7	4	1	1	1	1
PPI 8	3	1	1	1	0
PPI 9	21	10	10	1	0
Total	713	242	242	25	204

Since 1992, Fisheries New Zealand and its predecessors has commissioned biomass surveys for cockles and pipi in the northern North Island on beaches where there is known recreational and customary fishing pressure. The objective of the surveys is to determine the distribution, abundance and size frequency of cockles and pipi on selected beaches in the Auckland Fisheries Management Area. Over the years, a total of 35 beaches have been monitored. On average, 12 beaches are sampled each year.

The last survey was conducted in 2019 (see Berkenbush & Neubauer, 2019). Eleven of the northern survey sites supported pipi populations. Their population estimates varied from one beach to the next. The density varied between a high estimate of 2,333 pipi per m^2 in Ruakaka estuary, and an estimated mean of 3 pipi per m^2 in Kawakawa Bay.

1.1 Commercial fisheries

Commercial catches are measured in greenweight. The largest commercial fishery was in PPI 1A until Mair Bank closed to fishing in 2014 due to historically low biomass.

Regulations require that all commercial gathering is to be done by hand. Fishers typically use a mask and snorkel. There is no minimum legal size (MLS) for pipi, although fishers probably favor larger pipi (over 60 mm shell length). There is no apparent seasonality in the pipi fishery, as pipi are available for harvest year-round.

Some commercial catch was taken from PPI 1C during the 2005-06 to 2009-10 fishing years, but no landings have been reported since 2010 (Table 2 and Figure 1). The great majority of commercial catch was reported from PPI 1A until 2014 (see PPI 1A Working Group report).

New Zealand operates a mandatory shellfish quality assurance programme for all areas of commercially growing or harvesting bivalve shellfish for human consumption. Shellfish caught outside this programme can be sold only for bait. This programme is based on international best practice and is managed by Food Safety New Zealand in cooperation with the District Health Board Public Health Units and the shellfish industry[1]. Before any area can be used to grow or harvest bivalve shellfish, public health officials survey both the water catchment area to identify any potential pollution issues and microbiologically sample water and shellfish over at least a 12-month period, so that all seasonal influences are explored. This information is evaluated and, if suitable, the area is classified and listed by New Zealand Food Safety for harvest. There is then a requirement for regular monitoring of the water and shellfish flesh to verify levels of microbiological and chemical contaminants. Management measures stemming from this testing include closure after rainfall, to deal with microbiological contamination from runoff. Natural marine biotoxins can also cause health risks, so testing also occurs for this at regular intervals. If toxins are detected above the permissible level the harvest areas are closed until the levels fall below the permissible level. Products are also traceable so the source and time of harvest can always be identified in case of contamination.

Table 2: Reported commercial landings of pipi (t greenweight) from PPI 1C from 2004–05 to present.

Year	Reported landings	Limit (t)
2004–05	0	3
2005–06	0.86	3
2006–07	1.69	3
2007–08	1.80	3
2008–09	0.38	3
2009–10	0.62	3
2010–11	0	3
2011–12	0	3
2012–13	0	3
2013–14	0	3
2014–15	0	3
2015–16	0	3
2016–17	0	3
2017–18	0	3
2018–19	0	3

[1] For full details of this programme, refer to the Animal Products (Regulated Control Scheme-Bivalve molluscan Shellfish) Regulations 2006 and the Animal Products (Specifications for Bivalve Molluscan Shellfish) Notice 2006 (both referred to as the BMSRCS), at: http://www.foodsafety.govt.nz/industry/sectors/seafood/bms/growers-harvesters.htm

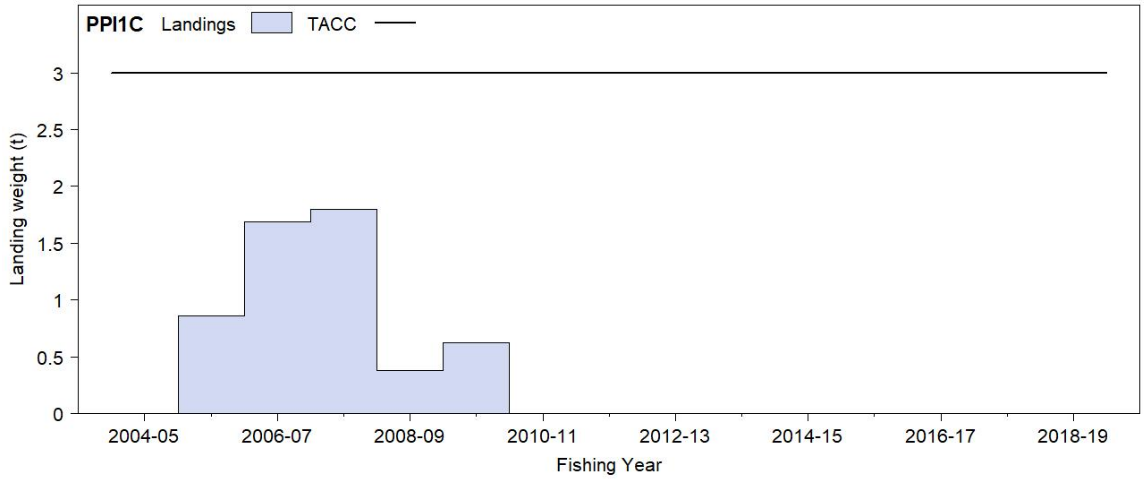


Figure 1: Reported commercial landings and TACC for PPI 1C (Hauraki Gulf and the Bay of Plenty).

1.2 Recreational fisheries

The recreational fishery is harvested entirely by hand digging. Large pipi 50 mm (maximum shell length) or greater are probably preferred. The 1996, 1999–00, and 2000–01 telephone-diary surveys recorded recreational harvests in FMA 1 of 2.1, 6.6, and 7.2 million pipi, respectively, but no mean weight was available to convert these harvest estimates to tonnages. The harvest estimates provided by these telephone-diary surveys are no longer considered reliable for various reasons. A Recreational Technical Working Group concluded that these harvest estimates should be used only with the following qualifications: a) they may be very inaccurate; b) the 1996 and earlier surveys contain a methodological error; and c) the 2000 and 2001 estimates are implausibly high for many important fisheries. In response to these problems and the cost and scale challenges associated with onsite methods, a National Panel Survey was conducted for the first time throughout the 2011–12 fishing year. The panel survey used face-to-face interviews of a random sample of 30 390 New Zealand households to recruit a panel of fishers and non-fishers for a full year. The panel members were contacted regularly about their fishing activities and harvest information collected in standardised phone interviews. The panel survey was repeated in 2017-18 (Wynne-Jones et al 2019). Harvest estimates (in numbers of pipi) are given in Table 3 (from Wynne-Jones et al 2014 and Wynne-Jones et al 2019).

Table 3: Recreational harvest estimates for pipi stocks from the national panel survey in 2011–12 (Wynne-Jones et al. 2014) and 2017–18 (Wynne-Jones et al 2019). Mean weights were not available from boat ramp surveys to convert these estimates to weights.

Stock	Number of pipi	CV
2011–12 (national panel survey)		
PPI 1A	21 620	0.89
PPI 1B	84 476	0.39
PPI 1C	255 207	0.30
PPI 2	167 155	0.54
PPI 3	5 295	0.51
PPI 7	10 057	0.58
PPI 8	32 632	0.52
PPI 9	45 847	0.48
PPI total	622 288	0.20
2017-18 (national panel survey)		
PPI 1A	0	-
PPI 1B	46 243	0.44
PPI 1C	315 540	0.38
PPI 2	16 157	0.59
PPI 3	14 892	0.82
PPI 5	12 326	1.00
PPI 7	27 997	0.70
PPI 8	102 037	0.53
PPI 9	112 785	0.63
PPI total	647 978	

1.3 Customary fisheries

In common with many other intertidal shellfish, pipi are very important to Maori as a traditional food. Limited quantitative information on the level of customary take is available from Fisheries New Zealand (Table 4). These numbers are likely to be an underestimate of customary harvest as only the catch in kilograms and numbers are reported in the table. After 1 October 2014 all take of pipi from Mair Bank (PPI 1A) was prohibited due to historically low pipi biomass levels.

Table 4: Fisheries New Zealand records of customary harvest of pipi (reported as weight (kg) and numbers), since 2001-02. – no data.

	PPI 1A				PPI 1B			
	Weight (kg)		Numbers		Weight (kg)		Numbers	
Fishing year	Approved	Harvested	Approved	Harvested	Approved	Harvested	Approved	Harvested
2001–02	–	–	–	–	–	–	–	–
2002–03	–	–	–	–	–	–	–	–
2003–04	–	–	–	–	–	–	–	–
2004–05	–	–	–	–	–	–	–	–
2005–06	–	–	–	–	–	–	–	–
2006–07	–	–	–	–	350	350	300	300
2007–08	–	–	–	–	150	150	–	–
2008–09	120	120	–	–	270	270	450	450
2009–10	235	235	–	–	100	100	–	–
2010–11	100	100	–	–	380	380	–	–
2011–12	80	40	–	–	350	350	–	–
2012–13	110	110	–	–	140	140	–	–
2013–14	–	–	–	–	–	–	400	400
2014–15	–	–	–	–	–	–	–	–
2015–16	–	–	–	–	–	–	–	–
2016–17	–	–	–	–	–	–	–	–
2017–18	–	–	–	–	–	–	–	–
2018–19	–	–	–	–	–	–	–	–

	PPI 1C				PPI 2			
	Weight (kg)		Numbers		Weight (kg)		Numbers	
Fishing year	Approved	Harvested	Approved	Harvested	Approved	Harvested	Approved	Harvested
2001–02	–	–	–	–	–	–	–	–
2002–03	–	–	–	–	–	–	–	–
2003–04	–	–	5 000	4 000	–	–	–	–
2004–05	–	–	–	–	–	–	–	–
2005–06	763	638	4 500	2 000	–	–	–	–
2006–07	10 411	9 806	12 850	9 850	–	–	9 076	8 076
2007–08	5 235	3 360	6 000	3 750	–	–	29 576	25 076
2008–09	5 760	4 889	10 000	8 000	–	–	30 250	24 350
2009–10	3 585	3 105	6 700	6 700	–	–	2 000	2 000
2010–11	4 558	3 741	4 430	4 430	–	–	56 000	54 200
2011–12	900	660	500	300	–	–	66 100	63 400
2012–13	1 340	950	–	–	–	–	92 600	58 300
2013–14	40	40	–	–	–	–	44 400	20 800
2014–15	3 035	2 800	5 000	5 000	–	–	–	–
2015–16	2 345	1 653	–	–	–	–	–	–
2016–17	2 675	1 878	30	0	–	–	–	–
2017–18	1 415	1 105			–	–	–	–
2018–19	640	450			–	–	–	–

