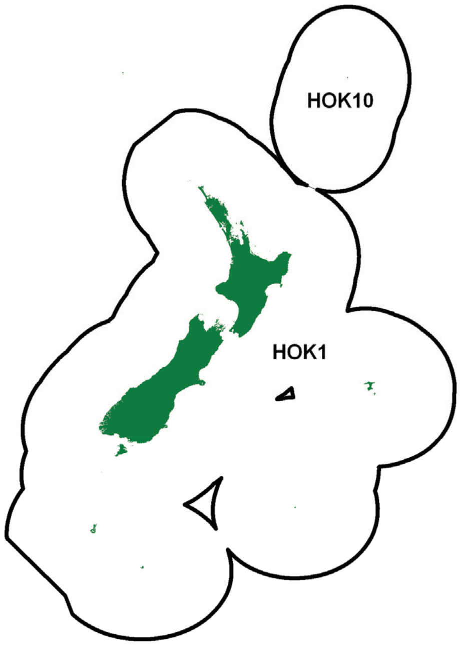
HOKI (HOK)

(*Macruronus novaezelandiae*)
Hoki



1. FISHERY SUMMARY

1.1 Commercial fisheries

Historically, the main fishery for hoki operated from mid-July to late August on 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. Since 1988, another major fishery has developed in Cook Strait, where separate spawning aggregations of hoki occur. The spawning season in Cook Strait runs from late June to mid September, peaking in July and August. Small catches of spawning hoki are taken from other spawning grounds off the east coast South Island (ECSI) and late in the season at Puysegur Bank.

Outside the spawning season, when hoki disperse to their feeding grounds, substantial fisheries have developed since the early 1990s on the Chatham Rise and in the Sub-Antarctic. These fisheries usually operate in depths of 400–800 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). Annual catches ranged between 175 000 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 have since declined as the TACC has been reduced (Table 2). From 1 October 2007 to 30 September 2009 the TACC was 90 000 t, increasing to 110 000 t from 1 October 2009.

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 1986-97 to 2008-09. Reported catches include TCEPR and CELF data (from 1989-90), LCER data (from 2003-04), NCELR data (from 2006-07), and TCER and LTCER data (from 2007-08). Catches are rounded to the nearest 500 t.

Year	Reported catch	Estimated catch	TACC
1986–1987	158 000	175 000	250 000
1987–1988	216 000	255 000	250 000
1988–1989	208 500	210 000	250 000
1989–1990	210 000	210 000	251 884
1990–1991	215 000	215 000	201 897
1991–1992	215 000	215 000	201 897
1992–1993	195 000	195 000	202 155
1993–1994	191 000	190 000	202 155
1994–1995	174 000	168 000	220 350
1995–1996	210 000	194 000	240 000
1996–1997	246 000	230 000	250 000
1997–1998	269 000	261 000	250 000
1998–1999	244 500	234 000	250 000
1999–2000	242 500	237 000	250 000
2000–2001	230 000	224 500	250 000
2001–2002	195 500	195 500	200 000
2002–2003	184 500	180 000	200 000
2003–2004	136 000	133 000	180 000
2004–2005	104 500	102 000	100 000
2005–2006	104 500	100 500	100 000
2006–2007	101 000	96 500	100 000
2007–2008	89 500	87 500	90 000
2008–2009	89 900	87 500	90 000

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.

The pattern of fishing has changed markedly since 1988–89 when over 90% of the total catch was taken in the WCSI spawning fishery (Tables 3 and 4). This has been due to a combination of TAC changes and re-distribution of fishing effort. The catch from the WCSI declined steadily from 1988–89 to 1995–96, increased again to between 90 000 and 107 000 t from 1996–97 until 2001–02, then dropped sharply over the last seven years, to 20 500 t in 2008–09, which is about 23% of the total hoki catch. In Cook Strait, catches peaked at 67 000 t in 1995–96, but have been below 25 000 t for the last five years. Non-spawning catches on the Chatham Rise increased from 1993–94, peaked at about 75 000 t in 1997–98 and 1998–99, then decreased to a low of 30 700 t in 2004–05. The Chatham Rise catch has increased over the past four years to 39 000 t in 2008–09, and is now the largest hoki fishery, contributing about 45% of the total catch. Catches from the Sub-Antarctic peaked at over 30 000 t in 1999–00 to 2001–02, declined to a low of 6200 t in 2004–05 before increasing slowly to 9 800 t in 2008–09. Catches from other areas have remained at relatively low levels (Table 3).

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 of Fisheries that 65% of the catch should be taken from the western fisheries to reduce pressure on the eastern stock. This agreement was removed 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 a further agreement with the Minister that only 40% of the catch should be taken from western fisheries. From 1 October 2007 the target catch from the western fishing grounds was further reduced to 25 000 t within the overall TACC of 90 000 t. This target was exceeded in both 2007–08 and 2008–09, with about 30 000 t taken from western areas (Table 3). Figure 1 shows the historical landings and TACC for HOK1, and also the eastern and western catch components of this stock since 1988-89.

Table 3: Estimated* total catch (t) of hoki by area, 1988–89 to 2008–09. Estimated catches were based on data reported on TCEPR and CELR forms from 1988–89, but also include data reported on LCER (from 2003-04), NCELR (from 2006-07), and TCER and LTCER data (both from from 2007-08). Estimated catches were scaled to reported (QMR or MHR) catch totals.

	Spawning fisheries				Non-spawning fisheries				
Fishing Year	WCSI	Puysegur	Cook Strait	ECSI	Sub-Antarctic	Chatham Rise and ECSI	ECNI	Unrep.	Total catch
1988–1989	188 000	3 500	7 000	–	5 000	5 000	–	–	208 500
1989–1990	165 000	8 000	14 000	–	10 000	13 000	–	–	210 000
1990–1991	154 000	4 000	26 500	1 000	18 000	11 500	–	–	215 000
1991–1992	105 000	5 000	25 000	500	34 000	45 500	–	–	215 000
1992–1993	98 000	2 000	21 000	–	26 000	43 000	2 000	3 000	195 000
1993–1994	113 000	2 000	37 000	–	12 000	24 000	2 000	1 000	191 000
1994–1995	80 000	1 000	40 000	–	13 000	39 000	1 000	–	174 000
1995–1996	73 000	3 000	67 000	1 000	12 000	49 000	3 000	2 000	210 000
1996–1997	91 000	5 000	61 000	1 500	25 000	56 500	5 000	1 000	246 000
1997–1998	107 000	2 000	53 000	1 000	24 000	75 000	4 000	3 000	269 000
1998–1999	90 100	3 000	46 500	2 100	24 300	75 600	2 600	–	244 500
1999–2000	101 100	2 900	43 200	2 400	34 200	56 500	1 400	500	242 400
2000–2001	100 600	6 900	36 600	2 400	30 400	50 500	2 100	100	229 900
2001–2002	91 200	5 400	24 200	2 900	30 500	39 600	1 200	–	195 500
2002–2003	73 900	6 000	36 700	7 100	20 100	39 200	900	–	184 700
2003–2004	45 200	1 200	40 900	2 100	11 700	33 600	900	–	135 800
2004–2005	33 100	5 500	24 800	3 300	6 200	30 700	500	100	104 400
2005–2006	38 900	1 500	21 800	700	6 700	34 100	700	–	104 400
2006–2007	33 100	400	20 100	1 000	7 700	37 900	700	–	101 000
2007–2008	21 100	300	18 200	2 400	8 700	37 900	700	–	89 300
2008–2009	20 500	200	17 600	1 100	9 800	39 000	600	–	88 800

– Catch less than 500 t.

From 1986 to 1990 surimi vessels dominated the catches and took about 60% of the annual WCSI catch. However, since 1991, the surimi component of catches has decreased and processing to head and gut, or to fillet product has increased, as has “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. Since 1998 twin-trawl rigs have been introduced in all hoki fisheries.

Table 4: Proportions of total catch.

	Spawning fisheries		Non-spawning fisheries	
Fishing	West	East	West	East
1988–1989	92%	3%	2%	3%
1989–1990	82%	7%	5%	6%
1990–1991	74%	13%	8%	5%
1991–1992	51%	12%	16%	21%
1992–1993	51%	11%	14%	24%
1993–1994	60%	19%	7%	14%
1994–1995	47%	23%	7%	23%
1995–1996	36%	33%	6%	25%
1996–1997	39%	26%	10%	25%
1997–1998	41%	20%	9%	30%
1998–1999	38%	20%	10%	32%
1999–2000	43%	19%	14%	24%
2000–2001	47%	17%	13%	23%
2001–2002	49%	14%	16%	21%
2002–2003	43%	24%	11%	22%
2003–2004	34%	32%	9%	25%
2004–2005	37%	27%	6%	30%
2005–2006	39%	21%	7%	33%
2006–2007	33%	21%	8%	38%
2007–2008	24%	23%	10%	43%
2008–2009	23%	21%	11%	45%

Total Allowable Commercial Catch (TACC) and area restrictions

In the 2008–09 fishing year the TACC for HOK1 was 90 000 t. This TACC applied to all areas of the EEZ except the Kermadec FMA which had a TACC of 10 t. There was an agreement with the Minister of Fisheries that only 25 000 t of the TACC should be taken from western stock areas.

Chartered vessels may not fish inside the 12-mile Territorial Sea and there are various vessel size restrictions around some parts of the coast. On the WCSI, a 25-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 large areas to bottom trawling and dredging (see section 5.1 below under Benthic Protected Areas).

The Hoki Fishery Management Company introduced a Code of Practice for hoki target trawling in 2001 with the aim of protecting small fish (less than 60 cm). The main components of this Code of Practice were: 1) a restriction on fishing in waters shallower than 450 m; and 2) a rule requiring vessels to ‘move on’ if there are more than 10% small hoki in the catch; 3) seasonal and area closures in spawning fisheries (see section 5.5). The Code of Practice was significantly revised by the DeepWater Group from 1 October 2009, and now aims to manage and monitor fishing effort within four industry Hoki Management areas, where there are thought to be high abundance of juvenile hoki (Narrows Basin of Cook Strait, Canterbury Banks, Mernoo, and Puysegur). These areas are closed to hoki target trawling by vessels greater than 28 m, 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 s less than 55 cm total length) comprise more than 20% of the hoki catch by number.

2008–09 Hoki fishery

The overall catch of 88 800 t was 1200 t lower than the TACC and similar to that in 2007–08. Catches increased in the non-spawning fisheries on the Chatham Rise and in the Sub-Antarctic, but declined slightly in the WCSI and Cook Strait spawning fisheries.

For the third year in a row, the Chatham Rise was the largest hoki fishery, with 39 000 t taken from this area in 2008–09. The median unstandardised catch in bottom trawls targeting hoki in 2008–09 was 1.7 t per hour. Catch rates on the Chatham Rise have been increasing since 2003–04. The Chatham Rise catch was dominated by small hoki from the 2004–06 year-classes and 57% of the catch by number was fish less than 65 cm.

The catch on the WCSI declined by 600 t from 2007–08 to 20 500 t in 2008–09. Recent catches from the WCSI are lowest from this area since the late 1970s. Catches inside the 25 nm line made up 6% of the total WCSI catch in 2008–09, down from a peak of 42% of the catch in 2003–04. Unstandardised catch rates in 2008–09 were similar to those in 2007–08, with a median catch from all midwater tows targeting hoki of 5.1 t per hour. Most of the hoki caught on the WCSI were fish from the 2000–06 year classes (ages 3–9). About 31% of the WCSI catch by number was less than 65 cm. From 1999–00 to 2003–04, the sex ratio of the WCSI catch was highly skewed, with many more females caught than males. This sex bias has reversed in the last five years as the catch of younger fish has increased, and in 2008–09 only 37% of fish in the catch by numbers were females.

The catch from Cook Strait was 17 600 t in 2008–09, the lowest level since 1989–90. Unstandardised catch rates in Cook Strait continue to be high, with a median catch rate of 24.8 t per hour in mid-water tows targeting hoki and a median tow duration of only 0.4 h (equivalent to a median catch of 10.2 t per tow). As on the WCSI, the catch was dominated by young fish from the 2000–06 year-classes (ages 3–9), with some larger older females. Females made up only 38% of the Cook Strait catch and 27% of the fish were less than 65 cm.

The catch from the Sub-Antarctic increased slightly to 9800 t in 2008–09. The percentage of the catch taken by the hoki target fishery in this area fell from over 96% in 2003–04 to 70% in 2006–07, but has increased over the past two years to 76% in 2008–09. The remainder of the hoki catch is taken mainly in fisheries targeting ling, squid, silver and white warehou, and hake. Unstandardised catch rates in bottom trawls targeting hoki have increased over the last three years to 1.2 t per hour in 2008–09, but are still lower than in the other hoki fisheries. Catch-at-age estimates showed the Sub-Antarctic catch, like that from the other areas, consisted mainly of fish from the 2000–06 year classes, but there was a higher proportion of larger older fish in the Sub-Antarctic. Only 25% of the catch was fish less than 65 cm.

As the hoki quota was fully caught before the end of the fishing year, catches in both Puysegur and ECSI in 2008–09 were lower than in some previous years, with 1100 t taken from the ECSI and 200 t from Puysegur.

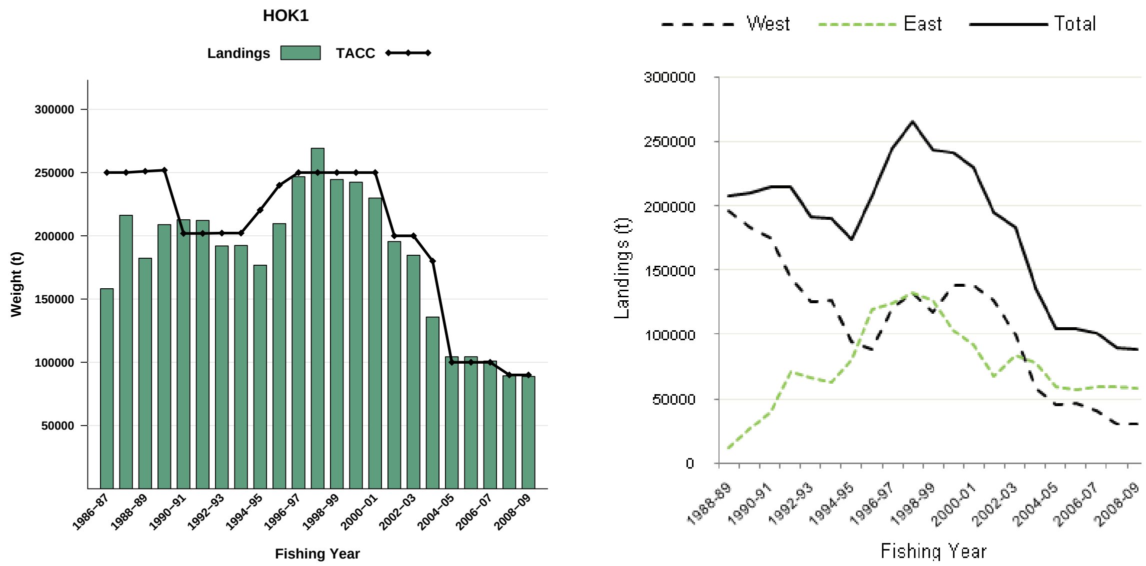


Figure 1: Left: Historical landings and TACC for HOK 1. Right: The Eastern and Western components of the total HOK 1 landings since 1988-89. Note that these figures do not show data prior to entry into the QMS.

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.

