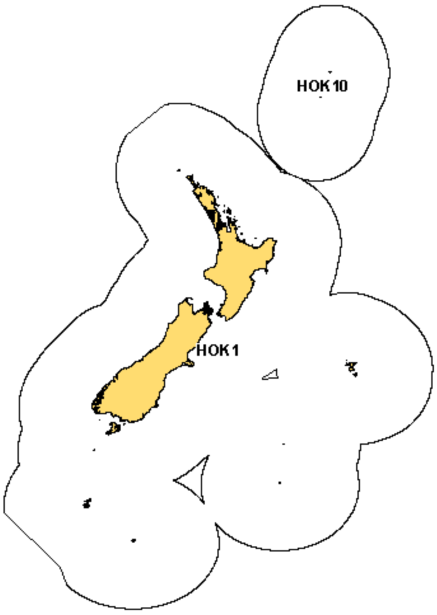
HOKI (HOK)

(*Macruronus novaezelandiae*)



1. FISHERY SUMMARY

(a) Commercial fisheries

Historically, the main fishery for hoki has 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 typically peak 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 1a). 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 1b). 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, and the TACC was reduced from 250 000 t to 200 000 t in the 2001–02 fishing year, to 180 000 t in 2003–04, and further to 100 000 t in 2004–05 (Table 1b). The TACC in 2006–07 is 100 000 t.

Table 1(a): 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 1 (b): Reported catch (t) from QMS or MHR, estimated catch (t) from TCEPR and CELR data, and TACC (t) for HOK 1 from 1986– 87 to 2005–06 (rounded to 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	242 000	237 000	250 000
2000–2001	230 000	226 000	250 000
2001–2002	196 000	200 000	200 000
2002–2003	185 000	177 000	200 000
2003–2004	136 000	132 000	180 000
2004–2005	104 000	102 000	100 000
2005–2006	104 000	101 000	100 000

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. The catch from the WCSI declined steadily from 1988–89 to 1995–96, increased again to between 90 000 and 110 000 t from 1996–97 until 2001–02, dropped sharply over the next three years to 33 500 t in 2004–05, before increasing to 38 500 t in 2005–06 (Table 1c). In Cook Strait, catches increased from 1988–89 to 1995–96, declined to a low of 22 000 t in 2001–02, peaked again at 41 000 t in 2003–04, before dropping to 21 500 t in 2005–06. Non-spawning catches on the Chatham Rise increased from 199394, peaked at over 70 000 t in 1997–98 and 1998–99, then decreased, with catches of 30 000–33 500 t in the last three years. Catches from the Sub-Antarctic peaked at over 30 000 t in 1999–2000 to 2001–02, but have declined to 6500 to

7000 t in 2004–05 and 2005–06. Catches from other areas have remained at relatively low levels, with only 1500 t taken from each of the spawning fisheries at Puysegur and on the ECSI in 2005–06 (Table 1c).

From 1999–2000 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 1d). 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. Since 2004–05 there has been a further agreement with the Minister that only 40% of the catch should be taken from western fisheries. About 45% of the catch was taken from western areas in 2005–06 (Table 1d).

Table 1 (c): Estimated[*] catch (t) of hoki by area, 1988–89 to 2005–06 (rounded to nearest 500 t).

	Spawning fisheries						Non-spawning fisheries		
Fishing Year	**WCSI**	**Puysegur**	**Cook Strait**	**ECSI**	**Sub-Antarctic**	**Chatham and ECSI**	**ECNI**	**Unrep.**	**Total catch**
1988–1989	188 000	3 500	7 000	–	5 000	5 000	–	–	208
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	96 000	3 000	46 000	500	23 000	73 500	2 500	–	244 500
1999–2000	103 000	2 500	42 000	1 000	34 000	57 000	1 500	1 000	242 000
2000–2001	103 500	5 500	35 500	2 000	30 000	50 500	2 000	1 000	230 000
2001–2002	91 000	5 000	22 000	3 000	31 000	43 000	1 000	–	196 000
2002–2003	74 000	5 000	34 000	7 000	21 000	43 000	1 000	–	185 000
2003–2004	45 000	1 000	41 000	3 000	12 000	33 000	1 000	–	136 000
2004–2005	33 500	5 000	24 500	4 000	6 500	30 000	500	–	104 000
2005–2006	38 500	1 500	21 500	1 500	6 500	33 500	500	–	104 000

* Estimated catches adjusted pro rata to the reported catch in Table 1(b) for 1988–89 to 2005–06.

– Catch less than 500 t.

Table 1(d): Proportions of total catch.

	Spawning fisheries		Non-spawning fisheries	
Fishing Year	**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	41%	19%	9%	31%
1999–2000	44%	18%	14%	24%
2000–2001	48%	16%	13%	23%
2001–2002	49%	13%	16%	22%
2002–2003	43%	22%	11%	24%
2003–2004	34%	32%	9%	25%
2004–2005	37%	28%	6%	29%
2005–2006	38%	22%	7%	33%

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. Although a greater proportion of the total catch is still taken during the spawning season, the hoki fishery now operates throughout the rest of the year as well, producing high quality fillet product from both spawning and non-spawning fisheries. More recently, the use of twin-trawl rigs has been increasing in all hoki fisheries, except Cook Strait and inside the line on the WCSI.

Total Allowable Commercial Catch (TACC)

In the 2005–06 fishing year the TACC for HOK1 was 100 000 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 40% of the catch 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.

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 are: 1) a restriction on fishing in waters shallower than 450 m; 2) a rule requiring vessels to ‘move on’ if there are more than 10% small hoki in the catch. More recently, the Code of Practice has been extended to include seasonal and area closures in spawning fisheries (see section 5e).

2005–06 hoki fishery

The overall catch of 104 400 t was the same as in 2004–05 and 4400 t higher than the TACC. Catches increased on the WCSI and the Chatham Rise, and declined in Cook Strait, Puysegur and the ECSI.

The WCSI is still the largest hoki fishery with catch of 38 500 t taken from this area in 2005–06. Unstandardised catch rates on the WCSI were the highest since 2002–03, with a median catch from all non-zero mid-water tows of 7.0 t per tow. Most of the catch was fish from the 2000–04 year classes (ages 2–6), with the mode at age 4 (2002 year-class). The percentage of young fish (those aged 3 or less) by number in the WCSI catch was 35%: lower than in 2004–05 (when 52% of the fish were 3 or younger) but still much higher than in any other previous year (previous maximum of 20% in 1994–95). Small hoki were caught in all areas of the WCSI fishery, both inside and outside the 25 n. mile line, and about 20% of the catch was fish less than 60 cm. Approximately equal numbers of males and female hoki were caught in 2005–06, but there has been an increasing sex bias in the catch from the WCSI at older ages. The observed proportion of males for fish aged 7 and older has declined from about 0.4 in the late 1980s to less than 0.2 in the last three years.

In 2005–06 the catch from the Sub-Antarctic was 6500 t, similar to 2004–05 and the second lowest since 1988–89. The percentage of the hoki catch taken by the hoki target fishery has also decreased, from over 96% in 2003–04 to 74% in 2005–06, with the remainder of the catch taken in fisheries targeting ling, squid and warehou. Median tow duration has increased and unstandardised catch rates in bottom trawls have declined to 0.1 t per hour, despite the increasing use of twin-rigs. Catch-at-age estimates showed the Sub-Antarctic catch, like that from the WCSI, consisted mainly of small fish from the 2000–04 year classes. About 32% of the catch was fish less than 60 cm.