	PPI 3				PPI 4			
	Weight (kg)		Numbers		Weight (kg)		Numbers	
Fishing year	Approved	Harvested	Approved	Harvested	Approved	Harvested	Approved	Harvested
2001–02	–	–	202	202	–	–	–	–
2002–03	–	–	–	–	–	–	–	–
2003–04	–	–	–	–	–	–	–	–
2004–05	–	–	–	–	–	–	–	–
2005–06	–	–	–	–	–	–	–	–
2006–07	–	–	1 000	30	–	–	–	–
2007–08	–	–	–	–	–	–	–	–
2008–09	–	–	2 500	1 987	–	–	–	–
2009–10	–	–	–	–	–	–	400	400
2010–11	–	–	100	100	–	–	–	–
2011–12	–	–	950	950	–	–	–	–
2012–13	–	–	–	–	–	–	–	–
2013–14	–	–	120	119	–	–	–	–
2014–15	–	–	–	–	–	–	–	–
2015–16	–	–	60	60	–	–	–	–
2016–17	–	–	–	–	–	–	–	–

Table 4 [Continued]

2017–18	–	–	350	350	–	–	–	–
2018–19	–	–	–	–	–	–	–	–

	PPI 5				PPI 7			
	Weight (kg)		Numbers		Weight (kg)		Numbers	
Fishing year	Approved	Harvested	Approved	Harvested	Approved	Harvested	Approved	Harvested
2001–02	–	–	–	–	–	–	–	–
2002–03	–	–	–	–	–	–	–	–
2003–04	–	–	–	–	–	–	–	–
2004–05	–	–	–	–	–	–	–	–
2005–06	–	–	–	–	–	–	–	–
2006–07	–	–	–	–	–	–	80	80
2007–08	–	–	–	–	–	–	–	–
2008–09	–	–	–	–	–	–	–	–
2009–10	–	–	–	–	–	–	–	–
2010–11	–	–	–	–	–	–	–	–
2011–12	–	–	–	–	–	–	–	–
2012–13	–	–	–	–	–	–	–	–
2013–14	–	–	–	–	–	–	–	–
2014–15	–	–	–	–	–	–	–	–
2015–16	–	–	50	50	–	–	–	–
2016–17	–	–	–	–	–	–	–	–
2017–18	–	–	–	–	–	–	–	–
2018–19	–	–	–	–	–	–	–	–

	PPI 9			
	Weight (kg)		Numbers	
Fishing year	Approved	Harvested	Approved	Harvested
2001–02	–	–	–	–
2002–03	–	–	–	–
2003–04	–	–	–	–
2004–05	–	–	–	–
2005–06	–	–	–	–
2006–07	–	–	–	–
2007–08	25	25	1 383	883
2008–09	80	80	4 000	3 500
2009–10	350	340	–	–
2010–11	60	60	–	–
2011–12	450	450	–	–
2012–13	390	308	–	–
2013–14	580	475	–	–
2014–15	670	670	–	–
2015–16	110	110	–	–
2016–17	230	130	–	–
2017–18	–	–	–	–
2018–19	–	–	–	–

1.4 Illegal catch
No quantitative information on the level of illegal catch is available.

1.5 Other sources of mortality
No quantitative nationwide information on the level of other sources of mortality is available.

2. BIOLOGY

The pipi (*Paphies australis*) is a common burrowing bivalve mollusc of the family Mesodesmatidae. Pipi are distributed around the New Zealand coastline, including the Chatham and Auckland Islands (Powell 1979), and are characteristic of sheltered beaches, bays and estuaries (Morton & Miller 1968). Pipi are tolerant of moderate wave action, and commonly inhabit coarse shell sand substrata in bays and at the mouths of estuaries where silt has been removed by waves and currents (Morton & Miller 1968). They have a broad tidal range, occurring intertidally and subtidally in high-current harbour channels to water depths of at least 7 m (Dickie 1986a, Hooker 1995a), and are locally abundant, with densities greater than 1000 m^{-2} in certain areas (Grace 1972).

Pipi reproduce by free-spawning, and most individuals are sexually mature at about 40 mm shell length (SL) (Hooker & Creese 1995a). Gametogenesis begins in autumn, and by late winter many pipi have mature, ready-to-spawn gonads (Hooker & Creese 1995a). Pipi have an extended breeding period from late winter to late summer, with greatest spawning activity occurring in spring and early summer. Fertilised eggs develop into planktotrophic larvae, and settlement and metamorphosis occur about three weeks after spawning (Hooker 1997). In general, pipi have been considered sedentary when settled, although Hooker (1995b) found that pipi may utilise water currents to disperse actively within a harbour. The trigger for movement is unknown, but this ability to migrate may have important implications to their population dynamics.

Pipi growth dynamics are not well known. Growth appears to be fairly rapid, at least in dynamic, high-current environments such as harbour channels. Hooker (1995a) showed that pipi at Whangateau Harbour (northeastern New Zealand) grew to about 30 mm in just over one year (16–17 months), reached 50 mm after about three years, and grew very slowly after attaining 50 mm. There was a strong seasonal component to growth, with rapid growth occurring in spring and summer, and little growth in autumn and winter. Williams et al (2007) used Hooker's (1995a) tag-recapture and length frequency time series data to generate formal growth estimates for Whangateau Harbour pipi (Table 5). Estimates are also available from time series of size frequencies on sheltered Auckland beaches (Table 5; Morrison & Browne 1999, Morrison et al. 1999), although these were likely to have been poorly estimated due to variability in the length data. Growth on the intertidal section of Mair Bank was estimated by Pawley et al. (2013) using the results of a notch-tagging experiment in 2009–10. These estimates are likely to underestimate growth of pipi in the commercial fishery because tagged shells came from the intertidal zone whereas commercial harvesting is conducted primarily in the subtidal (where growth is expected to be quicker).

Little is known about the natural mortality or maximum longevity of pipi. Haddon (1989) suggested that pipi are unlikely to live much more than 10 years, and used assumed maximum ages of 10, 15 and 20 years old to estimate maximum constant yield for Mair Bank pipi in 1989. The estimation of the rate of instantaneous natural mortality (M) is difficult for pipi owing to the immigration and emigration of individuals from different areas. As the timing and frequency of these movements are largely unknown, the separation of mortality from movement effects is likely to be problematic. Williams et al (2007) assumed values of M = 0.3, 0.4, and 0.5 to estimate yields for Mair Bank in 2005–06.

Table 5: Estimates of biological parameters for pipi.

Growth		**Location**	**Year**	**Source**
L_∞ (mm SL)	K			
57.3	0.46	Inner Whangateau Harbour site	1992–93	Williams et al (2007)
63.9	0.57	Whangateau Harbour entrance	1992–93	Williams et al (2007)
41.1	0.48	Cheltenham Beach, North Shore	1997–98	Morrison et al (1999)
58.9	0.15	Mill Bay, Manukau Harbour	1997–98	Morrison et al (1999)
84.6	0.09	Mill Bay, Manukau Harbour	1998–99	Morrison & Browne (1999)
Natural mortality				
M = 0.3–0.5 (assumed values)		-	-	Williams et al (2007)
Size at maturity				
40 mm SL		Whangateau Harbour	-	Hooker & Creese (1995a)

3. STOCKS AND AREAS

A molecular study was undertaken to determine patterns of population structure and genetic connectivity in *P. australis* and the location of any potential barriers to connectivity (Hannan et al 2016). The study suggested that, at a large spatial scale, *P. australis* could be differentiated into three genetically distinct groups (northern, south eastern, south western) but at a smaller spatial scale there was evidence for genetic differentiation amongst populations separated by only tens to hundreds of kilometers (Figure 2).

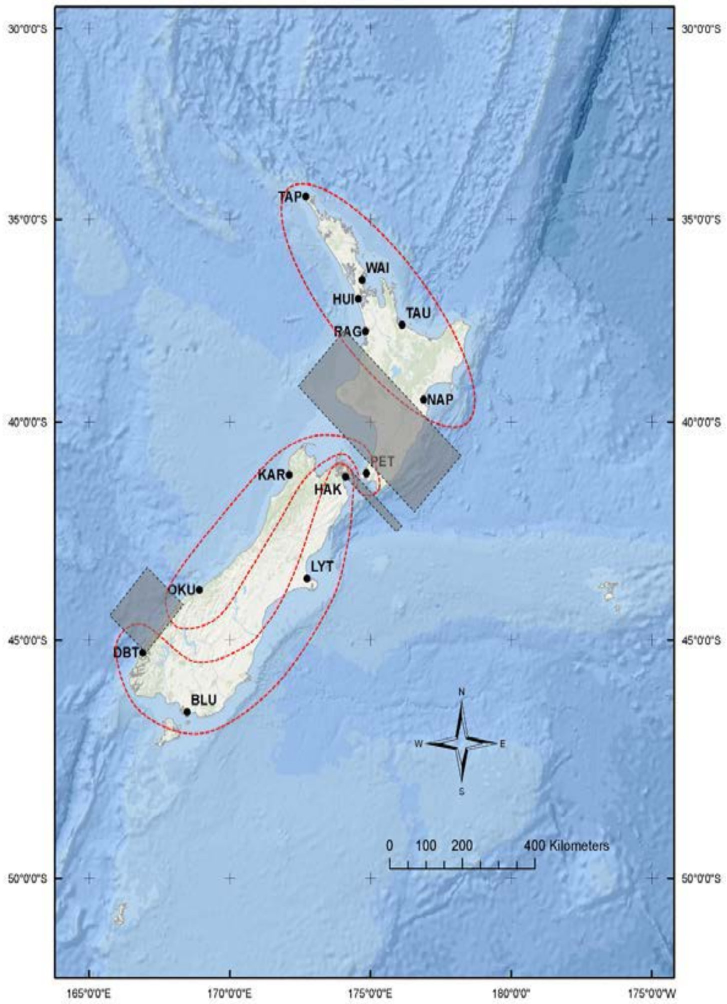


Figure 2: Location of genetically differentiated populations of *Paphies australis* and barriers to genetic connectivity. Populations are those sampling locations enclosed by red dashed lines. The geographic areas where barriers to genetic connectivity are assumed to occur are indicated by shaded grey boxes (these boxes cover large sections of coastline because it was not possible to pinpoint the exact location of barriers; it is assumed the barrier lies somewhere within the shaded area).

4. STOCK ASSESSMENT

A stock assessment has been conducted for PPI 1A.

5. STATUS OF THE STOCKS

There were negligible reported landings in 2012–13 for any PPI stocks except PPI 1A (which is reported separately). The status of all PPI stocks other than PPI 1A are unknown, but are assumed to be close to virgin biomass.