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 on 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 and Anderson (2008) noted that fish lost from the net during landing accounted for only a small fraction (0 - 14.5%) of the total fish discards 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 fish in catches on the WCSI in recent years may have resulted in some discarding 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 (i.e., that shed easily) such as hoki. Selectivity experiments in the 1970s indicated that the 50% selection length for hoki for a 100 mm mesh codend is about 57–65 cm total length (Fisher 1978, as reported by Massey & Hore 1987). More recent 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. Net damaged adult hoki have been recorded in the WCSI fishery in some years indicating that there may be some survival of escapees. The extent of damage and resulting mortality of fish passing through the net is unknown.

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

2. BIOLOGY

Hoki are widely distributed throughout New Zealand waters from 34^{o} S to 54^{o} S, from depths of 10 m to over 900 m, with greatest abundance between 200 and 600 m. Large adult fish are generally found deeper than 400 m, while juveniles are more abundant in shallower water. In the January 2003 Chatham Rise trawl survey, exploratory tows with mid-water gear over a hill complex east of the survey area found low density concentrations of hoki in mid-water at 650 m over depths of 900 m or greater in January 2003 (Livingston *et al*. 2004). The proportion of larger hoki outside the survey grounds is unknown. Commercial data also indicate that small catches of older hoki are targeted over other hill complexes outside the survey areas of both the Chatham Rise and Sub-Antarctic (Dunn & Livingston 2004), and are also 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 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 and

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 yrs) are found on the Chatham Rise throughout the year.

Hoki spawn from late June to mid-September, releasing multiple batches of eggs. 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 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 in the Sub-Antarctic in May 1992 and 1993 estimated that 67% of hoki age 7 years and older in 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 age 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 in prep.) A new method to estimate proportion spawning from summer samples of post-spawner hoki is under development (Parker 2007, Grimes & O'Driscoll 2006).

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 of 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 on both the Sub-Antarctic and Chatham Rise. Analyses of trawl survey (1991–02) and commercial data suggests 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 *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 less 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 considerable variability in growth rates in subsequent years and there has been a trend of increasing size at age in data from both the trawl surveys and the commercial catch since 1983 (Bull & Livingston 2000). In the past, hoki reached about 45, 55 and 60–65 cm TL at ages 2, 3, and 4 respectively. More recently, length modes have been centred at 45–50, 60–65, and 70–75 cm TL for ages 2, 3, and 4. Although smaller spawning fish are taken on the spawning grounds, males appear to mature mainly from 60–65 cm TL at 3–5 years, while 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, while 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 0.3 per year.

There is evidence that ageing error causes 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 to the preceding 1988 and 1987 year classes. A new ageing protocol has been developed to increase the consistency of hoki age estimation. 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 methodology and otolith readings.

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 biological parameters.

Fishstock							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		
HOK1		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 Southern Plateau), 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 on 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).

The Hoki Working Group has assessed the two spawning groups as separate stock units. The west coast of the North and South Islands and the area south of New Zealand including Puysegur, Snares and the Southern Plateau 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, the link between climate and recruitment is still unknown. Recent analyses (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. 2009).

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. 2009).

5. ENVIRONMENTAL EFFECTS OF FISHING

This section was updated for the May 2010 Plenary and has been considered by the Aquatic Environment Working Group. It includes a summary of the incidental bycatch of fish and invertebrates, marine mammals and seabirds, and benthic interactions in hoki fisheries. A more detailed assessment of the environmental effects of fishing across all fisheries will be available in the Ministry's Aquatic Environment Plenary that is under development.

Hoki fisheries have been certified by the Marine Stewardship Council since 2001, and the characterisation and understanding of the fishery interaction with the environment is one of three components assessed as part of certification. The types of environmental effects of fishing for hoki differ across fisheries. The potential interactions between hoki fisheries and the marine ecosystem are outlined by Livingston (2002) and MacDiarmid et al. (2005).

5.1 Role in the ecosystem

Hoki is the dominant species in the bottom fish community of the upper slope (200–800 m), particularly around the South Island (Francis et al. 2002), and as such are considered to be a key biological component of the slope ecosystem. Understanding the predator-prey relationships between hoki and other species in the slope community is important, particularly since substantial changes in the biomass of hoki have taken place since the fishery began. Other metrics can also provide insight into fishery interactions with fish populations. For example, changes in growth rate can be indicative of density dependent compensatory mechanisms in response to changes in population density; ecosystem indicators derived from fishery independent survey data can provide insight into temporal or spatial trends in a fish community. Understanding environmental trends and ecosystem changes of which hoki and the hoki fisheries are a part, provides context for interpreting the environmental effects of fishing, the status of the stocks, and management actions.

5.1.1 Trophic interactions

On the Chatham Rise, hoki is a benthopelagic and mesopelagic forager, preying primarily on lantern fishes and other mid-water fishes and natant decapods (Clark 1985a & b, Stevens et al. in prep, Dunn et al. 2009) with little seasonal variation. Hoki show ontogenetic shifts in their feeding preferences, and larger hoki (>80cm) consume proportionately more fish and squid than do smaller hoki (Dunn et al. 2009, Connell 2010). Hoki diet overlaps with alfonsino, arrow squid, hake, javelinfish, Ray's bream, and shovelnose dogfish (Dunn et al. 2009). Hoki are prey to several piscivores, particularly hake (also stargazers, smooth skates, several deep water shark species, and ling; Dunn et al. 2009). The proportion of hoki in the diet of hake averages 38% by weight, and has declined since 1992 (Dunn & Horn 2010), possibly because of a decline in the relative abundance of hoki on the Chatham Rise between 1991 and 2007.

A preliminary study of trophic energetics in the Sub-Antarctic using the mass balance model ECOPATH identified the need for quantitative data on prey consumption by dominant fish species such as hoki (Bradford-Grieve et al. 2003). The data collected on the Chatham Rise are currently being used as part of a broader project to develop a mass balance model of trophic energetics on the Chatham Rise (Coasts and Oceans OBI, FRST).

5.1.2 Ecosystem Indicators

Tuck et al. (2009) used the Sub-Antarctic trawl series data from 1991–2005 and the Chatham Rise trawl series from 1992–2007 to derive fish-based ecosystem indicators based on diversity, fish size, and trophic level. Species-based measures of diversity appear to be the most useful in identifying changes correlated with fishing intensity; Pielou's evenness appears to most consistently show a significant correlation but the Shannon-Wiener index, species richness, and Hill's N1 and N2 also showed some pattern (Tuck et al. 2009). These indices are described and defined by Tuck et al. (2009). Trends in diversity in relation to fishing are not necessarily downward, and depend on the nature of the community in question. Size-based indicators did not appear as useful for New Zealand trawl survey series as they have been elsewhere, and this may be related to the requirement to reduce the data set to key measured species. The size-based indicators did show significant trends over time (generally negative) for some strata, but these did not produce significant correlations with fishing intensity when all strata were considered. Where size-based approaches have been used successfully elsewhere, long time series of trawl surveys where all fish species are measured are available (e.g., North Sea; Tuck et al. 2009).

Between 1992 and 1999 the growth rates of all year classes increased by 10% in all four fishery areas but it is unclear whether this trend is because of reduced competition for food within and among cohorts (Bull & Livingston 2000). Current research on acoustic backscatter data from trawl surveys will provide insight into the trends and variability in mesopelagic prey availability (ENV2009-04; O'Driscoll & Hurst 2010).

5.2 Incidental catch (fish and invertebrates)

Two main sources of data are used to monitor trends in bycatch and discards in the hoki fishery. TCEPR forms provide catch estimates for the top five species in all tows, plus a daily summary of all species caught that day. Records from observers provide catch weights for all species caught on some of the individual tows, but cover only a small proportion of tows within in each of the hoki fisheries (usually less than 10%). Bycatch and discard rates for the combined hoki, hake and ling fishery fisheries between 2000–01 and 2006–07 were reported by Ballara et al. (2010a) and compared with earlier work (Anderson et al. 2001, Livingston et al. 2003, Anderson & Smith 2005). Summary tables of target bycatch are also provided in the annual FAR updated each year (e.g., Ballara et al. 2010b).

The main commercial bycatch species in hoki target fisheries off the West Coast S.I., Chatham Rise and Sub-Antarctic are hake, ling, silver warehou, jack mackerel and spiny dogfish. In Cook Strait, the main commercial bycatch species are ling and spiny dogfish. Hoki, hake, and ling accounted for 87% (77%, 6%, and 4% respectively) of the total observed catch from trawls targeting these species between 1 October 2000 and 30 September 2007. The remaining 13% was made up of a large range of species, especially javelinfish (2.1%), silver warehou (1.7%), rattails (1.4%), and spiny dogfish (1.1%). Non-commercial bycatch is more common on the Chatham Rise and Sub-Antarctic, and consists mostly of javelinfish and various other rattail species although up to 470 species or species groups have been identified by observers in the incidental catch. Most of these are non-commercial species caught in low numbers (Ballara et al. 2010a).

Bycatch rates in 2007–08 for ling, silver warehou, hake and spiny dogfish were generally less than 5% in all hoki fisheries except in the Sub-Antarctic. Other bycatch species are also taken, particularly in the non-spawning fisheries, but bycatch rates for these are usually less than 1% (Ballara et al. 2010b). The hoki fishery also has relatively low discard ratios relative to other fisheries, both in New Zealand and internationally. The hoki, hake, and ling fisheries are complex, with many confounding factors, and changes in fishing practice are likely to have contributed to variability in annual levels of bycatch and discards (Ballara et al. 2010a). Fishery independent trawl surveys on the Chatham Rise and Sub-Antarctic provide relative abundance time series for all fish species and some macro-invertebrates (e.g. Stevens et al. in press, O'Driscoll & Bagley in press).

Basking sharks are caught occasionally in hoki fisheries (Francis & Duffy 2002, Francis & Smith 2010, Ballara et al. 2010a). Basking shark are on the Department of Conservation's threat classification list (Hitchmough et al. 2005) and are listed in CITES (Appendix II). Unstandardised and standardised catch rates from observer data for this species showed the highest catch rates and catches occurred in 1989 on the west coast South Island, and in 1987–92 on the east coast South Island, and second smaller peaks in both areas in the late 1990s. Reported catches were greatest in the early 2000s, and have been low since (especially 2005–06 to 2007–08). Most basking sharks were taken in spring and summer and nearly all came from FMAs 3, 5, 6 and 7. Much of the recent decline in basking shark bycatch is probably attributable to a decline in fishing effort (Francis & Smith 2010).

5.3 Incidental catch (seabirds and mammals)

Capture estimates include only those animals landed (alive, injured or dead) on fishing vessels but may not include all sources of cryptic mortality (e.g., seabirds struck by the warp but not landed onboard the vessel). Various projects have estimated the total incidental captures in this fishery. This section refers to ratio estimates of incidental captures for all years and model based estimates where available (for methods see Abraham et al. 2010, Baird and Smith 2007, 2008, MacKenzie and Fletcher 2006, Thompson et al. in press).

Annual observed seabird capture rates ranged from 1.41 to 8.34 per hundred tows in hoki fisheries between 1998-99 and 2007-08, a relatively high rate within the context of New Zealand fisheries. Estimated means of total annual captures ranged from 138 to 2517 seabirds (ratio estimated) and 241 to 2055 (model estimated) with a declining trend since 2000-01 (Table 6), but the confidence intervals around these estimates are large due to moderate observer coverage and high variability in the capture rate (Abraham et al. 2010, Bradford 2002, MacKenzie & Fletcher 2006). The estimated total number of seabird captures reduced markedly over this period, as has the number of tows in hoki fisheries.

Seabird species that were observed caught in hoki fisheries from 1998-99 to 2007-08 are (with total numbers of each species observed caught during this period): white-capped albatross (910), sooty shearwater (609), white-chinned petrel (281), Buller’s albatross (38), albatrosses (unidentified) (25), petrel (unidentified) (24), Salvin’s albatross (19), seabird – small (19), seabird – large (15), shy albatross (14), southern royal albatross (7), Antarctic prion (6), black-browed albatross (unidentified) (5), common diving petrel (3), storm petrels (3), seabird (unspecified) (3), southern black-browed albatross (2), giant petrels (unidentified) (2), prions (unidentified) (2), cape petrels (1), and other species (10) (Abraham et al. 2010). Note that identification to species or group level is done by observers onboard and some birds are not readily identifiable.

Annual observed fur seal capture rates ranged from 1.65 to 5.63 per hundred tows in hoki fisheries between 1998-99 and 2007-08. Estimated means of total annual captures ranged from 214 to 1035 seabirds (ratio estimated) and 196 to 919 (model estimated) (Table 7), a high proportion of the total fur seal bycatch. In recent years, most of the fur seals observed caught in hoki fisheries have been caught in Cook Strait (Abraham et al. 2010, Thompson et al. in press).

Annual observed sea lion capture rates ranged from 0.03 to 0.05 per hundred tows in hoki fisheries between 1998-99 and 2007-08. Estimates of total annual captures ranged from 0 to 6 sea lions (Table 8), a small proportion of the total numbers captured in all commercial fisheries with a sea lion bycatch. The observed captures were located on the Stewart-Snares shelf (Thompson & Abraham 2009).

Table 6: Summary of all bird captures in the hoki trawl fisheries, for 10 fishing years, with the number of tows, number of tows observed, percentage of tows observed, number of observed captures, capture rate per hundred tows, total estimated captures with 95% confidence intervals, and percentage of tows included in the estimate (from Abraham et al. 2010) and model based estimates of captures with 95% confidence intervals or coefficient of variation (from MacKenzie & Fletcher 2006, Baird & Smith 2007, 2008, Abraham & Thompson in press).

	Observed					Ratio estimated			Model based estimates of captures (95% c.i. or c.v.)				
	Tows	No. obs	% obs	Captures	Rate	Captures (95% c.i.)		% effort in estimate	MacKenzie & Fletcher		Baird & Smith	Abraham & Thompson	
1998–99	32 242	3 558	11.0	133	3.74	1 063	(824 - 1339)	97.1	1 144	(950 - 1374)			
1999–00	33 061	3 273	9.9	91	2.78	1 075	(816 - 1375)	97.5	993	(821 - 1199)			
2000–01	32 018	3 549	11.1	296	8.34	2 517	(2065 - 3019)	97.6	2 055	(1803 - 2348)			
2001–02	27 224	3 274	12.0	50	1.53	429	(289 - 613)	98.1	1 133	(941 - 1358)			
2002–03	27 776	2 592	9.3	84	3.24	826	(437 - 1384)	97.9	1 182	(982 - 1424)		978	(606 – 1966)
2003–04	22 516	2 347	10.4	33	1.41	369	(177 - 649)	97.3	914	(753 - 1108)	540 (c.v. = 29%)	358	(255 – 563)
2004–05	14 529	2 133	14.7	46	2.16	278	(189 -390)	97.3			444 (c.v. = 26%)	402	(300 – 555)
2005–06	11 591	1 777	15.3	54	3.04	370	(252- 523)	97.8			412 (c.v. = 26%)	387	(256 – 698)
2006–07	10 630	1 757	16.5	23	1.31	138	(96 -186)	97.6				241	(134 - 561)
2007–08	8 788	1 869	21.3	31	1.66	147	(93 -217)	97.9					

Table 7: Summary of New Zealand fur seal captures in the hoki trawl fisheries, for 10 fishing years, with the number of tows, number of tows observed, percentage of tows observed, number of observed captures, capture rate per hundred tows, total estimated captures with 95% confidence intervals, percentage of tows included in the estimate (from Abraham et al. 2010) and model based estimates of captures with 95% confidence intervals (from Smith & Baird 2009 and Thompson et al. in press). Note that Smith & Baird (2009) estimated captures by area, therefore confidence intervals are not readily available when aggregated at this level.