Catches from Puysegur decreased from 5500 t in 2004–05 to 1500 t in 2005–06. High catch rates (median catch 15.5 t per mid-water tow) were taken during the spawning season. The fish from Puysegur were of similar size composition to those caught on the WCSI, with most fish smaller than

70 cm. This differs from 2004–05 when large catches of hoki over 80 cm length were taken at Puysegur.

The catch from Cook Strait was only 21 500 t in 2005–06. Unstandardised catch rates in Cook Strait continue to be high, with a median catch rate of 15.7 t per non-zero mid-water tow. The average size of hoki caught in Cook Strait was the largest of the four major fisheries: mean length 75 cm, compared to 71 cm on the WCSI, 68 cm in the Sub-Antarctic, and 66 cm on the Chatham Rise. The catch of males was dominated by fish from the 2000–03 year-classes (ages 3–6), but there was a broad age distribution of females from ages 3 to 12. Fewer fish from the 2004 year-class (age 2) were caught in Cook Strait than in the other fisheries, and only 11% of the catch was fish less than 60 cm.

About 1500 t of hoki was taken in the other eastern spawning fishery on the ECSI in 2005–06, the lowest catch from this area since 1999–00. The catch rate was high (median catch of 11.9 t per non-zero mid-water tow), and the length distribution of the catch was intermediate between that observed on the Chatham Rise and in Cook Strait, with a higher proportion of large females (greater than 80 cm) than were caught on the Chatham Rise but lower than caught in Cook Strait.

Catches from the Chatham Rise were 33 500 t in 2005–06. As in the Sub-Antarctic, there has been a general increase in tow duration on the Chatham Rise since the 1990s. The median unstandardised catch in bottom trawls has increased in the last three years to 0.8 t per hour in 2005–06, the highest catch rate since 1999–00. The Chatham Rise catch was dominated by small hoki from the 2000–04 year-classes, with few larger, older fish caught; 27% of the catch by numbers was less than 60 cm, and 43% was between 60 and 70 cm.

As the hoki quota was fully caught before end of the fishing year catches in both Puysegur and ECSI were lower than in the previous year. Higher catches were taken from WCSI and Chatham Rise but less from Cook Strait in 2005–06.

(b) Recreational fisheries

Recreational fishing for hoki is negligible.

(c) Maori customary fisheries

The level of this fishery is believed to be negligible.

(d) Illegal catch

No information is available about illegal catch.

(e) 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 1990–91 to 2002–03, Anderson and Smith (2005) noted that fish lost from the net during landing accounted for only a small fraction of the total discards in each year. They estimated the percentage of total discarding due to lost fish was from 0% to 8.7%.
- 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). 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° S to 54° 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 assessed as two 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 an average sized 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). Unlike in 1992 and 1993, the 1998 study was not preceded by a summer survey to allow estimation of the numbers of fish already departed from the Sub-Antarctic survey area. Further, the timing of this survey was a month earlier than either 1992 or 1993, and may therefore have underestimated the proportion spawning in 1998 (Livingston & Bull, 2000). A recent histological study of female hoki from the Sub-Antarctic in November–December of 2002 to 2004 (using a different methodology) estimated a higher proportion of hoki had spawned in the previous season (Grimes & O’Driscoll, 2006). These results and the methodology are being reviewed in 2007.

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 (1991-2002) 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. 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 2). 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 2 (but note that natural mortality was estimated in the model in the assessment).

Table 2: Estimates of biological parameters.

Fishstock	**Estimate**						
1. Natural mortality (M) (Sullivan & Coombs, 1989)							
	Females	**Males**					
HOK 1	0.25	0.30					
2. Weight = a (length)^b (Weight in g, length in cm total length) (Francis, 2003)							
HOK 1	a = 0.00479	b = 2.89					(Both stocks)
3. von Bertalanffy growth parameters (Horn & Sullivan, 1996)							
	Females			**Males**			
	K	**t_0**	**L_∞**	**K**	**t_0**	**L_∞**	
HOK 1	0.213	-0.60	104.0	0.261	-0.50	92.6	(Western stock)
HOK 1	0.161	-2.18	101.8	0.232	-1.23	89.5	(Eastern stock)

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.

5. ENVIRONMENTAL AND ECOSYSTEM CONSIDERATIONS

The hoki trawl fishery is extensive throughout the EEZ and the key potential effects of fishing on the environment and the marine ecosystem are considered below. As part of the Marine Stewardship Council certification process in 2001, a risk analysis was carried out to identify threats of the hoki fishery to the environment and ecosystem. The main topics were seabirds, mammals, the benthic environment and communities, target stock and by-catch.

(a) Sea-bed disturbance

Bottom trawling that targets hoki is carried out extensively across the Chatham Rise and in the Sub-Antarctic, in depths of 200–800 m throughout most of the year. The Chatham Rise has been subjected to about twice as much trawling for hoki as the Sub-Antarctic (Table 3), but effort has decreased on the Chatham Rise in recent years. The west coast spawning grounds have been subjected to a similar number of tows as the Chatham Rise, however, this is largely limited to the spawning season, and tends to be a mid-water fishery. Total effort in Cook Strait has been much less than in other areas. Although mid-water nets may be towed along the seabed bottom contact is substantially less than with bottom trawls. All areas show the number of tows in 2005-06 to be below the mean (Table 3). This is mainly the result of quota cuts in the hoki fishery.

Table 3. Summary of target tow data (TCEPR only) in the hoki fishery from fishing years 1989–90 to 2005–06 (FY, fishing year, MT, mid-water tows, BT, bottom tows).

	West Coast S.I.		Cook Strait		East Coast S.I.		Sub-Antarctic		Chatham Rise	
FY	**MT**	**BT**	**MT**	**BT**	**MT**	**BT**	**MT**	**BT**	**MT**	**BT**
1990	6599	992	871	21	3	0	29	2098	49	2024
1991	6767	1349	1843	12	110	7	83	3918	964	3484
1992	5255	789	1353	6	62	0	114	5435	456	5548
1993	5239	1502	1308	10	7	4	442	4905	1057	5262
1994	7487	1335	1756	88	11	1	561	2035	1329	3452
1995	6842	1227	1722	223	17	8	414	2325	2167	6251
1996	5373	1564	2916	765	66	41	421	2482	2296	7935
1997	6802	1321	3104	903	52	58	343	3417	2355	9315
1998	6473	998	1956	393	57	119	176	4367	3791	11424
1999	5016	1553	1787	373	30	48	424	3641	2440	11429
2000	4836	1700	1749	242	22	24	527	5910	2686	9505
2001	5516	2018	1596	91	108	36	666	5419	930	9876
2002	4393	2597	843	39	128	67	140	6432	874	7835
2003	4062	2426	1520	53	311	199	97	4391	503	9287
2004	4083	1759	1525	41	60	13	80	3015	401	7214
2005	2150	1191	1057	28	139	34	68	1426	347	5010
2006	1650	1344	878	23	34	10	74	718	146	4827
Total	88543	25665	27784	3311	1217	669	4659	61934	22791	119678
Mean	5208	1510	1634	195	72	39	274	3643	1340	7040
Fishery		Spawning		Spawning		Spawning*		Non spawning		Non-spawning

