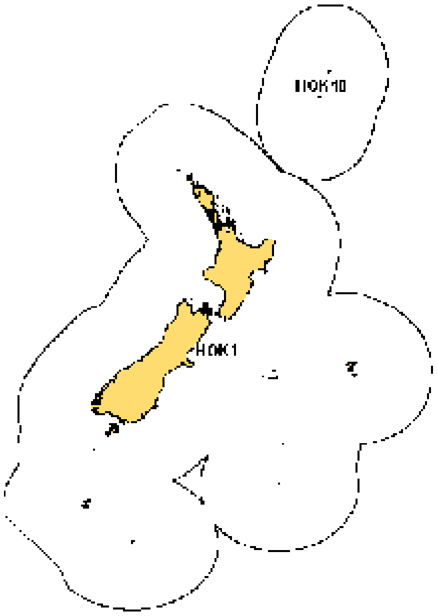
HOKI (HOK)

(*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 200 00 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 2005–06 is 100 000 t.

The pattern of fishing has changed markedly since 1988–89 when over 90% of the total catch was taken in the WCSI spawning fishery. 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, then dropped over the last three years to 34 000 t in 2004–05 (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 25 000 t in 2004–05. Non-spawning catches on the Chatham Rise increased from 1993–94, peaked at over 70 000 t in 1997–98 and 1998–99, then decreased over the last five years to 30 500 t in 2004–05. Catches from the Sub-Antarctic peaked at over 30 000 t in 1999–2000 to 2001–02, and then declined to 6500 t in 2004–05. Catches from other areas have remained at relatively low levels, with 5500 t taken from Puysegur and 4000 t from the ECSI spawning fishery in 2004–05 (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. In 2004–05 and 2005–06 there was a further agreement with the Minister that only 40% of the catch should be taken from western fisheries. About 43% of the catch was taken from western areas in 2004–05 (Table 1d).

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.

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 2004–05 (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	106 000	102 000	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.

Table 1: (c) Estimated* catch (t) of hoki by area, 1988–89 to 2004–05 (rounded to nearest 500 t).

	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	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	34 000	5 500	25 000	4 000	6 500	30 500	500	–	106 000

* Estimated catches adjusted pro rata to the reported catch in Table 1(b) for 1988–89 to 2003–04.

– 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%

Total Allowable Commercial Catch (TACC)

In the 2004–05 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).

2004–05 hoki fishery

Catches declined in all areas except Puysegur and the ECSI. Although the WCSI is still the largest hoki fishery, the catch taken from this area in 2004–05 was the lowest since 1982 and 11 000 t less than in 2003–04. Unstandardised catch rates on the WCSI in 2004–05 increased slightly from 2003–04, with a median catch from all non-zero midwater tows of 5.4 t per tow. The percentage of young fish (those aged 3 or less) in the WCSI catch was much higher than in any previous year: 52%, compared to a previous maximum of 20% (in 1994–95). Most of these young fish weremales from the 2002 and 2003 year classes. Hoki from the strong 1991–94 year-classes were still an important part of the WCSI catch, with another mode corresponding to hoki from the 2000 year-class. From 2000 to 2004, the sex ratio of the WCSI catch was highly skewed, with many more females caught than males. This bias was not apparent in 2005, with approximately equal numbers of males and females caught, but there was a strong size difference between the sexes. The mean length of males was 62 cm, while that of females was 82 cm. About 64% of hoki in the catch below 70 cm were males, but only 19% of hoki above 80 cm were male. Small hoki were caught in all areas of the WCSI fishery, both inside and outside the 25 n. mile line.

In the last four years, the catch from the western fishery in the Sub-Antarctic has dropped from 31 000 t to 6500 t, and the catch from this fishery in 2004–05 was the lowest since 1988–89. Median tow duration has increased and catch rates have declined to 0.2 t per hour, despite the increasing use of twin-rigs. Catch-at-age estimates showed the Sub-Antarctic catch consisted of a mixture of small fish from the 2000–02 year classes, and larger fish from the 1991–98 year-classes. However, the coverage of this fishery by observers was poor and age estimates were not considered representative of the catch. Catches from Puysegur increased from 1000 t in 2003–04 to 5500 t in 2004–05. Very high catch rates (median catch 20.7 t per midwater tow) of large (greater than 80 cm) hoki were taken at Puysegur during August 2005. This differs from previous years when catch rates were much lower and often consisted of smaller hoki.

The catch from Cook Strait decreased from 41 000 t in 2003–04 to 25 000 t in 2004–05, mostly due to the constraints on eastern catch. Unstandardised catch rates in Cook Strait continue to be high, with a median catch rate of 13.7 t per non-zero midwater tow in 2004–05. The modal age in the catch was 5 (2000 year-class) for both sexes, with a strong contribution from older ages. Although some male hoki from the 2002 year-class were caught in Cook Strait, there was a much lower catch of hoki less than 70 cm than in the WCSI and Chatham Rise fisheries. About 4000 t of hoki was taken in the other eastern spawning fishery on the ECSI in 2004–05. The catch rate was high (median catch of 17.6 t per non-zero midwater tow) and the length distribution of the ECSI catch was similar to that observed in Cook Strait.