	Observed					Ratio estimated			Model based estimates of captures (95% c.i.)		
	Tows	No.obs	% obs	Captures	Rate	Captures (95% c.i.)		% effort in estimate	Smith & Baird	Thompson et al.	
1998–99	32 242	3 558	11.0	84	2..36	737	(568 - 926)	95.6	919		
1999–00	33 061	3 273	9.9	102	3.12	743	(594 - 905)	95.8	764		
2000–01	32 018	3 549	11.1	66	1.86	628	(472 - 803)	97.6	804		
2001–02	27 224	3 274	12.0	110	3.36	808	(623 - 1008)	96.3	844		
2002–03	27 776	2 592	9.3	44	1.70	453	(284 - 653)	96.3	504	509	(300 - 851)
2003–04	22 516	2 347	10.4	49	2.09	405	(288 - 541)	96.7	411	581	(333 - 996)
2004–05	14 529	2 133	14.7	120	5.63	1 035	(757 - 1358)	93.1	625	633	(396 - 1 008)
2005–06	11 591	1 777	15.3	62	3.49	214	(151 - 293)	81.5	471	349	(214 -561)
2006–07	10 630	1 757	16.5	29	1.65	247	(160 - 345)	97.2		196	(103 - 345)
2007–08	8 788	1 869	21.3	58	3.10	327	(237 - 425)	96.9		273	(163 - 448)

Table 8: Summary of New Zealand sea lion captures in the hoki trawl fisheries, for 10 fishing years, with the number of tows, number of tows observed, percentage of tows observed, number of observed captures, capture rate per hundred tows, total estimated captures with 95% confidence intervals, and percentage of tows included in the estimate (from Abraham et al. 2010).

	Observed					Ratio estimated		
	Tows	No. obs	% obs	Captures	Rate	Captures	(95% c.i.)	% effort in estimate
1998–99	32 242	3 558	11.0	0	0.00	3	(0 - 6)	97.1
1999–00	33 061	3 273	9.9	1	0.03	6	(2 - 12)	97.5
2000–01	32 018	3 549	11.1	1	0.03	6	(2 - 12)	97.6
2001–02	27 224	3 274	12.0	0	0.00	5	(1 - 11)	98.1
2002–03	27 776	2 592	9.3	1	0.04	5	(2 - 10)	97.9
2003–04	22 516	2 347	10.4	0	0.00	2	(1 - 5)	97.3
2004–05	14 529	2 133	14.7	0	0.00	1	(0 - 3)	97.3
2005–06	11 591	1 777	15.3	0	0.00	0	(0 - 1)	97.8
2006–07	10 630	1 757	16.5	0	0.00	1	(0 - 1)	97.6
2007–08	8 788	1 869	21.3	1	0.05	1	(1 - 2)	97.9

5.4 Benthic interactions

5.4.1 Trawl effort

The main method of capture in the hoki fishery is trawling. Trawling on or near the seabed is of concern because it can change the structure of the seabed and affects associated benthic communities. Bottom trawl gear (single and twin rigs) is generally considered to affect seabed habitats more than midwater trawl gear because seabed contact is usually greater for the bottom trawl; some midwater gear is fished on or near the bottom. In the early years of the hoki fishery, vessels predominantly used the midwater trawl as most of the catch was taken during the spawning season of the West Coast S.I. (Table 3). As the demand for year round fishing increased, vessels increased fishing effort on the Chatham Rise and in the Sub-Antarctic, and the overall bottom trawl effort increased to a peak 1997-98 to 2003-04 (Fig 3). Bottom trawling has declined substantially across all areas since 2005-06, largely as a result of hoki TACC reductions. 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.

Midwater gear is used more frequently than bottom gear in the spawning season, because hoki tend to be more aggregated in midwater during spawning. Midwater trawl gear may be used on or near the seabed in the hoki fishery, and a more thorough analysis of the bottom trawl footprint, that includes midwater trawls towed within a metre or less of the seabed, is provided by Baird & Wood (2010). This work indicated that hoki targeted tows accounted for between 20 and 40% of the annual tows within the EEZ using bottom trawl gear and midwater gear on or near the sea floor, and 40-60% of the annual cumulative swept area. Bottom trawling is used almost exclusively on the Chatham Rise and Sub-Antarctic outside of the spawning season (Table 9).

Table 9: Summary of number of hoki target trawl tows (TCEPR only) in the hoki fishery by "fishing method" from fishing years 1989–90 to 2008–09. (FY, fishing year; MW, mid-water trawl; BT, bottom trawl)

Fishery	WCSI/Puys		Cook Strait/ECSI		Sub-Antarctic		Chatham Rise/ECSI		Totals		%Total
Season	Spawning		Spawning		Non spawning		Non-spawning		All areas combined		All
Method	MW	BT	MW	BT	MW	BT	MW	BT	MW	BT	BT
FY											
1990	7 465	1 035	878	21	27	2 102	43	2 029	8 413	5 187	38%
1991	7 082	1 671	1 955	19	79	3 922	964	3 491	10 080	9 103	47%
1992	5 437	1 544	1 424	6	114	5 438	461	5 555	7 436	12 543	63%
1993	5 335	1 740	1 317	14	440	4 909	1 057	5 269	8 149	11 932	59%
1994	7 838	1 559	1 769	88	560	2 039	1 336	3 455	11 503	7 141	38%
1995	7 002	1 417	1 751	230	410	2 327	2 180	6 266	11 343	10 240	47%
1996	5 569	2 000	3 009	816	411	2 504	2 310	7 991	11 299	13 311	54%
1997	7 277	1 825	3 181	965	334	3 435	2 349	9 390	13 141	15 615	54%
1998	6 615	1 334	2 025	516	164	4 391	3 795	11 514	12 599	17 755	58%
1999	5 186	1 972	1 823	418	417	3 660	2 444	11 482	9 870	17 532	64%
2000	5 019	2 107	1 777	263	512	5 935	2 708	9 535	10 016	17 840	64%
2001	5 900	2 261	1 719	119	661	5 433	926	9 902	9 206	17 715	66%
2002	4 677	2 846	976	103	129	6 448	866	7 861	6 648	17 258	72%
2003	4 385	2 601	1 839	244	94	4 399	505	9 318	6 823	16 562	71%
2004	4 120	1 801	1 591	55	78	3 022	386	7 231	6 175	12 109	66%
2005	2 370	1 250	1 200	61	68	1 428	342	5 022	3 980	7 761	66%
2006	1 674	1 438	913	33	74	721	142	4 829	2 803	7 021	71%
2007	1 082	647	756	65	25	1 194	58	4 775	1 921	6 681	78%
2008	604	437	318	310	36	924	78	4 240	1 036	5 911	85%
2009	610	309	673	110	38	927	11	3 921	1 332	5 267	80%
Total	95 247	31 794	30 894	4 456	4 671	65 158	22 961	133 076	153 773	234 484	60%

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.

Since 2005-06 there has been about four times as many tows on the Chatham Rise as the Sub-Antarctic, but overall effort has decreased in both areas since 2001-02 (Figure 2). Bottom trawling occurs more frequently than midwater trawling and the annual proportion of bottom tows has increased from 38% to 80% through time (Table 9).

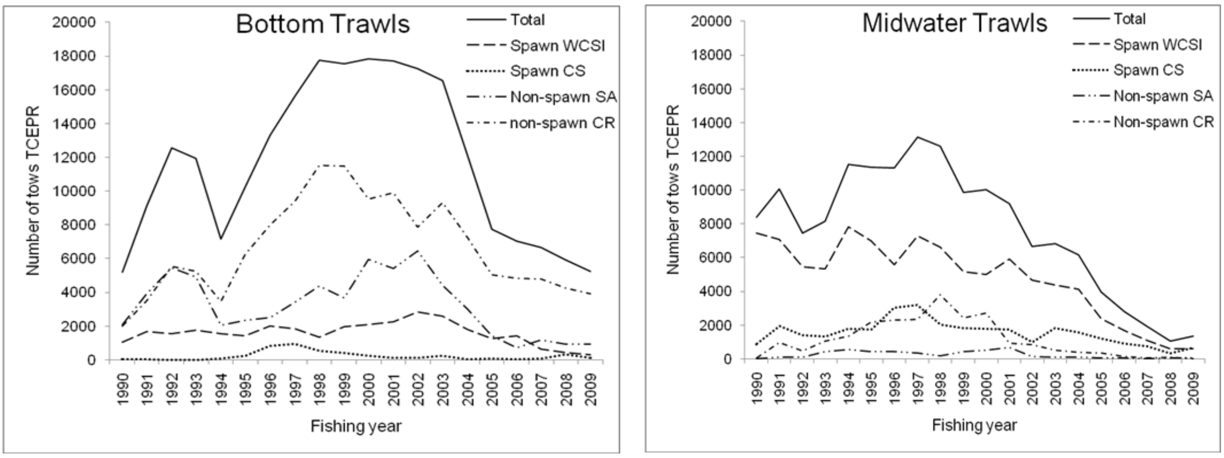


Figure 2: Summary of number of hoki target trawl tows (TCEPR) in the hoki fishery by "fishing method" from fishing years 1989–90 to 2008–09.)

NOTE: SpawnWCSI includes West Coast S.I. data (Jul-Sep) and Puysegur (Jul-Dec); Spawn CS includes Cook Strait and East Coast S.I. (Jul-Sep); Non-spawn CR includes ECSI (Aug-Jun), Chatham Rise (Aug-Jun); Non-spawn SA includes Sub-Antarctic data (Aug-Jun). TCER, CELR and North Island tows are excluded.

5.4.2 Trawling impacts

Most bottom trawling for hoki occurs on soft sediment habitats on the Chatham Rise and Sub-Antarctic (Baird & Wood 2010). The impacts of bottom trawling on soft sediment habitats and the associated benthic fauna are well understood in shallow water (Kaiser et al. 2002, 2006) and, in a qualitative sense, can be inferred for deeper systems (e.g., Rice 2006), particularly for habitats dominated by fragile, long-lived and slow growing biota. Most research on seabed interactions in New Zealand has focussed on mapping the footprint of trawl fisheries relative to habitat classes estimated using statistical classification schemes (Snelder et al. 2006, Baird et al. 2009, Baird & Wood 2010), and in relation to the preferred depth range of given species (Helson et al. 2010).

5.5 Other considerations

5.5.1 Spawning disruption

Fishing during critical phases of spawning behaviour may disrupt that spawning. Although there has been no research on the disruption of spawning hoki in New Zealand, the Hoki quota owners introduced closures to Hokitika Canyon spawning grounds off the WCSI as a precautionary measure from 2004 to 2009. This closure has now been lifted because the western hoki stock is no longer estimated to be below management target fishing levels.

5.5.2 Habitat of particular significance to fisheries management

Habitat of particular significance to fisheries management has not been defined for any fishery. Studies of potential relevance to this for hoki fisheries have identified areas of importance for spawning and for juveniles (O'Driscoll *et al*. 2003). Areas on Puysegur Bank, Canterbury Bight and Mernoo Bank have been subject to non-regulatory measures to reduce fishing mortality on juvenile hoki (Deepwater Group 2009). An emerging issue centres on how much of the optimum hoki habitat has been disturbed by fishing, and whether or not this is a matter for consideration of the overall productivity of the hoki fisheries.

5.5.3 Biodiversity

Few studies to date have focused on biodiversity in the hoki or middle depth fisheries. Using data from middle depth trawl surveys, McClatchie *et al*. (1997) found that species diversity was higher on the Chatham Rise than in the Sub-Antarctic. A time-trend analysis showed little trend in species diversity on the Chatham Rise from 1992 to 1999 (Bull *et al*. 2001). Biodiversity indices of fish from hoki trawl surveys formed part of the ecosystem indicator analysis by Tuck et al. (2009). Hewitt et al. (2010) calculated preliminary biodiversity indices for benthos across the Chatham Rise. Benthic Protection Areas (BPAs) to protect biodiversity from fishery interactions with benthic habitats in 31% of New Zealand's EEZ were introduced in 2007, and include about 11% of depths 250–750 m (Helson et al. 2010).

6. STOCK ASSESSMENT

A new stock assessment was carried out in 2010 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. New information included two trawl surveys, one acoustic survey, and updated catch at age data. The general-purpose stock assessment program, CASAL (Bull *et al*. 2008), was used and the approach, which used Bayesian estimation, was similar to that in the 2009 assessment (McKenzie & Francis 2009).

6.1 Methods

Model structure

The model partitions the population into two sexes, 17 age groups (1 to 17), two stocks [east (E) and west (W)], and four areas [Chatham Rise (CR), West Coast South Island (WC), Sub-Antarctic (SA), and Cook Strait (CS)]. The adult fish of the two stocks do not mix: those from the W stock spawn in WC and spend the rest of the year in SA; the E fish move between their spawning ground, CS, and their home ground, CR. Juvenile fish from both stocks live in CR, but natal fidelity is assumed (i.e., all fish spawn in the area in which they were spawned). 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 we have no direct observations of maturity to put in the model but we do have information about spawners (there are two April/May observations on SA 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 10). The first type involves only newly spawned fish, all of which are assumed to move from the spawning grounds (CS and WC) to arrive at CR at time step 2 and approximate age 1.6 y. The second affects only young W fish, some of which are assumed to migrate, at time step 3, from CR to SA. The last two types of migrations relate to spawning. Each year some fish migrate from their home ground (CR for E fish, SA for W fish) to their spawning ground (CS for E fish, WC for W 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 CR and SA) were split into two halves to allow some of the catch to be taken before the Whome migration, and some after.

Table 10: Annual cycle of the assessment 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 occur 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 is treated as being of age 2.25 in that time step. etc. The last column ("Propn. mort.") shows the proportion of that time step's total mortality that is assumed to have taken place when each observation is made.

					Observations	
Step	Approx. months	Processes	*M* fraction	Age fraction	Label	Propn. 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	–	
5	Jul-Sep	increment ages	0.25	0	CSacous	0.5
		spawning fisheries (Esp, Wsp)			WCacous	0.5

Data and error assumptions

Five series of abundance indices were used in the assessment (Table 11). New data were available from an acoustic survey of Cook Strait in August 2009 (O'Driscoll & Macaulay 2010), and trawl surveys of the sub-Antarctic in December 2009 (Bagley & O'Driscoll 2010) and Chatham Rise in January 2010 (Stevens et al. 2010).

Table 11: 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	417	–	–	–	–
1989	249	–	–	–	–
1990	255	–	–	–	–
1991	340	–	–	–	180
1992	345	80	68	120	–
1993	550	87	–	186	583
1994	–	100	–	146	592
1995	–	–	–	120	427
1996	–	–	89	153	202
1997	654	–	–	158	295
1998	–	–	68	87	170
1999	–	–	–	109	243
2000	396	–	–	72	–
2001	–	56	–	60	220
2002	–	38	–	74	320
2003	–	40	–	53	225
2004	–	14	–	53	–
2005	–	18	–	85	132
2006	–	21	–	99	126
2007	–	14	–	70	216
2008	–	46	–	77	167
2009	–	47	–	144	315*
2010		65*		98*	

The age data used in the assessment (Table 12) are similar to those used in 2009, but with an additional year's data. The most recent data suggest that the trend, noted in the 2007 Plenary Report, towards a decreasing proportion of older males (age 6 and older) in the W stock has reversed in the following three years (McKenzie 2010a).

Table 12: 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	1988–09*	otoliths
SA	WnspOLF	Catch at age	1992–94, 96, 99–00	OLF
	Wnspage	Catch at age	2001–04, 06–08	otoliths
	SAsumage	Trawl survey	1992–94, 2001–10*	otoliths
	SAautage	Trawl survey	1992, 96, 98	otoliths
	pspawn	Proportion spawning	1992, 93, 98	otoliths
CS	Espage	Catch at age	1988–09*	otoliths
CR	EnspOLF	Catch at age	1992, 94, 96, 98	OLF
	Enspage	Catch at age	1999–09*	otoliths
	CRsumage	Trawl survey	1992–10*	otoliths

The error distributions assumed were robust lognormal (Bull *et al*. 2008) 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). An arbitrary CV of 0.25 (as used by Cordue 2001) was assumed for the proportion spawning observations. Two alternative sets of CVs were used for the biomass indices (Table 13). The "total" CVs represent the best estimates of the uncertainty associated with these data, and were used in initial model runs. 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 set at 0.2, following Francis *et al*. (2001) (note that CVs add as squares: $CV_{total}^2 = CV_{process}^2 + CV_{observation}^2$). 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 include only the uncertainty associated with between-transect (and within-stratum) variation in total backscatter. In some model runs (including all final runs) it was decided to use the observation-error rather than the total CVs for all trawl survey biomass indices as a way of giving more weight to these data.