* East coast non-spawning tows included in Chatham Rise columns

Studies elsewhere in the world have shown that repeated trawl disturbances alter the benthic community by damaging or removing macro-fauna and encouraging anaerobic bacterial growth (e.g. Norse & Watling, 1999; Kaiser et al., 2002; Collie et al., 2000; Roberts et al., 2000). Bottom trawling also tends to homogenise the sediment, which damages the habitat for certain fauna. Benthic processes, such as the transfer of nutrients, remineralisation, oxygenation and productivity, which occur in undisturbed, healthy sediments, are also impaired (e.g. Kaiser et al., 2006; De Juan et al., 2007; Lohrer et al., 2004). Recovery rates depend on several factors, including levels of natural disturbance, the coarseness of the sediment, depth, and the type of benthic community that is disturbed. Coarse sediments and benthic communities that are subject to a lot of natural disturbances by currents or wind have much faster recovery rates than consolidated sediments. Conversely, fine sediments particularly those with slow growing fauna and high longevity usually have slow recovery rates. Rocky substrates with slow growing organisms such as deep-sea corals are also slow to recover. These generalisations apply to most systems studied worldwide, and are likely to apply to New Zealand sediments. Some data are available on the macro-benthic communities of the west coast South Island (Probert & Grove, 1998) and the Chatham Rise (Probert & McKnight, 1993, McKnight & Probert, 1997).

Most bottom trawling for hoki on the Chatham Rise and in the Sub-Antarctic occurs over medium grain sediments (sandy silt Chatham Rise, silty clay Sub-Antarctic) although there are some areas of rocky outcrops and foul ground in both areas. Hotspots of more intense effort have been identified, but the impact of hoki bottom trawls on the benthic communities is unknown (Baird et al., 2002). New data to map biodiversity and sediments on the Chatham Rise and Challenger Plateau 200-1200 m depths are being collected in 2007. Other research to investigate the impacts of fishing on the sea-bed is also underway.

Benthic Protection Areas (zones of no bottom contact fishing) will be introduced by Government in October 2007 to protect 30% of the EEZ from the effects of bottom fishing. Industry has voluntarily implemented these closures since October 2006. Some of these areas overlap with hoki fishing depths but are not significant hoki fishing locations.

The effects of dumping, burst bags, and the discard of frames and heads on water quality within the area of the west coast spawning ground were considered a potential problem in the mid-1980s. Photographs of the seabed at that time showed an influx of scavenging fauna during the spawning season (Grange, 1993), but there was little evidence of anoxic conditions, or even reduced dissolved oxygen levels near or on the seabed (Livingston & Rutherford, 1988). Modelling studies to compare the effects of mincing fish waste rather than dumping the waste whole suggested that little would be gained by this practice (Rutherford et al., 1987). The problem has largely been alleviated as most vessels now carry meal plants and most offal is processed on-board.

(b) Incidental catch (fish and invertebrates)

There are two main sources of data on catch weights and relative abundance of incidental catch in New Zealand: TCEPR forms provide greenweight catch totals of the top five species on a tow by tow basis, and a daily summary of all ITQ species caught. MFish Observer records provide catch weights on all ITQ and non-ITQ species caught on a tow by tow basis. In addition, fishery independent trawl surveys of the Chatham Rise and Sub-Antarctic provide abundance estimates of all finfish, cartilaginous and squid species, as well as the catch weights of macro-invertebrate species.

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, Peruvian jack mackerel and spiny dogfish (Ballara et al., 2006). Other commercial bycatch species on the Chatham Rise and in the Sub-Antarctic include ghostsharks, white warehou, sea perch and stargazers. In Cook Strait, the main bycatch species are ling and spiny dogfish. Commercial and non-commercial bycatch on the Chatham Rise are described by Livingston et al. (2003), and bycatch and discard rates across the fleet were estimated by Anderson et al. (2001) and Anderson & Smith (2005). The more abundant non-commercial species in trawl surveys include javelinfish, big-eye (Bollon’s) rattail, Oliver’s rattail, longnose chimaera and banded bellows fish on the Chatham Rise (Livingston & Stevens, 2002). In the Sub-Antarctic, there is a close overlap in bycatch species with the Chatham Rise, although ridge-scale rattails, small scale slickheads, longnose velvet dogfish and the oblique banded rattail are also important in the Sub-Antarctic (O’Driscoll & Bagley, 2006). Trends in abundance of 10 core bycatch species that are adequately sampled by trawl surveys on the Chatham Rise and 12 core species in the Sub-Antarctic are reported following each survey (e.g. Stevens & O’Driscoll, 2007; O’Driscoll & Bagley, 2006). This information is not available for other areas. A summary of the bycatch of benthic invertebrates on the Chatham Rise was reported in Probert et al. (1997). A review of technologies and practices to reduce bottom trawl bycatch and seafloor disturbance in New Zealand was completed in 2002 (Booth et al., 2002).

While no finfish or invertebrate bycatch species are on the international threatened species list at CITES, basking sharks, which are a bycatch of the hoki fishery (Francis & Duffy, 2002), are on Appendix 2 of the CITES listings (i.e. not facing extinction, but stocks rapidly declining), and both basking shark and deepsea skates (also a bycatch of the hoki fishery) are on the Department of Conservation’s threat classification list.

(c) Incidental Catch (seabirds and mammals)

Seabirds and marine mammals are caught in the hoki fishery and there has been considerable effort made to determine how many are caught, which species are caught and how to reduce these catches. Captures reported by observers and vessel returns are highly sporadic and often unrepresentative of the fleet. Estimation of total captures across the fleet is therefore difficult and has only been achieved consistently in the west coast and Sub-Antarctic fisheries (Table 4). Ratio estimators are available up to 2002-03. Recent estimates have used model based estimators which are considered to be more realistic. However, they are not directly comparable to the earlier estimates. The seabird species returned from the hoki fishery for autopsy from 2003-04 to 2004-05, in decreasing numbers are: sooty shearwater, Salvin’s albatross, Buller’s albatross, white chinned petrel, black browed albatross, southern cape pigeon, common diving petrel, and Westland petrel (Baird, 2005a). Due to unrepresentative sampling and identification problems estimates of catch by species are not possible. When estimated, highest catch rates and incident rates were recorded in Puysegur (Baird, 2005a).

Table 4: Estimates of total seabird capture in the hoki fishery 1998–99 to 2004-05 (1998-99 to 2002-03 from Baird, 2005a; 2003-04 to 2004-05 from Baird and Smith, 2007). CVs in parentheses; + birds were observed caught but totals were not estimated as coverage was less than 10%, * indicates where estimates were made and observer coverage was less than 10%, - no observations available. All estimates are based on ratio-estimators except those denoted with ^{m} which are model-based predictions.

Fishing Year	Chatham Rise	Cook Strait	West Coast South Island	Sub-Antarctic	Puysegur
1998–99	+	+	215 (18)	94 (23)	+
1999–00	+	+	69 (41)	209 (19)	+
2000–01	187 (20)	+	106 (26)	209 (27)	+
2001–02	80 (33)	+	108 (21)	155 (46)	+
2002–03	+	+	130 (27)	47 (43)	92 (53)
2003-04	340 (40)*	-	146 (30)^{m}	54 (116)^{m}	-
2004-05	194 (35)	182 (46)*	45 (39)^{m}	54 (129)*^{m}	26 (46)

Mitigation methods such as tori lines, Brady bafflers and offal management are all under investigation in the hoki trawl fishery. Codes of Practice have been put forward by the Hoki Fishery Management Company under the National Plan of Action – Seabirds (NPOA) in 2004 to mitigate seabird mortality. The effectiveness of these measures in reducing seabird captures in the hoki fishery is not yet known.