Catches from the Chatham Rise dropped slightly from 33 000 t in 2003–04 to 30500 t in 2004–05. As in the Sub-Antarctic, there has been a general increase in tow duration on the Chatham Rise since the 1990s, but the median unstandardised catch in bottom trawls rose slightly to 0.6 t per hour in 2004–05, the highest catch rate since 2001–02. The age distribution of the catch was dominated by small hoki from the 2000–02 year-classes, with a long right-hand tail of larger, older fish. The length mode of fish from the 2002 year-class was centred on about 60 cm.

(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 mortality

There may have been some dumping of small fish but the level is unknown. Net damaged fish have been recorded in the WCSI fishery in some years. The extent of damage and resulting mortality is unknown.

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 deepwater (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 and 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 were 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 estimated that 77% of hoki age 4 and older had spawned in the previous season (Grimes in prep.).

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 et al. 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 27–30 cm TL at the end of the first year. There is some variability in growth rates, but hoki reach about 40–45, 50–55 and 60–65 cm TL respectively in the following three years. Males appear to mature at 60–65 cm TL at 4–5 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 has been an increasing trend in size at age in data from both the trawl surveys and the commercial catch; length at age has increased by about 10% since 1983.

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. 2005) 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). 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 Francis et al. (2005) found this hard to interpret because the survey is an index of the combined recruitment to the eastern and western stocks.

5. ENVIRONMENTAL AND ECOSYSTEM CONSIDERATIONS (not updated in 2006)

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 MSC 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. The risk assessment results and impact assessment reports are both available on-line at www.hokinz.com.

(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 (Dunn & Livingston 2004). The west coast spawning fishery has been subjected to a similar number of tows as the Chatham Rise, however, they usually occurred during the spawning season, and only 23% used bottom trawl gear. Total effort in Cook Strait has been much less than in other areas and only 16% were bottom tows. Although midwater nets may be towed along the seabed bottom contact is substantially less than with bottom trawls.

Table 3. Summary of target tow data (TCEPR only) in the hoki fishery from fishing years 1989–90 to 2002–03 (updated from Dunn & Livingston 2004).

	Chatham Rise	Sub-Antarctic*	West Coast S.I.	Cook Strait
Total no. target tows 1990–2003	110 920	49 167	108 446	32 605
Mean no. target tows per year	7 932	3 782	7 746	2 329
% bottom tows	84	92	23	16
% midwater tows	16	8	77	84
Fishery seasonality	Year round	Year round	July-September	July-September

* 1991 to 2003 only

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 (see review by Cryer et al. in prep). 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 (Cryer et al. in prep.). 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).

Issues concerning 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 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 three sources of data on catch weights and relative abundance of incidental catch in New Zealand: TCEPR forms (provides 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 (but is limited by variable and patchy coverage), and 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. 2005). 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, Bollon’s rattail, Oliver’s rattail, longnose chimaera and banded bellows fish on the Chatham Rise (Livingston & Stevens 2005). 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 2005). 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., Livingston & Stevens 2005, O’Driscoll & Bagley 2005). 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). The need to improve reporting of captures to a high standard (achieved on only a few vessels currently) is recognised and is currently being reviewed. The highest reported captures include Buller’s albatross, white capped albatross, Salvin’s albatross and sooty shearwater. Other species caught include southern royal albatross, Campbell albatross, black-browed albatross, northern giant petrel, grey petrel, white-chinned petrel, short-tailed shearwater, cape pigeon, fairy prion, black-backed gull (Baird 2005). Highest catch rates and incident rates were recorded in Puysegur, but the coverage was not sufficient for reliable estimation (Baird 2005a).

Table 4. Estimates of total seabird capture in the hoki fishery 1998–99 to 2002–03 (after Baird 2005a). c.v.s in parentheses; + birds were observed caught but totals were not estimated as coverage was less than 10% (Baird 2005a)

Fishing Year	ChathamRise	Cook Strait	West coast S.I.	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)

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.

At least five species of marine mammals including fur seals, dusky dolphin and common dolphin have been caught on observed vessels targeting hoki during the fishing years 1997–2003. Over 95% of the mammals observed caught were New Zealand fur seals.

Table 5. Estimates of fur seal capture in the hoki fishery 1997–98 to 2002–03 (after Baird 2005b). c.v.s in parentheses; + fur seals were observed caught but totals were not estimated as coverage was less than 10% (Baird 2005b); - no observations available.

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)	+

As for seabirds, patchy observer coverage limits estimation of marine mammal captures across the fleet in most fisheries (Table 5). Fur seal captures vary by area and year and capture rates appear particularly high in Puysegur (Baird 2005b). A code of practice to avoid seal captures has been in place for many years in the hoki fisheries.