Table 13: Coefficients of variation (CVs) used with biomass indices in the assessment. Observation-error CVs were used when it was desired to up-weight a series of indices. Years are fishing years (1990 = 1989–90).

CRsumbio	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004
Total	0.21	0.22	0.22	0.21	0.22	0.22	0.23	0.23	0.23	0.22	0.23	0.22	0.24
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	0.13
	2005	2006	2007	2008	2009	2010							
Total	0.23	0.23	0.22	0.23	0.23	0.25							
Observation	0.12	0.11	0.08	0.11	0.11	0.15							
SAsumbio	1992	1993	1994	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010
Total	0.21	0.21	0.22	0.24	0.26	0.24	0.24	0.23	0.24	0.23	0.26	0.24	0.26
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	0.16
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	2006
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	0.34
Observation	0.13	0.15	0.06	0.12	0.09	0.12	0.10	0.10	0.12	0.13	0.17	0.11	0.17
	2007	2008	2009										
Total	0.46	0.30	0.39										
Observation	0.26	0.06	0.15										
WCacous	1988	1989	1990	1991	1992	1993	1997	2000					
Total	0.60	0.38	0.40	0.73	0.49	0.38	0.60	0.60					
Observation	0.22	0.15	0.06	0.14	0.14	0.07	0.10	0.14					

For the at-age data, overall CVs were treated as the sum of a process-error CV and an observation-error CV. The observation CVs for the otolith-based at-age data were calculated by a bootstrap procedure, which includes 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 some, which were forced to be higher than those from the spawning fisheries (Francis 2004). Process-error CVs for the at-age data were estimated within the model for all point estimates. For full Bayesian estimates, these CVs were fixed at their point estimates.

The age ranges used in the model varied amongst data sets (Table 14). In all cases, the last age for these data sets was treated as a plus group.

Table 14: 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 into the six fisheries of Table 15 according to area and month. This division was done using TCEPR, TCER, CELR, NCELR, LTCER LCER and 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 15) is the same as that used in the 2009 assessment, so the catches used in the model (Table 16) are unchanged, except for minor revisions to years 2001 to 2009 (including removing ET catches). For the 2010 year the new TACC is 110 000 t with a catch split arrangement for 60 000 t to be taken from the eastern fisheries and 50 000 t from the western fisheries. The assumed catch for 2010 in Table 16 is based on this catch split arrangement (Richard Well, pers. comm.)

Table 15: Method of dividing annual catches into the six fisheries of Table 6. The small amount of catch reported in the areas west coast North Island and Challenger (typically 100 t per year) was ignored (which means that this catch is pro-rated across all fisheries).

Area	Oct–Mar	Apr–May	Jun–Sep
West coast South Island; Puysegur	Wsp	Wsp	Wsp
Sub-Antarctic	Wnsp1	Wnsp2	Wnsp2
Cook Strait; Pegasus	Ensp1	Ensp2	Esp
Chatham Rise; east coasts of South Island & North Island; null[1]	Ensp1	Ensp2	Ensp2

[1] no area stated

Table 16: 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).

						Fishery
Year	Ensp1	Ensp2	Wnsp1	Wnsp2	Esp	Wsp
1972	1 500	2 500	0	0	0	5 000
1973	1 500	2 500	0	0	0	5 000
1974	2 200	3 800	0	0	0	5 000
1975	13 100	22 900	0	0	0	10 000
1976	13 500	23 500	0	0	0	30 000
1977	13 900	24 100	0	0	0	60 000
1978	1 100	1 900	0	0	0	5 000
1979	2 200	3 800	0	0	0	18 000
1980	2 900	5 100	0	0	0	20 000
1981	2 900	5 100	0	0	0	25 000
1982	2 600	4 400	0	0	0	25 000
1983	1 500	8 500	3 200	3 500	0	23 300
1984	3 200	6 800	6 700	5 400	0	27 900
1985	6 200	3 800	3 000	6 100	0	24 900
1986	3 700	13 300	7 200	3 300	0	71 500
1987	8 800	8 200	5 900	5 400	0	146 700
1988	9 000	6 000	5 400	7 600	600	227 000

Table 16 continued:

Year	Ensp1	Ensp2	Wnsp1	Wnsp2	Esp	Fishery Wsp
1989	2 300	2 700	700	4 900	7 000	185 900
1990	3 300	9 700	900	9 100	14 000	173 000
1991	17 400	14 900	4 400	12 700	29 700	135 900
1992	33 400	17 500	14 000	17 400	25 600	107 200
1993	27 400	19 700	14 700	10 900	22 200	100 100
1994	16 000	10 600	5 800	5 500	35 900	117 200
1995	29 600	16 500	5 900	7 500	34 400	80 100
1996	37 900	23 900	5 700	6 800	59 700	75 900
1997	42 400	28 200	6 900	15 100	56 500	96 900
1998	55 600	34 200	10 900	14 600	46 700	107 100
1999	59 200	23 600	8 800	14 900	40 500	97 500
2000	43 100	20 500	14 300	19 500	39 000	105 600
2001	36700	19900	13300	17100	35200	107500
2002	24900	18300	17000	13500	24800	97100
2003	24300	18700	12400	7800	41600	79800
2004	17900	19000	6400	5300	41000	46300
2005	19300	13800	4400	2000	26300	38700
2006	22000	14700	2000	4700	20500	40400
2007	22500	18400	4200	3500	18800	33700
2008	22000	19400	6500	2200	17900	21300
2009	29200	13100	6000	3800	15900	20800
2010	29700	13300	6100	3900	17000	40000

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 year-class strengths (YCSs). (The YCS for 1970, say, is for fish which were spawned in the winter of 1970, and which first arrive in the model, in area CR, at age 1.6 y, in about December 1971, which is in model year 1972). Associated with B_0 is an estimated mean recruitment, R_0, which is used, together with a Beverton-Holt stock-recruit relationship and the YCSs, to calculate the recruitment in each year. The first five YCSs (for years 1970 to 1974) are set equal to 1 (because of the lack of at-age data for the early years), but all the remaining YCSs (for 1975 to 2008) are estimated. The model corrects for bias in estimated YCSs arising from ageing error. YCSs are constrained to average 1 over the years 1975 to 2005, so that R_0 may be thought of as the average recruitment over that period. R_0 and a set of YCSs are estimated separately for each stock. The B_0 for each stock is calculated as the spawning biomass that would occur given no fishing and constant recruitment, R_0, and B_{INIT} is set equal to B_0.

As was the case for the 2009 assessment, the steepness of the stock-recruitment relationship was assumed to be 0.75.

Two alternative approaches are used in modelling natural mortality. In some model runs it is assumed to vary with age (following a double-exponential curve), separately for each sex; in others (where sex is ignored) it is assumed to be independent of age.

The model uses six selectivity ogives (one each for the four fisheries and one each for trawl surveys in areas CR and SA) and three migration ogives (Whome, Espmg, and Wspmg – see Table11).

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

Prior distributions are assumed for all parameters. The main priors used are given in Table 17. In addition, bounds are imposed for parameters with non-uniform distributions. For the catchability parameters these are those calculated by O'Driscoll *et al*. (2002) (who called them overall bounds); for other parameters they are set at the 0.001 and 0.999 quantiles of their distributions. Prior distributions for all other parameters are 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 17: 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	Parameters		Reference
log_Bmean_total	log($B_{0,E}$ + $B_{0,W}$)	uniform	11.6	16.2	
pE (= Bmean_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	
recruitment[W].YCS	year-class strengths (W)	lognormal	1	0.95	
q[CSacous].q	catchability, CSacous	lognormal	0.77	0.77	WG Minutes of 24-2-04
q[WCacous].q	catchability, WCacous	lognormal	0.57	0.68	O'Driscoll *et al* (2002)
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
[3] Used only in runs where *M* varied with age and sex

Calculation of fishing pressure and B_{MSY}

The fishing pressure for a given stock and model run was calculated as an annual exploitation rate, $U_y = \max_{as}\left(\sum_f C_{asfy} / N_{asy}\right)$, where the subscripts *a*, *s*, *f*, and *y* index age, sex, fishery, and year, respectively, *C* is the catch in numbers, *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 pressure on each stock. An alternative measure is the fishing pressure (F), which is virtually identical to U, except for the scale on which they are measured. However, as F may be less easily interpretable by non-scientists, U is preferred as a measure of fishing pressure.

For a given stock and run, the reference fishing pressures, $U_{35\%}$ and $U_{50\%}$, 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 pressures were calculated by simulating fishing using a harvest strategy in which the exploitation rate for fishery *f* was $mU_{f,\mathrm{current}}$, where $U_{f,\mathrm{current}}$ 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, $U_{x\%}$ was set equal to $m_{x\%}U_{\mathrm{current}}$, where the multiplier, $m_{x\%}$ (calculated by interpolation) was that which caused the equilibrium biomass of that stock to be *x*%B_0.

The same sets of simulations were used to calculate B_{MSY} for each stock and run. This was defined as the equilibrium biomass (expressed as %B_0) for the value of *m* which maximised the equilibrium catch from that stock.

Caution about the interpretation of this B_{MSY}

There are several reasons why B_{MSY}, as calculated in this way, is not a suitable target for management of the hoki fishery. First, it assumes a harvest strategy that is unrealistic in that it involves perfect knowledge (current biomass must be known exactly to calculate the target catch) and annual changes in TACC (which are unlikely to happen in New Zealand and not desirable for most stakeholders). Second, it assumes perfect knowledge of the stock-recruit relationship, which is actually very poorly known (Francis 2009). Third, it makes no allowance for extended periods of low recruitment, such as was observed in 1995–2001 for the W stock. 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.

6.2 Results

The assessment was done in two steps. First, a set of initial exploratory model runs was carried out, generating point estimates (so-called MPD runs, which estimate the mode of the posterior distribution). Their purpose was to provide information to make the decision as to which sets of assumptions should be carried forward and used in the final runs. The final runs were fully Bayesian, producing posterior distributions for all quantities of interest.

Initial runs

Three sets of analyses were carried out after the new year's data became available (McKenzie 2009a&b&c). In the 2008 assessment the model was unable to fit the threefold increase in estimated biomass between the 2007 and 2008 surveys in the summer sub-Antarctic series (see SAsumbio in Table 11). This biomass increase was sustained in the two subsequent surveys, and as in the previous assessment, it was decided that all series of trawl survey biomass observations should be upweighted in order to improve the fit to the SAsumbio series.

However, no upweighted runs fitted well to the SAsumbio series. Furthermore, the SAsumbio data shows large annual changes in numbers-at-age which cannot be explained by changes in abundance, and are suggestive of a change in catchability for the survey. To improve the fit to the SAsumbio series, an alternative approach to upweighting is to assume that the catchability has changed over time. This alternative approach was explored in runs in which two catchabilities were fitted for the SAsumbio series, instead of just one, and were found to improve the fit substantially.

Four final runs

Four final runs were chosen by the Working Group: two base runs, and two sensitivities to one of the base runs.

The two base runs adopted by the Working Group are distinguished by the mechanism they used to deal with the problem of the lack of old fish in both fishery-based and survey-based observations (Table 18). Run 2.1 allowed *M* (natural mortality) to be dependent on age; run 2.2 allowed the spawning fishery selectivities (Espsl, Wspsl) to be domed. When the domed selectivities were used it was also necessary to combine sexes in the model and make the selectivities age-based (Francis 2005). As in the previous assessment, the trawl biomass indices were upweighted to improve the fit to them.

Two sensitivities to run 2.1 were chosen by the Working Group as final runs. They differ from run 2.1 in that two catchabilities are fitted for the SAsumbio series instead of one (Table 18). In run 2.3 the catchability from 2004 to 2007 inclusive is estimated separately from the other years in the series, whereas for run 2.4 the catchability from 2008 to 2010 inclusive is estimated separately.

Table 18: Distinguishing characteristics for the four final model runs.

Label	Trawl surveys up-weighted?	Two catchabilities for SAsumbio?	Response to lack of old fish in the observations	Sex in model and selectivities length-based?
2.1	Y	N	*M* dependent on age	Yes
2.2	Y	N	Domed spawning selectivity	No
2.3	N	Y 04–07 separate	*M* dependent on age	Yes
2.4	N	Y 08–10 separate	*M* dependent on age	Yes

Bayesian posterior distributions were estimated for each of these runs using a Markov Chain Monte Carlo approach. For each run, three chains of length 2 million were completed, the initial quarter of each chain was discarded, and the remaining samples were concatenated and thinned to produce a posterior sample of size 1000.

The model estimates are summarised in Table 19 (estimates of biomass), Figures 3-4 (biomass trajectories, and year-class strengths), and Figures 5-6 (current biomass distributions). Both model runs show that: the biomasses of both stocks were at their lowest points ever in about 2005 and are now increasing; that the W stock is almost certainly more depleted than the E stock; and that the W stock experienced seven years of poor recruitment from 1995 to 2001, inclusive. Recruitment for the

W stock is estimated to have been near or above average in only 3 of the last 14 years (Figures 3-4). There is good agreement on estimates of year-class strengths, except that run 2.2 tends to estimate relatively stronger year classes in the early years and weaker in more recent years, and a weaker year class strength in 2007 for the W stock.

The current status of the W stock is improved compared to that in the 2009 assessment. In that assessment, for the two base model runs, there was a 0.57 and 0.85 probability that the stock was above 35 %B_0, whereas the probability for this year is 0.92 and 1.00.

In both the sensitivity runs, the current biomass estimates (%B_0) for both stocks are estimated to be as least as high as the associated base run, but with more uncertainty (Table 19, Figure 5).

Table 19: Estimates of spawning biomass for the final runs (median of marginal posteriors, with 95% confidence intervals in parentheses). $B_{current}$ is the spawning biomass in mid-season 2009–10.

	B_0(‘000 t)		$B_{current}$(‘000 t)		$B_{current}$(%B_0)		
Run	E	W	E	W	E	W	E+W
2.1	493(433,576)	808(748,893)	250(198,317)	326(254,454)	51(43,60)	40(33,53)	44(39,53)
2.2	807(568,1168)	912(780,1115)	461(312,682)	477(357,654)	57(47,70)	52(42,63)	54(48,62)
2.3	524(454,618)	880(793,1009)	303(220,413)	478(334,716)	58(45,71)	54(41,76)	56(45,71)
2.4	507(439,591)	835(764,940)	280(204,392)	342(230,522)	55(43,70)	41(29,58)	47(37,60)

Fishing pressure on both stocks was estimated to be at or near all-time highs in 2003 and is now substantially lower (Figure 7). The values for run 2.2 are much lower as this run assumes domed selectivity in the spawning fisheries. The peak pressure on the W stock was markedly higher than that on the E stock. The fishing pressures for the sensitivity runs (2.3 and 2.4) are similar to those for the base run 2.1.

Estimates of B_{MSY} were very similar for the two base runs: about 24% for the E stock and 25% for the W stock (Table 20)

Table 20: Estimates of B_{MSY} (expressed as %B_0) by stock for base runs 2.1 and 2.2.