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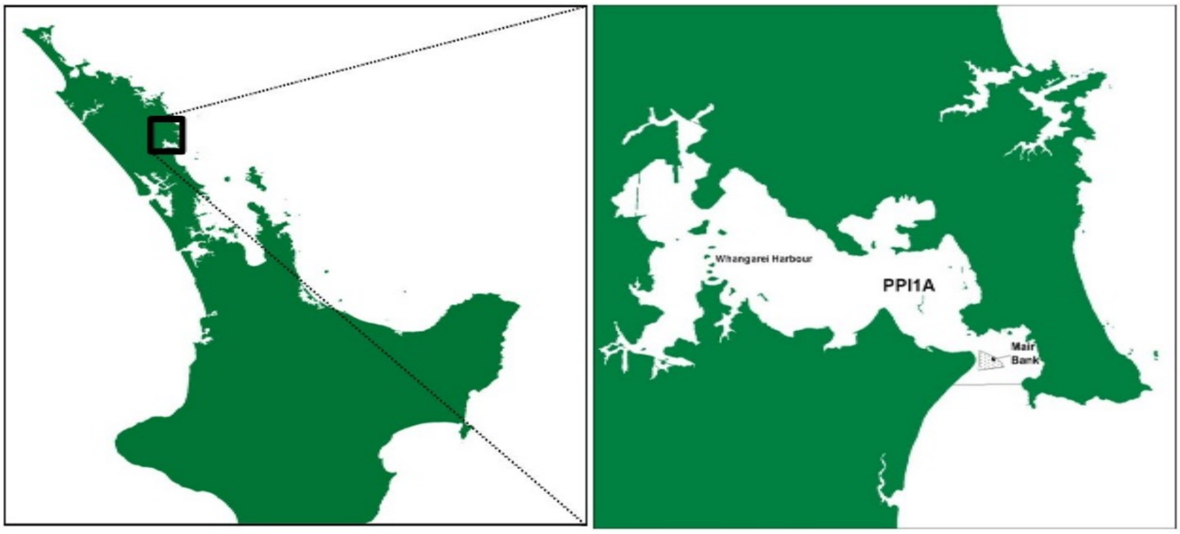
PPI (PPI 1A) Mair Bank (Whangarei Harbour)

(*Paphies australis*)
Pipi



1. FISHERY SUMMARY

Pipi 1A was introduced into the Quota Management System (QMS) on 1 October 2004 with a TAC of 250 t, comprising a TACC of 200 t, and customary and recreational allowances of 25 t each.

Marsden Bank was closed to the collection of pipi in February 2011, with the subsequent closure of adjacent Mair Bank on 1 October 2014 due to historically low pipi biomass levels. Marsden Bank was included in the monitoring programme in 2010–11, and has been surveyed four times since then (Berkenbusch & Neubauer, 2019). Pipi at this site have also been assessed in other recent surveys, including a community-based monitoring programme led by Patuharakeke iwi (Williams et al. 2017).

1.1 Commercial fisheries

Prior to the introduction of pipi, in Whangarei Harbour (PPI 1A) and FMA PPI 1, to the QMS in 2004, the commercial fishery area was defined in regulation as the area within 1.5 nautical miles of the coastline from Home Point, at the northern extent of the Whangarei Harbour entrance, to Mangawhai Heads, south of the harbour. Commercial fishers tend to gather pipi from the seaward edge of Mair Bank, particularly the southern end, and avoid the centre of the bank itself where there is a lot of shell debris. Regulations require that all gathering be done by hand, and fishers typically use a mask and snorkel. There is no minimum legal size (MLS) for pipi, although a sample measured from the commercial catch in PPI 1A in 2005 suggested that fishers favour larger pipi (over 60 mm SL, Williams et al. 2007). Pipi are available for harvest year-round, so there is no apparent seasonality in the fishery.

Over 99% of the total commercial landings of pipi in New Zealand have been from General Statistical Area 003 and PPI 1. Later on, where a distinction has been made, virtually all the landings have been from PPI 1A (Whangarei Harbour). Total commercial landings of pipi reported on Licensed Fish Receiver Returns (LFRRs) remained reasonably stable through time, averaging 177 t annually in New Zealand from 1986–87 until 2009-10 (Table 1). Landings subsequently decreased to an average of just 71 t in 2010-11 to 2011-12; no landings were reported after 2012. The highest recorded landings were in 1991–92 (326 t). There is no evidence of any consistent seasonal pattern in either the level of effort or catch per unit effort (CPUE) in the pipi fishery. CPUE in the pipi targeted fishery increased between

1989–90 and 1992–93, was then relatively stable up to 2002–03 but increased in 2003–04 and 2004–05 (Williams et al. 2007). No CPUE information has since been analysed.

Table 1: Reported commercial landings (from Licensed Fish Receiver Returns; LFRR) of pipi (t greenweight) in New Zealand since 1986–87. Prior to the introduction of PPI 1A to the QMS on 1 October 2004, the fishery was limited by daily limits which summed to 657 t greenweight in a 365 day year, but there was no explicit annual restriction. A TACC of 200 t was set for PPI 1A on 1 October 2004.

Year	Reported landings (t)	Limit (t)	Year	Reported landings (t)	Limit (t)
1986–87	131	657	2002–03	191	657
1987–88	133	657	2003–04	266	657
1988–89	134	657	2004–05	206	200
1989–90	222	657	2005–06	137	200
1990–91	285	657	2006–07	135	200
1991–92	326	657	2007–08	142	200
1992–93	184	657	2008–09	131	200
1993–94	258	657	2009–10	136	200
1994–95	172	657	2010–11	87	200
1995–96	135	657	2011–12	55	200
1996–97	146	657	2012–13	0	200
1997–98	122	657	2013–14	0	200
1998–99	130	657	2014–15	0	200
1999–00	143	657	2015–16	0	200
2000–01	184	657	2016–17	0	200
2001–02	191	657	2017–18	0	200
			2018–19	0	200

Prior to the introduction of PPI 1A to the QMS there were nine permit holders for Whangarei Harbour. No new entrants have entered the fishery since 1992 when commercial access to the fishery was constrained by the general moratorium on granting new fishing permits for non-QMS fisheries. Access to the fishery has, however, been restricted through other regulations since the mid-1980s, and more formally since 1988. Under previous non-QMS management arrangements, there was a daily catch limit of 200 kg per permit holder, meaning that, collectively, the nine permit holders could, theoretically, take 657 t of pipi per year. The permit holders have indicated that annual harvest quantities have been considerably less than the potential maximum, because of the relatively low market demand for commercial product rather than the availability of the resource. On 1 October 2004, pipi in Whangarei Harbour (PPI 1A) were introduced into the QMS, and the nine existing permits were replaced with individual transferable quotas. The 200 kg daily catch limit no longer applies. A total allowable catch (TAC) of 250 t was set, comprised of a total allowable commercial catch (TACC) of 200 t, a customary allowance of 25 t, and a recreational allowance of 25 t.

Figure 1 shows the historical landings and TACC values for PPI 1A. After 1 October 2014 all take of pipi from Mair Bank was prohibited due to historically low pipi biomass levels.

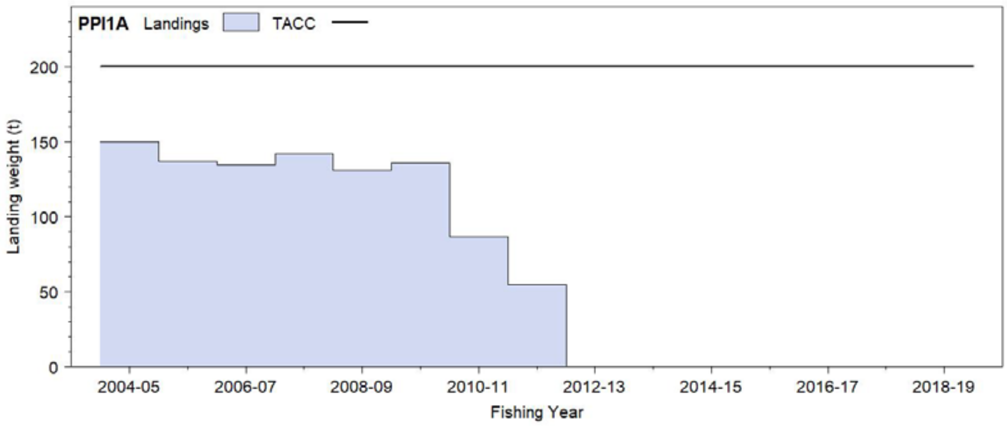


Figure 1: Total commercial landings and TACC for PPI 1A (Whangarei Harbour). QMS data from 2004–05 to present.

1.2 Recreational fisheries
The only estimate of recreational harvest of pipi comparable with the commercial fishery on Mair Bank is the estimate of harvest from the whole of Whangarei Harbour from the 2011–12 National Panel Survey (<1 tonne, see Table 3). Thus, the recreational harvest of pipi from the bank is small compared with commercial landings there prior to 1 October 2014. After 1 October 2014 all take of pipi from Mair Bank was prohibited due to very low biomass levels.

For further information on recreational fisheries refer to the introductory pipi Working Group Report.

1.3 Customary non-commercial fisheries
For further information on customary fisheries refer to the introductory pipi Working Group Report.

1.4 Illegal catch
For further information on illegal catch refer to the introductory pipi Working Group Report.

1.5 Other sources of mortality
There is some concern about the possibility of changes in bank stability that could arise from operations other than fishing in Whangarei Harbour (e.g., harbour dredging, port developments), which could lead to changes in the pipi fishery. Radical changes to the local hydrology could affect the size or substratum of Mair Bank with consequent effects on its pipi population. Also, as suspension feeders, pipi may be adversely affected by increased sediment loads in the water column.

The potential causes of low biomass from the 2014 biomass survey were investigated in the desktop report of Williams & Hume (2014). They concluded that: "*potential causes of the pipi decline were high natural mortality of an ageing pipi population and low recruitment, both of which may be related to observed changes in the morphology of Mair Bank. There was no evidence of disease in the population, and the decline did not appear to be associated with potential anthropogenic sources of mortality (e.g., sedimentation, contaminants, harvesting). It is possible that substances not measured in shellfish, sediment, or water quality monitoring work may have influenced the pipi decline*."

2. BIOLOGY

This is covered in the general pipi section.

3. STOCKS AND AREAS

Little is known of the stock structure of pipi. A study of biological connectivity that is currently underway includes pipi, but no results have not been finalised at the time of this report. The commercial fishery based on Mair Bank in Whangarei Harbour (PPI 1A) forms a geographically discrete area and is assumed for management purposes to be a separate stock.

4. STOCK ASSESSMENT

Stock assessment for Mair Bank pipi was conducted in 2005 and 2010 using absolute biomass surveys, and yield per recruit and spawning stock biomass per recruit modelling. MPI in association with Northland Regional Council and the Harbour board also commissioned a biomass survey in 2014 in response to local concerns about low biomass.

Following the closure to the collection of pipi on Marsden Bank in February 2011, the Bank was included in the monitoring programme in 2010–11, and has been surveyed four times since then. The population has fluctuated over time. In view of the population decline recorded in 2013–14, the 2018 survey data indicate some recovery of the pipi population, including the presence of recruits (Berkenbusch and Neubauer, 2018).

4.1 Estimates of fishery parameters and abundance

Estimates of the fishing mortality reference point $F_{0.1}$ are available from yield per recruit modelling (Table 2). Parallel spawning stock biomass per recruit modelling was conducted to estimate the SSBPR corresponding with each estimate of $F_{0.1}$. These estimates are sensitive to the assumed value of natural mortality (*M*) and uncertainty in pipi growth parameters.

Table 2: Estimates of the reference rate of fishing mortality $F_{0.1}$ and corresponding spawning stock biomass per recruit at three different assumed rates of natural mortality (*M*) for two harvest strategies ('no restriction' and 'current'). SL, shell length (at recruitment). Estimates from Williams et al (2007).