(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 2005, and this may have resulted in some effects on the trophic dynamics in the area (Bull et al 2000). 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). A new study on feeding interrelationships of hoki and middle depth fish species on the Chatham Rise is currently under way.

(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. 2004). 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). Intraspecific 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 2006 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 2005 assessment (Francis 2006). There was one main change to the stock assessment in 2006, the inclusion of an alternative stock hypothesis as one of the final runs.

(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 (used in previous assessments) assumes natal fidelity, but the alternative hypothesis (new to this 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. The second affects only young fish, which are assumed to migrate, at time step 3, from CR to SA. In the natal fidelity hypothesis, this migration involves only W fish, and is the same in every year. With the alternative hypothesis, 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 2005 (O'Driscoll draft), and trawl surveys of the sub-Antarctic in December 2005 (O'Driscoll & Bagley draft) and Chatham Rise in January 2006 (Stevens & O'Driscoll 2006). The other CSacous indices in Table 7 differ from those used in previous assessments because of a revision by O'Driscoll (draft), 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 12%), and they are used as relative abundance indices.

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	–	–	–	167
1992	345	80	68	120	–
1993	550	87	–	186	537
1994	–	100	–	146	544
1995	–	–	–	120	391
1996	–	–	89	153	185
1997	654	–	–	158	272
1998	–	–	68	87	156
1999	–	–	–	109	223
2000	396	–	–	72	–
2001	–	56	–	60	202
2002	–	38	–	74	293
2003	–	40	–	53	207
2004	–	14	–	53	–
2005	–	18	–	85	121*
2006	–	21*	–	99*	–

The age data used in the assessment (Table 8) are similar to those used in 2005, but with an additional year's data. No new catch-at-age data were available for the W non-spawning fishery (Wnspage) because of poor observer coverage of this fishery in 2004–05.

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	1988–05*	otoliths
SA	WnspOLF	Catch at age	1992–94, 96, 99–00	OLF
	Wnspage	Catch at age	2001–04,	otoliths
	SAsumage	Trawl survey	1992–94, 2001–06*	otoliths
	SAautage	Trawl survey	1992, 96, 98	otoliths
	pspawn	Proportion spawning	1992, 1998	otoliths
CS	Espage	Catch at age	1988–05*	otoliths
CR	EnspOLF	Catch at age	1992, 94, 96, 98	OLF
	Enspage	Catch at age	1999–05 *	otoliths
	CRsumage	Trawl survey	1992–06*	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 (c.v.). An arbitrary c.v. of 0.25 (as used by Cordue 2001) was assumed for the proportion spawning observations. Two alternative sets of c.v.s were used for the trawl-survey biomass indices (Table 9). The "total" c.v.s represent the best estimates of the uncertainty associated with these data, and were used in initial model runs. These were calculated as the sum of an observation-error c.v. (using the standard formulae for stratified random surveys, e.g., Livingston & Stevens 2002) and a process-error c.v., which was set at 0.2, following Francis et al (2001) (note that c.v.s add as squares: $\text{c.v.}_{\text{total}}^2 = \text{c.v.}_{\text{process}}^2 + \text{c.v.}_{\text{observation}}^2$). In some model runs (including all final runs) it was decided to use the observation-error rather than the total c.v.s on the trawl-survey biomass indices as a way of giving more weight to these data.

Table 9: Coefficients of variation (c.v.s) used with biomass indices in the assessment. For trawl-survey indices, observation-error c.v.s were used when it was desired to upweight these indices. Years are fishing years (1990 = 1989–90).

CRsumbio	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006
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
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

Table 9 ***(Continued)***

SAsumbio	1992	1993	1994	2001	2002	2003	2004	2005	2006			
Total	0.21	0.21	0.22	0.24	0.26	0.24	0.24	0.23	0.24			
Observation	0.07	0.06	0.09	0.13	0.16	0.14	0.13	0.12	0.13			
SAautbio	1992	1996	1998									
Total	0.22	0.22	0.23									
Observation	0.08	0.09	0.11									
CSacous	1991	1993	1994	1995	1996	1997	1998	1999	2001	2002	2003	2005
Total	0.41	0.52	0.91	0.61	0.57	0.40	0.44	0.36	0.30	0.34	0.34	0.32
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				

For the at-age data, overall c.v.s were treated as the sum of a process-error c.v. and an observation-error c.v. The observation c.v.s for the otolith-based at-age data were calculated by a bootstrap procedure, which includes explicit allowance for age estimation error. No observation-error c.v.s 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 2004b). Process-error c.v.s for the at-age data were estimated within the model for all point estimates. For full Bayesian estimates, these c.v.s 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. The method of dividing the catches (Table 11) is the same as that used in the 2005 assessment so the catches used in the model (Table 12) are unchanged, except for revisions to 2004 and 2005, and the addition of assumed catches for 2006.