	Stock	
Run	E	W
2.1	24.4	26.4
2.2	22.9	24.4

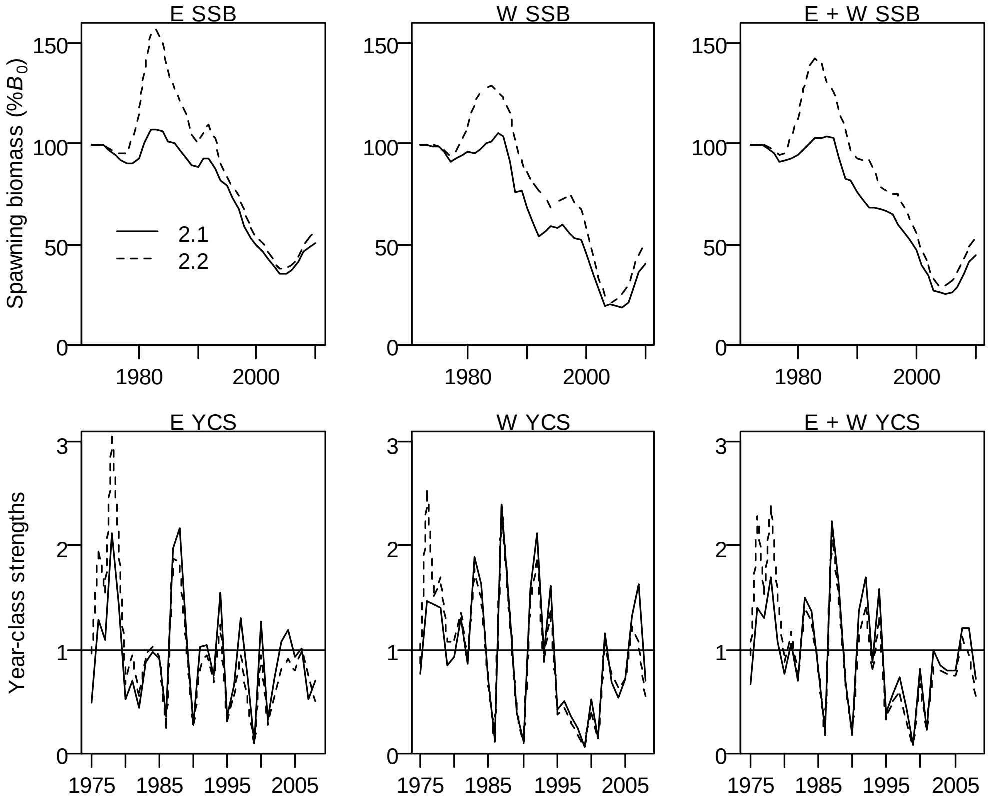


Figure 3: Estimated spawning biomass trajectories (SSB, upper panels) and year-class strengths (YCS, lower panels) for the E (left panels), W (middle panels) and E + W stocks (right panels) from the base final model runs. Plotted values are medians of marginal posterior distributions. Years are fishing years (1990 = 1989–90).

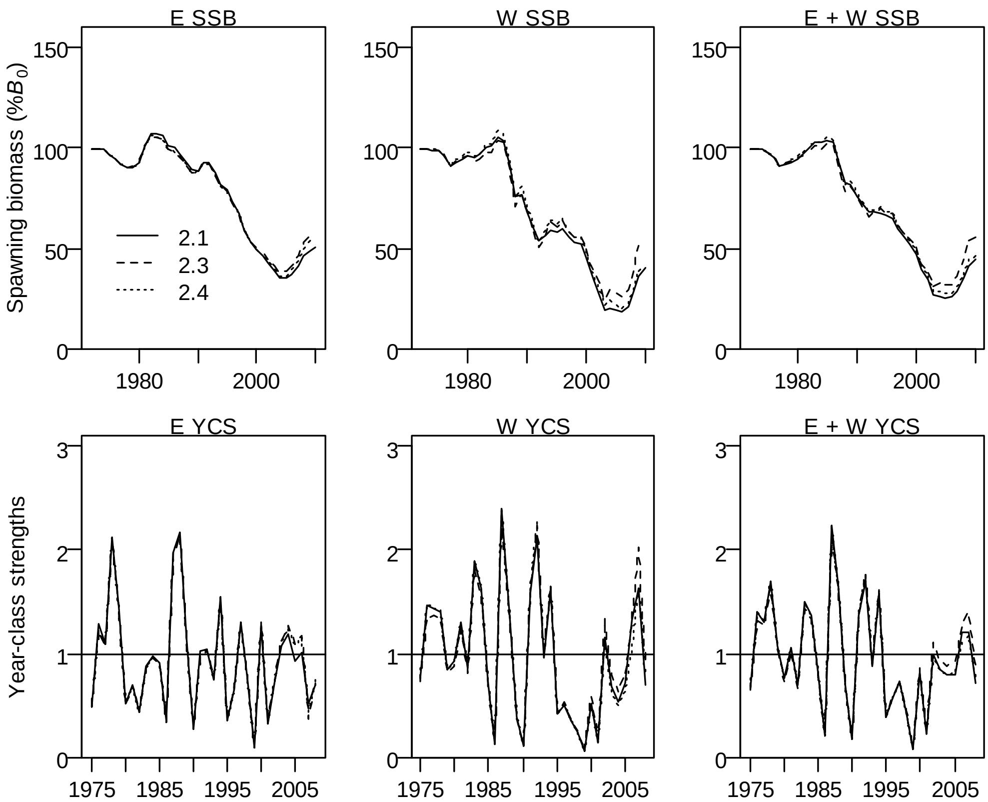


Figure 4: Estimated spawning biomass trajectories (SSB, upper panels) and year-class strengths (YCS, lower panels) for the E (left panels), W (middle panels) and E + W stocks (right panels) from the one of the base final model runs and two sensitivities. Plotted values are medians of marginal posterior distributions. Years are fishing years (1990 = 1989–90).

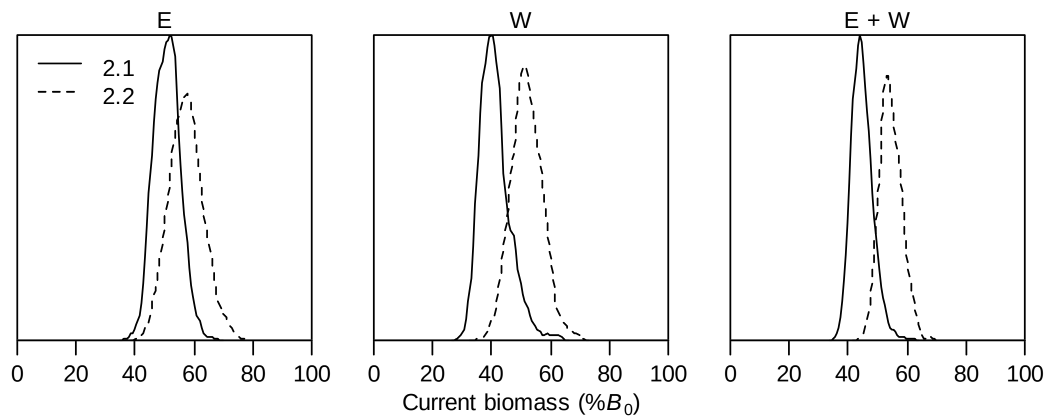


Figure 5: Estimated posterior distributions of current (spawning) biomass ($B_{2008–09}$), expressed as %B_0, for the E (left panel), W (middle panel) and E + W stocks (right panel) from the base final model runs.

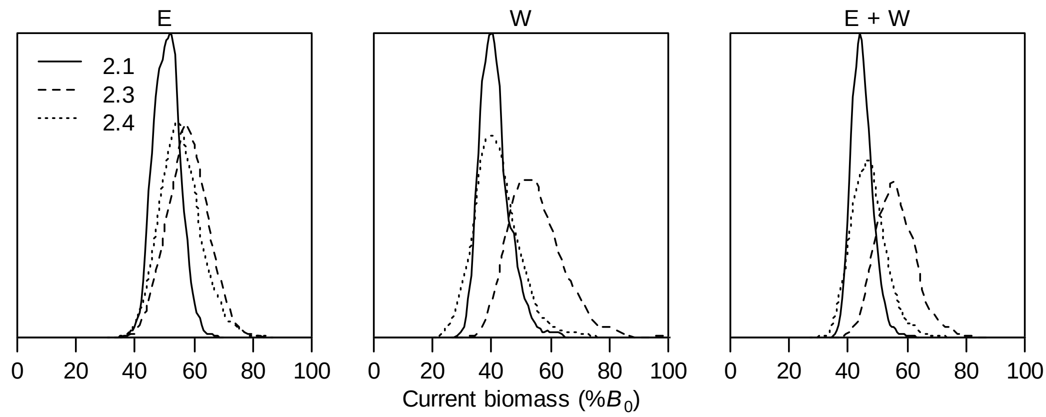


Figure 6: Estimated posterior distributions of current (spawning) biomass ($B_{2008–09}$), expressed as %B_0, for the E (left panel), W (middle panel) and E + W stocks (right panel) from one of the base final model runs and two sensitivities.

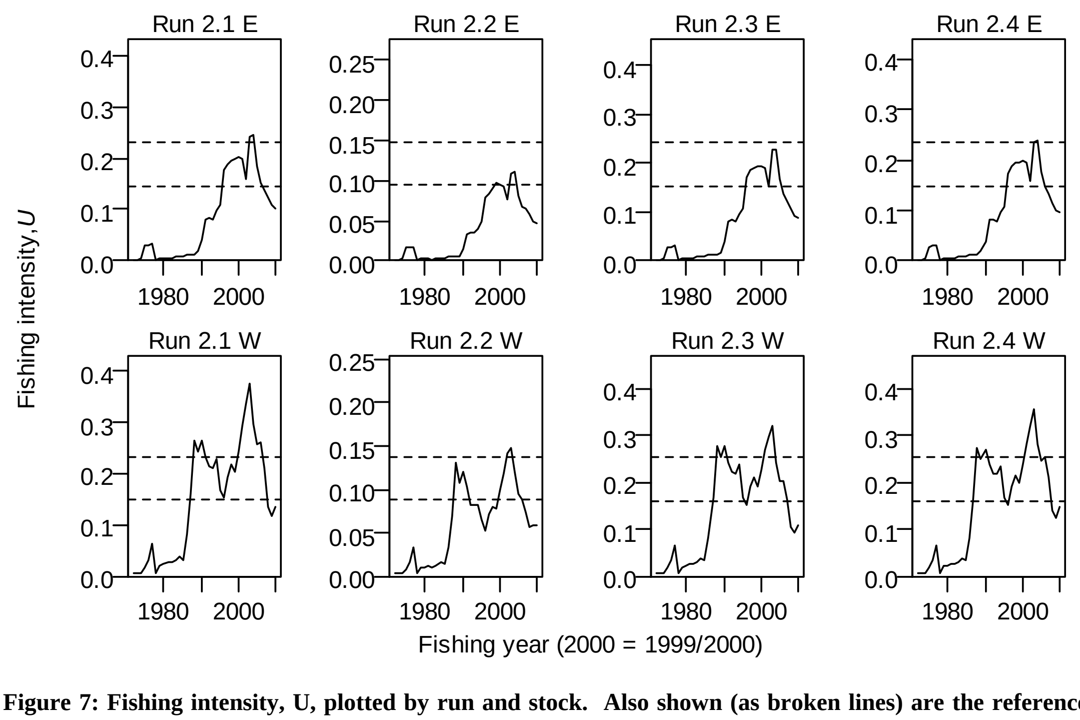


Figure 7: Fishing intensity, U, plotted by run and stock. Also shown (as broken lines) are the reference levels $U_{35\%}$ (upper line) and $U_{50\%}$ (lower line), which are the fishing intensities that would cause the spawning biomass to tend to 35%B0 and 50%B0, respectively. The y-axes are scaled so that the $U_{35\%}$ reference lines align horizontally (within and across the stocks).

6.3 Projections

Five-year projections were carried out, for each of the four final runs (2.1-2.4), under each of two alternative assumptions about future recruitment: 'long-term' (in which future recruitments were selected at random from those estimated for 1975–08) and 'recent' (future recruitments selected from 1995–08). The recent recruitment option was considered because of the recent period of below-average recruitment for the western stock, which may persist in the short-term. The eastern stock does not show such poor recruitment in recent years. In all projections, future catches in each fishery were assumed to be the same as for 2010 (i.e., as in the last line of Table 16). The projections indicate that with these assumed catches, the W biomass is likely to increase under either recruitment assumption; the E biomass will increase with long-term recruitment, but stay fairly constant with recent recruitment (Figures 8-9).

The probabilities of the current (2010) and projected spawning stock biomass being below the hard limit of 10% B_0, the soft limit of 20% B_0, and the lower and upper ends of the interim management target range of 35-50% B_0 are presented in Table 21 for the case where future catches remain at 2010 levels. The probability of either stock being less than either the soft or the hard limit over the five year projection period is negligible. Both stocks are projected to be within or above the 35-50% B_0 target range by the end of the projection period.

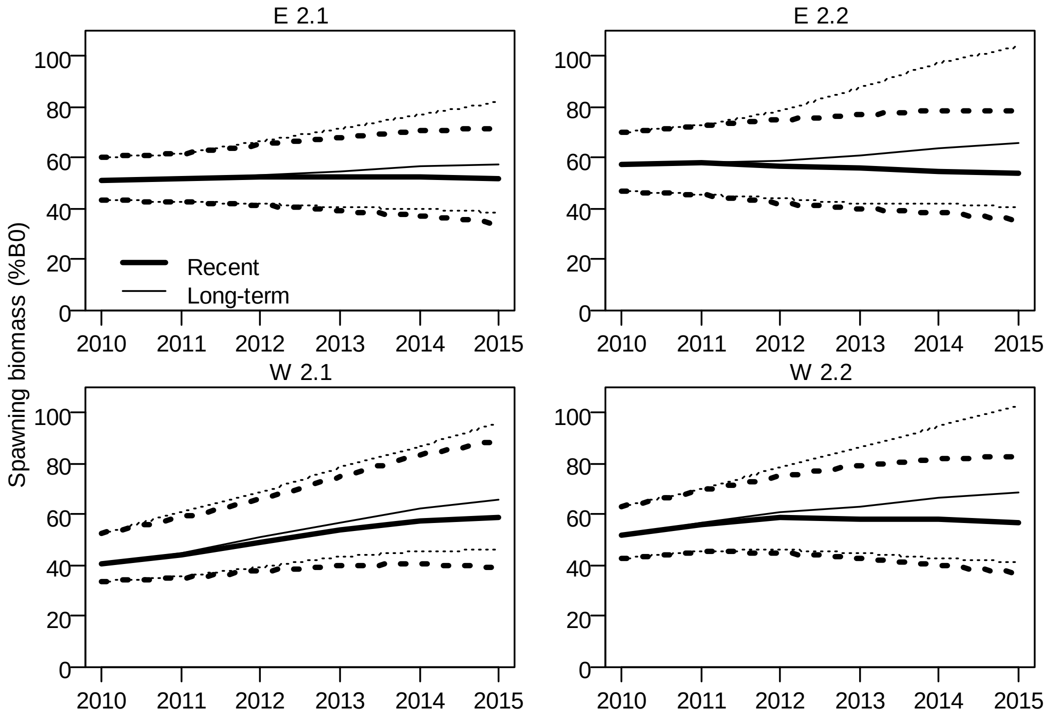


Figure 8: For the two base final model runs, projected spawning biomass (as %B_0) assuming long-term (thin lines) or recent (thick lines) recruitment: median (solid lines) and 95% confidence intervals (broken lines).