As for seabirds, unrepresentative and low observer coverage has limited estimation of marine mammal captures across the fleet in most fisheries (Table 5). Over 95% of the mammals observed caught were New Zealand fur seals. A code of practice to avoid seal captures has been in place for many years in the hoki fisheries. Fur seal captures vary by area and year and capture rates appear particularly high in Puysegur (Baird, 2005b). Other species caught on observed vessels targeting hoki during the fishing years 1997–2003 include dusky dolphin and common dolphin..

Table 5. Estimates of fur seal capture in the hoki fishery 1997–98 to 2004–05 (1997-98 to 2002-03 from Baird, 2005b; and 2003-04 and 2004-05 from Smith and Baird, 2007). CVs in parentheses; + fur seals were observed caught but totals were not estimated as coverage was less than 10% (Baird, 2005b); - no observations available. All estimates are based on ratio-estimators except those denoted with ^{m} which are model-based predictions.

Fishing Year	Chatham	Cook Strait	WCSI	Sub-Antarctic	Puysegur
1997–98	65 (36)	+	1 032 (17)	+	-
1998–99	+	+	215 (18)	94 (24)	+
1999–00	+	+	561 (13)	70 (25)	-
2000–01	+	+	242 (20)	+	+
2001–02	+	83 (22)	325 (18)	+	+
2002–03	+	+	146 (26)	16 (63)	+
2003-04	130 (53)^{m}	48 (88)^{m}	420 (73)^{m}	38 (101)^{m}	15 (115)^{m}
2004-05	92 (46)^{m}	301 (38)^{m}	386 (81)^{m}	31 (120)^{m}	52 (167)^{m}

(d) Community and trophic structure

Hoki dominate the bottom fish community of the upper slope (Francis et al., 2002). They generally feed on mesopelagic fish, squids and crustaceans (Clark, 1985a, 1985b; Stevens et al., in prep). There has been a 4-fold decline in the relative abundance of hoki on the Chatham Rise between 1991 and 2007, and this may have resulted in some effects on the trophic dynamics in the area (Bull et al., 2001). 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).

Preliminary results from the Chatham Rise trophic study indicate that hoki predominately eat lantern fishes, particularly *Lampanyctodes hectoris*, and other mid-water fishes (Dunn et al., 2007). They also consume significant quantities of natant decapods, notably pasiphaeid and sergestid shrimps, and euphausids. The results so far corroborate the findings of Clark (1985a, 1985b) on the diet of hoki from the Campbell Plateau, New Zealand.

The results also show that hoki are prey of stargazers, smooth skates, deep water sharks (spiny dogfish, shovelnose dogfish, school sharks and leafscale gulper sharks), ling and hake. Ling appear to eat hoki that has been discarded and a few other species ingest hoki opportunistically while in the trawl net. There is no evidence that hoki are cannibalistic.

(e) Spawning disruption

Although there has been no research on the disruption of spawning hoki by fishing, the Hoki Fishery Management Company has introduced closures to some spawning grounds as a precautionary measure (HFMC Code of Practice 2004–05). The closed areas include Hokitika Canyon, Puysegur, Pegasus Canyon, and the Narrows Basin in Cook Strait, at certain times of the year.

In the early history of the fishery when most fishing effort was on the west coast spawning fishery, the 25-mile restricted fishing zone protected hoki spawning aggregations in the head of Hokitika Canyon (the prime fishing ground) and other parts of the spawning grounds. The main fishing fleet consisted of large vessels, which operated outside the line both in the Canyon and to the north. In recent years, there has been a steady increase in the catch taken inside the 25-mile line by smaller vessels, from less than 2000 t per year to over 20 000 t per year since 2000–01 (Ballara et al., 2006). There is concern that the spawning aggregations, particularly in Hokitika Canyon, are now small enough to be more vulnerable to the effects of fishing than in the past. In Cook Strait, the entire spawning fishery lies inside a 25-mile restricted fishing zone that has been fished since 1988 by smaller vessels in the fleet.

(f) Habitats of special significance

Currently, habitats of special significance have not been formally defined for any fisheries. Previous studies that are potentially relevant to the hoki fishery have already identified areas of importance for spawning, pupping, egg-laying and juveniles of coastal fish (Hurst et al., 2000) and deepwater fish, pelagic fish and invertebrates (O’Driscoll et al., 2003).

(g) Biodiversity

Few studies to date have focused on biodiversity in the hoki or middle depth fisheries. A comparison of 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. The only time-trend analysis of these data showed little trend in species diversity on the Chatham Rise from 1992-99 (Bull et al., 2001). Intra-specific genetic diversity of hoki has not been studied.

(h) Aquaculture and enhancement

Not relevant to hoki fisheries.

6. STOCK ASSESSMENT

A new stock assessment was carried out in 2007 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., 2005), was used and the approach, which used Bayesian estimation, was similar to that in the 2006 assessment (Francis, in press). The only significant changes in model assumptions from 2006 concerned the runs in which natural mortality, *M*, was allowed to vary with age. In these runs a new (double-exponential) ogive and a new prior were used for *M*.

(a) Methods

Model structure

The model partitions the population into two sexes, 17 age groups (1 to 17), and four areas [Chatham Rise (CR), West Coast South Island (WC), Sub-Antarctic (SA), and Cook Strait (CS)]. The adult fish are divided into two groups: a western (W) group, which spawns in WC and spends the rest of the year in SA; and an eastern (E) group, with spawning ground CS and home ground CR. All juvenile fish live in CR. 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 has two variants, which are associated with different stock-structure hypotheses. These hypotheses differ only in whether they assume ‘natal fidelity’, that is that a fish that was spawned in one area (WC or CS) will grow up to spawn in the same area. The original hypothesis assumes natal fidelity, but the alternative hypothesis (used first in the 2006 assessment) does not. Under the natal fidelity hypothesis, each fish is labelled either E or W at birth according to where it was spawned. As the juvenile fish in CR grow up, those labelled W gradually migrate to their home ground (SA), whereas E juveniles remain in CR. With this hypothesis, the strength of a year class is determined, for both E and W fish, when they first enter the model at age about 1.6 y. Under the alternative hypothesis, there is only one biological stock, and the juveniles that arrive in CR are not yet labelled as being E or W. Each year, some of these juveniles migrate from CR to SA, and thenceforward become labelled as W fish. Those still remaining in CR at age 8 are E fish. With this alternative hypothesis, the strength of a total year class (E + W) is determined when the fish enter the model, but the proportion of the year class that will become E or W fish is only gradually determined, and depends on the annually-varying proportion of juveniles in CR which migrate to SA.

The model's annual cycle divides the fishing year into five steps and includes four types of migration (Table 6). 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 fish, which are assumed to migrate, at time step 3, from CR to SA. When natal fidelity is assumed, this migration involves only W fish, and is the same in every year; otherwise, the proportion migrating varies from year to year. 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 6: 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.