'No restriction' strategy (harvest pipi of a size that maximizes YPR)					
Assumed M	**Optimal age at recruitment (y)**	**SL (mm)**	**$F_{0.1}$**	**YPR (g)**	**SSBPR (%)**
0.3	3	52	0.437	4.93	44
0.4	2.75	51	0.550	3.50	45
0.5	2.5	49	0.648	2.58	45
'Current' strategy (harvest pipi 60 mm and over)					
Assumed M	**Age at recruitment (y)**	**SL (mm)**	**$F_{0.1}$**	**YPR (g)**	**SSBPR (%)**
0.3	5	60	0.564	3.98	62
0.4	5	60	0.755	2.41	70
0.5	5	60	0.949	1.47	76

4.2 Biomass estimates

Virgin biomass (B_0) and the biomass that will support the maximum sustainable yield (B_{MSY}) are unknown for Mair Bank pipi. Only four biomass estimates have been made for the Mair Bank pipi population: in 1989 using a grid survey, in 2005 using stratified random sampling, in 2010 using a systematic random start and in 2014 using a stratified grid sampling design. The 1989 estimate of 2245 t (± 10%) can be considered conservative because only the intertidal area of the bank was surveyed, and pipi are known to exist in the shallow subtidal area of the bank. Estimates of biomass are available for Mair Bank (excluding from the 2014 survey) and are sensitive to the assumed size at recruitment (Table 3). The high CV for the estimates from 2014 were due to the unexpectedly low and patchy biomass at the time.

Table 3: Estimated recruited biomass (*B*) of pipi on Mair Bank in 2005 and 2010 for different assumed sizes at recruitment to the fishery. Source: Williams et al (2007), Pawley et al (2013) and Pawley (2014).

Year	**Assumed shell length at recruitment (mm)**	**Intertidal stratum**		**Subtidal stratum**		**Mair Bank Total**	
		***B* (t)**	**CV (%)**	***B* (t)**	**CV (%)**	***B* (t)**	**CV (%)**
2005	1 (total biomass)	3 602	11.4	6 940	19.5	10 542	13.4
2005	40	3 569	11.4	6 922	19.5	10 490	13.4
2005	45	3 434	11.4	6 791	19.6	10 226	13.6
2005	50	2 986	11.3	5 989	20.1	8 975	14.0
2005	55	2 022	11.1	3 855	23.8	5 877	16.0
2005	60	1 004	13.1	2 013	37.5	3 017	25.4
2010	1 (total biomass)	2 233	17.4	2 218	33.0	4 452	15.2
2010	50	2 001	18.1	1 889	36.0	3 890	16.6
2010	60	1 751	18.3	1 393	33.7	3 145	17.4
2014	5 (total biomass)	46	50.8	28	25.9	73.5	30.8

4.3 Yield estimates and projections

Maximum Constant Yield (*MCY*) was estimated using method 2 (see the guide to biological reference points in the introduction chapter of this plenary document):

$$MCY = 0.5F_{0.1}B_{av}$$

where $F_{0.1}$ is a reference rate of fishing mortality and B_{av} is the historical average recruited biomass (estimated as the mean recruited biomass from the 2005 and 2010 surveys). *M* is assumed to be 0.3 and the corresponding $F_{0.1}$ is 0.564 (Williams et al 2007 revised version). The size at recruitment is assumed to remain at 60 mm and the corresponding B_{av} is 3081 t.

$$MCY = 0.5 \times 0.564 \times 3\,081\ t$$
$$= 869\ t$$

This estimate of *MCY* would have a CV at least as large as those associated with the 2005 and 2010 estimates of recruited biomass (17–25%), and is sensitive to the assumed size at recruitment to the fishery, the assumed natural mortality, and to uncertainty in $F_{0.1}$ (arising from the considerable uncertainty in model input values for growth and *M*) (Table 4).

Table 4: Sensitivity of maximum constant yield (*MCY*, method 2) to estimates of size at recruitment and the assumed natural mortality, *M*. B_{av}, the historical average recruited biomass, was estimated for two sizes at recruitment (50 and 60 mm SL) using the 2005 and 2010 survey data.

SL at recruitment (mm)	B_{av}	*M*	$F_{0.1}$	*MCY* (t)
50	6433	0.3	0.40	1 300
		0.4	0.54	1 729
		0.5	0.68	2 182
60	3081	0.3	0.56	869
		0.4	0.76	1 163
		0.5	0.95	1 462

CAY was not estimated because there is no estimate of current biomass.

5. STATUS OF THE STOCKS

Stock Structure Assumptions

For the purpose of this assessment PPI 1A is assumed to be a discrete stock.

Stock Status	
Year of Most Recent Assessment	2015
Reference Points	Target: Default 40% B_0 Soft Limit: 20% B_0 Hard Limit: 10% B_0 Overfishing threshold: F_{MSY}
Status in relation to Target	Very Unlikely (< 10%) to be at or above the target
Status in relation to Limits	Soft Limit: Very Likely (> 90%) to be below Hard Limit: Very Likely (> 90%) to be below
Status in relation to Overfishing	Unknown
Historical Stock Status Trajectory and Current Status	
Biomass has not been measured in consistent units for all surveys, but has declined sharply from a total biomass (> 1 mm) of 10 542 tonnes in 2005 to a total biomass (> 5 mm) of 73.5 tonnes in 2014.	

Fishery and Stock Trends	
Recent Trend in Biomass or Proxy	Surveys were conducted in 2005, 2010 and 2014. These surveys have shown a sharp decline in biomass to very low levels.
Recent Trend in Fishing Intensity or Proxy	No commercial landings have been reported since the 2011–12 fishing year.
Other Abundance Indices	-
Trends in Other Relevant Variables or Indicators	-

Projections and Prognosis	
Stock Projections or Prognosis	The stock has declined below limits (causing the fishery to be closed) due to unknown reasons and the likelihood of recovery is unknown.
Probability of Current Catch or TACC causing Biomass to remain below or to decline below Limits	There is no current legal catch as biomass has declined below the TACC and limits.
Probability of Current catch or TACC causing Overfishing to Continue or to commence	There is no current legal catch as biomass has declined below the TACC and limits. However, the amount of illegal take is unknown.

Assessment Methodology and Evaluation		
Assessment Type	Level 2 - Partial Quantitative Stock Assessment	
Assessment Method	Reference rate of fishing mortality applied to absolute biomass estimates from quadrat surveys	
Assessment Dates	Latest assessment: 2012	Next assessment: Unknown
Overall assessment quality rank	1 – High Quality	
Main data inputs (rank)	- Two absolute abundance estimates (quadrat surveys) - Biological parameters for YPR/SSBPR models	1 – High Quality 1 – High Quality
Data not used (rank)	-	
Changes to Model Structure and Assumptions	-	
Major Sources of Uncertainty	- Growth for the subtidal portion of this population is poorly known. The available data come from other areas or the intertidal portion, both of which can be expected to support slower growth than the area where the fishery occurs. This, together with poor information on M and the size at recruitment to the fishery, makes the YPR modelling and reference rate of fishing mortality very uncertain.	

Qualifying Comments
Recruitment appears from the 2005 and 2010 survey length frequency distributions to be variable. This may lead to larger variations in the spawning and recruited biomass than the estimates of biomass suggest. The 2014 survey showed very low biomass levels and the commercial, recreational and customary fisheries have been closed since 1 October 2014.

Fishery Interactions
This is a hand-gathering fishery with no substantial bycatch or other interactions.

6. FOR FURTHER INFORMATION

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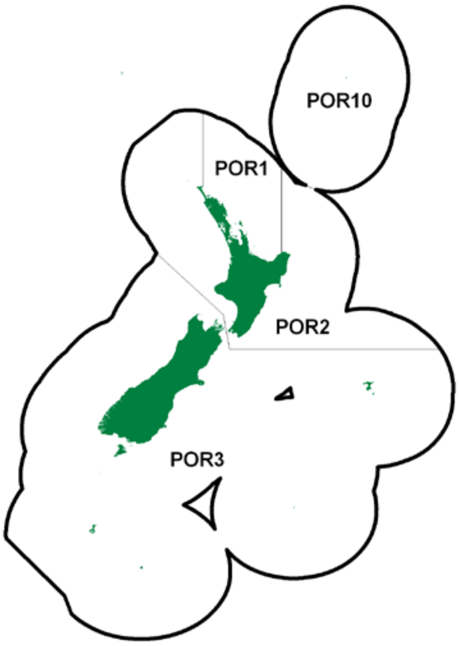
PŌRAE (POR)

(*Nemadactylus douglasii*)
Pōrae



1. FISHERY SUMMARY

Pōrae was introduced into the Quota Management System on 1 October 2004 with the following TACs, TACCs, and allowances (Table 1). These have not been changed.

Table 1: TACs (t), TACCs (t) and allowances (t) for pōrae.

Fishstock	Recreational Allowance	Customary non-commercial Allowance	Other sources of mortality	TACC	TAC
POR 1	6	3	4	62	75
POR 2	1	1	1	18	9
POR 3	1	1	1	2	5
POR 10	1	1	1	1	4
Total	9	6	7	83	93

1.1 Commercial fisheries

Commercial catches of pōrae throughout New Zealand are generally small. Landings were first reported in 1978 (Table 2). The proportion of vessels landing catch declined steadily during the 1990s; annual landings in FMA 1, where the majority of pōrae are caught, have approximately halved since the early 1990s when an average of 110 t were reported annually (Table 3). POR 1 landings have generally been lower than the TACC since its introduction in 2004, only slightly exceeding it in 2006–07, 2010–11, and 2016–17 (Figure 1, Table 4). Landings of POR 2 (FMAs 2, 8, and 9) have remained low and below the TACC (except for the fishing year 2016–17), averaging 14 t in 2013–14 to 2018–19. POR 3 landings have consistently remained below 1 t; no landings have been reported from FMAs 4, 5, or 6. POR 10 landings were last reported in 1994–95.

Pōrae is principally caught as a bycatch in inshore set net fisheries in northern New Zealand. It is generally taken in association with snapper and trevally off east Northland and Coromandel, and tarakihi and blue moki around Gisborne. Small quantities are taken by bottom longline and trawl fisheries targeting snapper off east Northland and Ninety Mile Beach.

Fishers may confuse the codes PAR (parore) and POR (pōrae) when reporting catches, but given that both species occur in shallow northern waters, misreporting is difficult to discern.