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 2006 are assumed equal to those in 2005. 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

Table 12 ***(continued)***

Year	Ensp1	Ensp2	Wnsp1	Wnsp2	Esp	Wsp
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	18 900	6 400	5 300	40 800	46 400
2005	19 600	14 100	4 500	2 100	26 600	39 400
2006	19 600	14 100	4 500	2 100	26 600	39 400

Further assumptions

Assumed maximum exploitation rates were 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 was assumed for each half. This is approximately equivalent to 0.5 for the two halves combined. Penalty functions were used to discourage model fits which exceeded these maxima.

A key output from the assessment is the unfished biomass, B_0, for each stock. This is defined as the spawning stock biomass that would occur, in the absence of fishing, given constant recruitment, R_0, where R_0 is the average estimated recruitment for specified years in the history of the fishery. In this assessment the specified years were 1975 to 2001. A Beverton-Holt stock-recruit relationship was assumed, with steepness 0.9 (following Cordue 2001).

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).

Prior distributions were assumed for all parameters. The main ones used are given in Table 13. In addition, bounds were imposed for parameters with non-uniform distributions. For the catchability parameters these were those calculated by O’Driscoll et al. (2002) (and labelled overall bounds); for other parameters they were set at the 0.001 and 0.999 quantiles of their distributions. Prior distributions for all other parameters were assumed to be uniform, with bounds that were either natural (e.g., 0,1 for proportion migrating at age), wide enough so as not to affect point estimation, or, for some ogive parameters, deliberately set to constrain the ogive to a plausible shape. For runs with age-dependent natural mortality the mortality priors in Table 13 were modified by multiplying the c.v.s by $17^{0.5}$, which ensured that the implied priors for mortality averaged over all ages had the same c.v.s as in Table 13. When sex was dropped from the model the prior for natural mortality was set equal to that for the average between males and females.

For each stock, the model estimates a mean recruitment, R_0, and uses year-class strengths (YCSs) for 35 years: 1970 to 2004, inclusive. (Note that 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+, in about December 1971, which is model year 1972). However, there are not sufficient data to estimate separate values for all these YCSs so further assumptions are necessary. First, because of the lack of at-age data for the early years, it was assumed that the YCSs for years 1970 to 1974 are all equal to 1, for both stocks. Information about the earliest YCSs estimated (1975 cohorts) comes only from observations in the 1988 and 1989 catch-at-age data from Wsp and Esp catches (when these cohorts were 13 and 14 years old). Second, as there is only a limited number of observations for them, the YCSs for the 2004 cohorts were assumed to be the same for each stock in point estimates (but this constraint was dropped in full Bayesian estimates). A final constraint is that the mean YCSs for 1975 to 2001 for each stock must be 1. This ensures that R_0 is equal to the mean recruitment for that period. The model corrects for bias in estimated YCSs arising from ageing error.

Table 13: Assumed prior distributions for key parameters. Parameters are bounds for uniform; mean (in natural space) and c.v. for lognormal; and mean and s.d. for normal and beta.

Parameter	Description	Distribution	Parameters		Reference
log_Bmean_total	log($B_{0,E}$ + $B_{0,W}$)	uniform	11.6	16.2	
Bmean_prop_stock1 (=pE)	$B_{0,E}$/($B_{0,E}$ + $B_{0,W}$)	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.avg	(M_{male} + M_{female})/2	lognormal	0.298	0.153	Smith(2004)
natural_mortality.diff	M_{male} - M_{female}	normal	0.05	0.025	Smith(2004)

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

(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

A major result of one group of initial runs was the development of the alternative stock hypothesis. Some modifications to CASAL were necessary to allow year-to-year variation in the proportion migrating and some required adjustments to the objective function (see section 7, Francis 2006). Two new 1-stock models were shown to provide slightly better overall fits to the data than analogous 2-stock models.

Another group of initial runs considered modifications to various constraints. As a result of these runs it was decided that, in the final runs for 2006, (i) a prior distribution would be applied to the selectivity shift parameter to discourage large year-to-year changes in the Wspsl ogive; (ii) the constraint (used only in MPD runs) that W and E YCSs should be equal would be applied only to the most recent year; (iii) a penalty function would be applied to encourage natural mortality to vary smoothly with age; and (iv) all trawl-survey biomass estimates would be upweighted by using only the observation error c.v.s rather than total c.v.s (Table 9) to ensure a good fit to the SAsumbio series.

A new set of data concerning the proportions, by age, of SA females that go to spawn each year was examined. These data are still preliminary, but suggest that these proportions are higher than indicated by the pspawn data set currently used in the assessment. More work needs to be done to resolve these differences. Runs in which pspawn was replaced by the newer data did not produce markedly different assessment outcomes. Because of this, and the still preliminary nature of the new data, it was decided to retain the original values of pspawn for the current assessment.

An examination of the at-age data found that, despite the depleted status of the W stock, there was no evidence that fish from this stock are now spawning at a younger age.