Step	Approx. months	Processes	*M* fraction	Age fraction	Observations	
					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	0.60	SAsumbio	0.5
		part1, non-spawning fisheries (Ensp1, Wnsp1)			CRsumbio	0.6
3	Apr-Jun	migration Whome: CR–>SA	0.25	0.90	SAautbio	0.1
		part2, non-spawning fisheries (Ensp2, Wnsp2)			pspawn	
4	End Jun	migrations Wspmg: SA–>WC, Espmg: CR–>CS	0.00	0.90	–	
5	Jul-Sep	increment ages	0.25	0.0	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 7). New data were available from an acoustic survey of Cook Strait in July/August 2006 (O'Driscoll, in prep), and trawl surveys of the sub-Antarctic in December 2006 (O'Driscoll & Bagley, in prep) and Chatham Rise in January 2007 (Stevens & O'Driscoll, in prep). The other CSacous indices in Table 7 differ from those used in previous assessments because of a revision in acoustic target strength (O'Driscoll, in prep), but this revision is of little consequence to the assessment because the proportional changes in the indices were all very similar (an increase of about 9%).

Table 7: 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*	–

The age data used in the assessment (Table 8) are similar to those used in 2006, but with an additional year's data.

Table 8: 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	1988–06*	otoliths
SA	WnspOLF	Catch at age	1992–94, 96, 99–00	OLF
	Wnspage	Catch at age	2001–04, 06*,	otoliths
	SAsumage	Trawl survey	1992–94, 2001–07*	otoliths
	SAautage	Trawl survey	1992, 96, 98	otoliths
	pspawn	Proportion spawning	1992, 1998	otoliths
CS	Espage	Catch at age	1988–06*	otoliths
CR	EnspOLF	Catch at age	1992, 94, 96, 98	OLF
	Enspage	Catch at age	1999–06*	otoliths
	CRsumage	Trawl survey	1992–07*	otoliths

The error distributions assumed were robust lognormal (Bull et al., 2005) 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 9). 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 some biomass indices as a way of giving more weight to these data.

Table 9: 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	2005	2006	2007
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	0.23	0.23	0.22
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	0.12	0.11	0.08

SAsumbio	1992	1993	1994	2001	2002	2003	2004	2005	2006	2007
Total	0.21	0.21	0.22	0.24	0.26	0.24	0.24	0.23	0.24	0.23
Observation	0.07	0.06	0.09	0.13	0.16	0.14	0.13	0.12	0.13	0.11

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

CSacous	1991	1993	1994	1995	1996	1997	1998	1999	2001	2002	2003	2005	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

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 10). In all cases, the last age for these data sets was treated as a plus group.

Table 10: 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 6 according to area and month. This division was done using TCEPR and CELR data, and the resulting values were then scaled up to sum to the official catch (including catch reported from outside the EEZ). The method of dividing the catches (Table 11) is the same as that used in the 2006 assessment so the catches used in the model (Table 12) are unchanged, except for revisions to years 2004 to 2006, and the addition of assumed catches for 2007. Note that in the last 2 years the total catch includes ET catches of 1800 t (2004–05) and 1600 t (2005–06), which are now known to have been caught off Tasmania. In previous years the amount of ET catch was much smaller (generally less than 10 t).

Table 11: 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 12: Catches (t) by fishery and fishing year (1972 means fishing year 1971–72), as used in this assessment. Catches for 2007 are assumed equal to those in 2006. 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
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	36 300	20 700	13 200	16 900	33 700	109 200
2002	24 600	18 700	16 900	13 400	23 900	98 000
2003	25 100	18 800	12 800	8 100	41 400	78 700
2004	17 900	19 100	6 400	5 300	40 800	46 300
2005	19 600	14 200	4 500	2 000	26 700	39 300
2006	22 500	15 100	2 000	4 800	20 700	40 700
2007	22 500	15 100	2 000	4 800	20 700	40 700

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 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 (with assumed steepness 0.9, following Cordue, 2001) 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 2005) 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 2002, so that R_0 may be thought of as the average recruitment over that period. Exactly how B_0 and the pre-fishery spawning biomass, B_{init}, are calculated depends on natal fidelity.

When natal fidelity is assumed, 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.

Without natal fidelity, only a single R_0 and set of YCSs are estimated for the combined stock (E plus W). What fraction of each year class ends up spawning in each of the two spawning grounds depends on the year-to-year variation in the Whome migration ogive. The value of this ogive in any year is calculated from the estimated base ogive and an annual multiplier term. The annual multiplier is set to 1 for the initial years (1972 to 1975), but estimated for all subsequent years. The pre-fishery biomass in all areas is calculated assuming constant recruitment, R_0, and a constant Whome migration at its base value, and B_0 is defined as being equal to B_{init}.

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 Table 6).

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 13. 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.

The only change to priors from the 2006 assessment affected natural mortality in runs in which this varied with age and sex. In 2006 there was a prior for the average between males and female natural mortality, and another prior for the between-sex difference (and both priors were applied to all ages). In 2007, a new prior is used, just for ages 5–9, and this was the same for males and females.

Table 13: 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[4])	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	0.95	
recruitment[W].YCS	year-class strengths (W)	lognormal	1.0	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	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

[4] See section 7.3.1 of Francis (2006) for the meaning of pE when natal fidelity is not assumed

(b) Results

The assessment was done in two steps. First, a set of initial exploratory model runs was carried out. Some of these runs were done before the new data were available and most generated only 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

From one set of initial runs it was concluded that a new double-exponential ogive should be used for age-dependent natural mortality and the new prior for natural mortality (Cordue, 2006) should be applied to both sexes, but only for ages 5 to 9.

Other initial runs, which explored MCMC performance and temporal trends in sex ratios, provided background information to the Working Group but had no effect on the choice of final runs.

Three final runs

The three final runs adopted by the Working Group are distinguished by four characteristics (Table 14). The first is the mechanism used to deal with the problem of the lack of old fish in both fishery- and survey-based observations. Two mechanisms were considered: making *M* (natural mortality) dependent on age (runs 4.4 and 4.7) or allowing the spawning fishery selectivities (Espsl, Wspsl) to be domed (run 4.5). When the domed selectivities were used it was also necessary to combine sexes in the model and make the selectivities age-based (Francis, 2005). The third distinguishing characteristic is the assumption concerning natal fidelity. Run 4.7 does not assume natal fidelity but is otherwise identical to run 4.4 (Table 14). As in previous years, biomass indices were upweighted when this was necessary to obtain good fits to these indices. This year, upweighting was done for the trawl indices in all runs, and the acoustic indices in run 4.7.

Table 14: Distinguishing characteristics for the three final model runs.

Label	Response to lack of old fish in the observations	Sex in model and selectivities length-based?	Natal fidelity assumed? *	Biomass indices upweighted
4.4	*M* dependent on age	Yes	Yes	Trawl
4.5	Domed spawning selectivity	No	Yes	Trawl
4.7	*M* dependent on age	Yes	No	Trawl & acoustics

* see section 6a (above) for description of the natal fidelity assumption

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 15 (estimates of biomass), Figure 1 (biomass trajectories, and year-class strengths), and Figure 2 (current biomass distributions). All model runs agree that both stocks are at, or close to, their lowest point ever, that the W stock is more depleted than the E stock, and that the W stock experienced seven years of poor recruitment from 1995 to 2001, inclusive. The western stock is now estimated to have had only 1 year of near average recruitment in the last 11 years (Figure 1). There is also good agreement on estimates of year-class strengths, with the exception that run 4.5 tends to estimate relatively stronger year classes in the early years and weaker in more recent years.

