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Assessment of hoki (*Macruronus novaezelandiae*)
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EXECUTIVE SUMMARY

McKenzie, A.; Francis, R.I.C.C. (2009). Assessment of hoki (*Macruronus novaezelandiae*) in 2009.

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A new assessment is presented for hoki. This is similar to the 2008 assessment in using the same program (CASAL), stock structure (two stocks in four fishing grounds), and estimation procedure (Bayesian with lognormal errors, including a distinction between observation and process errors). Three data types were used: biomass indices (from trawl and acoustic surveys), proportions at age and sex (from trawl surveys and the four fisheries), and proportion spawning. Data new to this assessment were from a Cook Strait acoustic survey, two trawl surveys (Chatham Rise and Sub-Antarctic), and proportions at age from the four fisheries.

Initial runs using the new year's data helped in deciding what assumptions should be made for the 2009 assessment, and also in interpreting the assessment. It was decided that additional weight should be given to all trawl-survey biomass estimates to ensure a good fit to the decline shown in the Sub-Antarctic survey series. However, no model runs were able to mimic the three-fold increase in the last two biomass estimates from this series, and it was concluded that this increase was probably due to unusually high catchability in 2007 and 2008.

The Hoki Working Group agreed on two final model runs which were similar to the two final model runs used in 2008. These provided alternative explanations for the relative lack of old fish in the data: age-dependent natural mortality, and domed selectivities for the spawning fisheries. Both hoki stocks are estimated to be increasing after reaching in about 2005 their lowest levels since the fishery began. The West stock is more depleted (36–39 % B_0) than the East stock (47–49 % B_0). The West stock experienced an extended period of poor recruitment from 1995 to 2001, but there is evidence of better (though still mostly below average) recruitment in subsequent years (2002–07). Projections suggest that continued fishing at current levels is likely to increase the biomass of the East and West stocks.

1. INTRODUCTION

Hoki (*Macruronus novaezelandiae*) is the most abundant commercial fish species in New Zealand waters, and has been our largest fishery since the mid 1980s. It is widely distributed throughout New Zealand's Exclusive Economic Zone in depths of 50–800 m, but most commercial fishing is at depths of 200–800 m. There are four main fisheries: two on spawning grounds (west coast South Island and Cook Strait), and two on feeding grounds (Chatham Rise and Sub-Antarctic) (Figure 1). Since the introduction of the QMS, hoki has been managed as a single fishstock, HOK 1 (ignoring HOK 10, which is purely administrative). Until recently, the TACC has oscillated between 200 000 t and its initial (1986–87) level of 250 000 t. In response to a series of poor recruitments the TACC was dropped to 180 000 t for 2003–04, to 100 000 t for 2004–05, and to 90 000 t in 2007–08 (Ministry of Fisheries 2008).

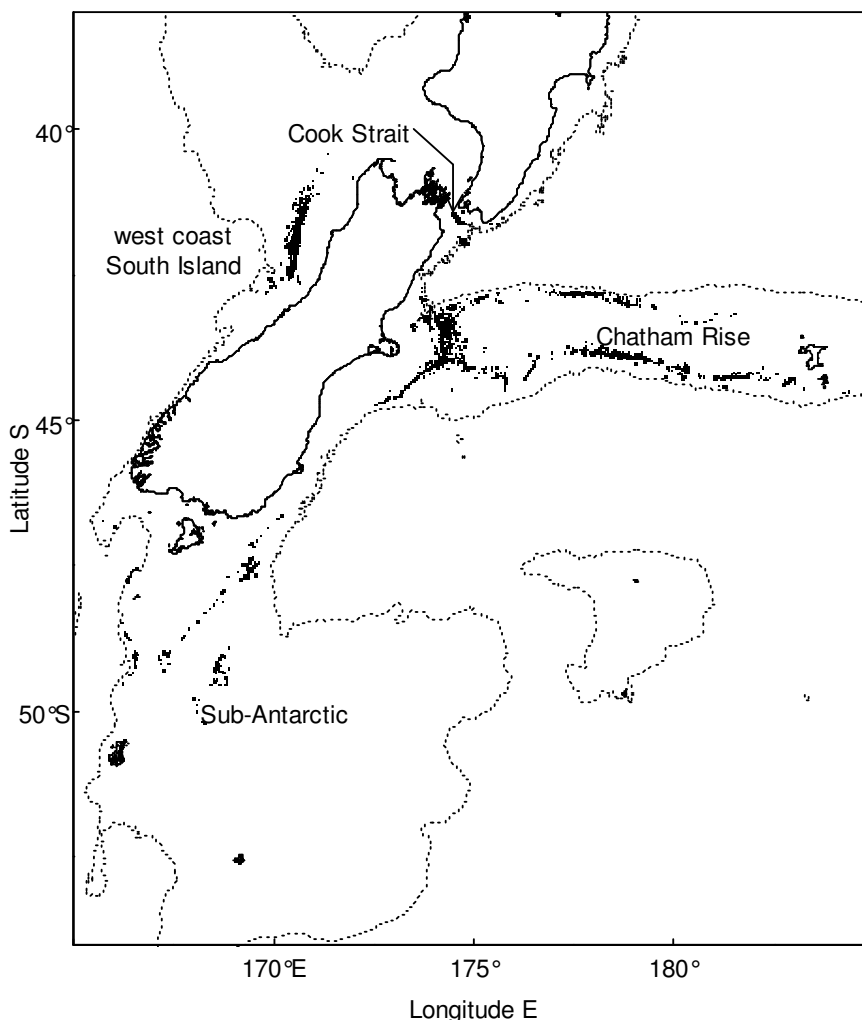


Figure 1: Southern New Zealand, showing the main hoki fishing grounds, the 1000 m contour (broken line), and the position of all 2007–08 tows from TCEPRs (Trawl Catch and Effort Processing Returns) in which at least 10 t of hoki was caught (dots).

Within HOK 1 two stocks are recognised — eastern and western — and these have been assessed separately since 1989. Originally, the two stocks were assessed in parallel models. More recently (since 1998 in NIWA assessments, and 2001 in industry-sponsored assessments) the stocks have been assessed simultaneously, using two-stock models. The complicated interactions inherent in a

two-stock model, together with the large array of data sets that are available for HOK 1 — the 2004 NIWA assessment used more than 1800 individual observations spread over 15 data sets (Francis 2005) — make this one of the most complex of all New Zealand assessments. For most years in the 1990s there were two separate assessments — one funded by the Ministry of Fisheries (MFish) and one by industry — using different models and often reaching different conclusions.

This report documents the 2009 assessment of HOK 1, which is the eighth hoki assessment to use NIWA's general-purpose stock-assessment model CASAL (Bull et al. 2008). Since the last assessment (Francis 2009) there has been another acoustic survey in Cook Strait in August 2008 (O'Driscoll 2009) and two more trawl surveys by NIWA – in the Sub-Antarctic in December 2008 (O'Driscoll & Bagley 2009) and Chatham Rise in January 2009 (Stevens 2009).

The work reported here addresses objective 1 of MFish project HOK200701B: *To update the stock assessment of hoki in the year 2009, including estimates of biomass, risk and yields.*

2. MODEL ASSUMPTIONS AND INPUTS FOR 2009

This section provides a fairly detailed summary of all model assumptions and inputs for the 2009 assessment. A complete description is contained, for the final runs only, in the files referred to in Appendix 1 (which should be read in conjunction with the CASAL manual, Bull et al. (2008)).

The model uses Bayesian estimation. In describing the model assumptions it will sometimes be necessary to distinguish between different types of model runs: MPD versus MCMC, or initial versus final. MPD runs are so called because they estimate the Mode of the Posterior Distribution, which means they provide a point estimate, whereas MCMC (or full Bayesian) runs provide a sample from the posterior distribution using a Markov Chain Monte Carlo technique (this sample is sometimes referred to as a chain). MCMC runs are more informative, but much more time consuming to produce. For this reason only MPD runs were used for the initial exploratory analyses (Section 3). These runs were used to define the assumptions for the final model runs (Section 4), which were full Bayesian, and whose results provide the formal stock assessment.

The model is based on the fishing year, which is labelled by its second part, so 1990 refers to the 1989–90 fishing year. This convention is applied throughout, so that, for instance, the most recent Sub-Antarctic survey, carried out in November–December 2008, is referred to as the 2009 survey.

A number of abbreviations are used to describe the model and its data inputs (Table 1).

Table 1: Abbreviations used in describing the model and observations.

Quantity	Abbreviation	Description
Stock	E	eastern stock
	W	western stock
Area	CR	Chatham Rise
	CS	Cook Strait
	SA	Sub-Antarctic
	WC	west coast South Island
Fishery	Esp	E spawning fishery
	Wsp	W spawning fishery
	Ensp1, Ensp2	first and second parts of E non-spawning fishery
	Wnsp1, Wnsp2	first and second parts of W non-spawning fishery
Observation	CSacous	CS acoustic biomass index
	WCacous	WC acoustic biomass index
	CRsumbio, CRsumage	biomass index & propns at age from CR summer trawl survey
	SAsumbio, SASumage	biomass index & propns at age from SA summer trawl survey
	SAautbio, SAautage	biomass index & propns at age from SA autumn trawl survey
	pspawn	proportion spawning (estimated from SA autumn trawl survey)
	Espage, Wnspage, etc	proportions at age in catch from given fishery (from otoliths)
	EnspOLF, WnspOLF	proportions at age in catch from given fishery (from OLF ¹)
Migrations	Ertn, Wrtn	return migrations of E and W fish from spawning
	Whome	migration of juvenile fish from CR to SA
	Espmg, Wspmg	spawning migrations of E and W fish
Selectivity	Epsl, Wpsl, Enspsl, Wnpsl	selectivity in commercial fisheries
	CRsl, SAsl	selectivity in trawl surveys

¹OLF is a computer program that estimates proportions at age from length frequency data (Hicks et al. 2002).

2.1 Model structure and catches

Two stocks are assessed. Fish from the eastern (E) stock spawn in Cook Strait (CS) and have their home grounds in Chatham Rise (CR); the western (W) stock spawn in west coast South Island (WC) and have their home grounds in Sub-Antarctic (SA) (these areas are shown in Figure 1). Soon after being spawned, all juveniles move to CR. In some earlier assessments two alternative assumptions concerning the juveniles have been modelled. One assumption is that the juveniles show natal fidelity – that is, they grow up to spawn on the ground where they were spawned. Under this assumption, the stock to which a fish belongs is determined at birth. At some time before age 8 all W juveniles migrate to their home ground, SA. The alternative assumption, used first in 2006, is that there is no natal fidelity. In the 2009 assessment all model runs assumed natal fidelity.

The model partition divides the population into two sexes, 17 age groups (1 to 17+), four areas corresponding to the four fisheries (CR, WC, SA, and CS), and two stocks (E and W). The annual cycle (Table 2) is the same as in 2008.

Table 2: 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). This is unchanged from that used in 2005. *M* fraction is the proportion of natural mortality which occurs within the time step. 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. The last column (“propn. mort.”) shows the proportion of that time step’s mortality that is assumed to have taken place when each observation is made.

Step	Approx. months	Processes	<i>M</i> fraction	Age fraction	Observations	
					label	propn. mort.
1	Oct-Nov	migrations Wrtn: WC→SA, Ertn: CS→CR	0.17	0.25	–	
2	Dec-Mar	recruitment at age 1+ to CR (for both stocks) part1, non-spawning fisheries (Ensp1, Wnsp1)	0.33	0.60	SAsum CRsum	0.5 0.6
3	Apr-Jun	migration Whome: CR→SA part2, non-spawning fisheries (Ensp2, Wnsp2)	0.25	0.90	SAaut pspawn	0.1
4	End Jun	migrations Wspm: SA→WC, Espm: CR→CS	0.00	0.90	–	
5	Jul-Sep	increment ages spawning fisheries (Esp, Wsp)	0.25	0.0	CSacous WCacous	0.5 0.5

As in 2008, the catches used in the model (Table 3) were calculated by apportioning the official total catch for each year amongst the six fisheries using the method described in Table 4. The catches from 2001 to 2008 were slightly revised using the most recent data from MFish, and the catch for 2008 is scaled up to the MHR total of 89 328 t. For the current year (2009), the same catch as used in 2008 was assumed, as directed by the Ministry of Fisheries. The proportion of the catch taken from the western fisheries increased between 1996 and 2002, but has since dropped as fishers shifted effort from West Coast South Island (Wsp) to Cook Strait (Esp) to reduce pressure on the W stock (Figure 2).

The fixed biological parameters in the model are unchanged from those used in 2008 (Table 5).

Table 3: Catches (t) by fishery and fishing year (1972 means fishing year 1971–72), as used in the assessment.

Year	Fishery					
	Ensp1	Ensp2	Wnsp1	Wnsp2	Esp	Wsp
1972	1500	2500	0	0	0	5000
1973	1500	2500	0	0	0	5000
1974	2200	3800	0	0	0	5000
1975	13100	22900	0	0	0	10000
1976	13500	23500	0	0	0	30000
1977	13900	24100	0	0	0	60000
1978	1100	1900	0	0	0	5000
1979	2200	3800	0	0	0	18000
1980	2900	5100	0	0	0	20000
1981	2900	5100	0	0	0	25000
1982	2600	4400	0	0	0	25000
1983	1500	8500	3200	3500	0	23300
1984	3200	6800	6700	5400	0	27900
1985	6200	3800	3000	6100	0	24900
1986	3700	13300	7200	3300	0	71500
1987	8800	8200	5900	5400	0	146700
1988	9000	6000	5400	7600	600	227000
1989	2300	2700	700	4900	7000	185900
1990	3300	9700	900	9100	14000	173000
1991	17400	14900	4400	12700	29700	135900
1992	33400	17500	14000	17400	25600	107200
1993	27400	19700	14700	10900	22200	100100
1994	16000	10600	5800	5500	35900	117200
1995	29600	16500	5900	7500	34400	80100
1996	37900	23900	5700	6800	59700	75900
1997	42400	28200	6900	15100	56500	96900
1998	55600	34200	10900	14600	46700	107100
1999	59200	23600	8800	14900	40500	97500
2000	43100	20500	14300	19500	39000	105600
2001	36700	20100	13300	17100	35100	107500
2002	24900	18800	16900	13500	24700	96700
2003	24300	18800	12300	7800	41400	79900
2004	17900	19000	6400	5300	40800	46300
2005	19200	14000	4400	1900	26200	38600
2006	22000	14800	2000	4700	20500	40400
2007	22400	18500	4200	3500	18800	33600
2008	22000	19400	6500	2200	17800	21400
2009	22000	19400	6500	2200	17800	21400

Table 4: Method of dividing annual catches into the six model fisheries (Esp, Wsp, Ensp1, Ensp2, Wnsp1, and Wnsp1). The small amount of catch reported in the areas west coast North Island and Challenger (typically 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

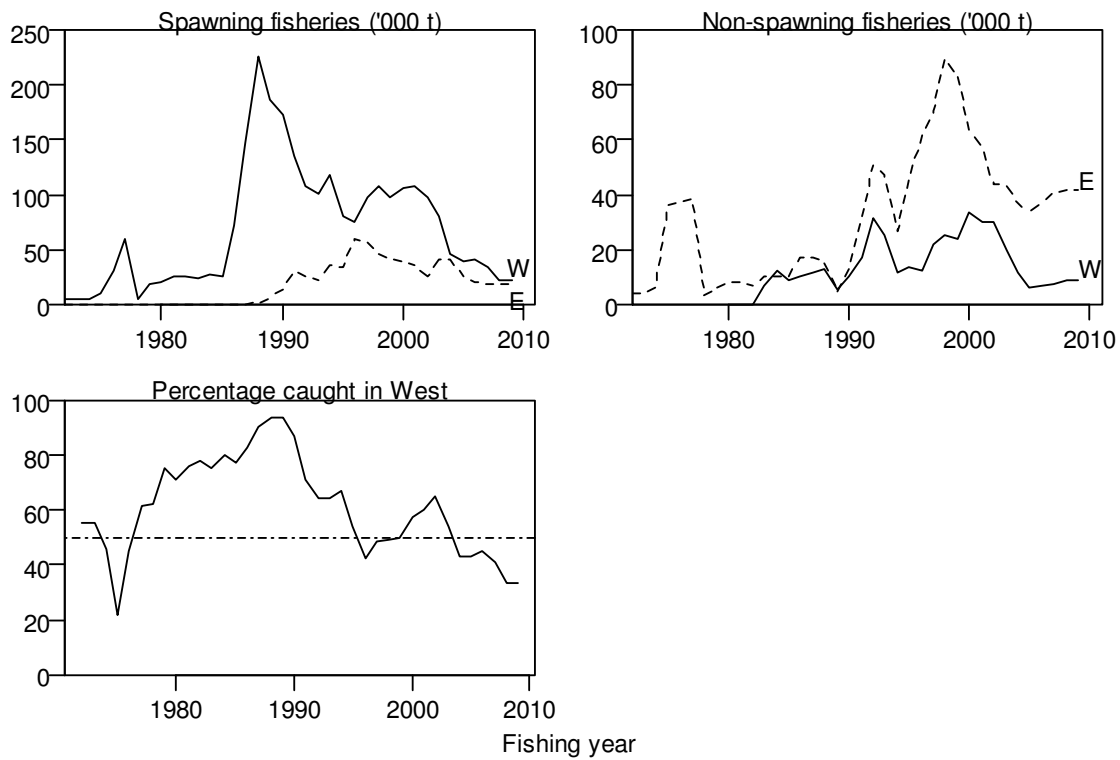


Figure 2: Annual catches by fishery for the spawning (top left panel) and non-spawning (top right panel) fisheries, and annual percentage of catch caught in western fisheries (Wsp, Wnsp1, Wnsp2) (bottom panel).

