Assessment of hoki (*Macruronus novaezelandiae*) in 2010

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EXECUTIVE SUMMARY

An updated assessment is presented for hoki that is based on the 2009 assessment. The assessment uses 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 an acoustic survey of Cook Strait, two trawl surveys (Chatham Rise and Sub-Antarctic), and proportions at age from three fisheries.

It was decided by the Hoki Working Group that additional weight should be given to all trawl-survey biomass estimates to ensure a good fit to the Sub-Antarctic survey series. However, no model runs were able to mimic the increase in the last three biomass estimates from this series, and it was concluded that this increase was probably due to a change in catchability.

The Hoki Working Group agreed on two final base model runs which were similar to the two final model runs used in 2009. 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. As an alternative to giving additional weight to the Sub-Antarctic trawl series, two sensitivity model runs were carried out for one of the base model runs. In these sensitivities the trawl survey data were not upweighted but two catchabilities were fitted to this series instead of just one.

Both the East and West hoki stocks are estimated to be increasing after reaching their lowest levels in 2005. The West stock is estimated to be 40–52 %B_0 and the East stock 51–57 %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 (2002–08).

Five-year projections were carried out for each final base model run with alternative recruitment scenarios: 'long-term' (future recruitment selected from estimated levels in 1975–2008) and 'recent' (recruitment selected from 1995–2008). Future catches for each fishery were assumed equal to those assumed for 2010. The projections suggest that continued fishing at current levels is likely to increase the biomass of the West stock, and that the East stock will either increase slightly ('long-term' scenario) or remain constant or decrease slightly ('recent' scenario).

CONTENTS

1. INTRODUCTION

Hoki (*Macruronus novaezelandiae*) is the most abundant commercial finfish 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 (Quota Management System), hoki has been managed as a single fishstock, HOK 1, ignoring HOK 10, which is purely administrative (Figure 2). Until recently, the TACC has fluctuated 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 2010). The assessment in 2009 indicated that stock status had improved and the TACC was raised to 110 000 t for 2009–10.
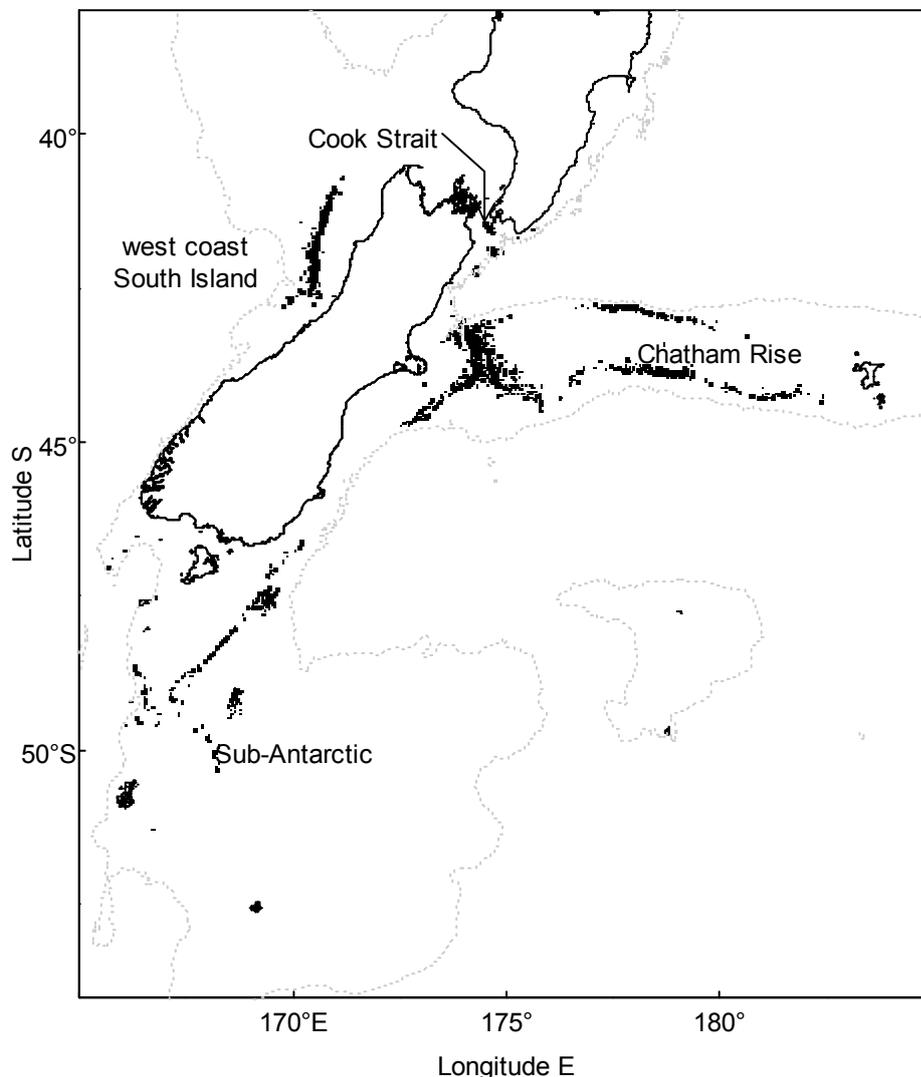