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

Year	POR 1	POR 2	POR 3	Year	POR 1	POR 2	POR 3
1931-32	0	0	0	1957	0	0	0
1932-33	0	0	0	1958	0	0	0
1933-34	0	0	0	1959	0	0	0
1934-35	0	0	0	1960	0	0	0
1935-36	0	0	0	1961	0	0	0
1936-37	0	0	0	1962	0	0	0
1937-38	0	0	0	1963	0	0	0
1938-39	0	0	0	1964	0	0	0
1939-40	0	0	0	1965	0	0	0
1940-41	0	0	0	1966	0	0	0
1941-42	0	0	0	1967	0	0	0
1942-43	0	0	0	1968	0	0	0
1943-44	0	0	0	1969	0	0	0
1944	0	0	0	1970	0	0	0
1945	0	0	0	1971	0	0	0
1946	0	0	0	1972	0	0	0
1947	0	0	0	1973	0	0	0
1948	0	0	0	1974	0	0	0
1949	0	0	0	1975	0	0	0
1950	0	0	0	1976	0	0	0
1951	0	0	0	1977	0	0	0
1952	0	0	0	1978	191	4	0
1953	0	0	0	1979	107	0	0
1954	0	0	0	1980	83	4	0
1955	0	0	0	1981	82	8	0
1956	0	0	0	1982	92	5	0

Notes:
1. The 1931–1943 years are April–March but from 1944 onwards are calendar years.
2. Data up to 1985 are from fishing returns: Data from 1986 to 1990 are from Quota Management Reports.
3. Data for the period 1931 to 1982 are based on reported landings by harbour and are likely to be underestimated as a result of under-reporting and discarding practices. Data includes both foreign and domestic landings.

Table 3: Reported landings (t) of pōrae by FMA, fishing years 1989–90 to 2003–04.

	FMA 1	FMA 2	FMA 3	FMA 7	FMA 8	FMA 9	FMA 10
1989–90	98	4	< 1	< 1	< 1	0	0
1990–91	115	2	0	0	< 1	4	0
1991–92	121	5	< 1	0	0	3	0
1992–93	121	8	0	1	< 1	< 1	0
1993–94	77	12	2	0	< 1	1	< 1
1994–95	109	5	0	0	< 1	1	< 1
1995–96	94	8	< 1	< 1	< 1	4	0
1996–97	80	7	< 1	1	< 1	2	0
1997–98	75	4	< 1	< 1	< 1	3	0
1998–99	58	3	3	< 1	< 1	1	0
1999–00	55	4	< 1	2	< 1	1	0
2000–01	64	2	1	< 1	< 1	2	0
2001–02	55	3	1	< 1	< 1	< 1	0
2002–03	62	2	< 1	0	< 1	2	0
2003–04	32	2	< 1	< 1	< 1	2	0

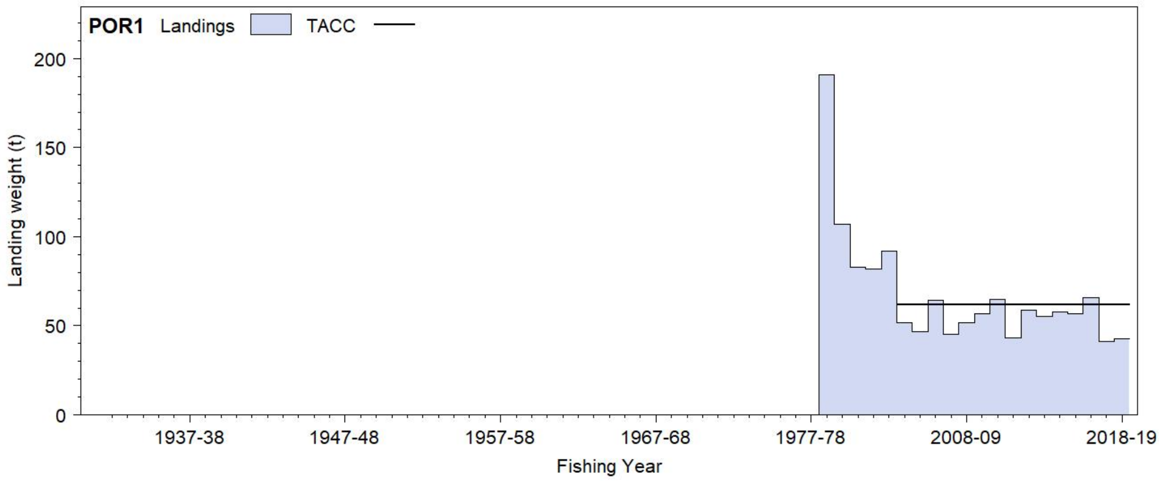


Figure 1: Reported commercial landings and TACC for POR 1 (Auckland East).

Table 4: Reported domestic landings (t) and TACC (t) by pōrae Fishstock, fishing years 2004–05 to 2018–19.

Fishstock	POR 1		POR 2		POR 3		POR 10			
FMA	1		2, 8&9		3,4,5,6&7		10		Total	
	Landings	TACC	Landings	TACC	Landings	TACC	Landings	TACC	Landings	TACC
2004–05	52	62	5	6	< 1	2	0	1	57	71
2005–06	47	62	2	6	< 1	2	0	1	49	71
2006–07	64	62	9	6	0	2	0	1	73	71
2007–08	45	62	7	6	< 1	2	0	1	53	71
2008–09	52	62	5	6	0	2	0	1	57	71
2009–10	57	62	11	6	< 1	2	0	1	68	71
2010–11	65	62	7	6	< 1	2	0	1	72	71
2011–12	43	62	7	6	< 1	2	0	1	51	71
2012–13	58	62	9	18	0	2	0	1	67	83
2013–14	55	62	10	18	< 1	2	0	1	66	83
2014–15	58	62	14	18	< 1	2	0	1	72	83
2015–16	57	62	9	18	< 1	2	0	1	66	83
2016–17	66	62	24	18	< 1	2	0	1	90	83
2017–18	41	62	13	18	< 1	2	0	1	55	83
2018–19	43	62	12	18	< 1	2	0	1	55	83

1.2 Recreational fisheries

A National Panel Survey of recreational fishers was conducted for the first time throughout 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 (Wynne-Jones et al 2014). The panel members were contacted regularly about their fishing activities and harvest information collected in standardised phone interviews. The national panel survey was repeated during the 2017–18 fishing year using very similar methods to produce directly comparable results (Wynne-Jones et al 2019). Recreational catch estimates from the two national panel surveys are given in Table 5. Note that national panel survey estimates do not include recreational harvest taken under s111 general approvals.

Table 5: Recreational harvest estimates for pōrae stocks (Wynne-Jones et al 2014, 2019). Mean fish weights were obtained from boat ramp surveys (Hartill & Davey 2015, Davey et al 2019).

Stock	Year	Method	Number of fish	Total weight (t)	CV
POR 1	2011/12	Panel survey	12 371	15.4	0.25
	2017/18	Panel survey	5 397	6.7	0.36
POR 2	2011/12	Panel survey	695	0.9	0.62
	2017/18	Panel survey	1 604	2.0	0.53
POR 3	2011/12	Panel survey	1 938	2.4	0.90
	2017/18	Panel survey	0	0	-

1.3 Customary non-commercial fisheries

There is no quantitative information on customary non-commercial harvest levels of pōrae. Customary non-commercial fishers are likely to catch small quantities of pōrae when targeting other species such as snapper, tarakihi and trevally.

2. BIOLOGY

Pōrae (*Nemadactylus douglasii*) is a common inshore species of northern New Zealand (Kermadec Islands, west Auckland and Northland, east Northland, Hauraki Gulf, and the Bay of Plenty). It is also found at some localities as far south as Kapiti Island, Cook Strait, and Kaikoura over the summer months, but has not been recorded around the Chatham Islands. Pōrae also occurs in southeast Australia (New South Wales to Tasmania), where it is known as the grey or rubberlip morwong.

Pōrae are generally found on reef/sand interfaces in 10–60 m depths, but have been recorded at 100 m. This diurnal species tends to aggregate to form small to large groups over sandy areas. Adults are thought to occupy distinctive home ranges, with individuals residing in the same area for many years. A study along the east coast of Northland recorded an average of 200 pōrae for each kilometre of rocky coastline.

Very little is known about the biology of this species. Pōrae spawn in late summer and autumn, and have an extended planktonic post-larval stage. Juveniles settle to the seafloor when 8–10 cm long. Although they attain a maximum length of at least 70 cm, the average size is 40−60 cm. They live to at least 30 years and growth is believed to slow substantially at maturity (Ayling & Cox 1984, Francis 2001).

3. STOCKS AND AREAS

There is no biological information to suggest separate stocks around New Zealand. However, evidence of residential behaviour and the fact that they are long-lived, suggests that localised depletion is likely to occur.

4. STOCK ASSESSMENT

There is no fishery independent stock assessment information to determine the stock status of pōrae. Biomass estimates have not been determined for pōrae.

5. STATUS OF THE STOCK

Estimates of current and reference biomass are not available. It is not known if recent catch levels or TACs are sustainable. The status of POR 1, 2 and 3 relative to B_{MSY} is unknown.

TACCs and reported landings for the 2017–18 fishing year are summarised in Table 6.

Table 6: Summary of TACCs (t) and reported landings (t) of pōrae for the 2018–19 fishing year.

Fishstock		FMA	2018–19 Actual TACC	2018–19 Reported landings
POR 1	Auckland (East)	1	62	43
POR 2	Central (East)	2	18	12
POR 3	South east, Southland, sub-Antarctic, Challenger	3,4,5,6,7, 8 &9	2	<1
POR 10	Kermedec	10	1	0
Total			83	55

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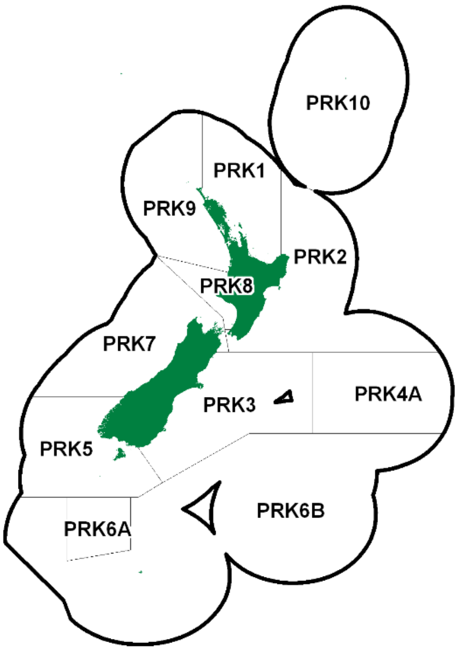
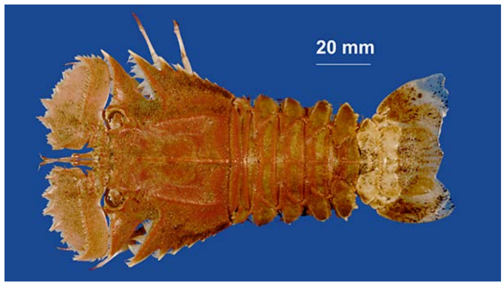
PRAWN KILLER (PRK)

(*Ibacus alticrenatus*)





1. FISHERY SUMMARY

1.1 Commercial fisheries

Prawn killer (*Ibacus alticrenatus*) was introduced into the Quota Management System on 1 October 2007, with a combined TAC of 37.4 t and TACC of 36 t. There are no allowances for customary non-commercial or recreational fisheries, and 1.4 t was allowed for other sources of mortality. Almost all prawn killer are taken as a bycatch in the scampi target bottom trawl fishery in SCI 1 and SCI 2. Reported catches in PRK 1 peaked at 42 t in 1992–93, but declined to less than 0.5 t since 2011–12. Landings in PRK 2 reached a maximum of 8 t in 2002–03, but have been minimal since with less than 0.01 t reported in 2018–19 (Table 1). Landings are minimal to non-existent in other QMAs. Years with higher landings coincide with years in which the scampi fleet fished at shallower depths than usual. They can be legally discarded under Schedule 6 of the Fisheries Act but it is still likely that reported catches are lower than actual catches due to non-reporting.