Table 5: Fixed biological parameters used by the model. Sources: a, Horn & Sullivan (1996) by sex, and Francis (2005) for both sexes combined; b, Francis (2003); c, assumed.

Type	Symbol	All fish	W stock			E stock			Source
			Male	Female	Both	Male	Female	Both	
Growth	L_{∞}		92.6	104.0	102.1	89.5	101.8	100.8	a
	k		0.261	0.213	0.206	0.232	0.161	0.164	
	t_0		-0.5	-0.6	-0.96	-1.23	-2.18	-2.16	
Length-weight [W(kg)=aL(cm) ^b]	a	4.79×10^{-6}							b
	b	2.89							
Proportion by sex at birth		0.5							c

2.2 Ogives

The ogives used in the model are the same as in 2008: six selectivity ogives (one for each of the four fisheries — Espsl, Wpsl, Enspsl, Wnpsl — and one each for trawl surveys in areas CR and SA – CRsl, SAsl), and three migration ogives (for migrations Whome, Espmg, and Wspmg). As in previous years, two alternative sets of ogive assumptions were used for the final runs (Table 6).

The home migration ogive, Whome, applied only to the W juveniles in CR and was the same in every year. At age 8, all W juveniles remaining in CR were forced to migrate to SA. In previous years this ogive has had a different interpretation in models without natal fidelity (Francis 2008).

Table 6: Ogive assumptions for the two final runs. In the ogive constraints, $O_{7,F,E}$ refers to the ogive value at age 7 for female fish from the E stock, etc.

Runs	Ogive type	Description	Constraints
1.1	Spawning selectivity	Length-based, logistic	same for M and F, same for E and W
	Non-spawning selectivity	Length-based, double-normal	same for M and F, must be domed ¹
	Survey selectivity	Length-based, double-normal	same for M and F, must be domed ¹
	Spawning migration	Free, ages 1–8	$O_{8,M,E} = O_{8,M,W}$, $O_{8,F,E} = O_{8,F,W} \geq 0.6$ $O_A = O_8$ for $A > 8$
1.1	Home migration	Free, ages 1–7	same for M and F, =1 for age > 7
1.2	Spawning selectivity	Age-based, double-normal	same for E and W
	Non-spawning selectivity	Age-based, double-normal	
	Survey selectivity	Age-based, double-normal	
	Home migration	Free, ages 1–7	=1 for age > 7
	Spawning migration	Free, ages 1–8	$O_A = O_8$ for $A > 8$

¹ see figure 11, and associated text, of Francis et al. (2003) for an explanation of what this means

As in previous years, the model attempted to estimate annual changes in Wpsl (the selectivity ogive for W spawning fishery). Following the recommendation of Francis (2006), these changes were restricted to years for which there were Wspage data (i.e., from 1988 onwards). The changes were driven by the median day of the fishery (Table 7). Annual changes in the selectivity for the other fisheries were not estimated because these were shown not to improve model fits in 2003 (Francis 2004).

Table 7: Median catch day by year for Wsp, as used in estimating annual changes in the selectivity Wpsl. The mean value was used for all years for which there was catch but no Wspage data (i.e., before 1988 and in the 2009 year). In the 2008 assessment (Francis 2009), the mean value was inadvertently calculated from 1983 onwards giving a value of 305. For the 2009 assessment 1988 onwards is used as recommended (Francis 2006).

1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999
299	302	298	301	306	304	308	307	312	310	311	309
2000	2001	2002	2003	2004	2005	2006	2007	2008	Mean		
309	309	308	309	307	309	310	307	301	306		

2.3 Other structural assumptions

For each stock, the population at the start of the fishery was assumed to have a stable age structure with biomass, B_0 , and constant recruitment, R_0 . The Francis parameterisation of recruitment was used. Thus, recruitment at age 1 in year y in each stock was given by

$$R_y = R_{\text{mean}} \times \text{YCS}_{y-2} \times \text{SR}(\text{SSB}_{y-2}),$$

where YCS_y is the year-class strength for fish spawned in year y , SR is a Beverton-Holt stock-recruit relationship with assumed steepness 0.75, R_{mean} is the expected recruitment (ignoring the stock-recruit relationship), and SSB_y is the mid-season spawning stock biomass in year y . R_0 is calculated as $R_{\text{mean}} Y_{\text{mean}}$, where Y_{mean} is the mean year class strength (YCS) over the years 1975 to 2004, inclusive (so R_0 is mean recruitment over those years, ignoring the effect of the stock-recruit relationship).

Thirty-three YCSs were estimated for each stock, for 1975 to 2007, inclusive. YCSs for the initial years (1970 to 1974) were fixed at 1. The E and W YCSs for 2007 were constrained (by a penalty function) to be equal for MPD runs, but this constraint was removed for the full Bayesian runs.

The maximum exploitation rates assumed were the same as in previous years: 0.3 in each part of the two non-spawning fisheries (which is approximately equivalent to 0.5 for the two parts combined), and 0.67 for both spawning fisheries. A penalty function was used to strongly discourage model estimates for which these maximum exploitation rates were exceeded.

As in previous years, the model's expected age distributions had ageing error applied to them before they were compared with the observed distributions (i.e., before they were used to calculate the objective function value).

2.4 Observations

Three types of observations were used in the model: biomass indices (Table 8), proportions at age (and sex) (Table 9, Figure 3), and proportion spawning (Table 10). Biomass indices new to this assessment came from an acoustic survey in Cook Strait in August 2008 (O'Driscoll 2009), and trawl surveys of the Sub-Antarctic in December 2008 (O'Driscoll & Bagley 2009) and Chatham Rise in January 2009 (Stevens 2009).

The proportions-at-age data fall into three groups. The first group — trawl survey (CRsumage, SASumage, SAautage) and spawning catch at age (Wspage, Espage) — is the most substantial and reliable. These data are otolith-based, and use an age-length key to transform proportions at length to proportions at age. The non-spawning otolith-based data (Enspage, Wnspage) are available only since sufficient otoliths have been collected from these fisheries. Because the fisheries are spread over many months, these proportions at age must be estimated directly (rather than via an age-length key). The third group of data (EnspOLF, WnspOLF), which is OLF-based, is less reliable because of the difficulty of inferring age distributions from length data alone.

Although both the CR and SA trawl surveys provide information about year-class strengths (YCSs) the CR survey is more reliable for recent year classes. This is shown in the greater consistency for CR, compared to SA, for between-survey estimates of numbers at age for the youngest ages (Figure 4). Furthermore, the correlation between these estimates and model estimates of YCS is not strong until age 4 for the SA survey, but is quite strong at age 1 for the CR survey (Francis 2008, figure 32).

The proportions-spawning data (Table 10) have been changed to the recommended estimates of Francis (2009).

The way the proportions-at-age data enter the model varies amongst data sets (Table 11). As in 2002 (and all subsequent years), all proportions less than 0.0001 were replaced by 0.0001 (for reasons, see Francis et al. (2003)). For the otolith-based data sets the maximum ages were set as high as was possible without allowing the percentage of data points requiring this adjustment to exceed 2%.

The proportions of young fish in the west spawning fish has risen slightly from 2007, but still remains much lower than the peak in 2005 (Figure 5). The increase in the proportion of older fish in the Wspage, Espage, and SAsumage data sets has been sustained for another year (Figure 6).

Table 8: Biomass indices ('000 t) used in the assessment, with observation and total c.v.s (respectively) in parentheses. Bold values are new to this assessment.

	<u>CRsumbio</u>	<u>SAsumbio</u>	<u>SAautbio</u>	<u>CSacous</u>	<u>WCacous</u>
1988	–	–	–	–	417 (0.22,0.60)
1989	–	–	–	–	249 (0.15,0.38)
1990	–	–	–	–	255 (0.06,0.40)
1991	–	–	–	180 (0.13,0.41)	340 (0.14,0.73)
1992	120 (0.08,0.21)	80 (0.07,0.21)	68 (0.08,0.22)	–	345 (0.14,0.49)
1993	186 (0.10,0.22)	87 (0.06,0.21)	–	583 (0.15,0.52)	550 (0.07,0.38)
1994	146 (0.10,0.22)	100 (0.09,0.22)	–	592 (0.06,0.91)	–
1995	120 (0.08,0.21)	–	–	427 (0.12,0.61)	–
1996	153 (0.10,0.22)	–	89 (0.09,0.22)	202 (0.09,0.57)	–
1997	158 (0.08,0.22)	–	–	295 (0.12,0.40)	654 (0.10,0.60)
1998	87 (0.11,0.23)	–	68 (0.11,0.23)	170 (0.10,0.44)	–
1999	109 (0.12,0.23)	–	–	243 (0.10,0.36)	–
2000	72 (0.12,0.23)	–	–	–	396 (0.14,0.60)
2001	60 (0.10,0.22)	56 (0.13,0.24)	–	220 (0.12,0.30)	–
2002	74 (0.11,0.23)	38 (0.16,0.26)	–	320 (0.13,0.35)	–
2003	53 (0.09,0.22)	40 (0.14,0.24)	–	225 (0.17,0.34)	–
2004	53 (0.13,0.24)	14 (0.13,0.24)	–	–	–
2005	85 (0.12,0.23)	18 (0.12,0.23)	–	132 (0.11,0.32)	–
2006	99 (0.11,0.23)	21 (0.13,0.24)	–	126 (0.17,0.34)	–
2007	70 (0.08,0.22)	14 (0.11,0.23)	–	216 (–,0.46)	–
2008	77 (0.11,0.23)	46 (0.16,0.26)	–	167 (–,0.30)	–
2009	144 (0.11,0.23)	47 (0.14,0.24)	–	–	–

Table 9: Description of the proportions-at-age observations used in the assessment. These data derive either from otoliths or from the length-frequency analysis program OLF (Hicks et al. 2002). Data new to this assessment are in bold type.

Area	Label	Data type	Years	Source of age data
WC	Wspage	Catch at age	1988– 08	otoliths
SA	WnspOLF	Catch at age	1992–94, 96, 99–00	OLF
	Wnspage	Catch at age	2001–04, 06– 08	otoliths
	SAsumage	Trawl survey	1992–94, 2001– 09	otoliths
	SAautage	Trawl survey	1992, 96, 98	otoliths
CS	Espage	Catch at age	1988– 08	otoliths
CR	EnspOLF	Catch at age	1992, 94, 96, 98	OLF
	Enspage	Catch at age	1999– 08	otoliths
	CRsumage	Trawl survey	1992– 09	otoliths

Table 10: Proportion spawning data, pspawn. These are estimates from the 1992, 1993, and 1998 SAaut surveys, of the proportion, by age, of females that were expected to spawn in the following winter (Francis 2009, table 43).

Year	Age						
	3	4	5	6	7	8	9+
1992	0.13	0.44	0.48	0.54	0.67	0.61	0.66
1993	–	0.64	0.58	0.65	0.66	0.71	0.60
1998	0.27	0.46	0.39	0.42	0.49	0.44	0.54

Table 11: Age ranges used for at-age data sets. In all cases the last age was treated as a plus group.

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

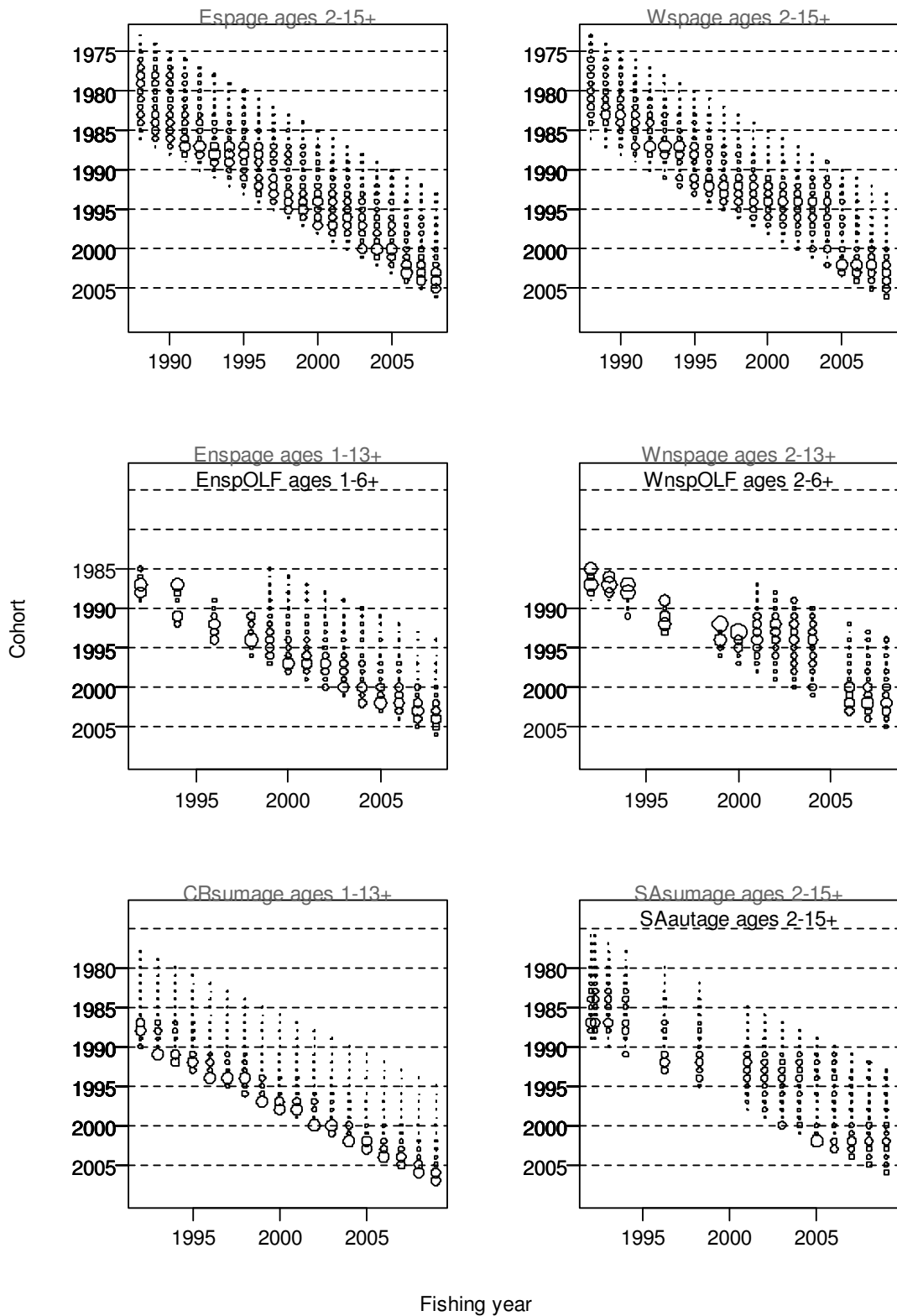


Figure 3: Proportions-at-age data, plotted by cohort and fishing year, with both sexes combined. The area of each circle is proportional to the associated proportion at age. Circle positions for the SAautage data have been offset horizontally to allow them to be plotted on the same panel as the SAsumage data. In all panels the right-most column of circles is new to this assessment.

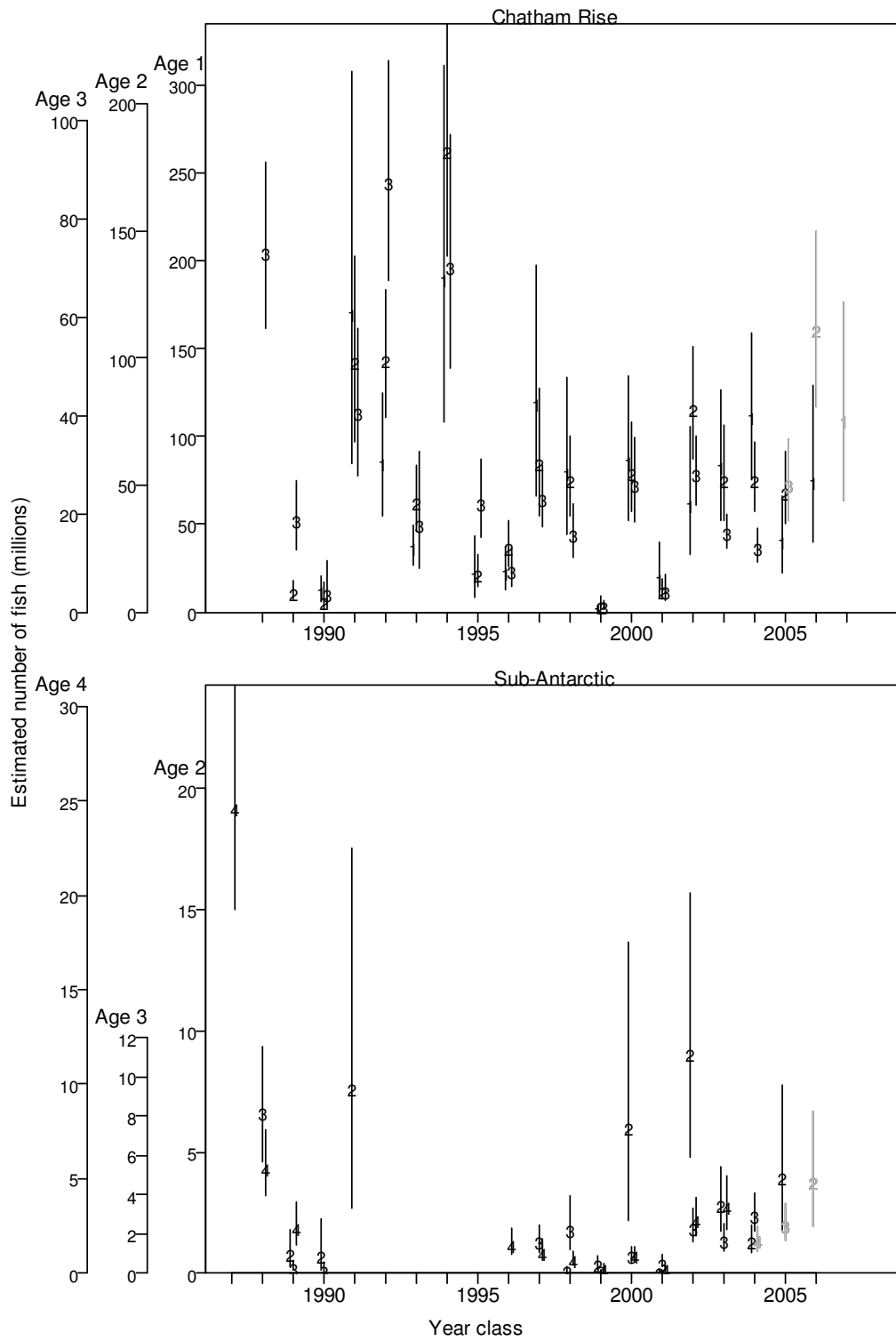


Figure 4: Estimated numbers at age for each of the three youngest ages in the two main trawl survey series. Vertical bars indicate 95% confidence intervals; data points new to this assessment are plotted in grey.