This assessment is, compared to that in 2006, more pessimistic for the W stock. The estimated biomass trajectory for this stock no longer shows an increase in recent years, and year-class strengths after 2001 are now estimated to be below average rather than near average.

Table 15: 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 2006–07.

	B_0 (‘000 t)		B_{current} (‘000 t)		B_{current} (%B_0)		
Run	E	W	E	W	E	W	E + W
4.4	535(466,639)	930(822,1083)	245(189,312)	182(118,321)	46(37,54)	20(13,32)	29(24,38)
4.5	792(545,1141)	1207(945,1614)	299(191,437)	288(185,465)	37(30,48)	24(19,31)	29(25,35)
4.7	432(297,651)	1115(847,1365)	221(158,288)	164(106,282)	51(32,77)	15(10,26)	25(21,30)

Exploitation rates for both spawning fisheries were estimated to be at or near all-time highs in 2003 (Figure 3). The peak exploitation rate for the W spawning fishery was estimated to be 0.33–0.43 in all runs (i.e., the catch was estimated to be 33–43% of the beginning-of-season vulnerable biomass). Estimated peak rates were lower for the E spawning fishery (0.23–0.25), and lower again for the non-spawning fisheries (always less than 0.16 for the W and 0.08 for the E).

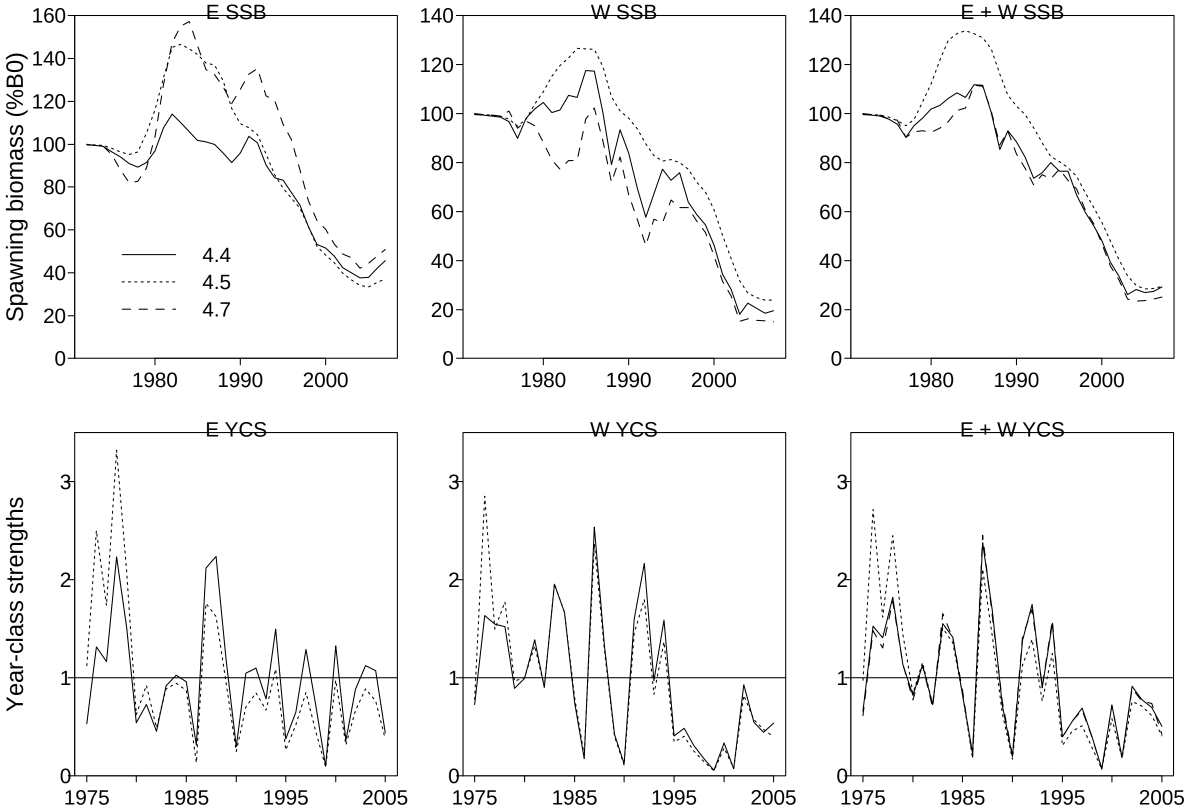


Figure 1: Estimated spawning biomass trajectories (SSB, upper panels) and year-class strengths (YCS, lower panels) for the E (left panels), W (middle panels) and E + W stocks (right panels) from the final model runs. For run 4.7, YCSs are defined only for E + W (and are very similar to those for 4.4). Plotted values are medians of marginal posterior distributions. Years are fishing years (1990 = 1989–90).

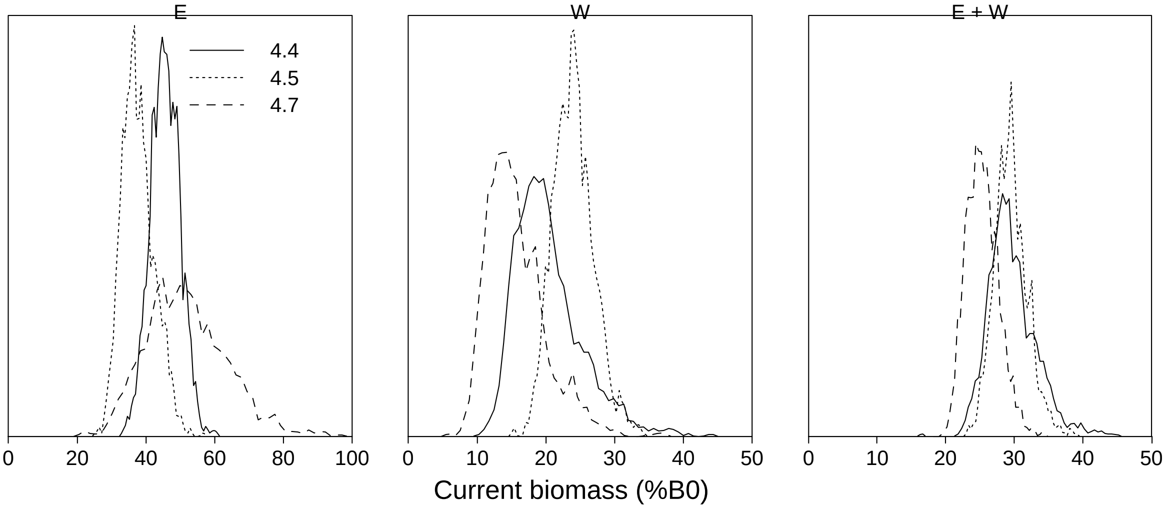


Figure 2: Estimated posterior distributions of current (spawning) biomass ($B_{2006–07}$), expressed as %B_0, for the E (left panel), W (middle panel) and E + W stocks (right panel) from the final model runs.