Table 1: TACCs and reported landings (t) of prawn killer by Fishstock from 1990–91 until the present from CELR and CLR data. QMAs are shown as defined in 2007–08. [Continued on next page]

	PRK 1		PRK 2		PRK 3		PRK 4A	
Fishing year	Landings	TACC	Landings	TACC	Landings	TACC	Landings	TACC
1990–91	11.59	–	0	–	0	–	0	–
1991–92	3.34	–	0.48	–	0	–	0	–
1992–93	42.24	–	6.86	–	0	–	0	–
1993–94	10.95	–	0.03	–	0	–	0	–
1994–95	0.52	–	0	–	0	–	0	–
1995–96	1.78	–	0	–	0	–	0	–
1996–97	23.13	–	0	–	0	–	0	–
1997–98	0	–	0	–	0	–	0	–
1998–99	0	–	0.19	–	0	–	0	–
1999–00	0.08	–	0	–	0	–	0	–
2000–01	0	–	0	–	0	–	0	–
2001–02	6.05	–	0.37	–	0	–	0	–
2002–03	20.99	–	8.09	–	0	–	0	–
2003–04	24.35	–	0.57	–	0.01	–	0.01	–
2004–05	3.25	–	1.15	–	0	–	0	–
2005–06	2.25	–	0.20	–	0	–	0	–
2006–07	4.6	–	0.10	–	0	–	0	–
2007–08	5.36	24.5	0.92	3.5	0.01	1	0.02	1
2008–09	0.22	24.5	0.08	3.5	0	1	0	1

Table 1 [Continued]

	PRK 1		PRK 2		PRK 3		PRK 4A	
Fishstock	**Landings**	**TACC**	**Landings**	**TACC**	**Landings**	**TACC**	**Landings**	**TACC**
2009–10	0.75	24.5	0.03	3.5	0	1	0	1
2010–11	3.55	24.5	0.08	3.5	0	1	0	1
2011–12	0.42	24.5	0.17	3.5	0	1	0	1
2012–13	0.26	24.5	0.02	3.5	0	1	0	1
2013–14	0.10	24.5	0.04	3.5	0	1	0	1
2014–15	0.00	24.5	0.04	3.5	0	1	0	1
2015–16	0.02	24.5	0.07	3.5	0	1	0	1
2016–17	0.35	24.5	0.15	3.5	0	1	0.01	1
2017–18	0.45	24.5	0.01	3.5	0	1	0	1
2018–19	0.30	24.5	<0.01	3.5	0	1	<0.01	1

	PRK 5		PRK 6A		PRK 6B		PRK 7	
Fishstock	**Landings**	**TACC**	**Landings**	**TACC**	**Landings**	**TACC**	**Landings**	**TACC**
1990–91	0	–	0	–	0	–	0	–
1991–92	0	–	0	–	0	–	0	–
1992–93	0	–	0	–	0.02	–	0	–
1993–94	0	–	0	–	0	–	0	–
1994–95	0	–	0	–	0	–	0	–
1995–96	0	–	0	–	0	–	0	–
1996–97	0	–	0	–	0	–	0	–
1997–98	0	–	0	–	0	–	0	–
1998–99	0	–	0	–	0	–	0	–
1999–00	0	–	0	–	0	–	0	–
2000–01	0	–	0	–	0	–	0	–
2001–02	0	–	0	–	0	–	0	–
2002–03	0	–	0	–	0	–	0	–
2003–04	0	–	0	–	0	–	0	–
2004–05	0	–	0	–	0	–	0	–
2005–06	0	–	0	–	0	–	0.01	–
2006–07	0	–	0	–	0	–	0.03	–
2007–08	0	1	0	1	0	1	1.2	1
2008–09	0	1	0	1	0	1	0.88	1
2009–10	0	1	0	1	0	1	0.48	1
2010–11	0	1	0	1	0	1	0.69	1
2011–12	0	1	0	1	0	1	0.73	1
2012–13	0	1	0	1	0	1	0.60	1
2013–14	0.001	1	0	1	0	1	0.66	1
2014–15	0	1	0	1	0	1	1	1
2015–16	0	1	0	1	0	1	1.66	1
2016–17	0	1	0	1	0	1	1.37	1
2017–18	0	1	0	1	0	1	0.55	1
2018–19	0	1	0	1	0	1	0.45	1

	PRK 8		PRK 9		TOTAL	
Fishstock	**Landings**	**TACC**	**Landings**	**TACC**	**Landings**	**TACC**
1990–91	0	–	0	–	11.58	–
1991–92	0	–	0	–	3.82	–
1992–93	0	–	0	–	49.12	–
1993–94	0	–	0	–	10.98	–
1994–95	0	–	0	–	0.52	–
1995–96	0	–	0	–	1.78	–
1996–97	0	–	0	–	23.13	–
1997–98	0	–	0	–	0	–
1998–99	0	–	0	–	0.19	–
1999–00	0	–	0	–	0.08	–
2000–01	0	–	0	–	0	–
2001–02	0	–	0	–	6.42	–
2002–03	0	–	0	–	29.08	–
2003–04	0	–	0	–	24.94	–
2004–05	0	–	0	–	4.40	–
2005–06	0	–	0.01	–	2.47	–
2006–07	0	–	0	–	4.73	–
2007–08	0	1	0	1	7.51	36
2008–09	0	1	0	1	1.18	36
2009–10	0	1	0	1	1.27	36
2010–11	0.01	1	0	1	4.33	36
2011–12	0	1	0	1	1.32	36
2012–13	0.01	1	0.01	1	0.90	36
2013–14	0.01	1	0.15	1	0.94	36
2014–15	0	1	0	1	1.04	36
2015–16	0.01	1	0.02	1	1.78	36
2016–17	0	1	1.26	1	3.14	36
2017–18	0	1	0	1	1.01	36
2018–19	0	1	0.01	1	0.76	36

1.2 Recreational fisheries
Given the depths and locations at which prawn killer are found recreational catch is likely to be negligible or non-existent.

1.3 Customary non-commercial fisheries
Given the depths and locations at which prawn killer are found customary catch is likely to be negligible or non-existent.

1.4 Illegal catch
No quantitative information is available on the level of illegal catch of prawn killer. Given the low value and lack of markets illegal catches are unlikely.

1.5 Other sources of mortality
There is no quantitative information on other sources of mortality, although analysis of benthic invertebrate samples and the distribution of trawl tows in the Bay of Plenty (PRK 1) suggests that this species is negatively affected by trawling.

2. BIOLOGY

Ibacus alticrenatus is widely distributed around the New Zealand coast, principally in depths of 80–300 m. Prawn killers are found on soft sediment seafloors, where they dig into the substrate and cover themselves with sediment.

There is not much information about growth and development of *I. alticrenatus* in New Zealand waters, but females are thought to mature at a carapace length of about 40 mm. Trawl surveys of the Bay of Plenty and Hawke Bay and Wairarapa regions have found maximum carapace length of 46 and 52 mm for males and females respectively. Information from Australia suggests that this species has relatively low fecundity (1700–14 800 eggs, increasing with size) and spawns annually. Larval development takes 4–6 months, an intermediate duration for a Scyllarid lobster. Females of other *Ibacus* species reach maturity about two years after settlement and longevity is suggested to be five years or more. No ageing work has been carried out on prawn killer in either New Zealand or Australia.

The following species may also be caught as bycatch of the prawn killer catch – *Ibacus brucei*, *Antipodarctus aoteanus*, and *Scyllarus mawsoni* (which is thought to be rare).

3. STOCKS AND AREAS

For management purposes stock boundaries are based on those used for scampi. There is no biological information on stock structure, recruitment patterns, or other biological characteristics which might indicate stock boundaries, but there are three main fishing areas where they are caught: Bay of Plenty, and to a lesser extent Hawke Bay and Wairarapa and the northern west coast of the South Island. The lack of prawn killer bycatch in the scampi target fisheries on the Mernoo Bank (PRK 3) and around the Auckland Islands (PRK 6A) would suggest the prawn killer numbers are very low to non-existent south of the three main areas described above and they probably prefer warmer waters.

4. STOCK ASSESSMENT

4.1 Estimates of fishery parameters and abundance
There are no estimates of fishery parameters or abundance for any prawn killer fishstock. Sporadic and varying catches by the scampi fleet mean that development of reliable CPUE indices is not possible.

4.2 Biomass estimates
There are no reliable biomass estimates for any prawn killer fishstock. Combined trawl and photographic surveys for scampi in the Bay of Plenty (PRK 1) and Hawke Bay and Wairarapa (PRK 2) are the only

trawl surveys that catch prawn killer regularly. Prawn killer biomass estimates from these surveys are variable from year to year and have high coefficients of variation. The focus of these surveys has changed over the years to focus more on photographic work and not all strata have been surveyed in all years.

4.3 Yield estimates and projections

There are no estimates of *MCY* or *CAY* for any prawn killer fishstock.

5. STATUS OF THE STOCKS

There are no estimates of reference or current biomass for any prawn killer fishstock. It is not known whether prawn killer stocks are at, above, or below a level that can produce *MSY*.

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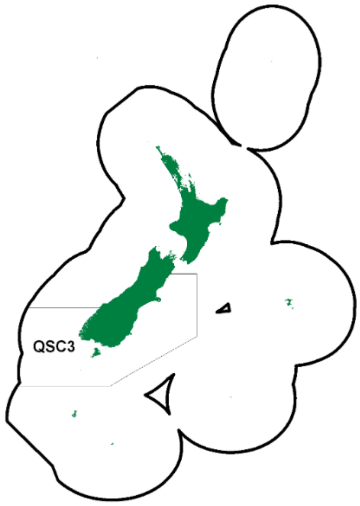
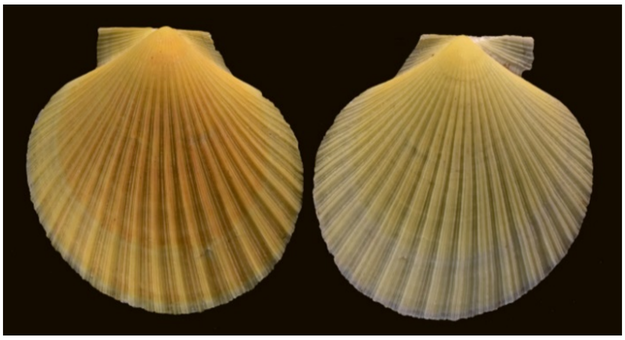
QUEEN SCALLOPS (QSC)

(*Zygochlamys delicatula*)





1. FISHERY SUMMARY

Queen scallops were introduced into the QMS in October 2002, with a current TACC (unchanged since its introduction) of 380 t and a 20 t allowance for other sources of fishing related mortality. The fishing year runs from 1 October to 30 September and the catch is reported in greenweight.