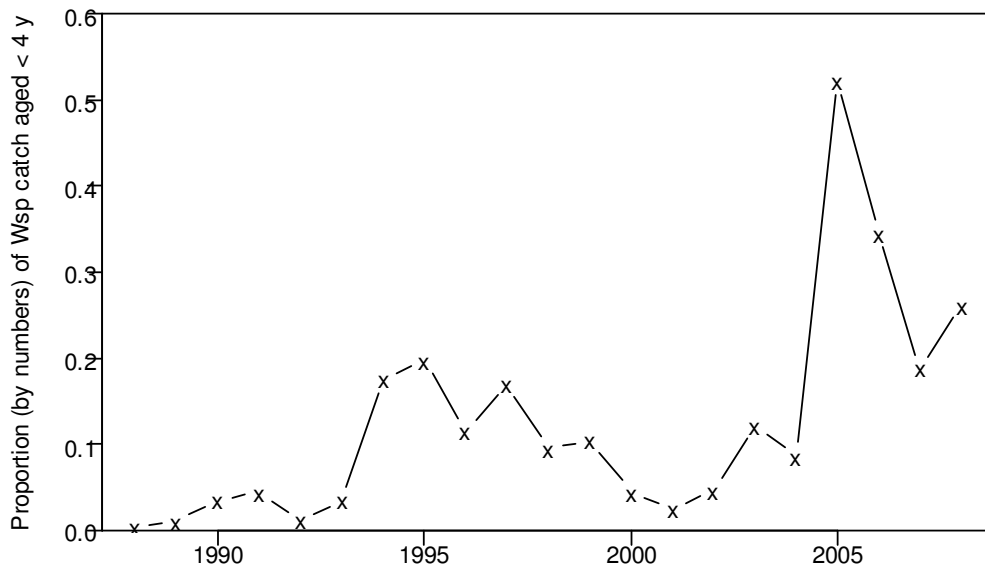


Figure 5: Annual proportion of young fish (aged less than 4 y) in the catch from the west spawning fishery. Note that all plotted proportions are based on numbers of fish; proportions based on weight would be much smaller.

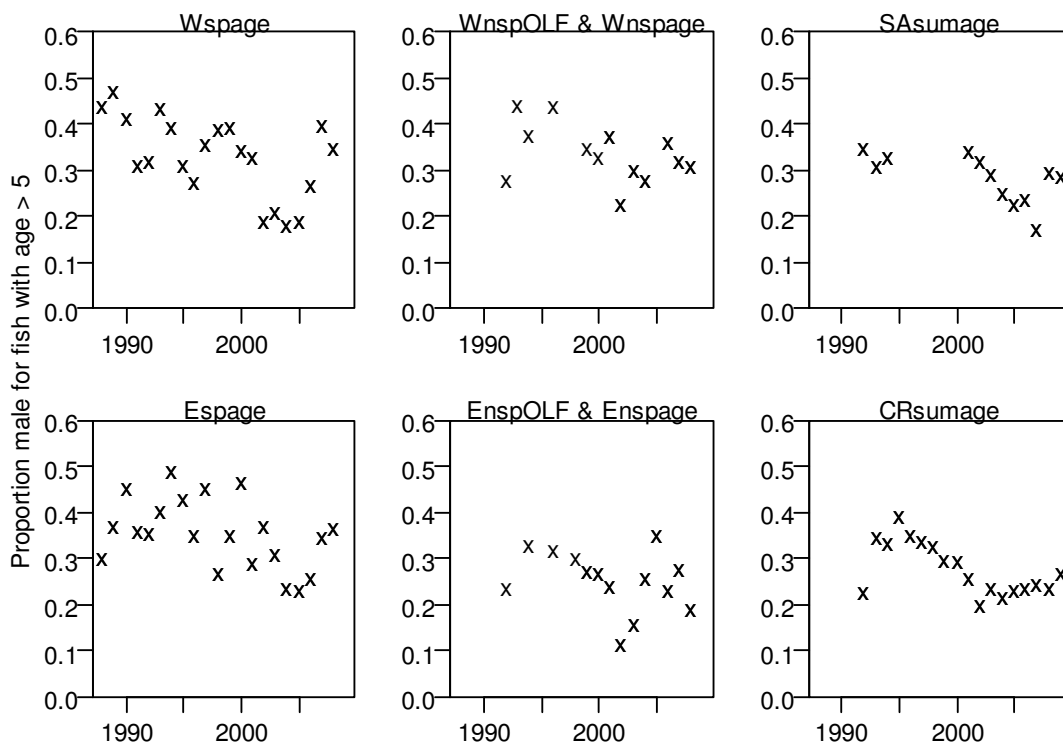


Figure 6: Observed ('x') of proportions male, by year and data set, for older fish (ages > 5 y).

2.5 Error assumptions

The error distributions assumed were robust lognormal (Bull et al. 2008) for the proportions-at-age data, and lognormal for all other data. This means that the weight assigned to each datum was controlled by an error c.v. In this section we describe how these c.v.s were assigned.

For the biomass indices, two alternative sets of c.v.s were available (see Table 8). The total c.v.s represent the best estimates of the uncertainty associated with these data, and were used in all initial model runs. For the acoustic indices, these were calculated using a simulation procedure intended to include all sources of uncertainty (O'Driscoll 2002), and the observation-error c.v.s were calculated in a similar way but including only the uncertainty associated with between-transect (and within-stratum) variation in total backscatter. For the trawl indices, the total c.v.s 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: $c.v._{total}^2 = c.v._{process}^2 + c.v._{observation}^2$). In some model runs (see below) it was decided to upweight some trawl biomass indices by using their observation, rather than total, c.v.s.

For almost all of the proportions-at-age observations, total c.v.s were treated as the sum of a process-error c.v. and an observation-error c.v. (the only exception was pspawn, for which an arbitrary c.v. of 0.25 was assumed, following Cordue (2001)). Observation-error c.v.s for the remaining otolith-based data were calculated by bootstrapping. For the OLF-based data the c.v.s used were the same as in 2004 (Francis 2005). As is typical with proportions, estimated c.v.s decreased as proportions increase (Figure 7).

Process-error c.v.s for the at-age data were estimated within the model (one c.v. for each data set) for all point estimates, as in previous years. For full Bayesian estimates, these c.v.s were fixed. Although there is some evidence that these process-error c.v.s should decrease with increasing age, there does not appear to be a strong need to implement such a relationship (Francis 2004).

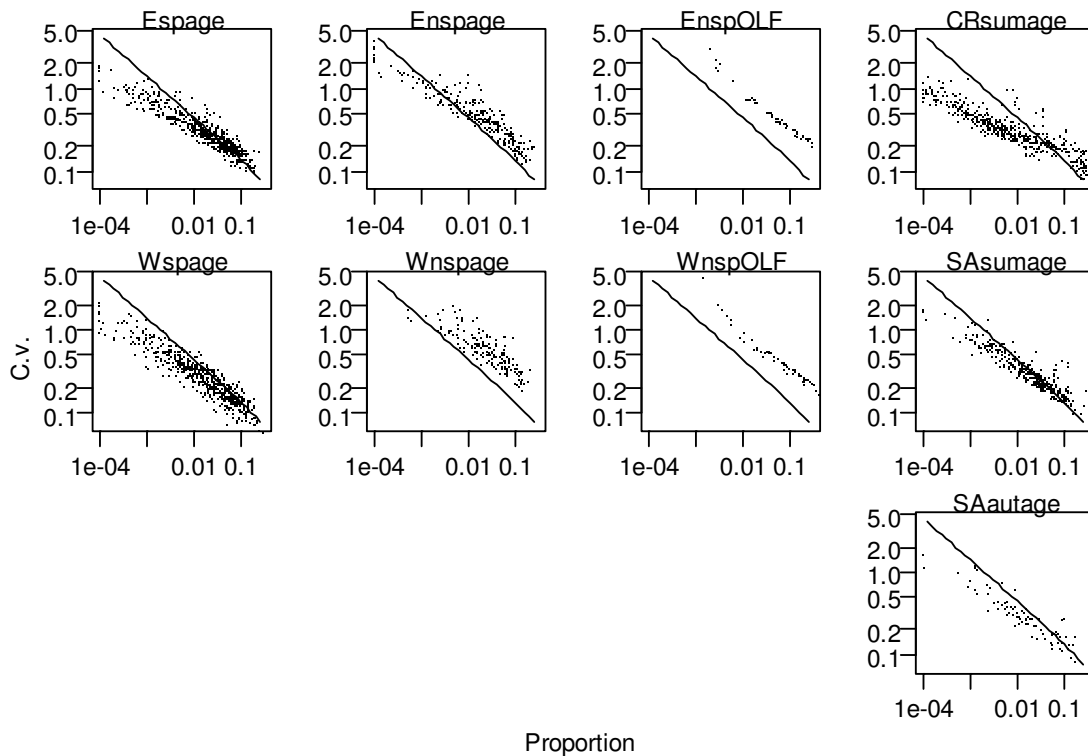


Figure 7: Observation-error c.v.s for the proportions-at-age data sets. Each point represents a proportion at a specific age and sex for a given year. The diagonal line, which is the same in each panel, is added to aid comparison between panels; it shows the relationship between proportion and c.v. that would hold with simple multinomial sampling with sample size 500.

2.6 Parameters, priors, and penalties

The number of parameters estimated in the final model runs was 143 (for run 1.1) or 121 (for run 1.2) (Table 12). Most of the associated prior distributions were intended to be uninformative; the main exceptions were those for the catchabilities (O'Driscoll et al. 2002), pE , and natural mortality (Smith 2004). For selectivity[Wspsl].shift_a and migration[Whome].annual_variation_values, normal priors were used with standard deviations more or less arbitrarily chosen to discourage extreme values (see sections 7.1 and 7.3, respectively, of Francis (2006)).

As in previous assessments, the model estimated natural mortality separately by sex (when sex was included in the model) because of the trends with age in the sex ratio.

Table 12: Parameters estimated in the final model runs, and their associated prior distributions. Where the number of parameters varied between model runs the two values given are for runs 1.1 and 1.2, respectively. Distribution parameters are: bounds for uniform and uniform-log; mean (in natural space) and c.v. for lognormal; and mean and s.d. for normal and beta.

Parameter(s)	Description	Type	Distribution		No. of parameters
			Parameters		
log_Bmean_total	$\log(B_{\text{mean,E}} + B_{\text{mean,W}})$	uniform	12.6 ^a	16.2	1
Bmean_prop_stock1 (=pE)	$B_{\text{mean,E}}/(B_{\text{mean,E}} + B_{\text{mean,W}})$	beta[0.1,0.6] ^b	0.344	0.072	1
recruitment.YCS	year-class strengths	lognormal	1	0.95	66
q[CSacous].q	catchability, CSacous	lognormal	0.77	0.77	1
q[WCacous].q	catchability, WCacous	lognormal	0.57	0.68	1
q[CRsum].q	catchability, CRsumbio	lognormal	0.15	0.65	1
q[SAsum].q	catchability, SAsumbio	lognormal	0.17	0.61	1
q[SAAut].q	catchability, SAAutbio	lognormal	0.17	0.61	1
natural_mortality	$M_{\text{male}} \& M_{\text{female}}$ ages 5–9	lognormal	0.182	0.509	8,0
natural_mortality.all	M	lognormal	0.298	0.153	0,1
process error c.v.s		uniform	0.1	1	7
selectivity[Wspsl].shift_a	Wspsl shift	normal	0	0.25	1
migrations	Whome, Wspmng, Espmng	uniform	various		40,24
comm. selectivities	Epspl, Wpspl, Enpspl, Wnpspl	uniform	various		8,9
surv. selectivities	CRsl, SAsl	uniform	various		<u>6</u>
					143,121

^a A lower bound of 13 was used for run 1.2

^b This is a beta distribution scaled to have its range from 0 to 0.6, rather than the usual 0 to 1

In addition to the priors, bounds were imposed for all parameters with non-uniform distributions. The catchability parameters were those calculated by O'Driscoll et al. (2002) (where they are called “overall bounds”); for other parameters they were usually set at the 0.001 and 0.999 quantiles of their distributions. Some bounds were adjusted in some runs to avoid poor model behaviour; these adjustments did not appear to have a significant effect on the model results.

Penalty functions were used for three purposes. First, any parameter combinations that caused any exploitation rate to exceed its assumed maximum (Section 2.3) were strongly penalised. Second, the most recent YCSs were forced to be the same for E and W (but this penalty was dropped in MCMC runs) (Section 2.3). The third use of penalty functions was to link the spawning migration ogives for the two stocks (as per the constraints in Table 6).

3. INITIAL EXPLORATORY MODEL RUNS

In this section we perform preliminary analyses with the new data, investigate any problems that arose, and inform which runs should be used in the formal assessment (presented in Section 4).

The first MPD runs using all the new observations were labelled 1.1 and 1.2. Runs 1.1 and 1.2 were based on the final runs 2.3 and 2.4 respectively from 2008 (Table 13) with the following changes:

- all runs used the new year's data
- the recommended pspawn data for the 2009 assessment are used
- the mean value for the median catch day was amended (Table 7)

Table 13: Relationship between initial 2009 model runs and those from the 2008 assessment. Runs 2.3 and 2.4 are the two final model runs selected by the Hoki Working Group for the 2008 assessment. In all model runs in this table the trawl survey biomass data are upweighted.

2009 label	2008 label	Response to lack of old fish in the observations	Sex in model and selectivities length-based?
1.1	2.3	M dependent on age	Yes
1.2	2.4	Domed spawning selectivity	No

The following MPD runs (1.4 and 1.5) are the same as 1.1 and 1.2 except the trawl survey biomass indices are not upweighted. In the sensitivity run 1.7 the 2008 pspawn data is used instead of the 2009 recommended values; in sensitivity run 1.12 a different mean value is used for the median catch day.

There was very little difference between the weighted and non-upweighted model runs regarding the fits to the data sets SAautbio, CSacous, and WCacous (Table 14, Figures 8–9).

However, for the upweighted model runs the fits to the CRsumbio are slightly worse (Table 14), though visually the difference is very minor and the fits in both cases are adequate (Figure 10). The fits to the associated proportions-at-age have tended to improve since 2001 (Figures 11–12).

For upweighted model runs the fit to the SAsumbio is better (Table 14), but the fit is not good for the last two years (Figure 13). While the fits to the associated proportions-at-age for 2008 are not much worse than in previous years, the fits for 2009 are the worst for the past three years (Figures 14–15). A trend in the normalised residuals for male and females begins to appear in 2004, with an increasing proportion of older fish being observed than the model predicts (Figure 16). The catchability for 2008 seems higher relative to 2007, with the catchability for 2009 being about the same as in 2008 (Figure 17). Relative to two years earlier, the catchability for both 2008 and 2009 seem higher (Figure 18).

Upweighting the trawl biomasses leads to lower current biomass estimates (as a percentage of virgin) for both east and west stocks (Table 15). The model runs are insensitive to the change in the pspawn data or the change in the mean value used for the median catch day (Table 15).

Table 14: Goodness of fit to biomass indices as measured by the SDNR (standard deviation of the normalised residuals) for some new model runs. For this table the normalised residuals were calculated using the original c.v.s (i.e., ignoring changes in c.v.s. for upweighting trawl biomass data sets).

Run	Description	CRsumbio	SAsumbio	SAautbio	CSacous	WCacous
1.1	As in 2.3	0.86	1.47	0.81	0.94	1.11
1.2	As in 2.4	0.85	1.53	0.93	0.99	1.04
1.4	As in 1.1, no upweighting	0.95	1.71	0.80	0.96	1.12
1.5	As in 1.2, no upweighting	0.92	1.91	0.83	0.98	0.95

Table 15: Comparison of key aspects of some initial MPD fits.