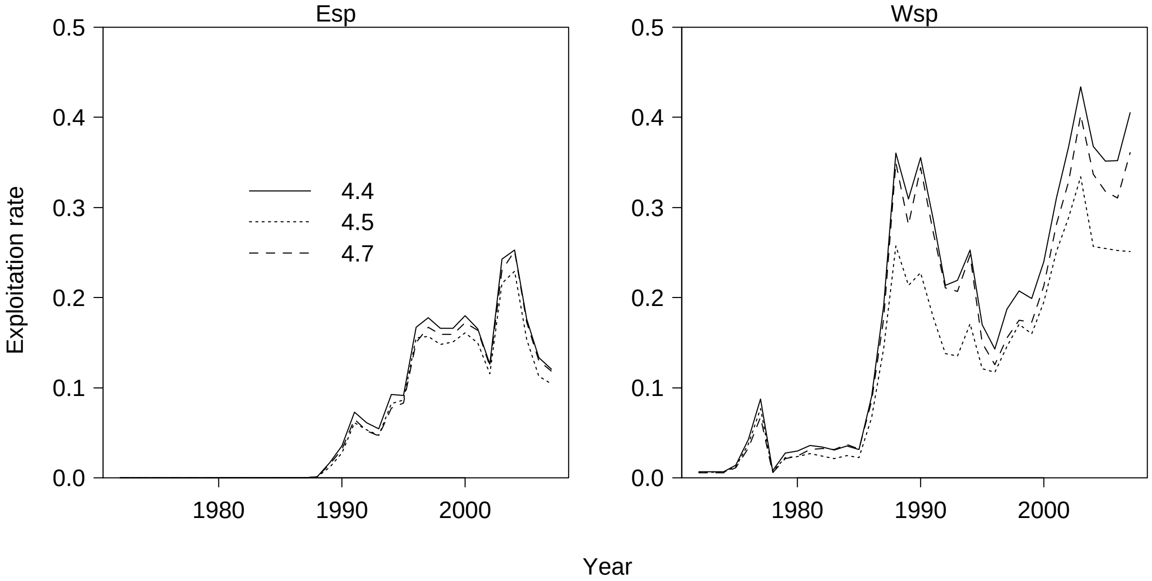


Figure 3: Estimated exploitation rates for the two spawning fisheries (Esp and Wsp) from the final model runs.

(c) Projections

Five-year projections were carried out, for each of the three final runs (4.4, 4.5, and 4.7), under each of nine scenarios for future catch (Table 16). All but one of these scenarios were defined by specifying the total catch to be taken in each year (between 0 t and 106 000 t) and the percentage of that catch that would be taken from the E fisheries (between 50% and 75%) (the exception was scenario 80kt.cutCR, which is described below). The assumed catch levels for individual fisheries were proportional to those in 2006 (see Table 12), subject to these specifications.

Table 16: Nine scenarios for future catches in projections, and the recruitment scenarios considered for each option.

	Catches by fishery (t)				Area subtotals (t)		Total	Recruitment assumptions
Label	Ensp	Wnsp	Esp	Wsp	All E	All W	catch (t)	considered
100kt60%E	38 700	5 700	21 300	34 300	60 000	40 000	100 000	Long-term, recent
106kt55%E	37 600	6 800	20 700	40 900	58 300	47 700	106 000	Recent
110kt60%E	42 600	6 300	23 400	37 700	66 000	44 000	110 000	Recent
100kt75%E	48 400	3 600	26 600	21 400	75 000	25 000	100 000	Recent
80kt50%E	25 800	5 700	14 200	34 300	40 000	40 000	80 000	Recent
80kt75%E	38 700	2 900	21 300	17 100	60 000	20 000	80 000	Recent
80kt60%E	30 900	4 600	17 100	27 400	48 000	32 000	80 000	Recent
80kt.cutCR	18 700	5 700	21 300	34 300	40 000	40 000	80 000	Recent
0kt	0	0	0	0	0	0	0	Recent

* status quo option

The first catch scenario (labelled 100kt60%E) assumes that the TAC will remain at 100 000 t and not be over-caught, and that the target 60:40 east-west split will be exactly achieved. This scenario was evaluated under two recruitment assumptions: 'long-term' (in which future recruitments were selected at random from those estimated for 1975–2003) and 'recent' (future recruitments selected from 1995–2003). For run 4.7, future multipliers for the Whome migration ogive were selected at random from those estimated for years 1977–2005, for the 'long-term' assumption, or for 1997–2005, for the 'recent' assumption. 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. With the first catch scenario, all three runs predicted that both stocks would increase under the long-term recruitment assumption, but show little change under the recent recruitment assumption (Figure 4).

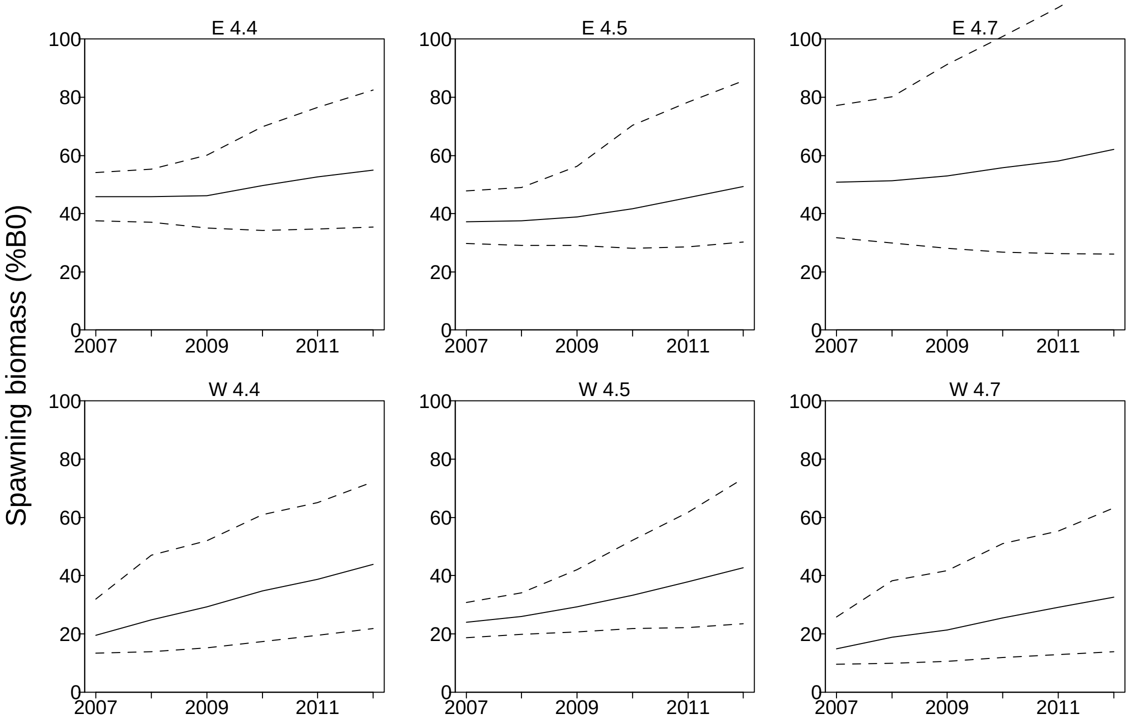


Figure 4A: Projected spawning biomass (as %B_0) for catch option 100kt60%E (see Table 16) assuming long-term recruitment: median (solid lines) and 95% confidence intervals (broken lines).