Figure 1: Southern New Zealand, showing the main hoki fishing grounds, the 1000 m contour (broken grey line), and the position of all 2008–09 tows from TCEPRs (Trawl Catch and Effort Processing Returns) in which at least 10 t of hoki was caught (dots).
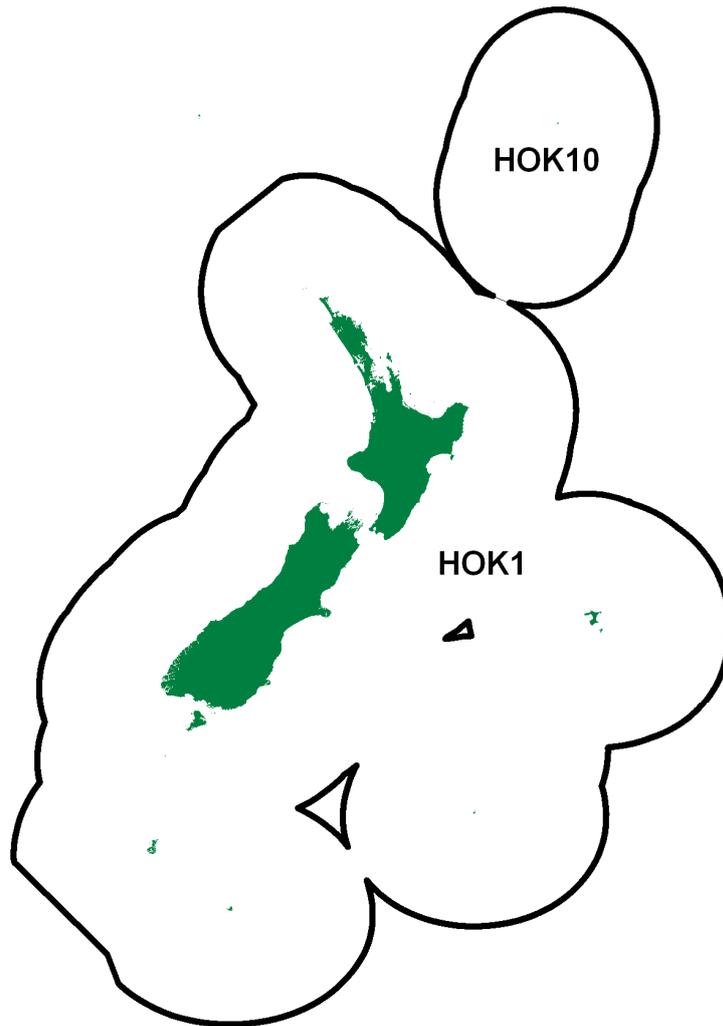
Figure 2: The Quota Management Areas for hoki.

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. Since 1998, 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, make this one of the most complex of all New Zealand assessments (e.g., the 2004 NIWA assessment used more than 1800 individual observations spread over 15 data sets (Francis 2005)).

This report documents the 2010 assessment of HOK 1, which is the ninth hoki assessment to use NIWA's general-purpose stock-assessment model CASAL (Bull et al. 2008). Since the last assessment (McKenzie & Francis 2009) there has been another acoustic survey in Cook Strait in winter 2009 (O'Driscoll & Macaulay 2010) and two more trawl surveys – in the Sub-Antarctic in summer 2009 (Bagley & O'Drisocoll unpublished results) and Chatham Rise in January 2010 (Stevens et al. in press).