Run	Description	Objective function	$B_{\text{current}}(\%B_0)$	
			E	W
1.1	As in 2.3	-260.9	46.4	35.8
1.2	As in 2.4	-330.7	41.6	33.8
1.4	As in 1.1, no upweighting	-301.9	55.2	37.8
1.5	As in 1.2, no upweighting	-377.6	45.9	50.1
1.7	As in 1.2, using 2008 pspawn	-329.8	40.9	32.8
1.12	As in 1.2, using mean of 305*	-331.8	41.9	33.6

* See Table 7

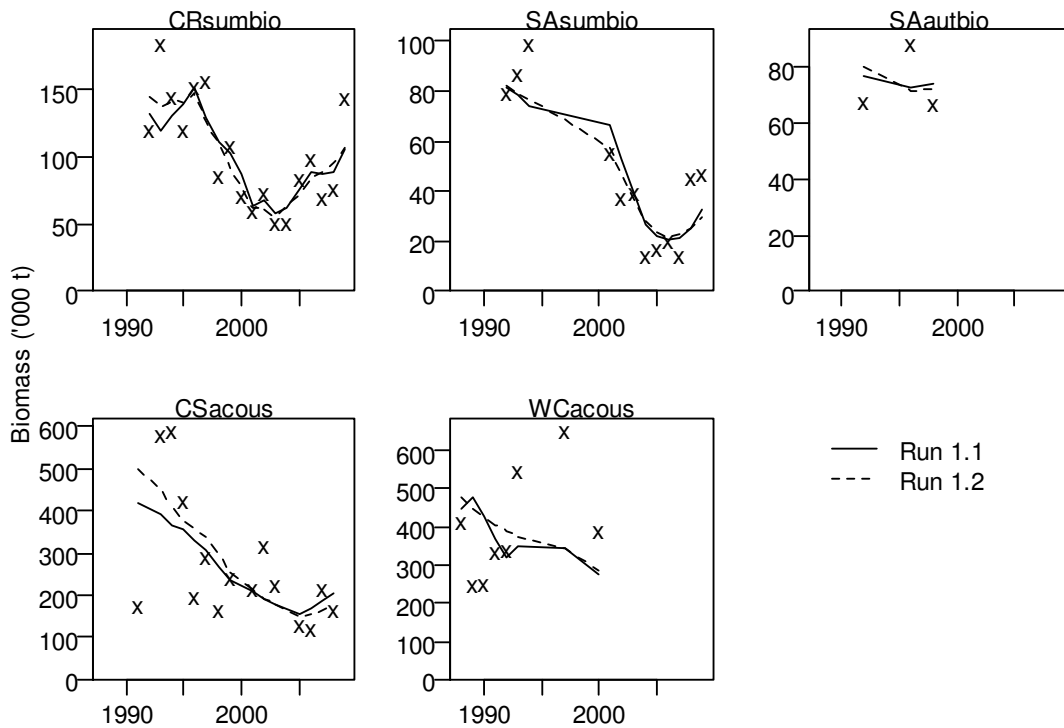


Figure 8: Fit to biomass indices for runs 1.1 and 1.2, showing observed ('x') and expected values (lines). In these model runs the trawl survey biomass data are upweighted.

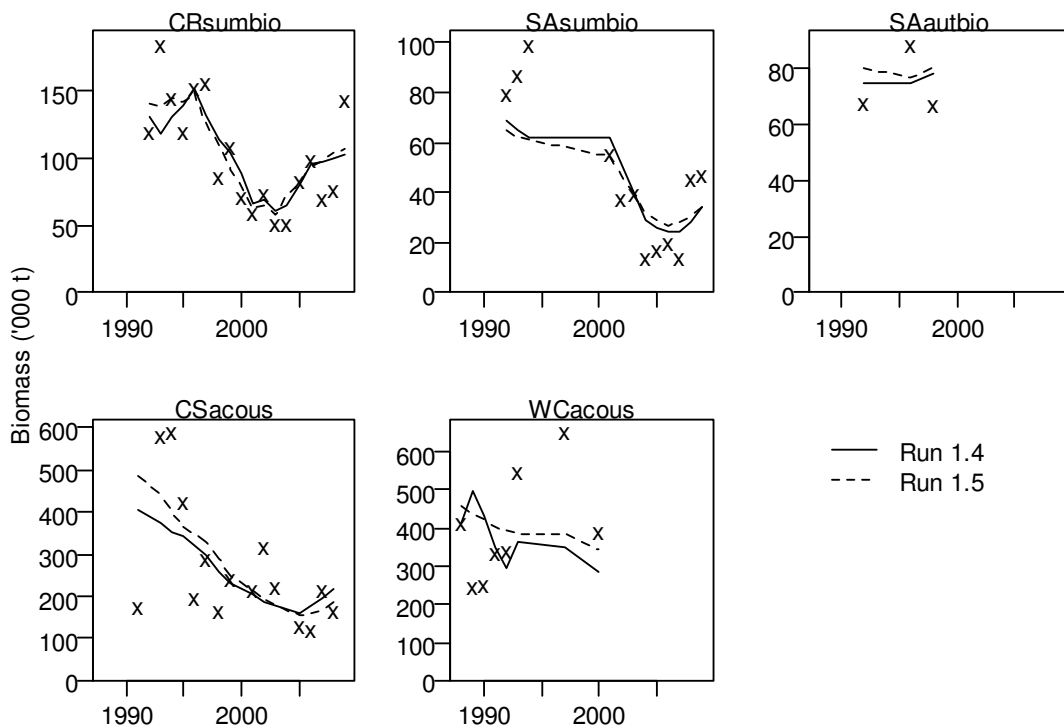


Figure 9: Fit to biomass indices for runs 1.4 and 1.5, showing observed ('x') and expected values (lines). In these model runs the trawl survey biomass data has no upweighting.

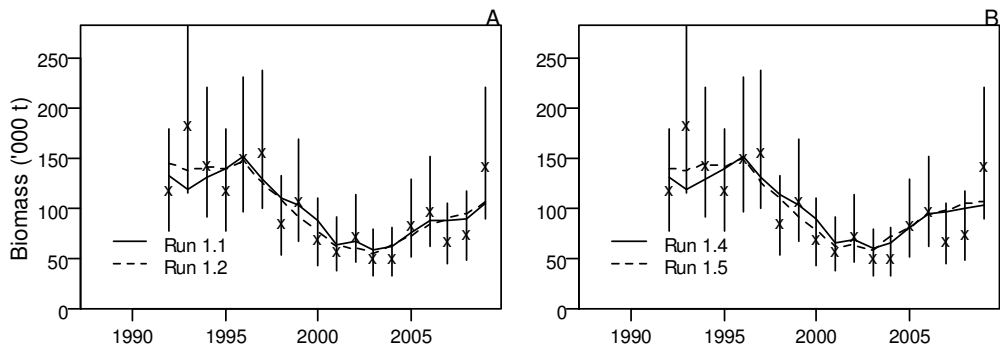


Figure 10: Fits to CRsumbio for runs 1.1, 1.2, 1.4, and 1.5, showing observed ('x', with vertical lines showing 95% confidence intervals) and expected values (lines). Plotted years are as in the model (so the last survey is plotted at 2009). The trawl survey indices are upweighted for the left-hand graph, and unweighted for the right-hand graph.

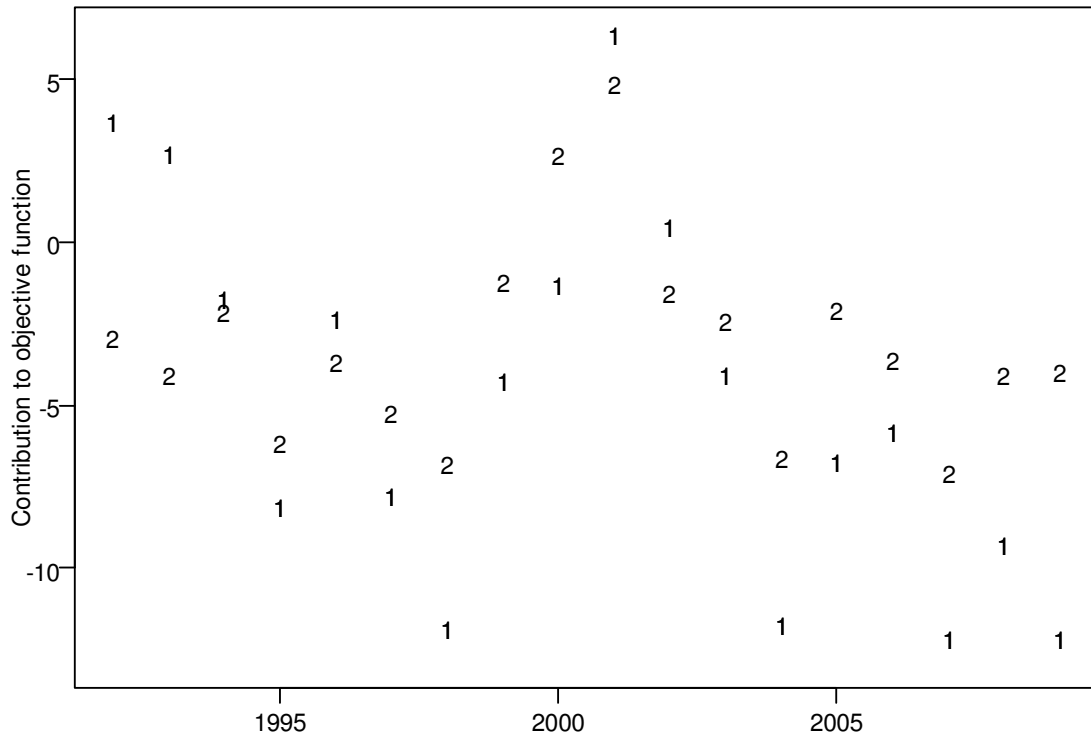


Figure 11: Goodness of fit to the CRsumage data, by year, for runs 1.1 ('1') and 1.2 ('2'). The y-value for each point indicates the contribution to the objective function from one year's CRsumage data; smaller values indicate a better fit. Plotted years are as in the model (so the last survey is plotted at 2009).

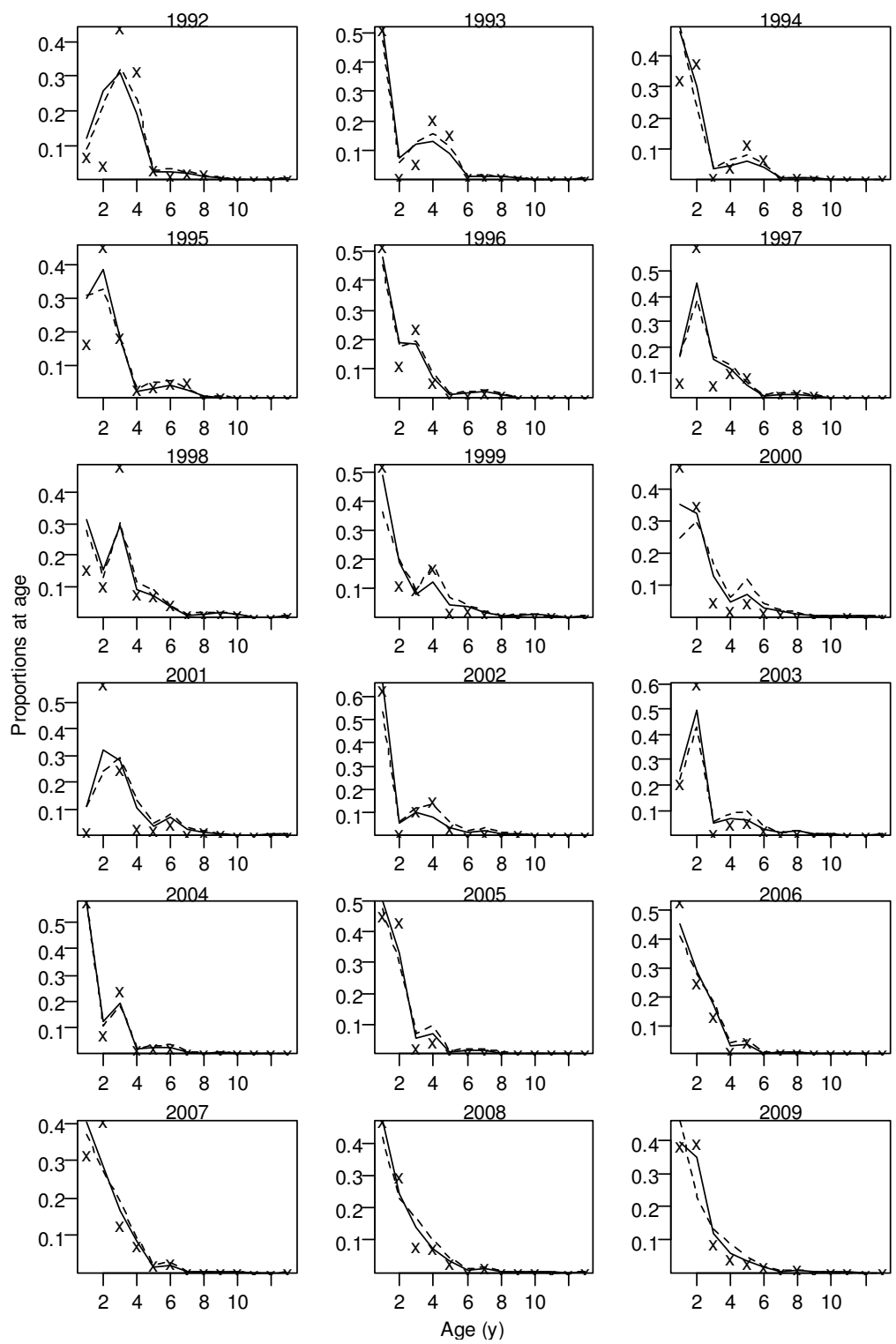


Figure 12: Observed ('x') and expected (lines) proportions at age in the summer Chatham Rise survey (data set CRsumage) for runs 1.1 (solid line) and 1.2 (broken lines).

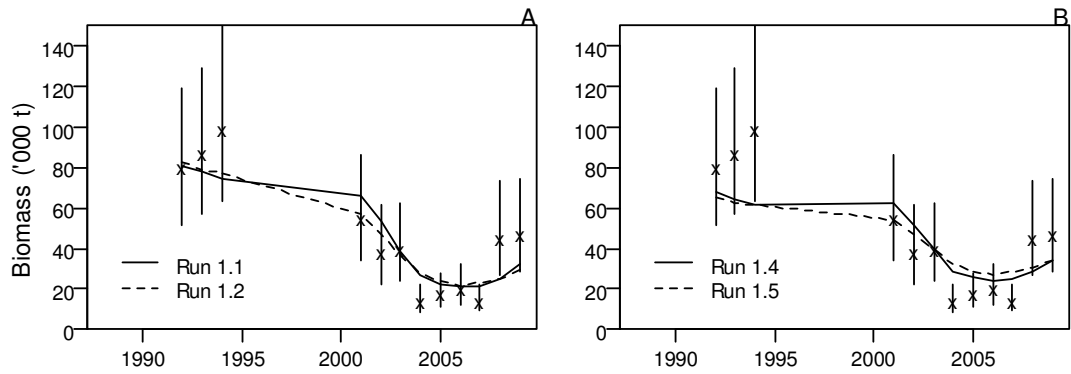


Figure 13: Fits to SASumbio for some initial MPD model runs, showing observed ('x', with vertical lines showing 95% confidence intervals) and expected values (lines). Plotted years are as in the model (so the last survey is plotted at 2009). The trawl survey indices are upweighted for the left-hand graph, and unweighted for the right-hand graph.

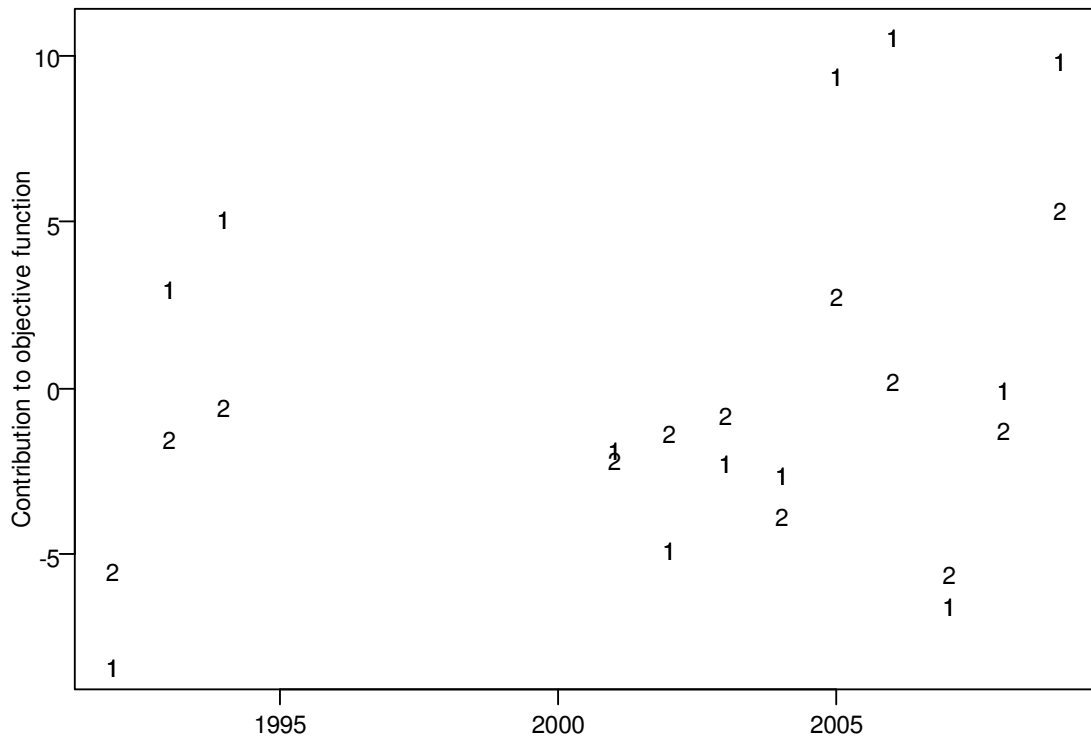


Figure 14: Goodness of fit to the SASumage data, by year, for runs 1.1 ('1') and 1.2 ('2'). The y-value for each point indicates the contribution to the objective function from one year's SASumage data; smaller values indicate a better fit. Plotted years are as in the model (so the last survey is plotted at 2009).