1.1 Commercial fisheries

The QSC 3 fishery initially developed in the 1984–85 fishing year; it is a small-scale fishery with only a few fishing vessels involved (Michael & Cranfield 2001). Queen scallops (*Zygochlamys delicatula*) are predominantly harvested commercially off the Otago coast, in depths of 130–200 m (predominately 150–200 m) near the edge of the continental shelf.

Reported landings from the QSC 3 fishery peaked at 711 t in the 1985–86 fishing year (not shown in the table below), before decreasing to an average of 33 t in the early 1990s. By the early 2000s landings increased to an average of 135 t, although this is more likely to be associated with economic, rather than biological, factors. Since 2010 landings have fluctuated between 1.9 and 70.5 t. The TACC was set in 2002 at a slightly higher level than recent landings but lower than the non-QMS competitive catch limit of 750 t which applied to FMA 3 from 1990–91; landings have remained well below the TACC since its introduction. Reported landings of queen scallops are given in Table 1, and Figure 1 shows historical landings and the TACC for QSC 3.

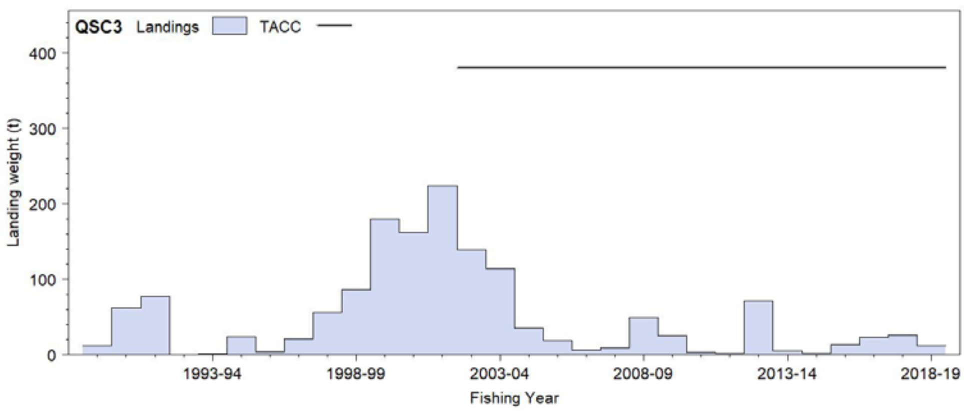


Figure 1: Reported commercial landings and TACC for QSC 3 (South East Coast, Southland).

The queen scallop fishery is a trawl fishery using specialised gear (including a relatively light 'tickler' chain or wire to induce swimming) and the catch is sorted both mechanically and by hand (Michael & Cranfield 2001, R. Belton pers. comm.).

Table 1: Reported landings (t greenweight) of queen scallops (QSC) by FMA, QMA and fishing year by all methods trawl and dredge) 1989–90 until the present day from Quota Management Reports (QMR), Monthly Harvest Returns (MHR) and Catch Effort Landing Returns (CELR landed and CELR estimated).

	QSC 3		FMA 3		FMA 5
Fishing year	Catch (QMR/MHR)	TACC*	Estimated catch (TCEPR/CELR)	Landings (CELR/CLR)	Landings (CELR/CLR)
1989–90	11.9	-	288.1	-	-
1990–91	61.8	-	238.3	-	22.9
1991–92	77.4	-	193.7	-	-
1992–93	0.4	-	104.7	-	-
1993–94	1.1	-	133.6	-	-
1994–95	23.6	-	146.9	-	-
1995–96	4.5	-	149.5	-	0.2
1996–97	20.9	-	118.0	-	6.6
1997–98	56.0	-	208.3	-	6.0
1998–99	85.9	-	81.7	-	-
1999–00	180.2	-	176.8	-	-
2000–01	162.2	-	162.1	-	-
2001–02	223.7	-	168.9	-	-
2002–03	139.0	380	-	-	-
2003–04	114.0	380	-	-	-
2004–05	35.1	380	-	-	-
2005–06	18.6	380	-	-	-
2006–07	6.5	380	-	-	-
2007–08	9.5	380	-	-	-
2008–09	48.7	380	-	-	-
2009–10	25.3	380	-	-	-
2010–11	2.8	380	-	-	-
2011–12	1.9	380	-	-	-
2012–13	70.5	380			
2013–14	5.024	380	-	-	-
2014–15	1.788	380	-	-	-
2015–16	13.55	380	-	-	-
2016–17	23.13	380	-	-	-
2017–18	25.74	380	-	-	-
2018–19	12.17	380	-	-	-

* QMS introduction 1 October 2002

1.2 Recreational fisheries
There is no known recreational fishery for queen scallops.

1.3 Customary fisheries
There is no known customary harvest of queen scallops.

1.4 Illegal catch
Current levels of illegal harvest are not known.

1.5 Other sources of mortality
No quantitative estimate of other sources of mortality is available. Some grading of catch may occur (queen scallops may be returned to the sea) and an allowance of 20 t for potential mortality has been set within the current TAC.

2. BIOLOGY

The New Zealand queen scallop (*Zygochlamys delicatula*) is also known as the southern queen scallop, southern fan scallop, and gem scallop. This small pectinid species is distributed on the outer continental shelf along the east coast of the South Island, from Kaikoura down to Macquarie Island. There are nine other species in the genus, none of which have attracted commercial interest, probably because of their small size. Similar species such as *Chlamys islandica* and *Chlamys varia* support important fisheries in other countries. New Zealand queen scallops are distributed from Kaikoura to the southern islands including the Snares, Bounty, Antipodes, and Macquarie Islands. There are no records of live queen scallops being caught north of Kaikoura, or on the west coast of the South Island.

A dredge survey off Otago in October 1983 showed that queen scallops were distributed in long patches orientated along the slope of the continental shelf. They were most abundant in depths beyond 130 m, on the plateau between the Taiaroa and Papanui Canyons, and south. North of the Taiaroa Canyon catches diminished steadily towards the Karitane Canyon; few were caught north of the canyon. Only low numbers of queen scallops were caught in depths shallower than 110 m.

Juvenile queen scallops are frequently found attached to fragments of bryozoa and other biogenic debris, including the shells of other scallops and the dredge oyster. Height frequency distributions of samples show that the size composition of the population differs with area, and it is inferred that settlement probably varies spatially and temporally. The estimated 40–50 days larval life may result in queen scallop larvae being well mixed, both vertically and horizontally, in the water column. Predation of newly settled spat may also affect the pattern of recruitment and add to the variability in year class representation.

Estimates of growth for New Zealand queen scallops suggest that they become sexually mature at four years for males and five years for females. As length is slightly less than height, queen scallops are estimated to reach the minimum takeable size of 50 mm at about eight years. However, growth estimates are uncertain, with information from tagging studies suggesting that queen scallops enter the fishery much earlier, at three to five years.

3. STOCKS AND AREAS

Queen scallops are distributed throughout the QSC 3 area. From harvest records the scallops inhabit waters between 130 and 200 m depth. The extent to which various beds or populations are separate reproductively or functionally is not known.

4. STOCK ASSESSMENT

4.1 Estimates of fishery parameters and abundance

No estimates of fishery parameters or abundance are available at present.

4.2 Biomass estimates

A trawl survey, (Jiang et al 2005) carried out in February–April 2004, provided estimates of total and recruited biomass (shells at least 50 mm) available from the fished area of QSC 3, from Moeraki to just north of the Nuggets within the depth range 130 to 200 m, which covers 90% of the fished area within QSC 3 (Table 2). These estimates assumed that the efficiency of the survey trawl was 100%. However trawl efficiency is unlikely to be 100% and in other scallop fisheries can vary significantly depending on dredge and substrate type. Consequently estimates of current absolute biomass cannot be estimated. The Shellfish Working Group had concerns over methodology and conduct of the survey, and that the reported survey CVs may not be reliable.

Table 2: Estimated scallop biomass (recruit and pre-recruit) (t) in fished areas of QSC 3 February–April 2004.

Biomass Recruit (CV)	Biomass (CV) Pre-recruit	Total Biomass (CV)
1 950.8 (18.2)	363.6 (21.48)	2 314.4 (18.22)

4.3 Yield estimates and projections

As absolute biomass has not been estimated, *MCY* cannot be estimated

CAY cannot be estimated.

5. STATUS OF THE STOCKS

Stock structure assumptions

QSC 3 is assumed to be a single stock.

- QSC - *Zygochlamys delicatula*

Stock Status	
Most Recent Assessment Year	2004
Assessment Runs Presented	Recruited biomass (shells ≥ 50 mm)
Reference Points	Target: Undefined Soft Limit: 20% B_0 Hard Limit: 10% B_0 Overfishing threshold: -
Status in relation to Target	-
Status in relation to Limits	Unknown
Historical Stock Status Trajectory and Current Status -	

Fishery and Stock Trends	
Recent Trend in Biomass or Proxy	Unknown
Recent Trend in Fishing Mortality or Proxy	Unknown
Other Abundance Indices	-
Trends in Other Relevant Indicators or Variables	Landings are less than a quarter of the TACC and have generally been declining since 2002–03.

Projections and Prognosis		
Stock Projections or Prognosis	Unknown	
Probability of Current Catch or TACC causing Biomass to remain below or to decline below Limits	Soft Limit: Unknown Hard Limit: Unknown	
Probability of Current Catch or TACC causing Overfishing to continue or to commence	-	
Assessment Methodology		
Assessment Type	-	
Assessment Method	-	
Assessment Dates	-	Next assessment: Unknown
Overall assessment quality rank	-	
Main data inputs (rank)	-	
Data not used (rank)	-	
Changes to Model Structure and Assumptions	-	
Major Sources of Uncertainty	-	

Qualifying Comments
Landings are thought to be declining in recent times due to economic rather than biological factors.

Fishery Interactions
-

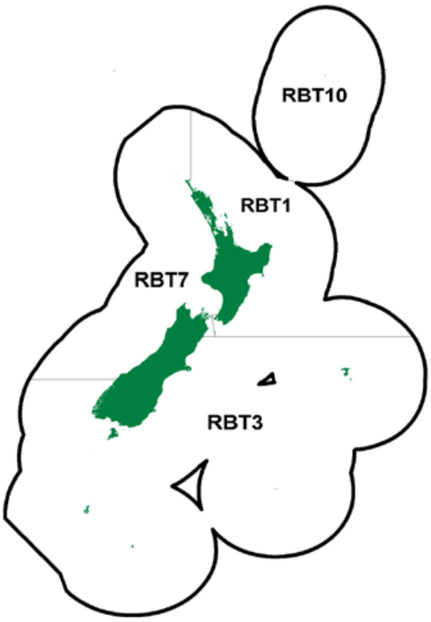
6. FOR FURTHER INFORMATION

Jiang, W; Gibbs, M; Hatton, S (2005) Stock assessment of the queen scallop fishery in QSC3. Final Research Report for Ministry of Fisheries project QSC2002/01. (Unpublished report held by Fisheries New Zealand, Wellington.)

Michael, K P; Cranfield, H J (2001) A summary of the fishery, commercial landings, and biology of the New Zealand queen scallop, *Zygochlamys delicatula* (Hutton, 1873). *New Zealand Fisheries Assessment Report 2001/68*. 25p.