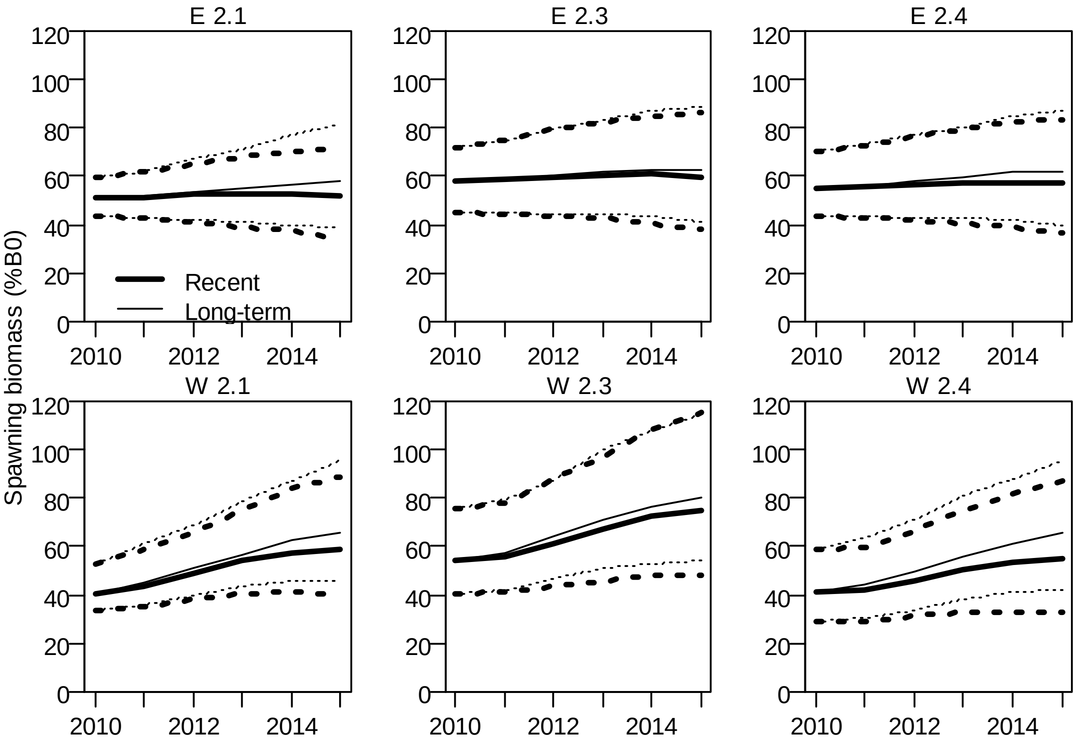


Figure 9: For the one of the base final model runs and two sensitivities, projected spawning biomass (as %B_0) assuming long-term (thin lines) or recent (thick lines) recruitment: median (solid lines) and 95% confidence intervals (broken lines).

Table 21: Probabilities (rounded to two decimal places) associated with projections for SSB (%B_0) in Figures 6-7.

	2010				2015: Recent recruitment				2015: Long-term recruitment			
	2.1	2.2	2.3	2.4	2.1	2.2	2.3	2.4	2.1	2.2	2.3	2.4
EAST												
P(SSB<10%B_0)	0	0	0	0	0	0	0	0	0	0	0	0
P(SSB<20%B_0)	0	0	0	0	0	0	0	0	0	0	0	0
P(SSB<35%B_0)	0	0	0	0	0.03	0.02	0.01	0.02	0.01	0.01	0	0.01
P(SSB<50%B_0)	0.42	0.09	0.12	0.21	0.40	0.37	0.19	0.27	0.24	0.11	0.12	0.17
WEST												
P(SSB<10%B_0)	0	0	0	0	0	0	0	0	0	0	0	0
P(SSB<20%B_0)	0	0	0	0	0	0	0	0	0	0	0	0
P(SSB<35%B_0)	0.08	0	0	0.16	0.01	0.02	0	0.05	0	0.01	0	0
P(SSB<50%B_0)	0.94	0.35	0.31	0.87	0.21	0.31	0.04	0.36	0.07	0.10	0.01	0.12

7. STATUS OF THE STOCKS

Stock Structure Assumptions

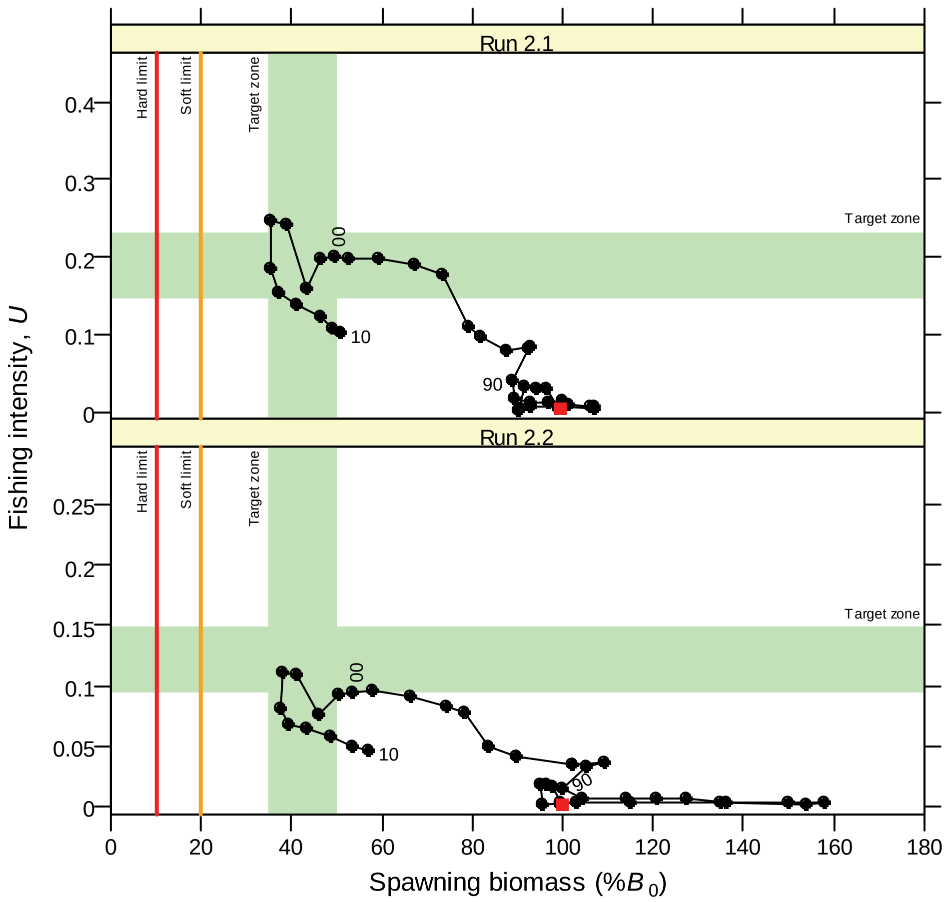
Hoki are assessed as two intermixing biological stocks, based on the presence of two main areas where spawning takes place simultaneously (Cook Strait and WCSI), and observed and inferred migration patterns of adults and juveniles:

- 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 Southern Plateau;
- 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	2010
Assessment Runs Presented	Two alternate model runs, considered equally plausible, were used to evaluate hoki stock status in this assessment: Model Runs 2.1 and 2.2
Reference Points	B_{MSY}: 24% B_0 Management Target: 35-50% B_0 Soft Limit: 20% B_0 Hard Limit: 10% B_0
Status in relation to Target	B_{2010} was estimated to be 51-57% $B_{0;}$ Virtually Certain (> 99%) to be above the lower end of the Management Target in both runs
Status in relation to Limits	B_{2010} is Exceptionally Unlikely (< 1%) to be below both the Soft and Hard Limits in both runs
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 square), to 2010. The vertical line at 10%B_0 represents the hard limit, that at 20%B_0 is the soft limit, and the shaded area represents the interim management target ranges in biomass and fishing intensity. Biomass estimates are based on MCMC results, while fishing intensity is based on corresponding MPD results.

Fishery and Stock Trends	
Recent Trend in Biomass or Proxy	The minimum estimate of biomass was 35% B_0 (in 2005). Biomass has subsequently been increasing.
Recent Trend in Fishing Mortality or Proxy	Fishing pressure is estimated to have been continuously decreasing since 2004.
Other Abundance Indices	-

Trends in Other Relevant Indicators or Variables	Recent recruitment (1995-2008) is estimated to be near the long-term average for this stock.

Projections and Prognosis	
Stock Projections or Prognosis	The biomass of the eastern hoki stock is expected to stay steady over the next 5 years at assumed 2009-10 eastern fishery catch levels.
Probability of Current Catch or TACC causing decline below Limits	Soft Limit: Exceptionally unlikely (< 1%) Hard Limit: Exceptionally unlikely (< 1%)

Assessment Methodology		
Assessment Type	Level 1 – Quantitative stock assessment	
Assessment Method	Age-structured CASAL model with Bayesian estimation of posterior distributions.	
Main data inputs	- Research time series of abundance indices (trawl and acoustic surveys). - Proportions at age data from the commercial fisheries and trawl surveys. - Estimates of biological parameters. New information since the 2009 assessment included two trawl surveys, one acoustic survey, updated catch and catch-at-age data and new proportion spawning data.	
Period of Assessment	Latest assessment: 2010	Next assessment: 2011
Changes to Model Structure and Assumptions	None since the 2009 assessment.	
Major Sources of Uncertainty	The two Model Runs represent different ways of dealing with the unexplained lack of older fish in commercial catches and surveys; the first estimates natural mortality at age which results in older fish suffering high natural mortality; the second assumes natural mortality does not vary with age but that some older fish are not vulnerable to fishing. Aside from natural mortality, other major sources of uncertainty include stock structure and migration patterns, stock-recruit steepness and natal fidelity assumptions. Uncertainty about the size of recent year classes affects the reliability of stock projections.	

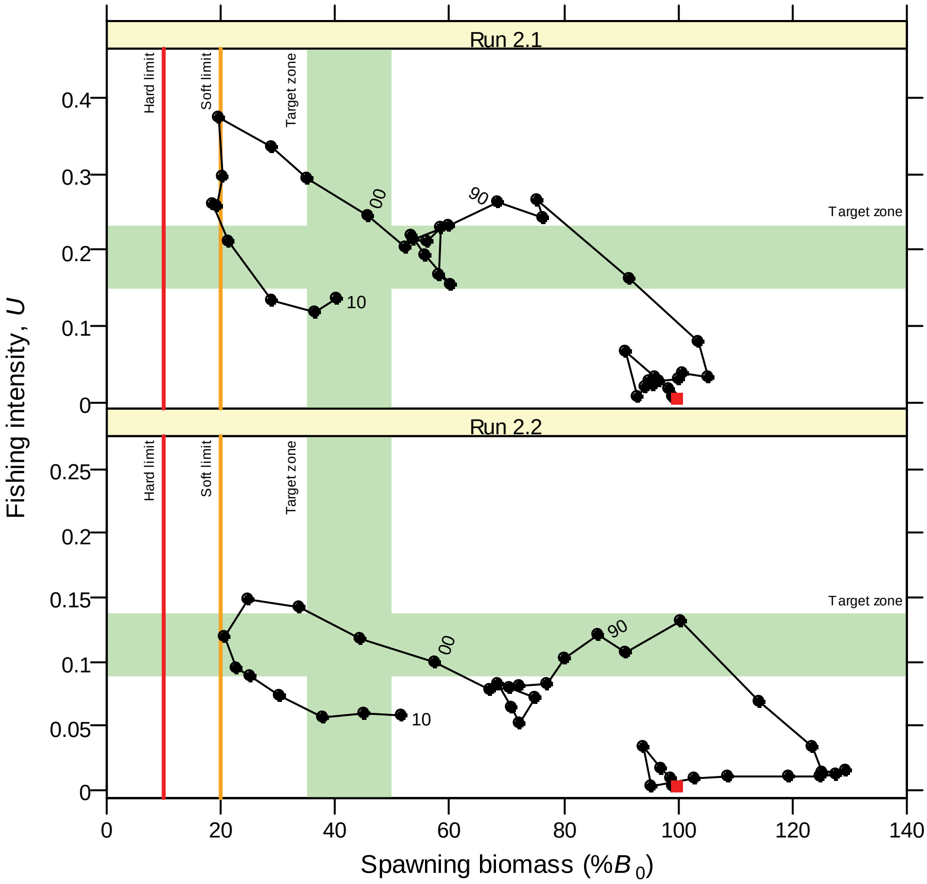
Qualifying Comments
None

Fishery Interactions
Main bycatch species are hake, ling, silver warehou and spiny dogfish, with lesser bycatches of ghostsharks, white warehou, sea perch and stargazers. Bycatch species of concern include basking sharks, deepsea skates, fur seals and seabirds.

- **Western Hoki Stock**

Stock Status	
Year of Most Recent Assessment	2010
Assessment Runs Presented	Two alternative model runs, considered equally plausible, were used to evaluate hoki stock status in this assessment: Model Runs 2.1 and 2.2

Reference Points	B_{MSY}: 25% B_0 Management Target: 35-50% B_0 Soft Limit: 20% B_0 Hard Limit: 10% B_0
Status in relation to Target	Model run 2.1: B_{2010} was estimated to be 40% B_0; Very Likely (> 90%) to be above the lower end of the Management Target Model Run 2.2: B_{2010} was estimated to be 52% B_0; Virtually Certain (> 99%) to be above the lower end of the Management Target
Status in relation to Limits	Both Model Runs: B_{2010} Exceptionally Unlikely (< 1%) to be below both the Soft and Hard Limits
Historical Stock Status Trajectory and Current Status	



Trajectory over time of fishing intensity (*U*) and spawning biomass (%B_0), for the western hoki stock from the start of the assessment period in 1972 (represented by a red square), to 2010. The vertical line at 10%B_0 represents the hard limit, that at 20%B_0 is the soft limit, and the shaded area represents the interim management target ranges in biomass and fishing intensity. Biomass estimates are based on MCMC results, while fishing intensity is based on corresponding MPD results.

Fishery and Stock Trends	
Recent Trend in Biomass or Proxy	Biomass is estimated to have more than doubled from historical lows (19% B_0 for Model Run 2.1 and 21%B_0 for Model Run 2.2) that occurred during the period 2003-06.
Recent Trend in Fishing Mortality or Proxy	Fishing pressure is estimated to have been decreasing since 2003.
Other Abundance Indices	-
Trends in Other Relevant Indicators or Variables	This stock experienced an extended period of poor recruitment from 1995 to 2001. Year-classes after 2001 are estimated to be stronger, with two years in which recruitment is estimated to be near or above the long-term average.

Projections and Prognosis	
Stock Projections or Prognosis	The biomass of the western hoki stock is expected to increase over the next 5 years at assumed 2009-10 western fishery catch levels.
Probability of Current Catch or TACC causing decline below Limits	Soft Limit: Exceptionally unlikely (< 1% Probability) Hard Limit: Exceptionally unlikely (< 1% Probability)

Assessment Methodology	Same as that outlined for the eastern stock above, plus one additional major source of uncertainty; namely, the lack of fit of the models to recent increases in the sub-Antarctic survey estimates of biomass.

Qualifying Comments
None

Fishery Interactions
Main bycatch species are hake, ling, silver warehou, jack mackerel and spiny dogfish, with lesser bycatches of ghostsharks, white warehou, sea perch and stargazers. Bycatch species of concern include basking sharks, deepsea skates, fur seals and seabirds.

8. FOR FURTHER INFORMATION

Abraham, E.R., Thompson, F.N., Oliver, M.D. (2010). Summary of the capture of seabirds, mammals, and turtles in New Zealand commercial fisheries, 1998–99 to 2007–08. New Zealand Aquatic Environment and Biodiversity Report No.45. 149p.

Anderson OF., Smith MH. 2005. Fish discards and non-target fish catch in the New Zealand hoki trawl fishery, 1999-2000 to 2002-03. New Zealand Fisheries Assessment Report 2005/3. 37p.