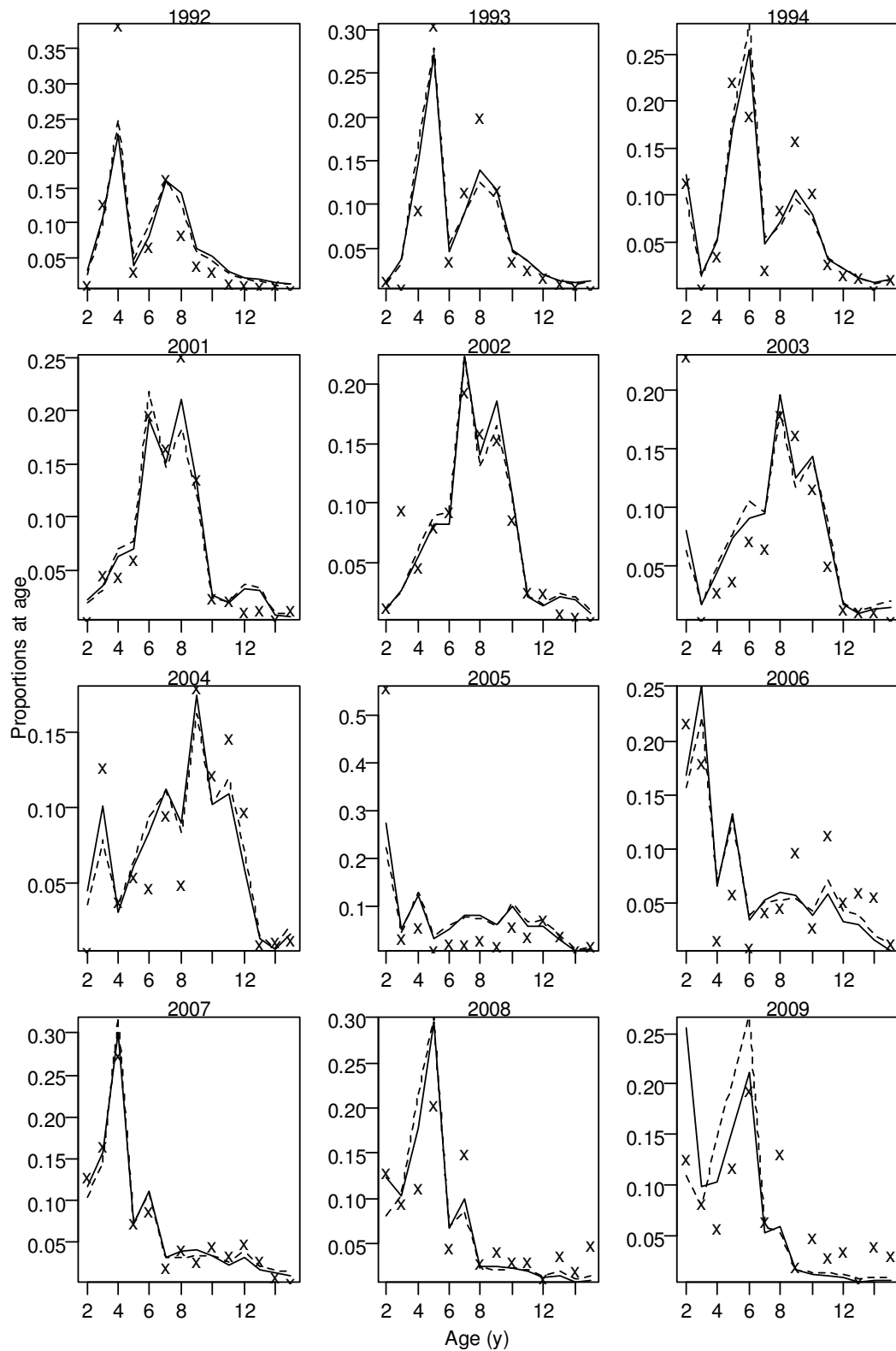


Figure 15: Observed ('x') and expected (lines) proportions at age in the summer Sub-Antarctic survey (data set SASumage) for runs 1.1 (solid line) and 1.2 (broken lines).

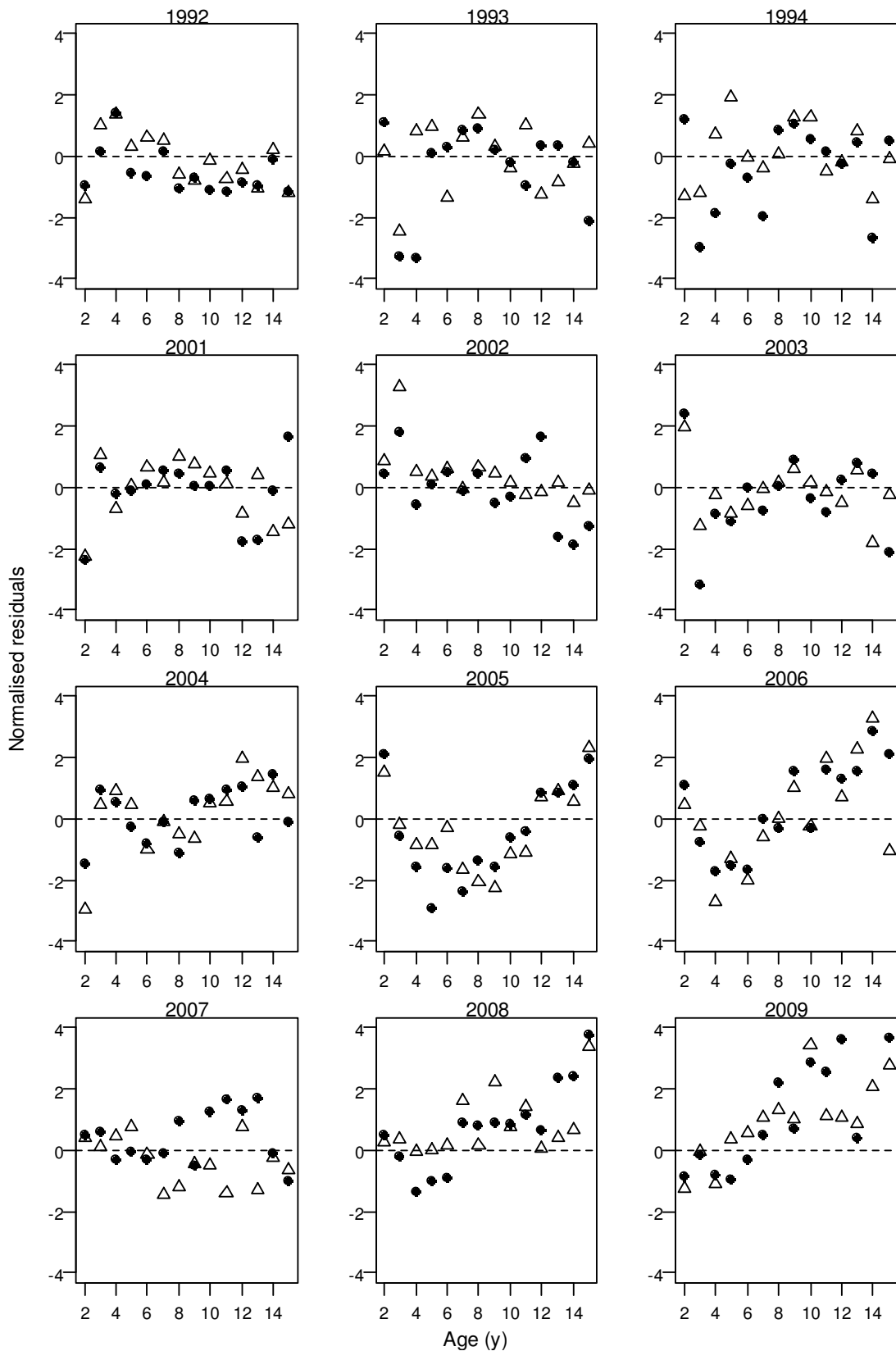


Figure 16: Normalised residuals by sex for the summer Sub-Antarctic survey (data set SASumage) for run 1.1 (triangle = male, solid dot = female).

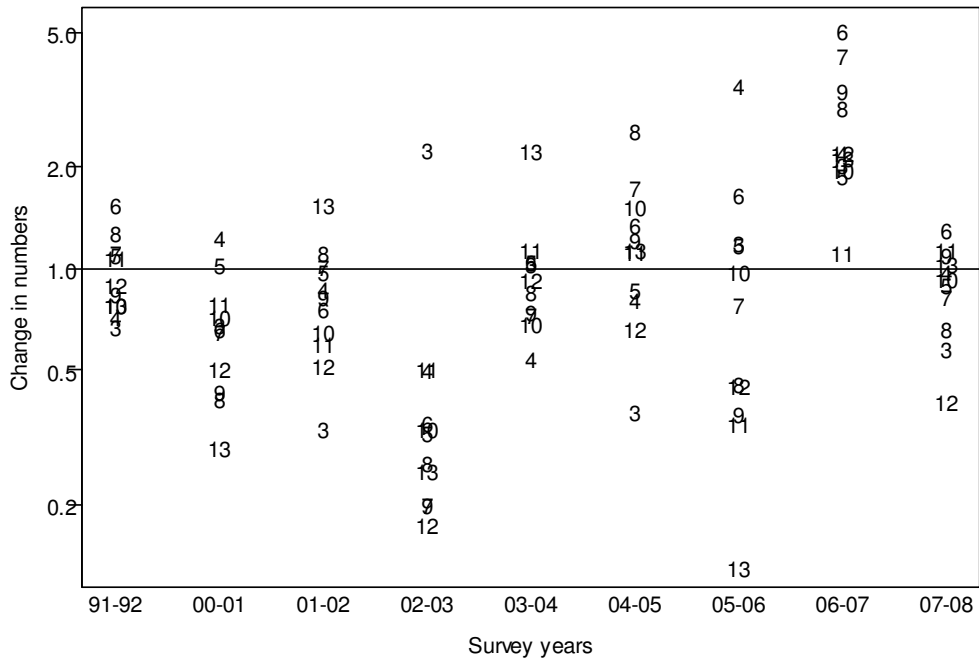


Figure 17: Changes, between surveys one year apart in the Sub-Antarctic summer series, in estimated numbers of selected cohorts. Each plotted point indicates how the estimated number in a cohort changed between the two surveys; the plotting symbol is the age of the cohort in the earlier survey. For example, for the 06-07 survey years, the estimated number in the cohort that was aged 6 in the 2006 survey increased by a factor of about five in the 2007 survey.

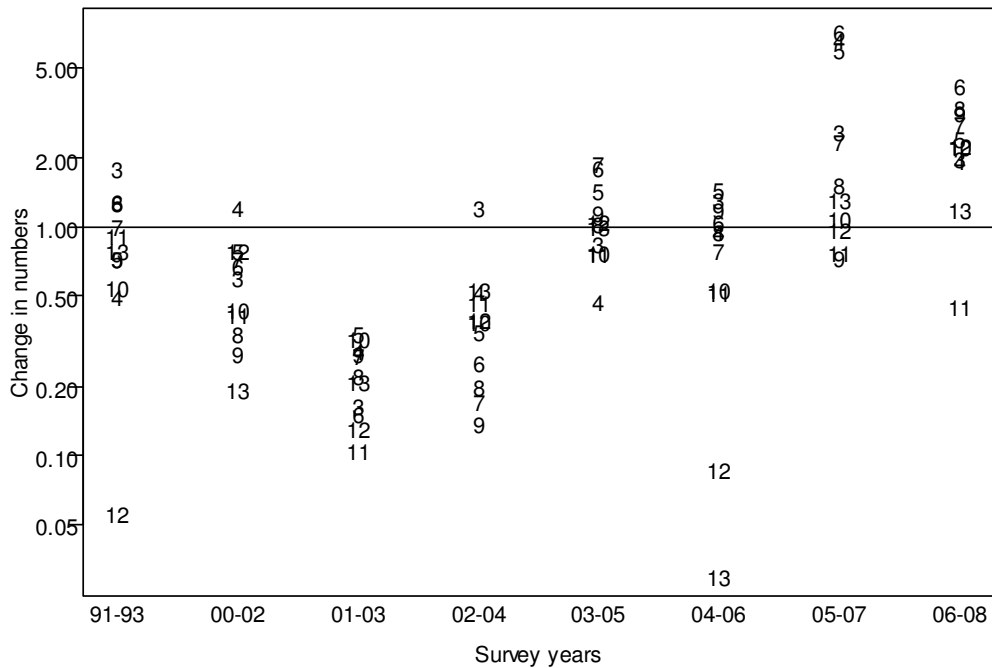


Figure 18: Changes, between surveys two years apart in the Sub-Antarctic summer series, in estimated numbers of selected cohorts. Each plotted point indicates how the estimated number in a cohort changed between the two surveys; the plotting symbol is the age of the cohort in the earlier survey. For example, the top left point in the plot shows that the estimated number in the cohort that was aged 3 in the 1991 survey almost doubled between the 1991 and 1993 surveys.

Retaining just the upweighted model runs, the biomass trajectories for these are compared to model runs from last year's assessment (Table 16, Figure 19). The biggest difference is for model 1.1, with the west stock biomass in 2008 substantially higher compared to model 2.3.

There is a marked contrast between the 2006 YCSs estimated in runs 1.1 and 1.2, particularly for the W stock (Table 17, Figure 20).

Table 16: Comparison of old and new biomass estimates for the individual stocks, E and W, and the combined E + W stock. In each group of runs, the first is from 2008 and the other is the analogous run for 2009.

	B_0 ('000 t)			B_{2008} (% B_0)			B_{2009} (% B_0)		
	E	W	E+W	E	W	E+W	E	W	E+W
2.3	510	880	1391	46	25	33	–	–	–
1.1	480	804	1284	46	34	39	46	36	40
2.4	637	1062	1699	39	29	32	–	–	–
1.2	672	1100	1772	38	30	33	42	34	37

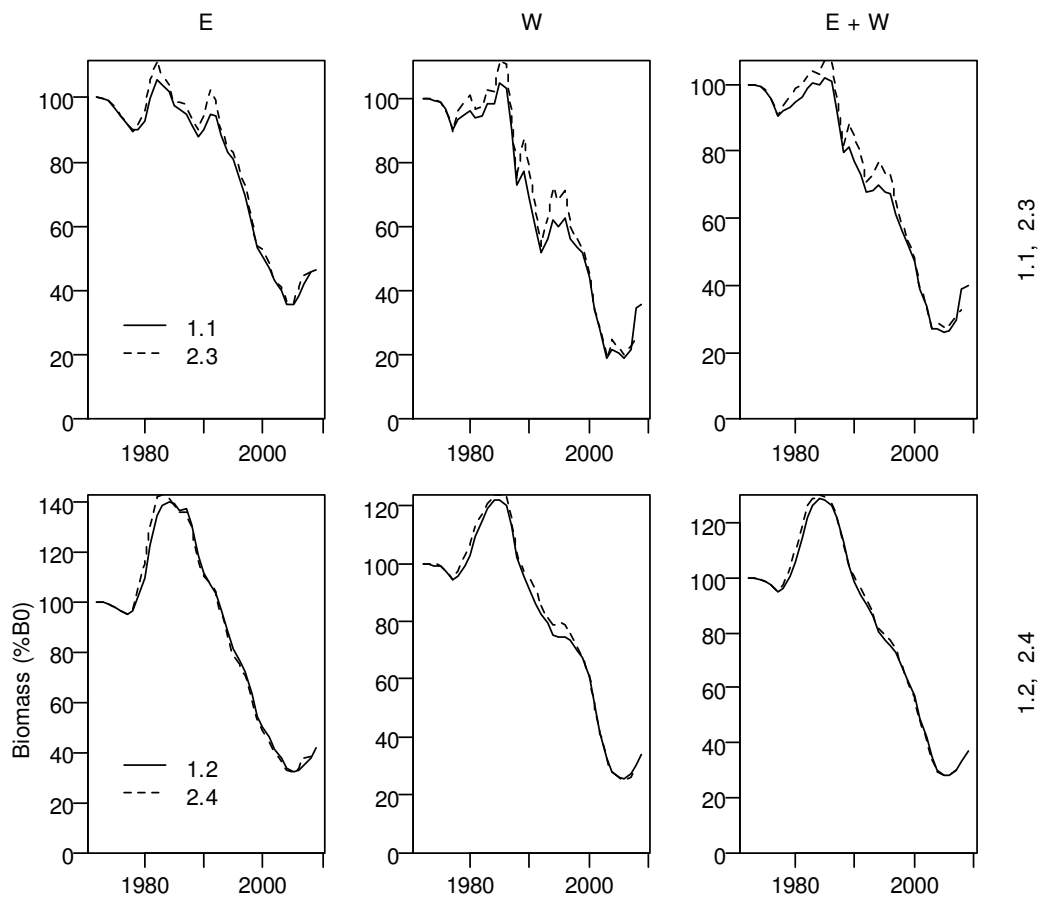


Figure 19: Comparison of biomass trajectories from different runs: E stock (left column), W stock (middle column), and E + W stocks combined (right column). The rows panels compare each new run (solid lines) with the corresponding run from 2008 (broken lines).