REDBAIT (RBT)

(*Emmelichthys nitidus*)



1. FISHERY SUMMARY

1.1 Commercial fisheries

Redbait (*Emmelichthys nitidus*) was introduced to the Quota Management System on 1 October 2009, with a combined TAC of 5 316 t and TACC of 5 050 t. There are no allowances for customary non-commercial or recreational fisheries, and 266 t was allowed for other sources of mortality.

RBT is mainly taken as bycatch of the jack mackerel target trawl fishery, but also widely taken as bycatch of barracouta trawl tows, with some taken in the squid and hoki fisheries. A target fishery developed in the mid-2000s. Reported total landings ranged from 2 184 to 4 307 t during the 2000s, but declined across all QMAs and target fisheries in 2009–10 and 2010–11 to nearer 1 000 t. Since the fishing year 2011-12 total landings have ranged between 1 456 and 2 856 t.

RBT 3 includes the southern fisheries for squid, and fisheries for jack mackerel on the Mernoo Bank and Chatham Rise, and accounted for most of the redbait landed in each year during the 1990s. From 2002–03 to 2009–10 however, the jack mackerel fishery on the west coast expanded into north and south Taranaki Bights, with landings from RBT 7 exceeding those from RBT 3. Since 2010 RBT 3 landings have declined, with RBT 3 catches once again making up the bulk of the landings. In 2017-18 just 26 t of RBT 7 were landed compared to 2 647 t of RBT 3. Landings of RBT 1 have been small (less than 5 t) in most years, increasing slightly in the late 2000s.

TACs, allowances and TACCs from 1 October 2009 are reported in Table 1. Table 2 and Figure 1 show historical landings from 2001–02 to the present, reported by QMAs.

Table 1: TACs, allowances and TACCs of redbait.

Fishstock	Other mortality	Customary non–commercial and recreational	TACC	TAC
RBT 1	1	0	19	20
RBT 3	115	0	2 190	2 305
RBT 7	150	0	2 841	2 991
RBT 10	0	0	0	0

Table 2: Reported landings (t) of redbait by Fishstock and TACCs from 2001–02 to 2018–19.

	RBT 1		RBT 3		RBT 7		RBT 10			
FMA	1, 2		3, 4, 5, 6		7, 8, 9		10		Total	
Fishstock	Landings	TACC	Landings	TACC	Landings	TACC	Landings	TACC	Landings	TACC
2001–02	1	-	1 638	-	1 669	-	0	-	3 308	-
2002–03	1	-	1 219	-	2 113	-	0	-	3 333	-
2003–04	1	-	1 535	-	2 771	-	0	-	4 307	-
2004–05	1	-	676	-	1 507	-	0	-	2 184	-
2005–06	3	-	2 016	-	1 936	-	0	-	3 955	-
2006–07	3	-	1 098	-	1 506	-	0	-	2 607	-
2007–08	5	-	560	-	2 376	-	0	-	2 941	-
2008–09	10	-	1 808	-	1 649	-	0	-	3 467	-
2009–10	9	19	886	2 190	170	2 841	0	0	1 066	5 050
2010–11	21	19	284	2 190	713	2 841	0	0	1 017	5 050
2011–12	2	19	1 229	2 190	369	2 841	0	0	1 599	5 050
2012–13	2	19	1 826	2 190	325	2 841	0	0	2 153	5 050
2013–14	4	19	2 774	2 190	78	2 841	0	0	2 856	5 050
2014–15	4	19	2 020	2 190	132	2 841	0	0	2 156	5 050
2015–16	5	19	1 068	2 190	383	2 841	0	0	1 456	5 050
2016–17	5	19	2 435	2 190	160	2 841	0	0	2 600	5 050
2017–18	2	19	1 687	2 190	75	2 841	0	0	1 764	5 050
2018–19	<1	19	2 647	2 190	26	2 841	0	0	2 673	5 050

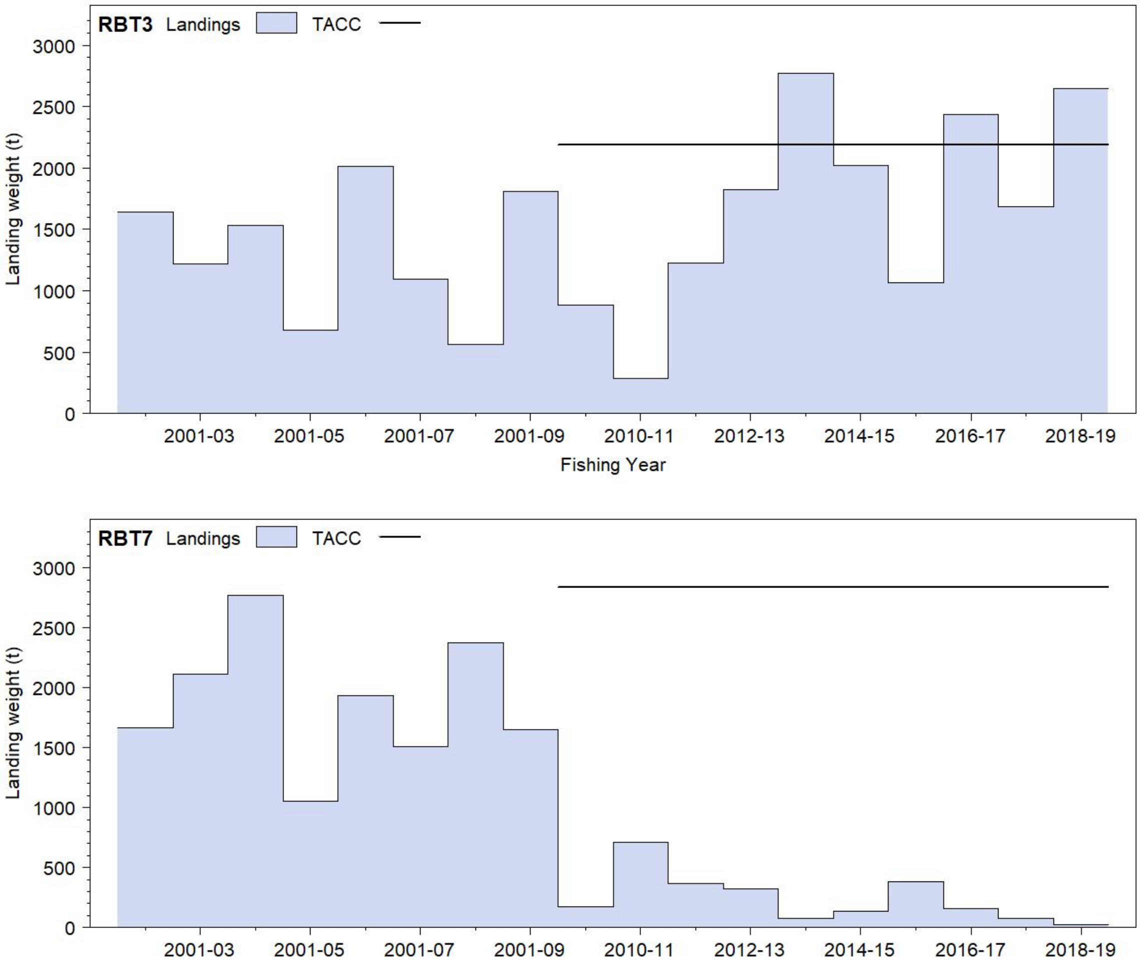


Figure 1: Reported commercial landings and TACC for the two main RBT stocks. From top: RBT 3 (South East Coast) and RBT 7 (Challenger).

1.2 Recreational fisheries
There is no known non-commercial fishery for redbait.

1.3 Customary non-commercial fisheries
There is no known customary non-commercial fishery for redbait.

1.4 Illegal catch
No quantitative information is available on the level of illegal catch of redbait.

1.5 Other sources of mortality
Taylor (2009) described up to 345 tonnes (but usually less than 200 t annually of redbait reported as discarded between 1988–89 and 2008–09.

2. BIOLOGY

Emmelichthys nitidus is a schooling, bathypelagic species that is closely related to rubyfish. It is widely distributed around New Zealand in depths from 85 to 500 m. Juveniles are found at the surface and adults near the bottom in deeper waters, including seamounts.

There is not much information about growth and development of redbait in New Zealand. Offshore studies suggest regional differences in maximum size with a maximum age of 10 years in east Victoria and 7 years in Tasmania, where the maximum reported size of redbait is 316 mm fork length. Spawning in Tasmania is thought to last 2–3 months during spring, with 50% mature at 24 cm FL and 2–3 years. Von Bertalanffy growth parameters of Tasmanian redbait for both sexes combined are given in Table 3.

Research data from New Zealand show that the maximum size of redbait here is about 420 mm FL, which is larger than most other regions where length of this species has been recorded, except South Africa. Recent validation of the ageing of the closely related rubyfish in New Zealand confirms maximum ages of 90+ suggesting that some emmelichthyids may be long-lived, so current estimates of growth and maximum age may not be reliable

Table 3 shows estimated biological parameters for redbait.

Table 3: Estimates of biological parameters for redbait. Growth is based on Australian studies (Welsford & Lyle 2003).

Fishstock		**Estimate**		**Source**
1. Weight = a (length)^b (Weight in g, length in cm fork length)				
	Combined sexes			Combined sexes
RBT (All)	**a**		**b**	
	0.004947		3.259168	
				NIWA (unpub. data)
2. von Bertalanffy growth parameters				
	Combined sexes			
RBT (Tasmania)	L_∞	k	t_0	
	28.7	0.56	-0.36	Welsford & Lyle (2003)

3. STOCKS AND AREAS

There is no information about stock structure, recruitment patterns, or other biological characteristics that would indicate stock boundaries. As the catch of redbait has been mainly (66%) from bycatch in the jack mackerel trawl fisheries, management boundaries have been set the same as those used for jack mackerel. Analysis of encounter rates suggests a north-south seasonal movement of redbait may occur at a spatial scale that is greater than QMAs.

4. STOCK ASSESSMENT

4.1 Estimates of fishery parameters and abundance

There are no estimates of fishery parameters or abundance for any redbait fishstock.

4.2 Biomass estimates

There are no biomass estimates for any redbait fishstock.

4.3 Yield estimates and projections

There are no yield estimates for any redbait fishstock.

5. STATUS OF THE STOCKS

There are no estimates of reference or current biomass for any redbait fishstock. It is not known whether redbait stocks are at, above, or below a level that can produce *MSY*.

6. FOR FURTHER INFORMATION

Bentley, N; Kendrick, T H; MacGibbon, D J (2014) Fishery characterisation and catch-per-unit-effort analyses for redbait (*Emmelichthys nitidus*), 1989–90 to 2010–11. (2014 Draft New Zealand Fisheries Assessment Report held by Fisheries New Zealand.)

Taylor, P R (2009) A summary of information on redbait *Emmelichthys nitidus*. Final Research Report for Ministry of Fisheries Project SAP2008-18. (Unpublished report held by Fisheries New Zealand, Wellington.)

Welsford, D C; Lyle, J M (2003) Redbait (*Emmelichthys nitidus*): a synopsis of fishery and biological data. *TAFI Technical Report Series 20*. 32 p.