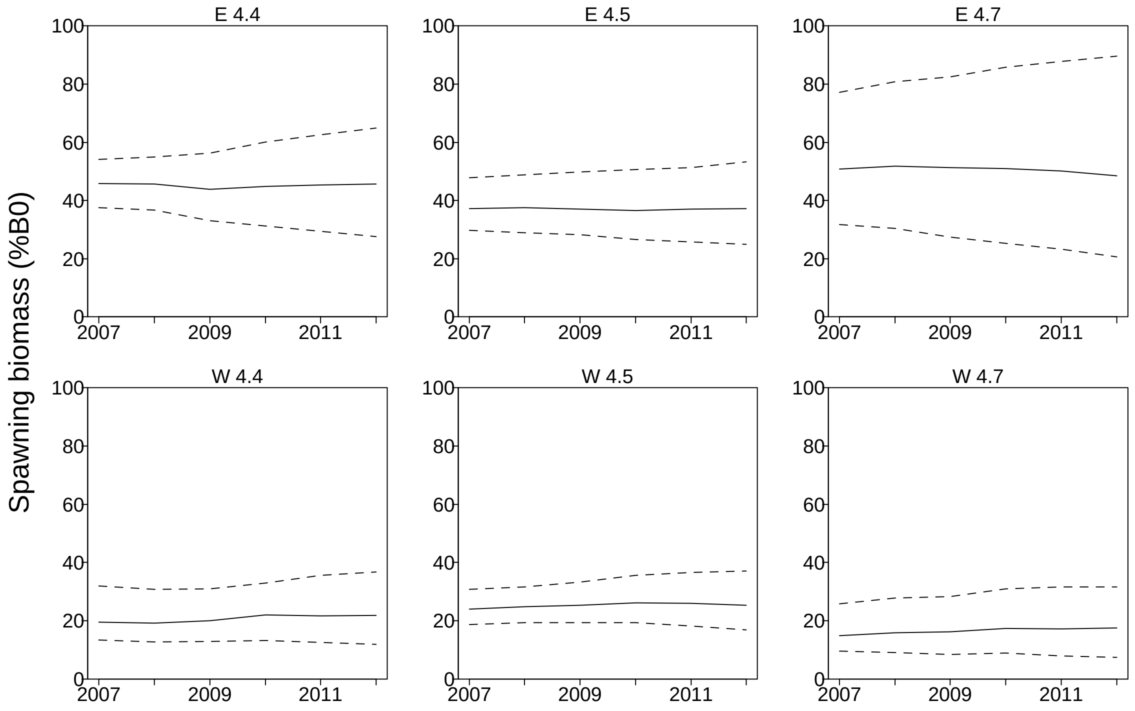


Figure 4B: As for Figure 4A but assuming recent recruitment.

The remaining eight scenarios were evaluated only with the recent recruitment assumption. The second scenario, 106kt55%E, may be thought to represent the status quo. It recognises the fact that the TAC has been over-caught in recent years and the target of a 60:40 east-west split has not been achieved. Four scenarios consider the effect of a catch reduction to 80 000 t, either with a specified east-west split (and assuming no overcatch), or, for scenario 80kt.cutCR, with the assumption that all the reduction in catch will come from the E non-spawning fishery (in area CR). The final scenario, with zero catch, is included to provide information about maximum rebuild rates under the recent recruitment assumption.

With the recent recruitment assumption, both stocks are expected to increase only if the annual catch from the associated fisheries is less than it was in 2006 (Table 17). For each stock, the expected amount of increase (or decrease) depends mainly on the annual catch from the associated fisheries (and, of course, the model run). For the western stock, long-term average recruitment has a greater influence on the speed and extent of stock rebuild than reducing catch.

(d) Other factors that may modify assessment results

The WG considered that there were a number of other factors that should be considered in relation to the stock assessment results presented here:

- There is potentially a problem of incidental mortality of hoki escaping through trawl meshes, particularly for the younger ages (under 4 years) that are not fully selected by the 100 mm mesh codend. The hoki fishery, particularly the western stock, is now largely recruitment driven and accurate estimation of fishing mortality is important for the assessment of current status and future projections.
- There is evidence from observer sampling on the WCSI spawning fishery and from Sub-Antarctic trawl surveys that the proportion of larger males in the western stock has declined. It is not known what the implications of this might be for spawning success (e.g., schooling behaviour, egg viability) and genetic diversity.

Table 17: Estimated median spawning biomass in 2012 for the eastern stock (upper half of table) and western stock (lower half of table) for each of the seven future-catch scenarios of Table 16 and three final runs. Results are given for the early recruitment assumption for all catch options, and for both recruitment assumptions for catch scenario 100kt60%E. In each half of the table the catch options are sorted in increasing order of the combined annual catch from the associated fisheries (given in the second column). Also given, for comparison, is the estimated spawning biomass in 2007.

Eastern stock

		Spawning biomass in 2012 ($\%B_0$)					
		Recent recruitment			Long-term recruitment		
Catch option	Annual catch from all E fisheries (t)	Run 4.4	Run 4.5	Run 4.7	Run 4.4	Run 4.5	Run 4.7
0kt	0	69	50	82			
80kt50%E	40 000	53	41	60			
80kt.cutCR	40 000	52	41	59			
80kt60%E	48 000	50	40	55			
106kt55%E*	58 300	46	37	49			
80kt75%E	60 000	46	37	49			
100kt60%E	60 000	46	37	49	55	49	62
110kt60%E	66 000	44	36	45			
100kt75%E	75 000	40	34	40			
		Spawning biomass in 2007 ($\%B_0$)					
		46	37	51			

Western stock

		Spawning biomass in 2012 ($\%B_0$)					
		Recent recruitment			Long-term recruitment		
Catch option	Annual catch from all W fisheries (t)	Run 4.4	Run 4.5	Run 4.7	Run 4.4	Run 4.5	Run 4.7
0kt	0	35	33	29			
80kt75%E	20 000	28	29	23			
100kt75%E	25 000	26	27	21			
80kt60%E	32 000	24	27	20			
80kt.cutCR	40 000	23	25	18			
80kt50%E	40 000	22	25	18			
100kt60%E	40 000	22	25	18	44	43	33
110kt60%E	44 000	20	24	16			
106kt55%E*	47 700	19	24	16			
		Spawning biomass in 2007 (%B0)					
		20	24	15			

* status quo option

7. STATUS OF THE STOCKS

The hoki stock assessment was updated in 2007. Three final runs are reported for each stock.

For the western stock, median estimates of current biomass are between 15 and 24 $\%B_0$, (95% confidence intervals for each run are given in Table 15), which is below the assumed value of B_{MSY} (30-40%B_0). The biomass has shown little change in recent years. This stock experienced an extended period of poor recruitment from 1995 to 2001 (Figure 1); year-class strengths after 2001 are now estimated to be below average rather than near average as estimated in 2006. Model projections suggest that the biomass of this stock will not increase unless future recruitment is better than it has been in recent years or catches from the associated fisheries are reduced.

For the eastern stock, current biomass was estimated to be between 37 and 51 $\%B_0$ (see Table 15), which is at or above B_{MSY}. Recent recruitment is estimated to be lower than but closer to the long-term average for this stock (Figure 1).

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