Table 17: Estimates of 2006 YCSs from runs 1.1 and 1.2

Run	YCS	
	E	W
1.1	0.3	1.8
1.2	0.6	0.7

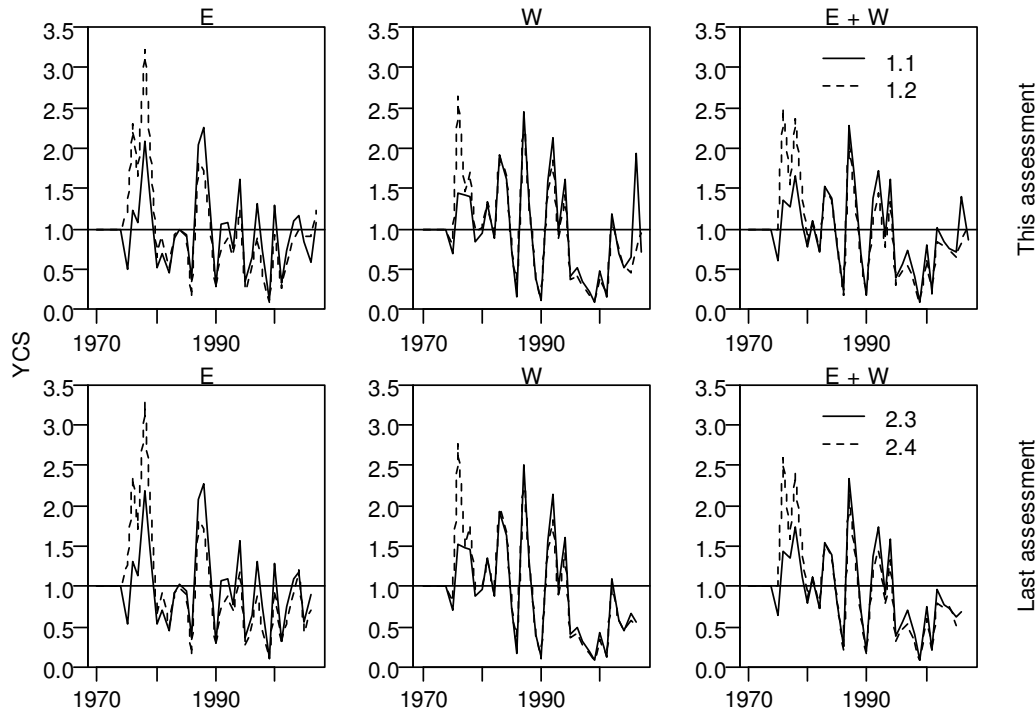


Figure 20: YCS estimates for new runs 1.1 and 1.2 (upper panels) and the main runs from last year’s assessment (lower panels).

Some of this difference may arise as a consequence of a pattern that has been observed in previous assessments when comparing pairs of runs analogous to 1.1 and 1.2. That is, for both stocks, estimated YCSs from runs like 1.2 tend to be higher in earlier years and lower in recent years compared to those from runs like 1.1 (Figure 20). Thus, it is not surprising that the estimated 2006 W YCS is markedly lower in 1.1 than in 1.2.

Posterior profiles for the parameter 2006 W YCS provide more information about the differences between runs 1.1 and 1.2 (Figure 21). The first point to notice about these profiles is that neither run has a strong preference for the strength of this year class. The change in the total objective function between low (0.7) and high (1.8) values of this parameter was only 2 for run 1.1 and 3 for run 1.2 (see thick lines in Figure 21). This suggests that the MCMC estimates of this parameter will be much more similar than is suggested by the MPD estimates.

The second point to notice is that when we look at the components of the objective function that are most affected by this YCS we see similar behaviour in the two runs. There are two components which were better fitted at high values of this parameter (Wspage and SASumbio) and two components which were better fitted at low values (SAsumage and the prior on the W YCS) (see thin lines in Figure 21).

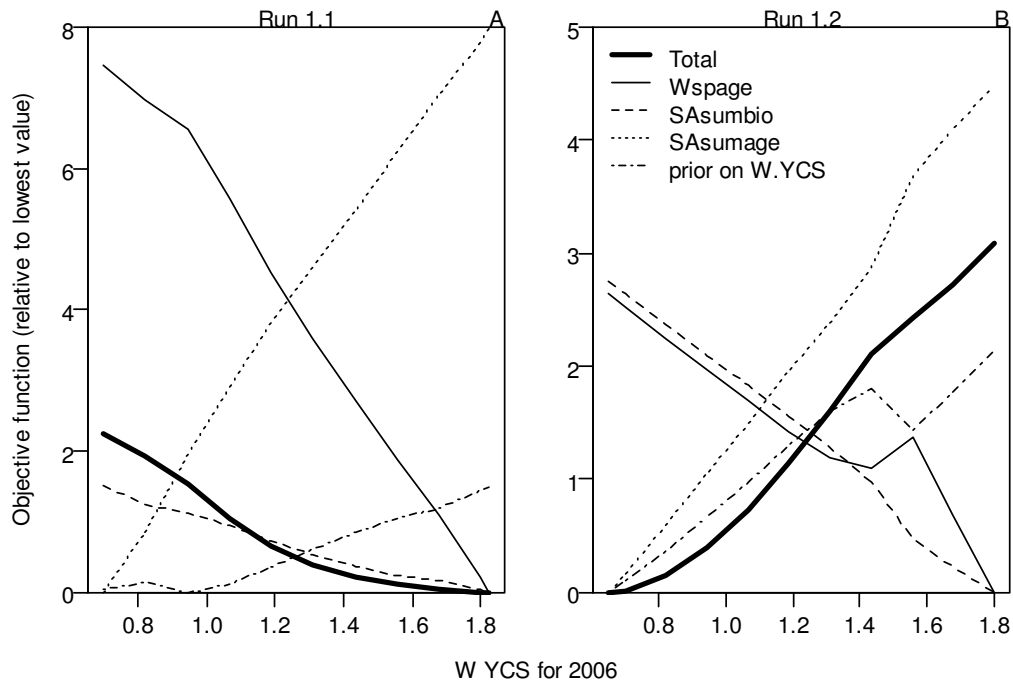


Figure 21: Results from posterior profiles on the parameter 2006 W YCS for A, run 1.1, and B, run 1.2. In each panel, the heavy line shows how the total objective function varies with this parameter and the other lines show this variation for selected components of the objective function.

E stock exploitation rates are very similar between model runs 1.1 and 1.2, and very similar to last year's assessment results (Figure 22). For the W stock the exploitation rates are lower for model 1.2, and recent exploitation rates as estimated for the 2009 assessment are lower than those estimated in 2008 (Figure 22).

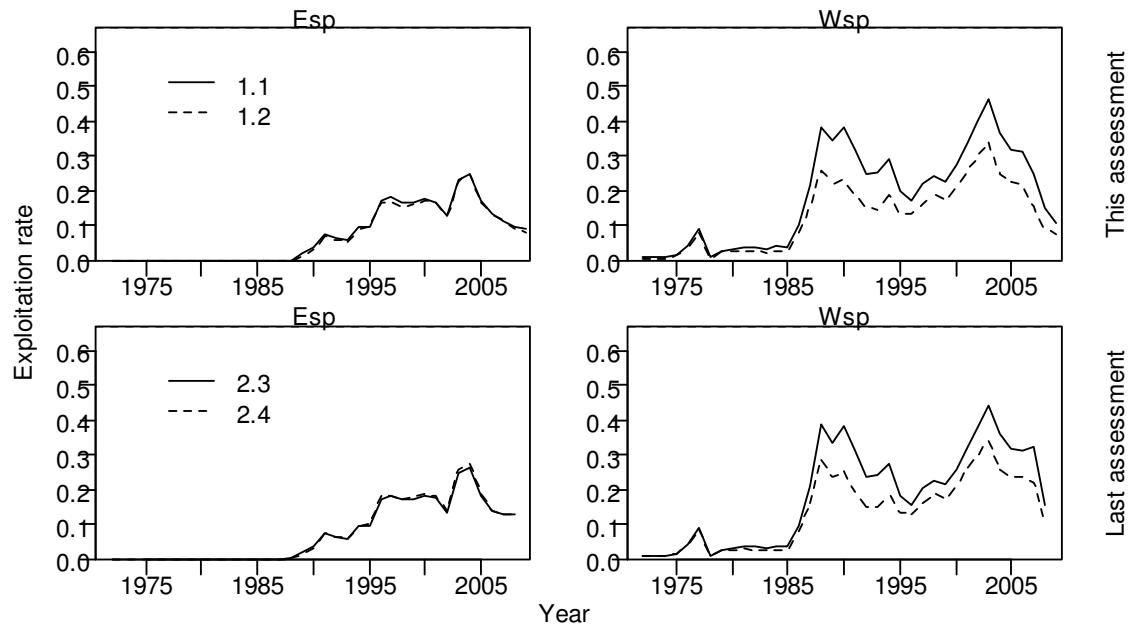


Figure 22: Estimated exploitation rates from runs 1.1 and 1.2 (upper panels) and the main runs from last year's assessment (lower panels).

4. FINAL MODEL ASSESSMENT RESULTS

The Hoki Working Group decided to take model runs 1.1 and 1.2 as the final model runs for the 2009 assessment (these are similar to the final model runs 2.3 and 2.4 in 2008).

Three MCMC chains of length 2 million samples were created for each final run, each chain having a different starting point, which was generated by stepping randomly away from the MPD. As in 2008, those migration or selectivity parameters that were found to be at a bound in the MPD run (Table 18) were fixed for the MCMC runs to improve convergence. Diagnostic plots comparing the three chains for each run suggest reasonably good convergence for all runs (Figure 23). For all the remaining results, the first quarter of each chain was discarded, the three chains for each run were concatenated, and the resulting chain was thinned to produce a posterior sample of length 1000.

Table 18: Migration and selectivity parameters held fixed in MCMC runs (with fixed values in parentheses).

Run	Parameters (fixed values)
1.1	WspmgM1(1), WspmgM2(1), EspmgF8[0.6], WspmgF8[0.6], Enspsl.sR(44), Wnpsl.sR(44), CRsl.a1(64), SAsl.a1(84), SAsl.sR(44)
1.2	Whome.6(1), CRsl.a1(1), CRsl.sL(1)

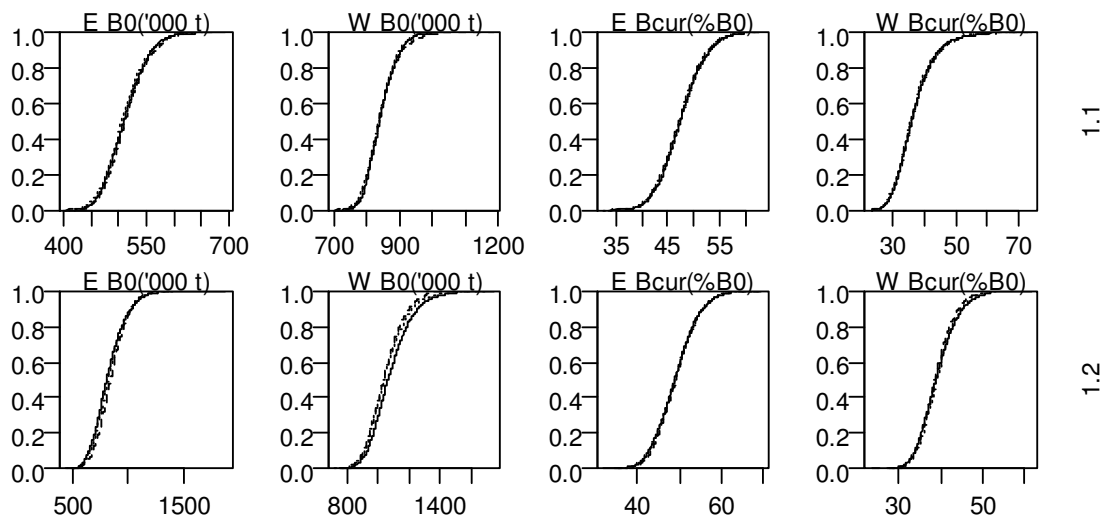


Figure 23: Diagnostics for MCMC chains for the three runs: 1.1 (top row) and 1.2 (bottom row). Each panel contains cumulative probability distributions, for B_0 or $B_{current}$, for three chains from the same model run.

The MCMC results for runs 1.1 and 1.2 show, as in 2008, that the W spawning stock was originally much larger than the E, and is currently about 25% larger than the E spawning stock (run 1.1) or about the same size (run 1.2) (Table 19, Figure 24). The current spawning biomass of the W spawning stock is more depleted than the E (Figure 24). In terms of estimated biomass in 2008, the new assessment is similar to that from last year for the E stock, but with an increased biomass for the W stock (Figure 25).

Both runs suggest both the E and W stocks are rebuilding, both in absolute terms (Figure 26) and relative to B_0 (Figure 27). Recent W YCSs are estimated to be higher than in the seven-year period of very weak recruitment, 1995–2001 (Figure 28). As in previous years, the selectivity and migration ogives for the runs assuming age-dependent natural mortality (run 1.1 in the current assessment) are very different from the run without this assumption (Figures 29–30).

The estimates of natural mortality for run 1.1. show the same pattern as the 2008 assessment with, except for the very young fish, a higher natural mortality for females (Figure 31). A comparison of priors and posteriors for various parameters showed no substantial changes from last year (Figure 32).

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

Run	B_0 ('000 t)		$B_{current}$ ('000 t)		$B_{current}$ (% B_0)		
	E	W	E	W	E	W	E+W
1.1	511(446,602)	843(766,954)	244(188,311)	301(219,470)	47(40,56)	36(27,53)	40(34,52)
1.2	831(591,1141)	1046(851,1332)	401(276,575)	410(298,602)	49(40,59)	39(32,49)	43(38,50)

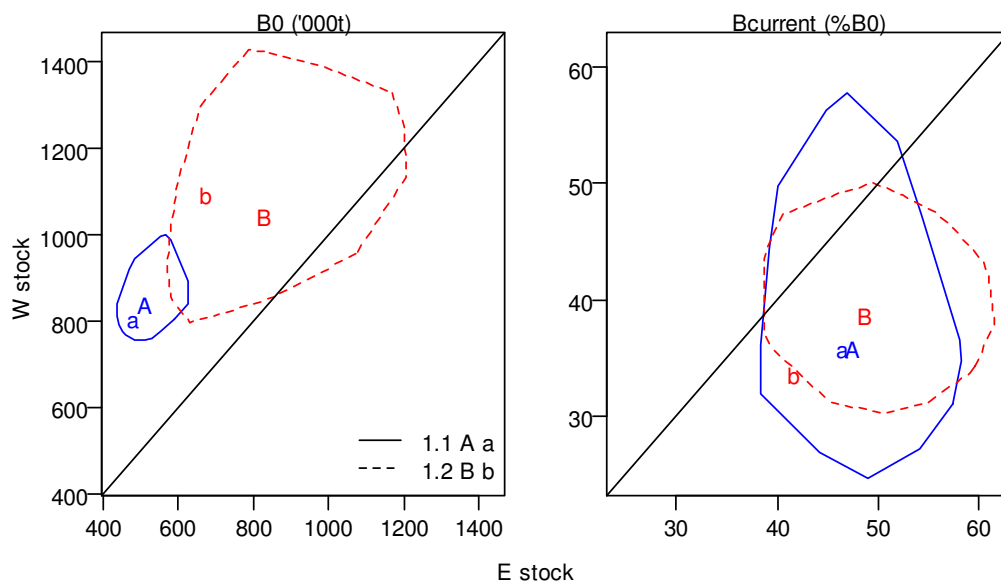


Figure 24: Estimates and approximate 95% confidence intervals for virgin (B_0) and current ($B_{current}$ as % B_0) biomass by stock for the two runs 1.1 and 1.2. In each panel the points 'A', 'B', 'C' indicate best estimates (median of the posterior distribution) for two three runs, 'a', 'b', 'c' are the MPD estimates, and the polygons (with solid, broken and dotted lines, respectively) enclose approximate 95% confidence intervals. Diagonal lines indicate equality ($y = x$).

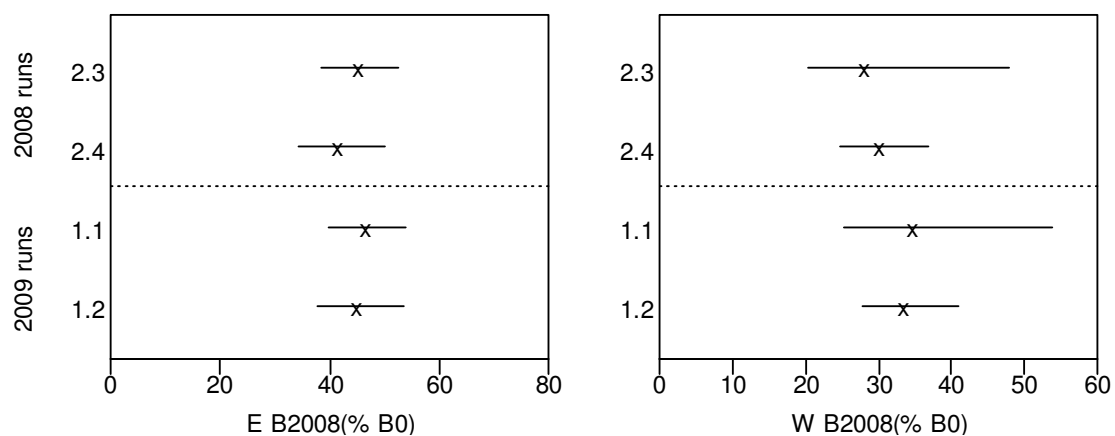


Figure 25: Comparison of 2009 runs (1.1, 1.2) with those from 2008 (2.3, 2.4): estimates of stock status in 2008 (B_{2008} as $\%B_0$), with 95% confidence intervals shown as horizontal lines.