Three final runs

The three final runs adopted by the Working Group are distinguished by three 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 2.4 and 2.6) or allowing the spawning fishery selectivities (Espsl, Wspsl) to be domed (run 2.5). When the domed selectivities were used it was also necessary to combine sexes in the model and make the selectivities age-based (Francis 2005a). The third distinguishing characteristic is the assumption concerning natal fidelity. Run 2.6 assumes the alternative stock hypothesis but is otherwise identical to run 2.4 (Table 14)

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?**
2.4	*M* dependent on age	Yes	Yes
2.5	Domed spawning selectivity	No	Yes
2.6	*M* dependent on age	Yes	No*

* see section 6a (above) for description of the alternative stock hypothesis

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 has just experienced seven years of below-average recruitment (1995 to and 2001) though there is some evidence of improvement in later years. There is also good agreement on estimates of year-class strengths, with the notable exception that run 2.5 tends to estimate relatively stronger year classes in the early years and weaker in more recent years.

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 2005–06.

	B_0 ('000 t)		$B_{current}$ ('000 t)		$B_{current}$ (%B_0)		
Run	E	W	E	W	E	W	E + W
2.4	557(480,673)	912(816,1062)	230(168,324)	220(142,358)	41(32,52)	24(16,37)	31(24,39)
2.5	780(542,1120)	1199(889,1698)	254(164,391)	282(160,514)	33(27,40)	24(17,31)	27(23,33)
2.6	561(450,703)	1143(999,1378)	272(188,394)	230(136,433)	49(36,64)	20(12,36)	30(23,39)

Exploitation rates for both spawning fisheries were estimated to be at or near all-time highs in 2003, but are expected to be lower in 2006 (Figure 3). The peak exploitation rate for the W spawning fishery was estimated to be 0.39 in all runs (i.e., the catch was estimated to be 39% of the beginning-of-season vulnerable biomass). Estimated peak rates were lower for the E spawning fishery (0.23 for all runs), and much lower for the non-spawning fisheries (always less than 0.11).

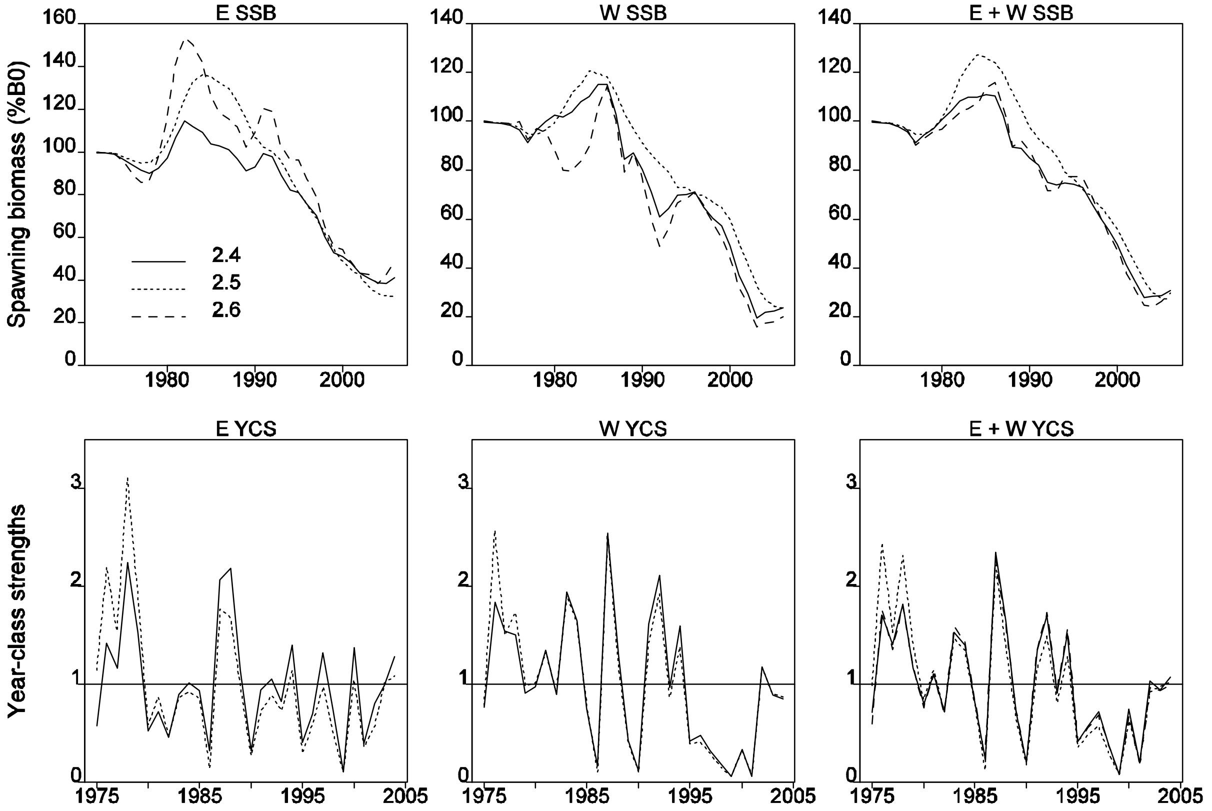


Figure 1: Estimated biomass trajectories (upper panels) and year-class strengths (lower panels) for the E (left panels), W (middle panels) and E + W stocks (right panels) from the final model runs. For run 2.6, year-class strengths are defined only for E + W (and are very similar to those for 2.4). Plotted values are medians of marginal posterior distributions. Years are fishing years (1990 = 1989–90).