The work reported here addresses objective 1 of MFish project HOK200701C: *To update the stock assessment of hoki in the year 2010, including estimates of biomass, risk and yields.*

2. MODEL ASSUMPTIONS AND INPUTS FOR 2010

This section provides a fairly detailed summary of all model assumptions and inputs for the 2010 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 2009, is referred to as the 2010 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 & proportions at age from CR summer trawl survey
	SAsumbio, SAsumage	biomass index & proportions at age from SA summer trawl survey
	SAautbio, SAautage	biomass index & proportions 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	Espsl, Wspsl, Enspsl, Wnspsl	selectivity in commercial fisheries
	CRsl, SAsl	selectivity in trawl surveys

[1]OLF 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 on the west coast South Island (WC) and have their home grounds in the Sub-Antarctic (SA) (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 fish migrate to their home ground, SA. The alternative assumption, used first in 2006, is that there is no natal fidelity. In the 2010 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 2009. In the model the non-spawning fishery is split into two parts, separated by the migration of fish from CR to SA, giving a total of six fisheries in the model (henceforth referred to as the model fisheries).

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 2009. *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	M 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 Wspmg: SA–>WC, Espmg: 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 2009, the catches used in the model (Table 3) were calculated by apportioning the official total catch for each year amongst the six model fisheries using the method described in Table 4. The catches from 2001 to 2009 were slightly revised using the most recent data from MFish, and the catch for 2009 is scaled up to the MHR (Monthly Harvest Return) total of 88 804 t. For the current year (2010), the new TACC is 110 000 t with a catch split arrangement for 60 000 t to be taken from the eastern stock and 50 000 t from the western stock. Estimates for the proportion of the catch split that would be taken between the spawning and non-spawning fisheries (Richard Wells, Deepwater Group Limited) were used to derive an assumed catch for 2010.

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, but is expected to increase again in 2010 (Figure 3).

The fixed biological parameters in the model are unchanged from those used in 2009 (Table 5).

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

				Fishery			
Year	Ensp1	Ensp2	Wnsp1	Wnsp2	Esp	Wsp	Total
1972	1500	2500	0	0	0	5000	9000
1973	1500	2500	0	0	0	5000	9000
1974	2200	3800	0	0	0	5000	11000
1975	13100	22900	0	0	0	10000	46000
1976	13500	23500	0	0	0	30000	67000
1977	13900	24100	0	0	0	60000	98000
1978	1100	1900	0	0	0	5000	8000
1979	2200	3800	0	0	0	18000	24000
1980	2900	5100	0	0	0	20000	28000
1981	2900	5100	0	0	0	25000	33000
1982	2600	4400	0	0	0	25000	32000
1983	1500	8500	3200	3500	0	23300	40000
1984	3200	6800	6700	5400	0	27900	50000
1985	6200	3800	3000	6100	0	24900	44000
1986	3700	13300	7200	3300	0	71500	99000
1987	8800	8200	5900	5400	0	146700	175000
1988	9000	6000	5400	7600	600	227000	255600
1989	2300	2700	700	4900	7000	185900	203500
1990	3300	9700	900	9100	14000	173000	210000
1991	17400	14900	4400	12700	29700	135900	215000
1992	33400	17500	14000	17400	25600	107200	215100
1993	27400	19700	14700	10900	22200	100100	195000
1994	16000	10600	5800	5500	35900	117200	191000
1995	29600	16500	5900	7500	34400	80100	174000
1996	37900	23900	5700	6800	59700	75900	209900
1997	42400	28200	6900	15100	56500	96900	246000
1998	55600	34200	10900	14600	46700	107100	269100
1999	59200	23600	8800	14900	40500	97500	244500
2000	43100	20500	14300	19500	39000	105600	242000
2001	36700	19900	13300	17100	35200	107500	229700
2002	24900	18300	17000	13500	24800	97100	195600
2003	24300	18700	12400	7800	41600	79800	184600
2004	17900	19000	6400	5300	41000	46300	135900
2005	19300	13800	4400	2000	26300	38700	104500
2006	22000	14700	2000	4700	20500	40400	104300
2007	22500	18400	4200	3500	18800	33700	101100
2008	22000	19400	6500	2200	17900	21300	89300
2009	29200	13100	6000	3800	15900	20800	88800
2010	29700	13300	6100	3900	17000	40000	110000

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 (this catch is pro-rated across all fisheries).