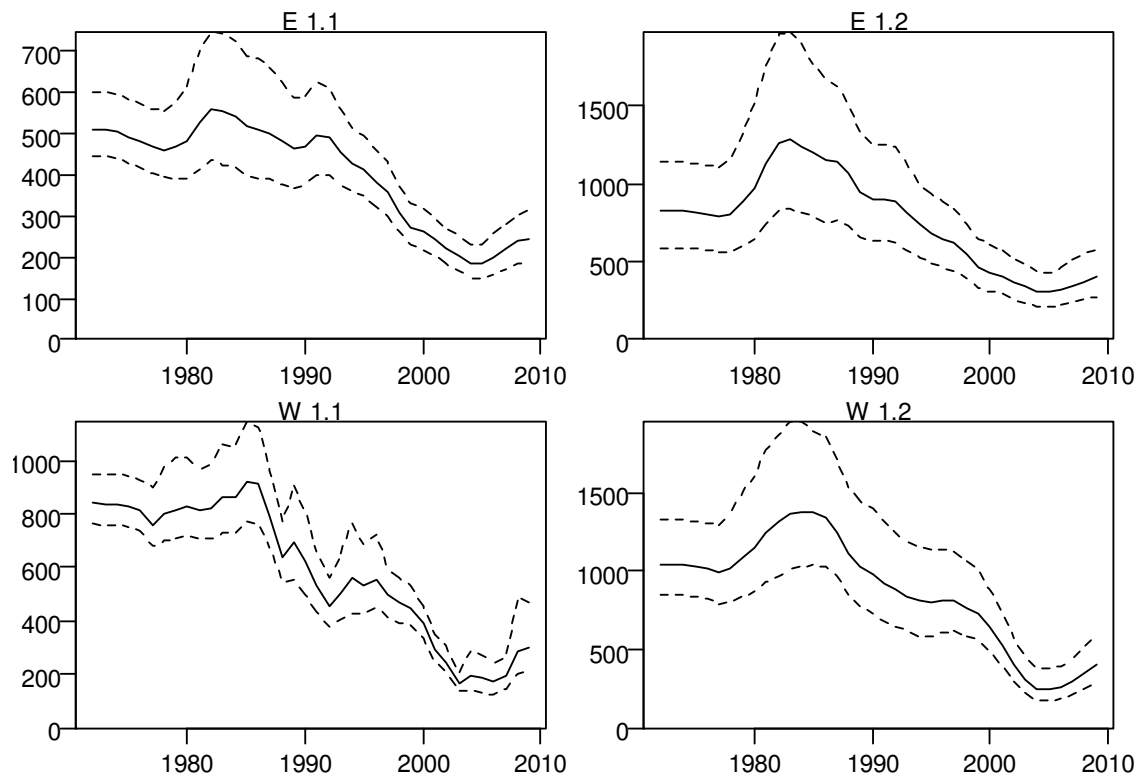


Figure 26: Estimated spawning-biomass trajectories from the MCMC runs, showing medians (solid lines) and 95% confidence intervals (broken lines) by run for E (upper panels) and W (lower panels).

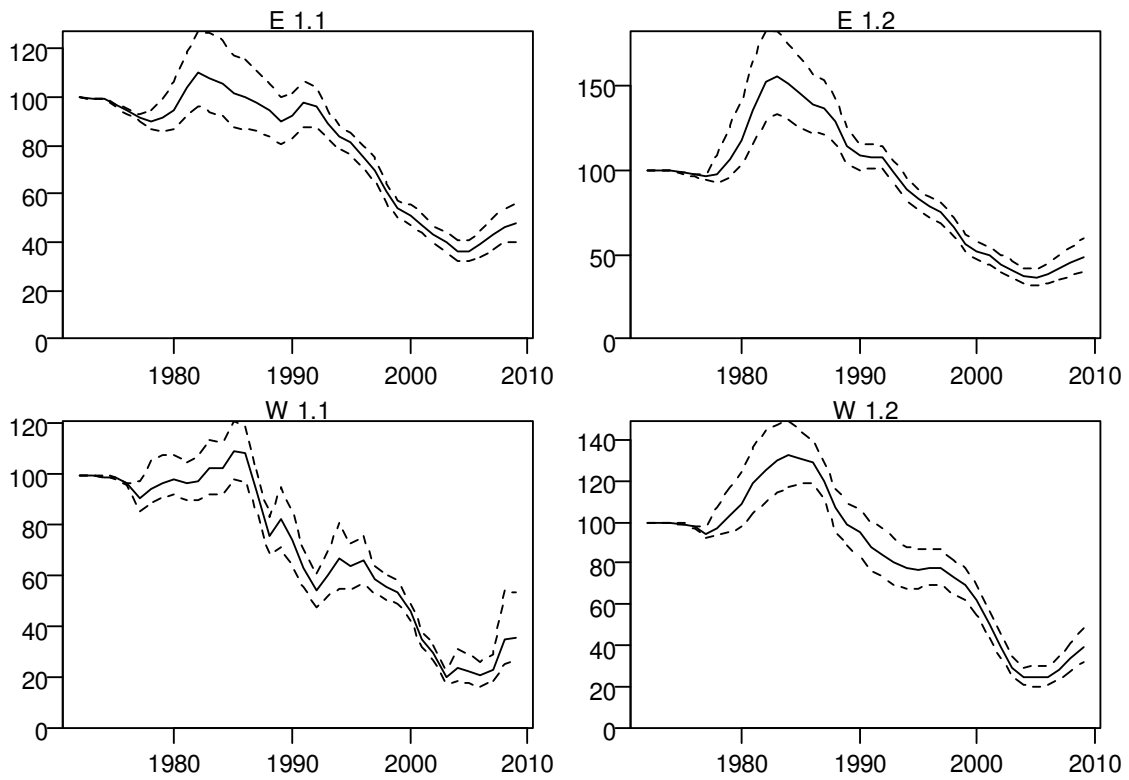


Figure 27: As for Figure 26, but plotted as % B_0 .

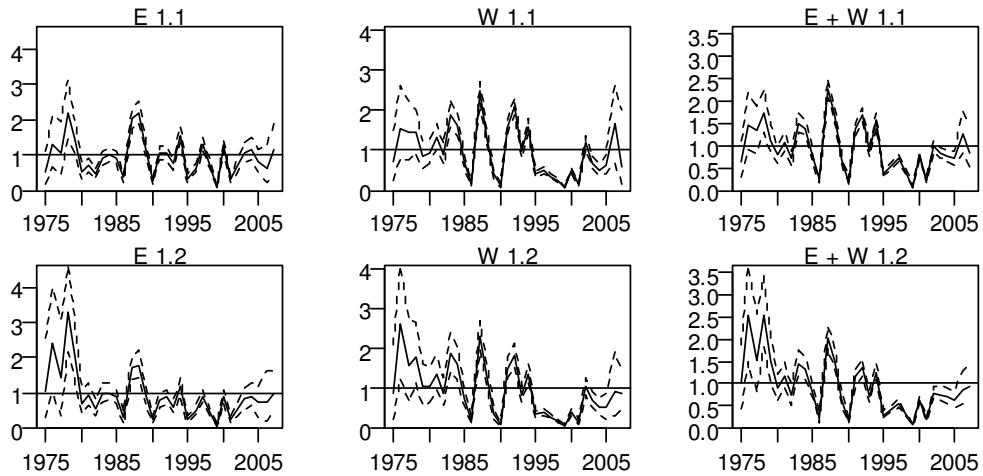


Figure 28: Estimated year-class strengths (YCSs) from the MCMC runs, showing medians (solid lines) and 95% confidence intervals (broken lines) by run for E (left panels), W (middle panels) and E + W (right panels).

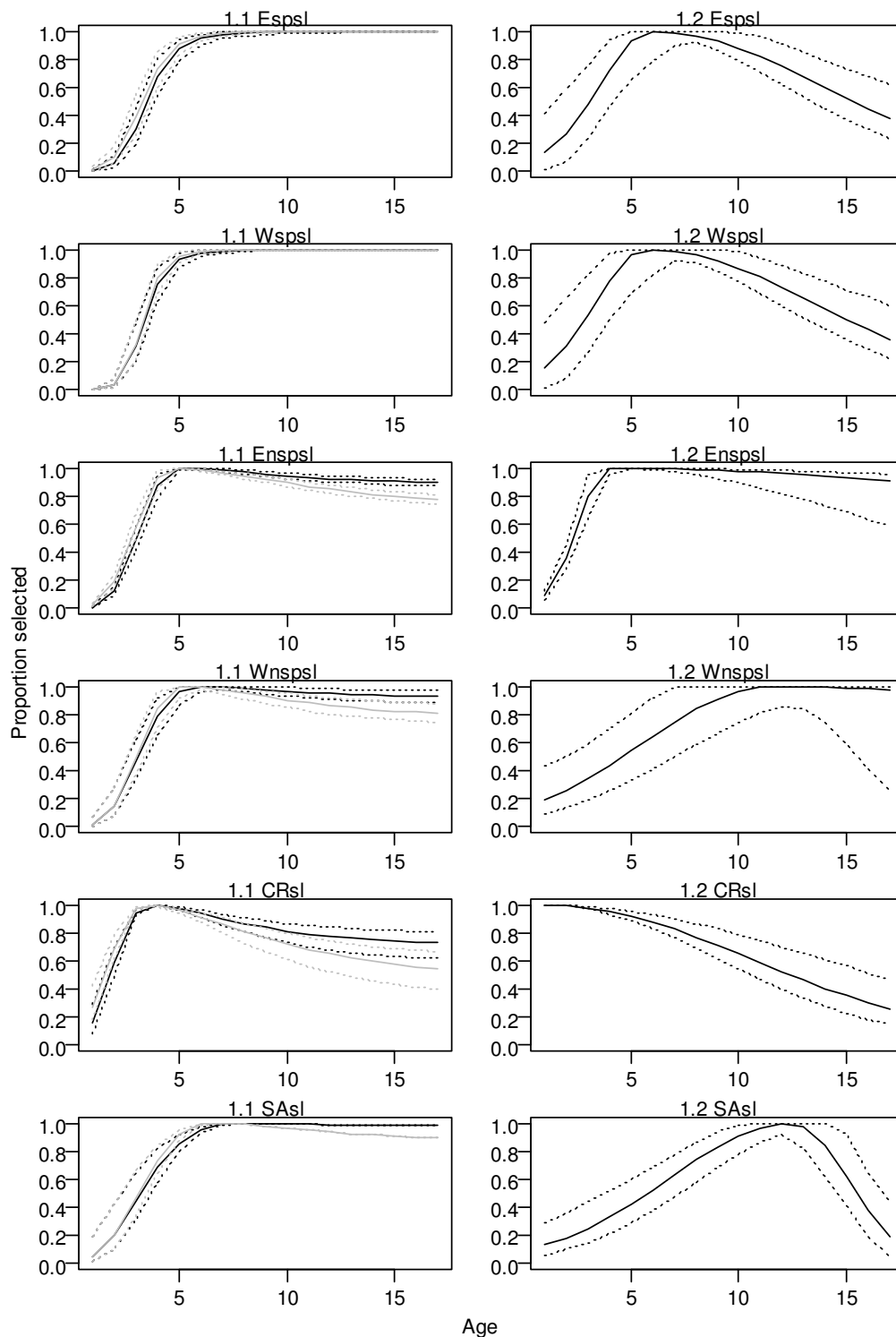


Figure 29: Posterior estimates of selectivity ogives for each for the two MCMC runs. Solid lines are medians, broken lines show 95% confidence intervals. Where ogives differ by sex they are plotted as black for males and grey for females. Where they differ by stock or time step the plotted curves are for one selected combination (E step 2 for Enpsl and CRsl, W step 2 for Wnpsl and SAsl).

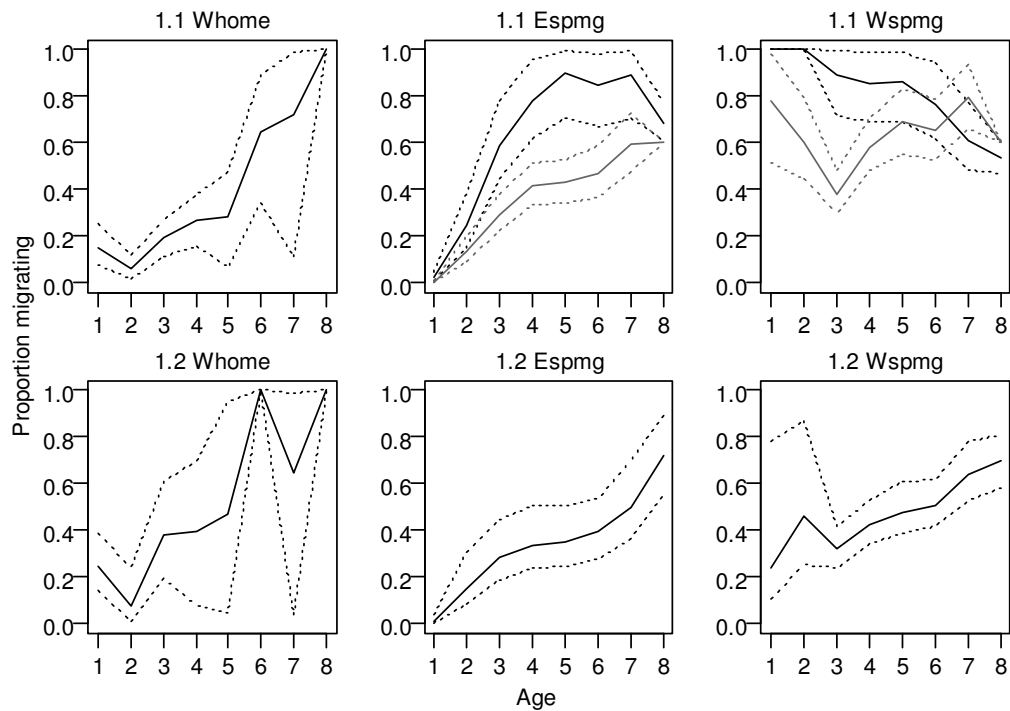


Figure 30: Migration ogives estimated in each of the two MCMC runs. Solid lines are medians, broken lines show 95% confidence intervals. Where ogives differ by sex they are plotted as black for males and grey for females.

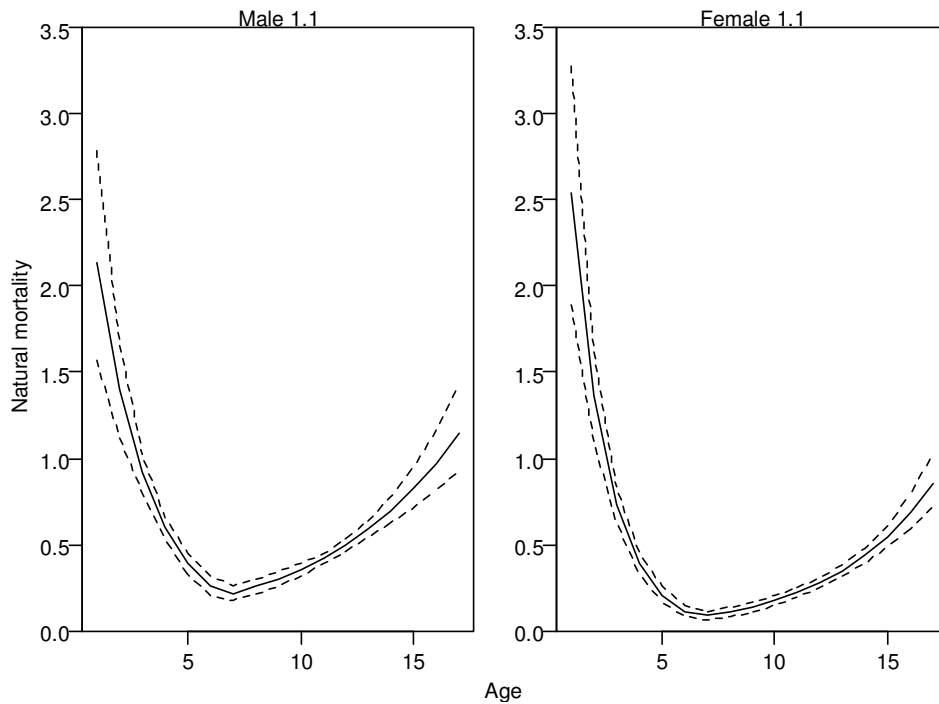


Figure 31: Estimates of age-dependent natural mortality ogives for run 1.1, showing median estimates (solid lines) and 95% confidence intervals (broken lines) for each sex.

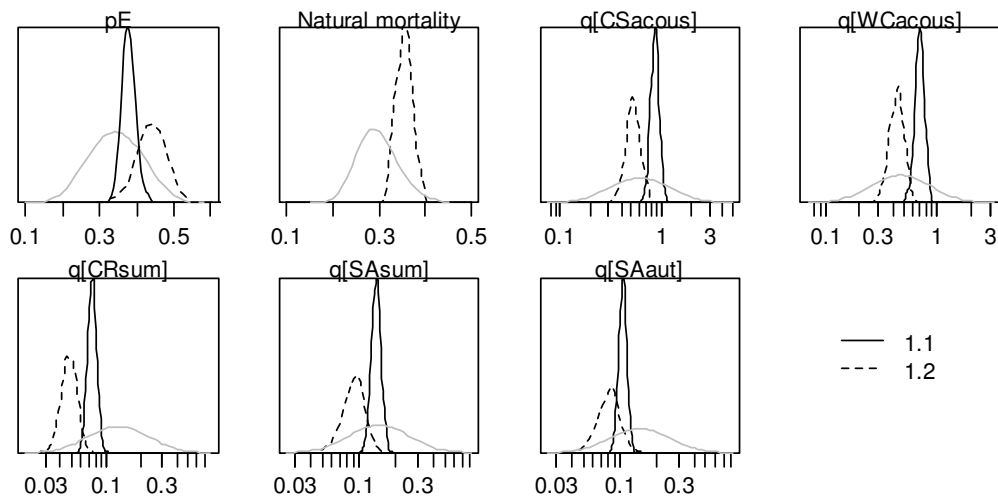


Figure 32: Prior (grey lines) and estimated posterior (black lines) distributions from the two MCMC runs for the following parameters: pE (proportion of B_0 in E stock), natural mortality (independent of age, run 1.2 only), and survey catchabilities (acoustic and trawl).