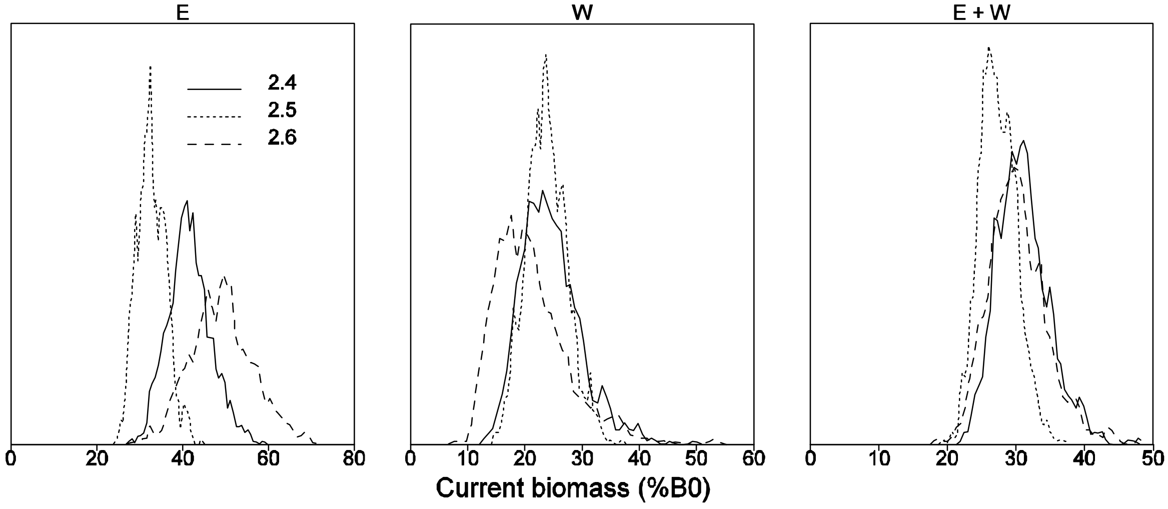


Figure 2: Estimated posterior distributions of current biomass ($B_{2005-06}$), expressed as $\%B_0$, for the E (left panel), W (middle panel) and E + W stocks (right panel) from the final model runs.

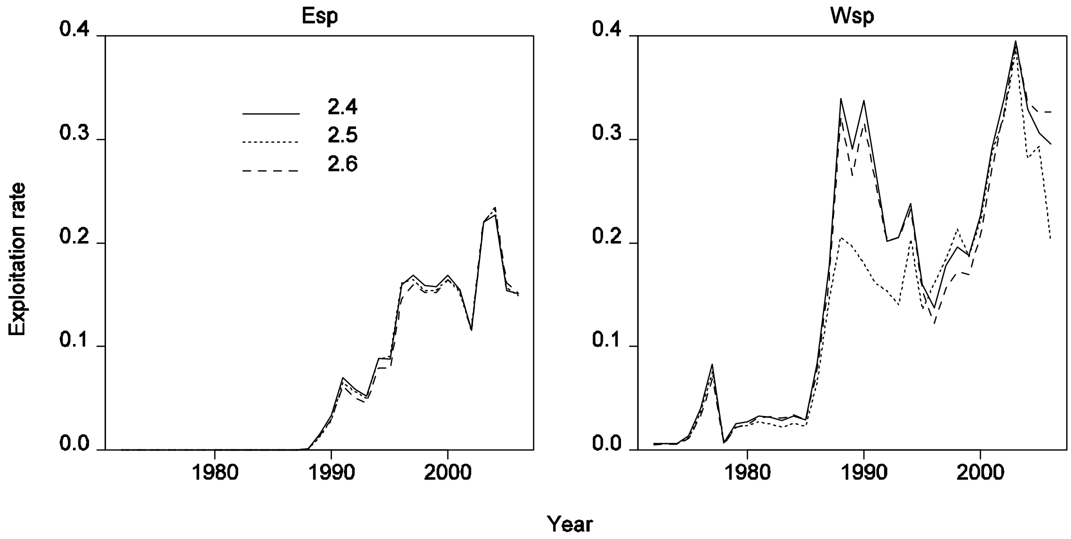


Figure 3: Estimated exploitation rates for the two spawning fisheries (Esp and Wsp) from the final model runs.