Anderson OF., Gilbert DJ., Clark MR. 2001. Fish discards and non-target catch in the trawl fisheries for orange roughy and hoki in New Zealand waters for the fishing years 1990-91 to 1998-99. New Zealand Fisheries Assessment Report 2001/16. 57p.

Bagley N, O'Driscoll RL. 2010. Results of Sub-Antarctic Trawl Survey**,** December 2009. WG-HOK-2010/06 24 p. (Unpublished report held by Ministry of Fisheries, Wellington.)

Baird SJ. 2005a. Incidental capture of seabird species in commercial fisheries in New Zealand waters, 2002–03. New Zealand Fisheries Assessment Report 2005/2. 50p.

Baird SJ. 2005b. Incidental capture of New Zealand fur seals (*Arctocephalus forsteri*) in commercial fisheries in New Zealand waters, 2002–03. New Zealand Fisheries Assessment Report 2005/12. 35p.

Baird SJ., Smith MH. 2007. Incidental capture of seabird species in commercial fisheries in New Zealand waters, 2003-04 and 2004-05. New Zealand Aquatic Environment and Biodiversity Report No. 9. 108p.

Baird, SJ., Smith, MH. 2008. Incidental capture of seabird species in commercial fisheries in New Zealand waters, 2005-06. New Zealand Aquatic environment and Biodiversity report No. 18. 125p.

Baird SJ., Bagley NW., Wood BA., Dunn A., Beentjes M. 2002. The spatial extent and nature of mobile bottom fishing methods within the New Zealand EEZ 1989–90 to 1998–99. Final Research Report for MFish Project ENV2000/05. 36p.

Baird SJ., Smith MH. (in press). Incidental capture of seabird species in commercial fisheries in New Zealand waters, 2005-06. New Zealand Aquatic Environment and Biodiversity Report 2008 No #. 124p.

Baird, S.J., Wood, B. (2010). Extent of coverage of 15 environmental classes within the New Zealand EEZ by commercial trawling with seafloor contact. Draft Final Research Report prepared as part completion of Objective 5 of BEN200601 for the Ministry of Fisheries. 33p.

Baird, S.J., Wood, BA., Bagley NW. (2009). Nature and extent of commercial fishing effort on or near the seafloor within the New Zealand 200 n. mile Exclusive Economic Zone, 1989–90 to 2004–05. New Zealand Aquatic Environment and Biodiversity Report 2009/xx. nn p

Ballara SL., O'Driscoll RL., Bagley NW., Stevens DW., Fu D. 2008. Hoki data collation: a report to the 2008 Hoki Working Group on the hoki trawl and acoustic surveys, catches, CPUE, size, and age structure of the hoki fishery, including the 2005–06 data update. WG HOK 2008/03. (Unpublished report held by Ministry of Fisheries, Wellington.)

Ballara SL., Hurst RJ., Cordue PL. 1999. Estimates of natural mortality for hoki. Final Research Report for Ministry of Fisheries Project HOK9801 Objective 10. 11p.

Ballara SL., O'Driscoll RL., Fu D. 2006. Catches, size, and age structure of the 2004–05 hoki fishery, and a summary of input data used for the 2006 stock assessment. New Zealand Fisheries Assessment Report 2006/49. 97p.

Ballara SL., Phillips NL., Smith MH., Dunn A. 2006. Descriptive analysis of hoki (*Macruronus novaezelandiae*) fisheries on the west coast South Island, Cook Strait, Chatham Rise, and sub-Antarctic, and catch-per-unit-effort analysis of the Chatham Rise hoki fishery for the years 1990-2003. New Zealand Fisheries Assessment Report 2006/19. 57p.

Ballara, S.L., O'Driscoll R.L., Anderson, O.F. (2010a)..Fish discards and non-target fish catch in the trawl fisheries for hoki, hake, and ling in New Zealand waters. New Zealand Aquatic Environment and Biodiversity Report 2010/xx. nn p

Ballara, S.L.; O'Driscoll, R.L.; Fu, D. (2010b). Catches, size, and age structure of the 2008–09 hoki fishery, and a summary of input data used for the 2010 stock assessment. New Zealand Fisheries Assessment Report 2010/XX. nn p.

Booth JD., Baird SJ., Stevenson ML., Bagley NW., Wood BA. 2002. Review of technologies and practices to reduce bottom trawl bycatch and seafloor disturbance in New Zealand. Final Research Report for MFish Project ENV2000/06.

Bradford, E. 2002. Estimation of the variance of mean catch rates and total catches of non-target species in New Zealand fisheries. New Zealand fisheries assessment report ; 2002/54. 60 p.

Bradford-Grieve, J., Livingston, ME., Sutton, P., Hadfield, M. 2007. Ocean variability and declining hoki stocks: an hypothesis as yet untested. New Zealand Science Review Vol. 63 (3-4): 76–80.
Bradford-Grieve JM., Probert PK., Baker AN., Best HA., Boyd P., Broekhuizen N., Childerhouse S., Clark M., Hadfield M., Hall JA., Hanchet S., Nodder SD., Safi K., Thompson D., Wilkinson I., Zeldis J. 2003. Pilot trophic model for subantarctic water over the Southern Plateau, New Zealand: a low biomass, high transfer efficiency system. Journal of Experimental Marine Biology289: 223–262.
Brander, KM. 2005. Cod recruitment is strongly affected by climate when stock biomass is low. ICES Journal of marine science 62: 339–343.
Bull B. 2000. An acoustic study of the vertical distribution of hoki on the Chatham Rise. New Zealand Fisheries Assessment Report 2000/05. 60p.
Bull B., Livingston ME. 2000. Hoki migration patterns: an analysis of commercial catches in New Zealand waters 1985–99. NIWA Client Report 2000/63. 49p.
Bull B., Livingston ME. 2001. Links between climate variation and the year class strength of New Zealand hoki (*Macruronus novaezelandiae)*: an update. New Zealand Journal of Marine and Freshwater Research 35(5). 871–880.
Bull B., Livingston ME., Hurst RJ., Bagley N. 2001. Upper-slope fish communities on the Chatham Rise, New Zealand, 1992-99. New Zealand Journal of Marine and Freshwater Research 35 (3): 795–815.
Bull B., Francis RICC., Dunn A., McKenzie A., Gilbert DJ., Smith MH., Bian R. 2008. CASAL (C++ algorithmic stock assessment laboratory): CASAL User Manual v2.20-2008/02/14. NIWA Technical Report 130. 275 p.
Clark MR. 1985a. The food and feeding of seven fish species from the Campbell Plateau, New Zealand. New Zealand Journal of Marine and Freshwater Research 33: 339–363.
Clark MR. 1985b. Feeding relationships of seven fish species from the Campbell Plateau, New Zealand. New Zealand Journal of Marine and Freshwater Research 19: 365–374.
Collie JS., Hall SJ., Kaiser MJ., Poiner IR. 2000. A quantitative analysis of fishing impacts on shelf-sea benthos. Journal of Animal Ecology 69: 785-798.
Connell, AM. 2009. Hoki (*Macruronus novaezelandiae*) diet variability and associated middle-depth demersal fish species depth distribution in the ecosystem on the Chatham Rise, New Zealand. M.Sc. Thesis, Victoria University of Wellington, New Zealand. 128 pp
Conservation Services Programme. 2008. Summary of autopsy reports for seabirds killed and returned from observed New Zealand fisheries, 1 October 1996 - 30 September 2005, with specific reference to 2002-03, 2003/04, 2004/05. DOC Research & Development Series 291. Department of Conservation, Wellington. 110p.
Coombs RF., Cordue PL. 1995. Evolution of a stock assessment tool: acoustic surveys of spawning hoki (*Macruronus novaezelandiae*) off the west coast of South Island, New Zealand, 1985–91. New Zealand Journal of Marine and Freshwater Research 29: 175–194.
Cordue PL. 2001. MIAEL estimation of biomass and fishery indicators for the 2001 assessment of hoki stocks. New Zealand Fisheries Assessment Report 2001/65. 59p.
Cordue PL. 2006. Report on the 13 November 2006 M-prior HWG sub-group meeting. Unpublished report to the Hoki Working Group, dated 17 November 2006
De Juan S., Thrush SF., Demestre M. 2007. Functional changes as indicators of trawling disturbance ona benthic community located in a fishing ground (NW Mediterranean Sea*).* Marine Ecology Progress Series 334: 117-129.
Deepwater Group. 2009 Operational Procedures: Hoki Fishery, v. 12 October 2009.
Dunn A., Livingston ME. 2004. Update catch-per-unit-effort indices and descriptive analyses for hoki (*Macruronus novaezelandiae*) fisheries on the west coast South Island, Cook Strait, Chatham Rise, and Sub-Antarctic, 1990 to 2002. New Zealand Fisheries Assessment Report 2004/35. 55p.
Dunn, M., Horn P. 2010. Trophic relationships of hoki, hake, and ling on the Chatham Rise. Ministry of Fisheries Project ENV2006-07 Final Report.
Dunn M., Connell A., Stevens D. 2007. Preliminary results from Chatham Rise Trophic Study presented at Marine Science Conference, Nelson 2006.
Dunn, M., Hurst, R., Renwick, J., Francis, R.C.C., Devine, J., McKenzie, A. 2009. Fish abundance and climate trends in New Zealand. New Zealand Aquatic Environment and Biodiversity Report No. 31.
Dunn, M., Horn, P., Connell, A., Stevens, D., Forman,J., Pinkerton, M., Griggs, L., Notman, P., Wood, B. (2009). Ecosystem-scale trophic relationships: diet composition and guild structure of middle-depth fish on the Chatham Rise. Ministry of Fisheries Research Project, ZBD2004-02 Final Report. 31p.
Francis MP., Duffy C. 2002 Distribution, seasonal abundance and bycatch of basking sharks (Cetorhinus maximus) in New Zealand, with observations on their winter habitat. Marine Biology 140(4): 831-842, 2002.
Francis MP., Smith, MH. 2010. Basking shark (*Cetorhinus maximus*) bycatch in New Zealand fisheries, 1994–95 to 2007–08 New Zealand Aquatic Environment and Biodiversity Report 2010/xx. nn p.
Francis MP., Hurst RJ., McArdle B., Bagley NW., Anderson OF. 2002. New Zealand demersal fish assemblages. Environmental Biology of Fishes 62(2): 215–234
Francis RICC. 2001. Improving the consistency of hoki age estimation. *New* Zealand Fisheries Assessment Report 2001/12. 18p.
Francis RICC. 2003. Analyses supporting the 2002 stock assessment of hoki. New Zealand Fisheries Assessment Report 2003/5. 34p.
Francis RICC. 2004. Preliminary analyses for the 2004 hoki assessment. WG-Hoki-2004/9. 28p. (Unpublished report held by Ministry of Fisheries, Wellington.)
Francis RICC. 2005. Assessment of hoki (*Macruronus novaezelandiae*) in 2004. New Zealand Fisheries Assessment Report 2005/35. 97p.
Francis RICC. 2006. Assessment of hoki (*Macruronus novaezelandiae*) in 2005. New Zealand Fisheries Assessment Report 2006/3. 96p.
Francis RICC. 2007. Assessment of hoki (*Macruronus novaezelandiae*) in 2006. New Zealand Fisheries Assessment Report 2007/15. 99p.
Francis RICC. 2008a. Assessment of hoki (*Macruronus novaezelandiae*) in 2007. New Zealand Fisheries Assessment Report 2008/4. 109p.
Francis RICC. 2009. Assessment of hoki (*Macruronus novaezelandiae*) in 2008. New Zealand Fisheries Assessment Report 2009/7. 80p.
Francis RICC., Hurst RJ., Renwick JA. 2001. An evaluation of catchability assumptions in New Zealand stock assessments. New Zealand Fisheries Assessment Report 2001/1. 37p.
Francis RICC., Hadfield MG., Bradford-Grieve JM., Sutton PJH. 2006. Links between climate and recruitment of New Zealand hoki (*Macruronus novaezelandiae*) now unclear. New Zealand Journal of Marine and Freshwater Research 40: 547-560.
Grange K. 1993. Hoki offal dumping on the continental shelf: a preliminary benthic assessment. NewZealand Marine Sciences Society Review 35: 15
Grimes PJ., O'Driscoll RL. 2006. Estimating the proportion of female hoki on the Southern Plateau which spawn each year by microscopic examination of gonad samples. Final Research Report for Ministry of Fisheries Project MDT2003/01 Objective 6. 40p.
Haist V., Hurst RJ., O'Driscoll RL., Middleton DAJ. 2007. Hoki codend retention study. Final report for Deepwater Group Ltd. Seafood Industry Council, October 2007. 26p.
Helson, J., Leslie, S., Clement, G., Wells, R., Wood, R. 2010. Private rights, public benefits: Industry driven seabed protection. *Marine Policy 34(3*): 557-566.