5. PROJECTIONS

Five-year projections were carried out for each run with alternative recruitment scenarios: ‘long-term’ (future recruitment selected from estimated levels in 1975–2007) and ‘recent’ (recruitment selected from 1995–2007). Future catches for each fishery were assumed equal to those assumed for 2009.

With long-term recruitment, median spawning biomass increased for both stocks in all years; with recent recruitment, it also increased but by not as much (Figure 33). Exploitation rates are expected to decrease for both stocks, with very little difference between the recruitment scenarios (Figure 34).

Under the Harvest Strategy Standard hoki is managed with a hard limit of $10\%B_0$, soft limit of $20\%B_0$, and interim management target range of $35\text{--}50\% B_0$. The probability of falling below the soft limit, hard limit, and lower and upper ends of the interim management target range are given in Table 20, with future catches assumed equal to those for 2009. For either recruitment scenario, the biomass is highly unlikely to fall below the soft and hard limits during any year of the five year projections. At the end of the five year projection period the probability that the biomass is below the lower end of the target range ($35\%B_0$) is at most 0.04.

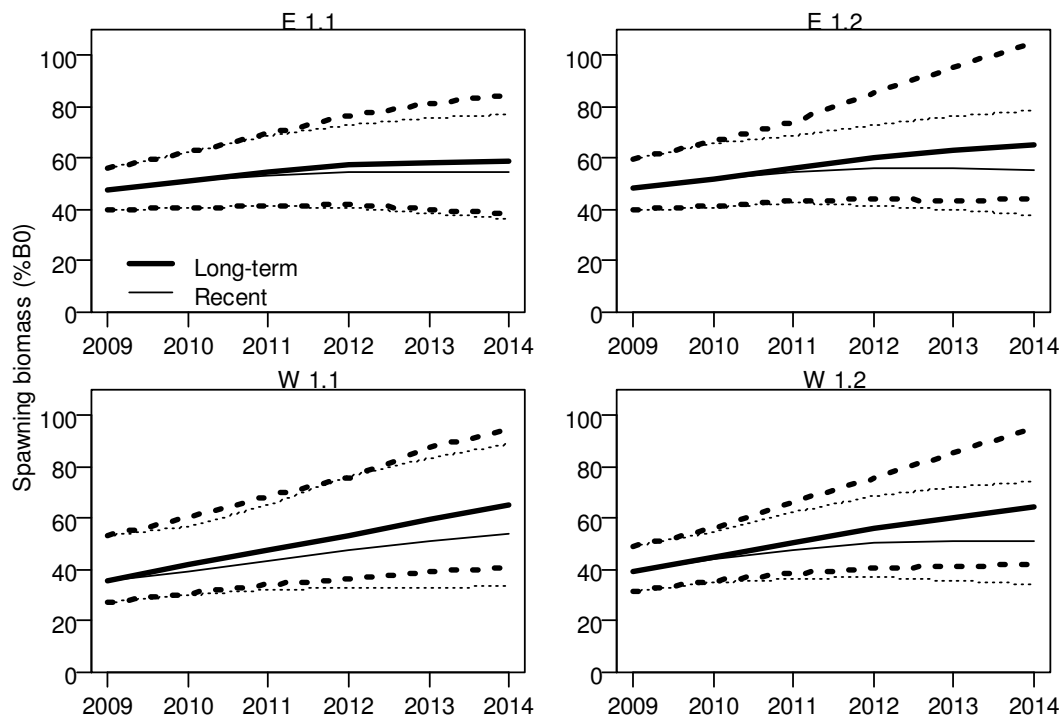


Figure 33: Trajectories of median spawning biomass (as % B_0) from the projections (solid lines) together with lower and upper bounds of a 95% confidence interval (broken lines) assuming 'long-term' (heavy lines) or 'recent' recruitment (light lines). Each panel shows results for one stock (E or W) from one of the two MCMC runs.

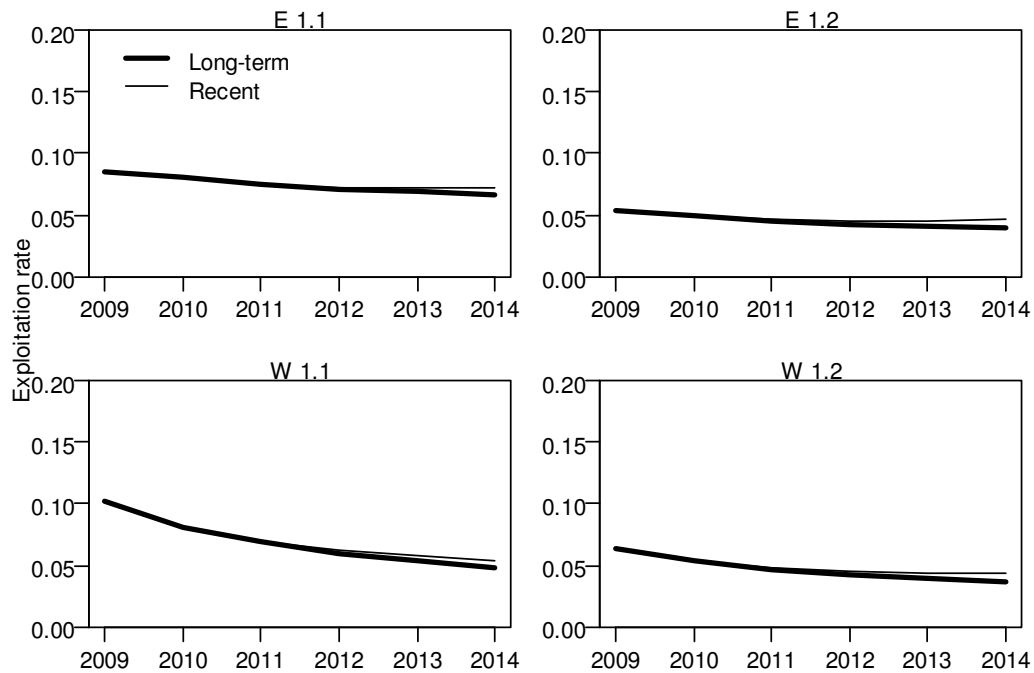


Figure 34: Estimated exploitation rates for 2009 and future years assuming long-term recruitment (heavy lines) or recent recruitment (light lines). Each panel shows results for one stock (E or W) from one of the two runs (1.1, 1.2).

Table 20: Probabilities associated with the projections of SSB(% B₀) in Figure 33.

	RUN 1.1						RUN 1.2					
	2009	2010	2011	2012	2013	2014	2009	2010	2011	2012	2013	2014
EAST: Long-term recruitment												
P(SSB<10%B ₀)	0	0	0	0	0	0	P(SSB<10%B ₀)	0	0	0	0	0
P(SSB<20%B ₀)	0	0	0	0	0	0	P(SSB<20%B ₀)	0	0	0	0	0
P(SSB<35%B ₀)	0	0	0	0	0	0	P(SSB<35%B ₀)	0	0	0	0	0
P(SSB<50%B ₀)	0.72	0.41	0.25	0.21	0.21	0.19	P(SSB<50%B ₀)	0.59	0.35	0.19	0.12	0.11
EAST: Recent recruitment												
P(SSB<10%B ₀)	0	0	0	0	0	0	P(SSB<10%B ₀)	0	0	0	0	0
P(SSB<20%B ₀)	0	0	0	0	0	0	P(SSB<20%B ₀)	0	0	0	0	0
P(SSB<35%B ₀)	0	0	0	0	0.01	0.02	P(SSB<35%B ₀)	0	0	0	0	0.01
P(SSB<50%B ₀)	0.72	0.43	0.31	0.30	0.31	0.31	P(SSB<50%B ₀)	0.59	0.36	0.25	0.22	0.25
WEST: Long-term recruitment												
P(SSB<10%B ₀)	0	0	0	0	0	0	P(SSB<10%B ₀)	0	0	0	0	0
P(SSB<20%B ₀)	0	0	0	0	0	0	P(SSB<20%B ₀)	0	0	0	0	0
P(SSB<35%B ₀)	0.43	0.14	0.04	0.02	0.01	0.01	P(SSB<35%B ₀)	0.15	0.02	0.01	0	0
P(SSB<50%B ₀)	0.96	0.85	0.61	0.38	0.22	0.13	P(SSB<50%B ₀)	0.99	0.83	0.49	0.26	0.16
WEST: Recent recruitment												
P(SSB<10%B ₀)	0	0	0	0	0	0	P(SSB<10%B ₀)	0	0	0	0	0
P(SSB<20%B ₀)	0	0	0	0	0	0	P(SSB<20%B ₀)	0	0	0	0	0
P(SSB<35%B ₀)	0.43	0.20	0.08	0.05	0.04	0.04	P(SSB<35%B ₀)	0.15	0.02	0.02	0.01	0.02
P(SSB<50%B ₀)	0.96	0.91	0.78	0.61	0.45	0.37	P(SSB<50%B ₀)	0.99	0.85	0.63	0.47	0.44

6. FISHING PRESSURE

Fishing pressure on both stocks was estimated to be at or near all-time highs in 2003 and substantially less than that now (Figure 35). The peak pressure on the W stock was markedly higher than that on the E stock.

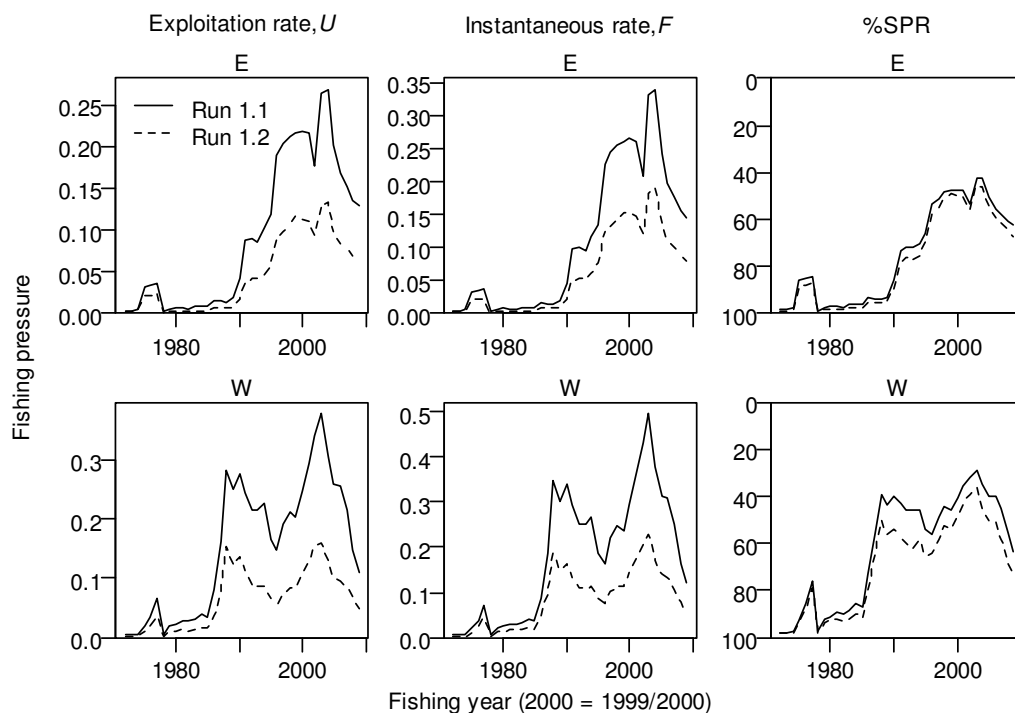


Figure 35: Three alternative measures of fishing pressure, as estimated in runs 1.1 (solid lines) and 1.2 (broken lines) for the E stock (upper panels) and W stock (lower panels): exploitation rates, U (left panels); instantaneous mortality rates, F (middle panels); and spawning potential ratio, %SPR (right panels). All measures are MPD estimates.

Three measures of fishing pressure are presented in Figure 35 because the Working Group could not reach agreement as to which was best. All three measures were deemed to be better than what has been presented in previous assessments – spawning-fishery exploitation rates – because they do not ignore the effect of the non-spawning fisheries, and thus represent the total fishing pressure on each stock. The two rate measures (U and F) are virtually identical, except for the scale on which they are measured. F is more commonly used by fishery scientists; U may be more easily interpretable by non-scientists. The two rate measures differ from %SPR in two significant ways. First, they are designed to measure different things: the rates measure the actual pressure on the stock in each year, whereas %SPR measures, for each year, the long-term effect of continuing to fish at the same rate as obtained in that year. Second, because of this design difference, the rate measures produce different between-run and between-stock contrasts in fishing pressure. All three measures show higher fishing pressure for run 1.1 than for run 1.2, and also usually higher pressure for the W stock than for the E stock, but these differences are greater for the rate measures than for %SPR. Brief definitions of the three measures follow. The annual equivalent exploitation rate, U_y , is calculated as

$$\max_{as} \left[\left(\sum_f C_{asfy} \right) / \left(N_{asy} e^{-0.5M_{as}} \right) \right],$$

where the subscripts a , s , f , and y index age, sex, fishery, and year, respectively, C is the catch in numbers, N is the number of fish in the population immediately before the first fishery of the year, and M is the instantaneous rate of natural mortality. The annual

equivalent instantaneous mortality rate, F_y , is given by $\max_{as} \sum_t \left[\log \left(N_{asty}^{\text{pre}} / N_{asty}^{\text{post}} \right) - M_{as} d_t \right]$, where t indexes the within-year time steps in the model, d_t is the fraction of natural mortality that occurs in

time step t , and N_{pre} and N_{post} and the numbers of fish immediately before and after fishing. %SPR for a given year is calculated from two simulation experiments. In the first experiment, fishing is simulated for many years with deterministic recruitment and the same exploitation rates and selectivities that were estimated for that year. Simulations continue until the population reaches equilibrium. The second experiment is the same, but with no fishing. %SPR is the equilibrium spawning biomass per recruit from the first experiment, expressed as a percentage of that from the second experiment.

7. CALCULATION OF B_{MSY}

B_{MSY} was calculated, for each stock and each of model runs 1.1 and 1.2, assuming a harvest strategy in which the exploitation rate for fishery f was $mU_{f,2009}$, where $U_{f,2009}$ is the estimated 2009 exploitation rate for that fishery, and m is some multiplier (the same for all fisheries). For each of a series of values of m , simulations were carried out with this harvest strategy and deterministic recruitment, with each simulation continuing until the population reached equilibrium. For each stock and run, the value of the multiplier, m , was found that maximised the equilibrium catch from that stock. B_{MSY} for that stock and run was then defined as the equilibrium biomass (expressed as % B_0) at that value of m .

Estimates of B_{MSY} were very similar for the two runs: about 23% B_0 for the E stock, and 25% B_0 for the W stock (Table 21). Sensitivity analyses (not presented) showed that these values changed very little (always by less than 1% B_0) when the calculations were repeated using the final runs from the 2008 assessment, or when the harvest strategy was based on exploitation rates from a different year.

Table 21: Estimates of B_{MSY} (expressed as % B_0) by stock for runs 1.1 and 1.2.

Run	Stock	
	E	W
1.1	23.4	25.3
1.2	23.0	24.6

There are several reasons why B_{MSY} , as calculated in this way, is not a suitable target for management of the hoki fishery. First, it assumes a harvest strategy that is unrealistic in that it involves perfect knowledge (current biomass must be known exactly to calculate the target catch) and annual changes in TACC (which are unlikely to happen in New Zealand and not desirable for most stakeholders). Second, it assumes perfect knowledge of the stock-recruit relationship, which is actually very poorly known (Francis 2009). Third, it makes no allowance for extended periods of low recruitment, such as was observed in 1995–2001 for the W stock. Fourth, it would be very difficult with such a low biomass target to avoid the biomass occasionally falling below 20% B_0 , the default soft limit according to the Harvest Strategy Standard.

8. DISCUSSION

Both hoki stocks are estimated to be increasing after reaching in about 2005 their lowest levels since the fishery began. The W stock is more depleted (36–39 % B_0), than the E stock (47–49 % B_0). The W stock experienced an extended period of poor recruitment from 1995 to 2001, but there is evidence of better (though still mostly below average) recruitment in subsequent years (2002–07). Projections indicate that the current catch levels are likely to allow the W stock to rebuild; the E stock is likely to remain stable if future recruitment is similar to that in recent years, and to increase if that recruitment is comparable to the long-term average.

The uncertainty in this assessment is almost certainly greater than is implied by the confidence limits presented above. We may think of this uncertainty as having three types. The first of these –

random error in the observations – is reasonably well dealt with in the assessment by the c.v.s that are assigned to individual observations. The second, which arises from annual variability in population processes (e.g., growth and migration – but not recruitment, which is modelled explicitly) and fleet behaviour (which affects selectivities) is more problematic. We deal with this, rather simplistically, by adding process error. This assumes that the structure of our model is correct “on average”, but that the real world fluctuates about that average. The problem is that we cannot be at all sure about this assumption. This leads to the third type of uncertainty: we cannot be sure that our model assumptions are correct on average.

9. ACKNOWLEDGMENTS

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Appendix 1: Files defining the final runs

Each of the final model runs is completely defined, in the context provided by the CASAL manual (Bull et al. 2008), by two input files — population.csl and estimation.csl — and, for run 1.1, a user.prior_penalty.cpp file. These files are presented in this appendix, which may be obtained as a pdf, from the Science Officer at MFish (science.officer@fish.govt.nz).