(d) Projections

Six sets of five-year projections were carried out, covering all combinations of:

- the three final runs, 2.4, 2.5, and 2.6,
- two recruitment scenarios, long-term (select future recruitment from estimated levels in 1975–2002) and recent (select from 1995–2002).

These projections were intended to evaluate the effect of continued fishing with the current TACC and the agreed catch splits, so catches by fishery for all projected years were calculated by scaling those for 2005 (see Table 12) so that they summed to 60 000 t in the E fisheries (Esp, Ensp1, Ensp2) and 40 000 t in the W fisheries (Wsp, Wnsp1, Wnsp2).

The recent recruitment option was adopted as an alternative scenario because the recent period of below-average recruitment for the western stock may be driven by environmental changes, which could persist in the short term. The eastern stock does not show the same pattern of poor recruitment in recent years.

Both stocks are expected to increase or stay near current levels with current catches (Figure 4).

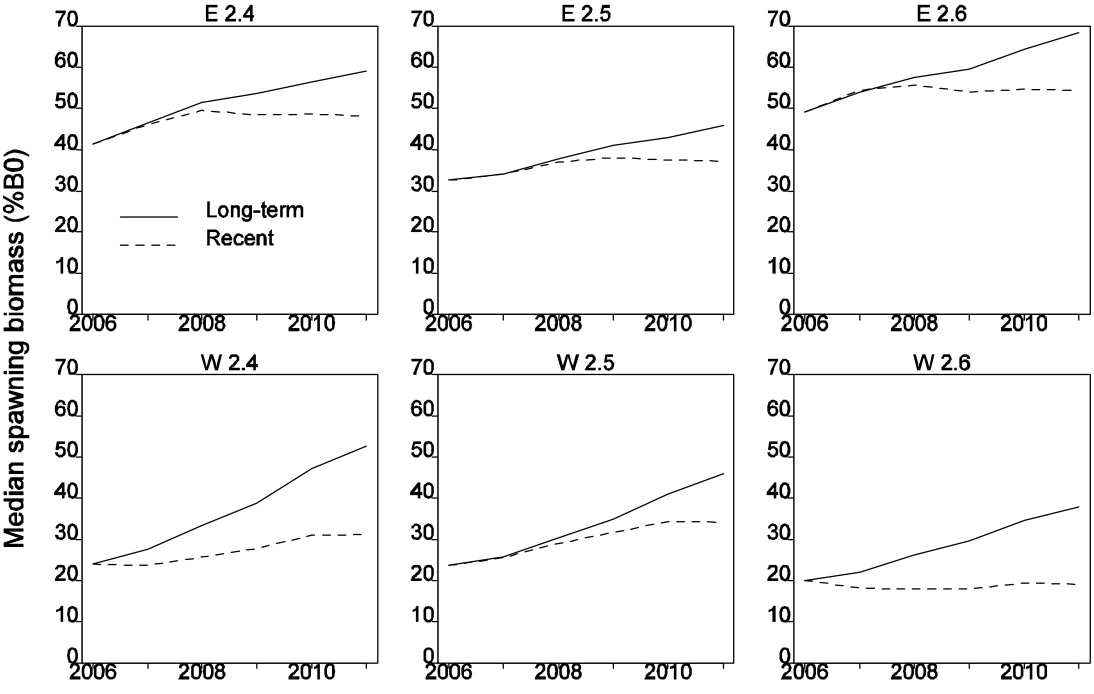


Figure 4: **Trajectories of spawning biomass from forward projections assuming long-term (solid lines) or recent (broken lines) recruitment.**

Figure 5 shows the probability of spawning biomass increasing from the 2006 level over each of the next 5 years under the 2 alternative recruitment assumptions (total catch of 100 000 t).