Hewitt, J., Floer, O.,Bowden, D. 2010. Challenger Plateau and Chatham Rise communities and habitats. Presentation to the Biodiversity research Advisory group April 2010 as part of Ministry of Fisheries project ZBD2007-01, Objectives 9, 10.
Hicks AC., Gilbert DJ. 2002. Stock discrimination of hoki (*Macruronus novaezelandiae*) based on otolith ring measurements. New Zealand Fisheries Assessment Report 2002/2. 31p.
Hicks AC., Cordue PL., Bull B. 2002. Estimating proportion at age and sex in the commercial catch of hoki (*Macruronus novaezelandiae*) using length frequency data. New Zealand Fisheries Assessment Report 2002/43. 51p.
Hicks AC., Smith PJ., Horn PL., Gilbert DJ. 2003. Differences in otolith measurements and gill raker counts between the two major spawning stocks of hoki (*Macruronus novaezelandiae*) in New Zealand. New Zealand Fisheries Assessment Report 2003/7. 23p.
Hitchmough, R., L. Bull, et al. 2005. New Zealand Threat Classification System lists. Wellington, Science & Technical Publishing, Department of Conservation. 194p.
Horn PL., Sullivan KJ. 1996. Validated aging methodology using otoliths, and growth parameters for hoki (*Macruronus novaezelandiae*) in New Zealand waters. New Zealand Journal of Marine and Freshwater Research 30: 161–174.
Hurst RJ., Bagley NW., Anderson OF., Francis MP., Griggs LH., Clark MR., Paul LJ. and Taylor, P.R. (2000). Atlas of juvenile and adult fish and squid distributions from bottom and mid-water trawls and tuna longlines in New Zealand waters. NIWA Technical Report 84. 162p.
Hurst, R.J. Renwick J.A., Sutton, P.J.H Uddstrom, M.J. Kennan, S.C. Law, C.S. Rickard, G.J. Korpela, A. Stewart, C.. Evans J (2009). Climate and ocean trends of potential relevance to fisheries in the New Zealand Region, Aquatic Environment and Biodiversity report XX. 220 p.
Jones JB. 1993. Net damage injuries to New Zealand hoki, *Macruronus novaezelandiae*. New Zealand Journal of Marine and Freshwater Research 27: 23–30.
Kaiser MJ., Collie JS., Hall SJ., Jennings S., Poiner IR. 2002. Modification of marine habitats by trawling activities: prognosis and solutions. Fish and Fisheries 3: 114-136.
Kaiser MJ., Clarke KR., Hinz H., Austen MCV., Somerfield PJ., Karakassis I. 2006. Global analysis of response and recovery of benthic biota to fishing. Marine Ecology Progress Series 311: 1-14
Kalish JM., Livingston ME., Schofield KA. 1996. Trace elements in the otoliths of New Zealand blue grenadier (*Macruronus novaezelandiae*) as an aid to stock discrimination. Marine and Freshwater Research 47: 537–542.
Langley AD. 2001. Summary report of biological data collected from the hoki fishery by the Hoki Management Company Limited during the 1999 –2000 fishing year. New Zealand Fisheries Assessment Report 2001/77. 34p.
Leathwick, J.R.; Rowden, A.; Nodder, S.; Gorman, R.; Bardsley, S.; Pinkerton, M.; Baird, S.J.; Hadfield, M. ; Currie, K.; Goh, A. (2009). Development of a benthic-optimised marine environment classification for waters within the New Zealand EEZ. Draft Final Research Report prepared as part completion of Objective 5 of BEN200601 for the Ministry of Fisheries. 52 p.
Livingston, M.E. (1990a). Stock structure of New Zealand hoki, *Macruronus novaezelandiae*. N.Z. Fisheries Assessment Research Document 90/8. 21 p.
Livingston, M.E. (1990b). Spawning hoki (*Macruronus novaezelandiae* Hector) concentrations in Cook Strait and off the east coast of the South Island, New Zealand, August-September 1987. New Zealand Journal of Marine and Freshwater Research (24): 503–517.
Livingston ME. 2000. Links between climate variation and the year class strength of New Zealand hoki (Macruronus novazealandiae) Hector. New Zealand Journal of Marine and Freshwater Research 34: 55–69.
Livingston, ME. 2002. Potential interactions between New Zealand's hoki fishery and key components of the marine ecosystem and associated processes. NIWA Client Report WGTN 2002/53: 41p.
Livingston ME., Bull B. 2000. The proportion of female hoki developing to spawn on the Southern Plateau, April 1998. New Zealand Fisheries Assessment Report 2000/13. 20p.
Livingston ME., Renwick J. 2003. Climate change and implication for fisheries. Seafood New Zealand 11(11): 40–41.
Livingston ME., Rutherford K. 1988. Hoki wastes on west coast fishing grounds. Catch, March 1988: 16-17.
Livingston ME., Schofield KA. 1996a. Annual changes in the abundance of hoki and other species on the Chatham Rise, Jan 1992-Jan 1995 and the Southern Plateau, Dec 1991-Dec 1993. N.Z. Fisheries Assessment Research Document 1996/14. 35p.
Livingston ME., Schofield KA. 1996b. Stock discrimination of hoki (*Macruronus novaezelandiae* Merlucciidae) in New Zealand waters, using morphometrics. New Zealand Journal of Marine and Freshwater Research 30: 197–208.
Livingston ME., Stevens DW. 2002. Review of trawl survey abundance data available as inputs to the hoki stock assessment. New Zealand Fisheries Assessment Report 2002/48. 69p.
Livingston ME., Pinkerton, M. 2004. Sampling programme to construct and quantify food webs supporting important fish and invertebrate species in New Zealand waters. Final Research Report for Ministry of Fisheries Research Project ENV2002/07 Obj.1.
Livingston ME., Schofield KA., Sullivan KJ. 1992. The discrimination of hoki groups in New Zealand waters using morphometrics and age-growth parameters. New Zealand Fisheries Assessment Research Document 1992/18. 30p.
Livingston ME., Vignaux M., Schofield KA. 1997. Estimating the annual proportion of non-spawning adults in the New Zealand hoki, *Macruronus novaezelandiae* Hector. Fishery Bulletin 95: 99–113.
Livingston ME., Bull B., Gilbert DJ. 2000. The observed sex ratios of hoki (*Macruronus novaezelandiae*) in New Zealand, 1983–99. New Zealand Fisheries Assessment Report 2000/24. 40p.
Livingston ME., Bull B., Stevens DW. 2002. Migration patterns during the life-cycle of hoki (*Macruronus novaezelandiae*): an analysis of trawl survey data in New Zealand waters 1991–2002. Final Research Report for Ministry of Fisheries Research Project HOK2000/01 Objective 6.
Livingston ME., Clark M., Baird SJ. 2003. Trends in incidental catch of major fisheries on the Chatham Rise for fishing years 1989-90 to 1998-99. New Zealand Fisheries Assessment Report 2003/52. 74p
Livingston ME., Stevens DW., O'Driscoll RL., Francis RICC. 2004. Trawl survey of hoki and middle depth species on the Chatham Rise, January 2003 (TAN0301). New Zealand Fisheries Assessment Report 2004/16. 71p.
Lohrer DAM., Trush SF., Gibbs M. 2004. Bioturbators enhance ecosystem function through complex biogeochemical interactions. Nature 431: 1092-1095
Macaulay GJ. 2006. Target strength estimates of hoki. Final Research Report for Ministry of Fisheries Project HOK2004/03 Objective 3. 13p.
MacDiarmid, A.M., Thompson, D., Oliver, M. (2005). Ecosystem Effects of the Hoki Trawl Fishery. NIWA Client Report: WLG2005- 77.
MacKenzie, D., Fletcher, D., (2006). Characterisation of seabird captures in commercial trawl and longline fisheries in New Zealand 1997/98 to 2003/04. Final Research Report for ENV2004/04, held by Ministry of Fisheries, New Zealand. 102p.
Massey BR., Hore AJ. 1987. A preliminary trawl mesh selection study of barracouta (Thyrsites atun) Central Fisheries Region Internal Report No. 6. 28p. (Draft report, held by MAFFish Central Region, Napier)
McClatchie S., Millar RB., Webster F., Lester PJ., Hurst R., Bagley N. 1997. Demersal fish community diversity off New Zealand: Is it related to depth, latitude and regional surface phytoplankton? Deep-Sea Research I 44 (4): 647–667.
McClatchie S., Pinkerton M., Livingston ME. 2005. Relating the distribution of a semi-demersal fish, *Macruronus novaezelandiae*, to their pelagic food supply. Deep- Sea Research Part I 52: 1489–1501.

Mckenzie A. 2010a. Initial assessment results for hoki in 2010. WG-HOK-2010/13. 20p. (Unpublished report held by Ministry of Fisheries, Wellington.)

Mckenzie A. 2010b. Impact on the assessment of a time varying catchability for the sub-Antarctic summer trawl survey series . WG-HOK-2010/16. 5p. (Unpublished report held by Ministry of Fisheries, Wellington.)

Mckenzie A. 2010c. Initial MCMC results for hoki in 2010 . WG-HOK-2010/19. 18p. (Unpublished report held by Ministry of Fisheries, Wellington.)

McKenzie, A.; Francis, R.I.C.C. 2009. Assessment of hoki (Macruronus novaezelandiae) in 2009. New Zealand Fisheries Assessment Report 2009/63. 43 p.

McKnight DG., Probert PK. 1997. Epibenthic communities on the Chatham Rise, New Zealand. New Zealand Journal of Marine and Freshwater Research 31:505–513

Murdoch RC. 1990. Diet of hoki larvae (*Macruronus novaezelandiae*) off Westland, New Zealand. New Zealand Journal of Marine and Freshwater Research 24: 519-527.

Murdoch RC. 1992. A review of the ecology of hoki *Macruronus novaezelandiae* (Hector), larvae in New Zealand waters. Bureau of Rural Resources Proceedings 15: 3-16.

Murdoch RC., Guo R., McCrone A. 1990. Distribution of hoki (*Macruronus novaezelandiae*) eggs and larvae in relation to hydrography in eastern Cook Strait, September 1987. New Zealand Journal of Marine and Freshwater Research 24: 533-543.

Norse EA., Watling L. 1999. Impacts of mobile fishing gear: the biodiversity perspective. American Fisheries Society Symposium 22: 31-40

O'Driscoll RL. 2002. Review of acoustic data inputs for the 2002 hoki stock assessment. New Zealand Fisheries Assessment Report 2002/36. 67p.

O'Driscoll RL. 2004. Estimating uncertainty associated with surv*eys of spawning hoki (Macruronus novaezelandiae*) in Cook Strait, New Zealand. ICES Journal of Marine Science 61: 84–97.

O'Driscoll RL. 2006. Acoustic survey of spawning hoki in Cook Strait during winter 2005, and revision of hoki acoustic abundance indices for Cook Strait and the west coast South Island. New Zealand Fisheries Assessment Report 2006/44. 46p.

O'Driscoll RL. 2007. Acoustic survey of spawning hoki in Cook Strait and off the east coast South Island in winter 2006. Fisheries Assessment Report 2007/21. 52p.

O'Driscoll, R.L. (2009). Acoustic survey of spawning hoki in Cook Strait and off the east coast South Island during winter 2008. New Zealand Fisheries Assessment Report 2009/17. 52 p.

O'Driscoll RL., Bagley NW. 2001. Review of summer and autumn trawl survey time series from the Southland and Sub-Antarctic area 1991–98. NIWA Technical Report 102. 115p

O'Driscoll RL., Bagley NW. 2006. Trawl survey of hoki, hake, and ling in the Southland and Sub-Antarctic areas, November–December 2005 (TAN0515). New Zealand Fisheries Assessment Report 2006/45. 64p.

O'Driscoll RL., Bagley NW. 2008. Trawl survey of hoki, hake, and ling in the Southland and Sub-Antarctic areas, November–December 2006 (TAN0617). New Zealand Fisheries Assessment Report 2008/30. 61p.

Bagley NW., O'Driscoll RL. 2009 Trawl survey of middle depths species in the Southland and Sub-Antarctic areas, November–December 2008 (TAN0813). New Fisheries Assessment Report 2009/56. 67p.

O'Driscoll RL., Dunford AJ. 2008. Acoustic survey of spawning hoki in Cook Strait during winter 2007. NIWA Client Report WLG2008-1 for The Deepwater Group Ltd. 44p.

O'Driscoll, R., Hurst, R.J. 2010.Trends in relative mesopelagic biomass using time series of acoustic backscatter data from trawl surveys. ENV2009-04 Research Progress Report.

O'Driscoll RL., Macaulay GJ. 2005. Using fish processing time to carry out acoustic surveys from commercial vessels. ICES Journal of Marine Science 62: 295–305.

O'Driscoll RL., Macaulay GJ. 2010. Industry acoustic survey in Cook Strait, winter 2009. WG-HOK-2010/2. 33p. (Unpublished report held by Ministry of Fisheries, Wellington.)

O'Driscol R., Hurst R., Livingston M., Cordue P., Starr P. 2002. Report of Hoki Working Group technical meeting 8 March 2002. WG–HOK–2002/27.

O'Driscoll RL., Booth JD., Bagley NW., Anderson OF., Griggs LH., Stevenson ML., Francis MP. 2003. Areas of importance for spawning, pupping or egg-laying, and juveniles of New Zealand deepwater fish, pelagic fish, and invertebrates. NIWA Technical Report 119. 377p.

O'Driscoll RL., Bagley NW., Macaulay GJ., Dunford AJ. 2004. Acoustic surveys of spawning hoki off South Island on FV *Independent 1*in winter 2003. New Zealand Fisheries Assessment Report 2004/29. 48 p.

Probert PK., Grove SL. 1998. Macrobenthic assemblages of the continental shelf and upper slope off the west coast of South Island, New Zealand. Journal of the Royal Society of New Zealand 28:259-280.

Probert PK., McKnight DG. 1993. Biomass of bathyal macrobenthos in the region of the Subtropical Convergence, Chatham Rise, New Zealand. Deep-Sea Research I 40: 1003–1007.

Probert PK., McKnight DG., Grove SL. 1997. Benthic invertebrate bycatch from a deep-water trawl fishery, Chatham Rise, New Zealand. Aquatic Conservation: In, Trophic Relationships in the Marine Environment. Aberdeen University Press, Aberdeen, 439-452.

Roberts JM., Harvey SM., Lamont PA., Gage JD., Humphery JD. 2000. Seabed photography, environmental assessment and evidence of deep-water trawling on the continental margin west of the Hebrides. Hydrobiologia 441: 173-183

Rutherford JC., Roper DS., Nagels JW. 1988. A preliminary study of the dispersion of hoki wastes and potential oxygen depletion off the west coast South Island. Unpublished Report prepared for Fisheries Research Division, MAFFISH, Wellington, by the Ministry of Works Water Quality Centre, Hamilton. 36p.

Schofield KA., Livingston ME. 1998. Ovarian development and the potential annual fecundity of western stock hoki (*Macruronus novaezelandiae)*.New Zealand Journal of Marine and Freshwater Research 32(1): 147–159.

Smith MH. 2004. Fitting priors for natural mortality and proportion of virgin hoki biomass in eastern stock. WG-HOK-2004/14. 7p. (Unpublished report held by Ministry of Fisheries, Wellington.)

Smith PJ., Patchell G., Benson PG. 1981. Genetic tags in the New Zealand hoki *Macruronus novaezelandiae*. Animal Blood Groups and Biochemical Genetics 12: 37–45.

Smith PJ., McVeagh SM., Ede A. 1996. Genetically isolated stocks of orange roughy (*Hoplostethus atlanticus*), but not of hoki (*Macruronus novaezelandiae*), in the Tasman sea and southwest Pacific ocean around New Zealand. Marine Biology 125: 783–793.

Smith PJ., Bull B., McVeagh SM. 2001. Evaluation of meristic characters for determining hoki relationships. Final Research Report for Ministry of Fisheries Research Project HOK1999/05 Objective 1. 10p.

Snelder, T.H., Leathwick, J.R., Dey, K.L., Rowden, A.A., Weatherhead, M.A., Fenwick, G.D., Francis, M.P., Gorman, R.M., Grieve, J.M., Hadfield, M.G., Hewitt, J.E., Richardson, K.M., Uddstrom, M.J., Zeldis, J.R. (2006). Development of an ecological marine classification in the New Zealand region. *Environmental Management*, *39*: 12–29.

Stevens DW., O'Driscoll RL. 2007. Trawl survey of hoki and middle depth species on the Chatham Rise, January 2006 (TAN0601). New Zealand Fisheries Assessment Report 2007/5. 73p.

Stevens DW., O'Driscoll RL., Horn PL 2009. Trawl survey of hoki and middle depth species on the Chatham Rise, January 2009 (TAN0901). New Zealand Fisheries Assessment report 2009/55. 95p.

Stevens DW., O'Driscoll RL., Gauthier S. 2008. Trawl survey of hoki and middle depth species on the Chatham Rise, January 2007 (TAN0701). New Zealand Fisheries Assessment Report 2008/52. 81p.

Stevens DW., O'Driscoll RL., Ballara SL., Horn PL. 2010. Trawl survey of hoki and middle depth species on the Chatham Rise, January 2009 (TAN1001). WG-HOK-2010/4. 24 p. (Unpublished report held by Ministry of Fisheries, Wellington.)

Sullivan KJ., Coombs RF. 1989. Hoki stock assessment 1989. New Zealand Fisheries Assessment Research Document 1989/4. 26p.

Thompson, F.N.; Abraham, E.R. 2009. Dolphin bycatch in New Zealand trawl fisheries, 1995–96 to 2006–07. New Zealand Aquatic Environment and Biodiversity Report No.36. 24p.

Thompson, F.N., Abraham, E.R., Oliver, M.D., in press. Estimation of fur seal bycatch in New Zealand sea lions trawl fisheries, 2002-03 to 2007-08. DRAFT New Zealand Aquatic Environment and Biodiversity Report. 39p.

Tuck, I., Cole, R., Devine, J. 2009. Ecosystem indicators for New Zealand fisheries. New Zealand Aquatic Environment and Biodiversity Report 42. 188 p.

Vignaux M. 1994. Catch per unit of effort (CPUE) analysis of west coast South Island and Cook Strait spawning hoki fisheries, 1987–93. New Zealand Fisheries Assessment Research Document 1994/11. 29p.

Zeldis JR., Murdoch RC., Cordue PL., Page MJ. 1998. Distribution of hoki (*Macruronus novaezelandiae*) eggs, larvae and adults off Westland, New Zealand, and the design of an egg production survey to estimate hoki biomass. Canadian Journal of Fisheries and Aquatic Science 55: 1682–1694.