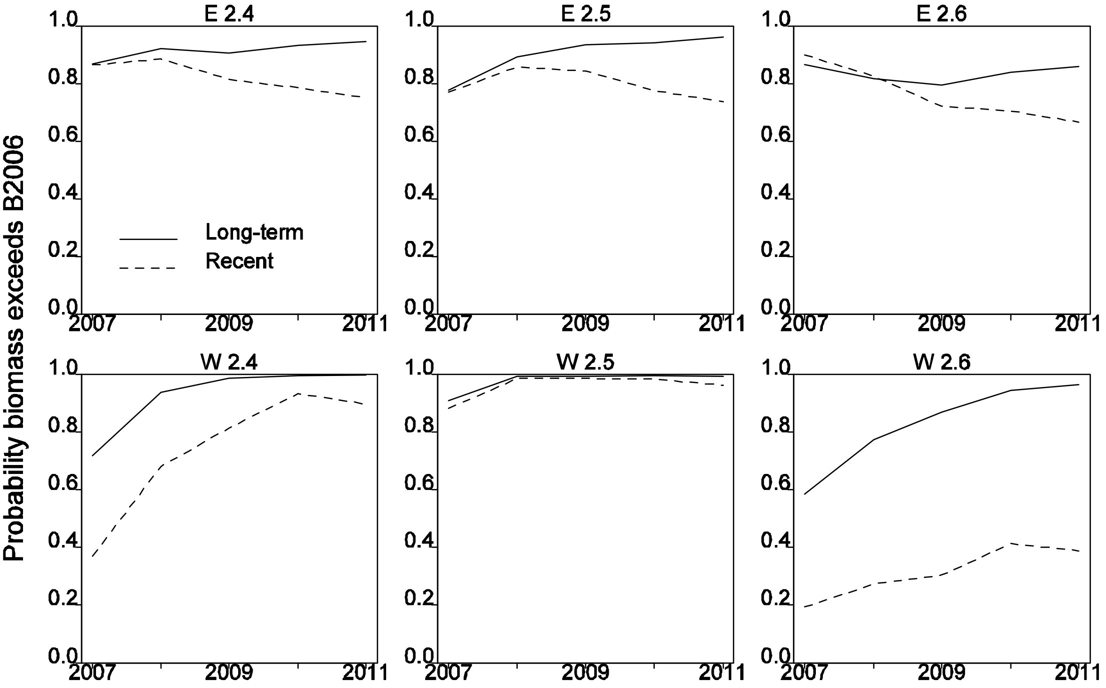


Figure 5: **Estimates, from forward projections, of the probability that future biomasses will exceed that in 2006, assuming long-term (solid lines) or recent (broken lines) recruitment.**

Figure 6 shows that exploitation rates are expected to continue to decline in both spawning fisheries as the stock rebuilds.

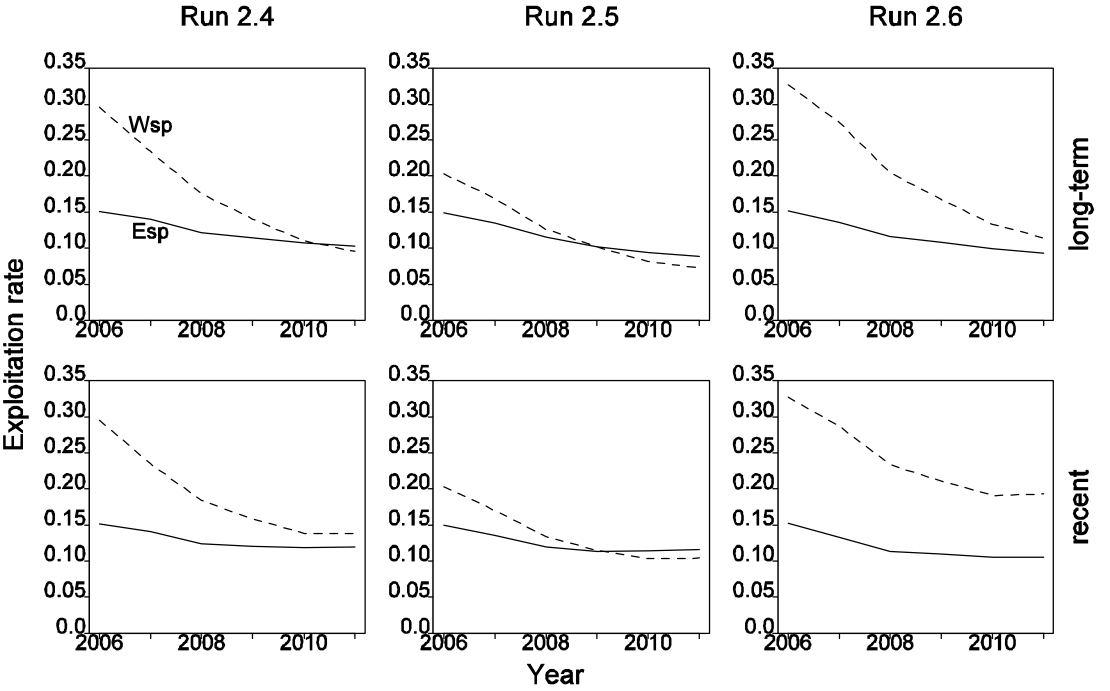


Figure 6: Estimated future exploitation rates in the spawning fisheries (solid lines for Esp, broken lines for Wsp) assuming long-term (upper panels) or recent (lower panels) recruitment scenarios.

7. STATUS OF THE STOCKS

B_{msy} has not been defined for hoki; however, it is likely to be in the range 30-40% B_0.

The hoki stock assessment was updated in 2006. Three final runs are reported for each stock. For the western stock, median estimates of current biomass are between 20 and 24 %B_0, (95% confidence intervals for each run are given in Table 15). This stock experienced an extended period of poor recruitment from 1995 to 2001 but there is some evidence of improvement in more recent years. For the eastern stock, current biomass was estimated to be between 33 and 49 %B_0 (see Table 15). Recent recruitment is estimated to be close to the long term average. For both stocks, the model projections suggest that continued fishing at the current TACC (with the agreed 60:40 catch splits) is likely to be sustainable and to allow biomass to increase unless future recruitment is poor.

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