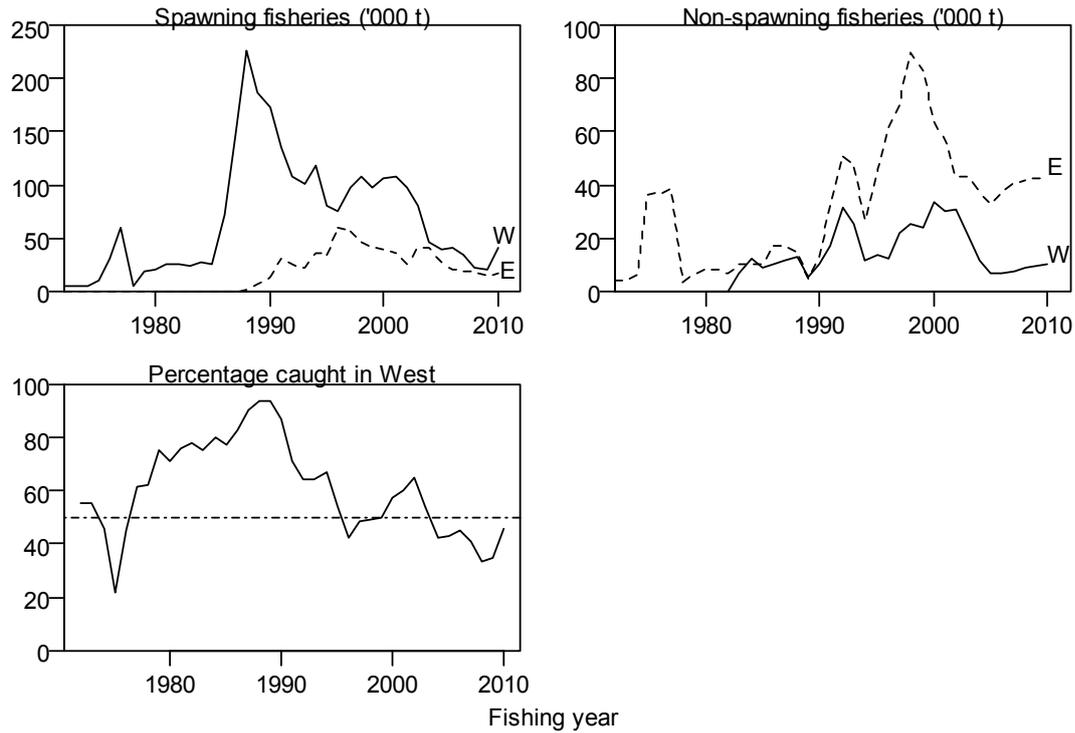| Area	Oct–Mar	Apr–May	Jun–Sep
West coast South Island; Puysegur	Wsp	Wsp	Wsp
Sub-Antarctic	Wnsp1	Wnsp2	Wnsp2
Cook Strait; Pegasus	Ensp1	Ensp2	Esp
Chatham Rise; east coasts of South Island & North Island; null[1]	Ensp1	Ensp2	Ensp2

[1] no area stated

Figure 3: 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 Male	Female	Both	E stock Male	Female	Both	Source
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	a	4.79×10^{-6}							b
[W(kg)=aL(cm)^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 2009: six selectivity ogives (one for each of the four fisheries — Espsl, Wspsl, Enspsl, Wnspsl — and one each for trawl survey 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 fish 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 (Section 4). 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
2.1	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 $A > 8$
2.1	Home migration	Free, ages 1–7	same for M and F, =1 for age > 7
2.2	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 Wspsl (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 Wspsl. The mean value was used for all years for which there was catch but no Wspage data (i.e., before 1988 and in the 2010 year).

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	2009	Mean
309	309	308	309	307	309	310	307	301	295	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

$$R_y = R_{mean} \text{ x } YCS_{y-2} \text{ x } SR(SSB_{y-2}),$$

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 $R_{mean}Y_{mean}$, where Y_{mean} is the mean year class strength (YCS) over the years 1975 to 2005, 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 2008, inclusive. YCSs for the initial years (1970 to 1974) were fixed at 1. The E and W YCSs for 2008 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 4), and proportion spawning (Table 10). Biomass indices new to this assessment came from an acoustic survey in Cook Strait in winter 2009 (O'Driscoll & Macaulay 2010), and trawl surveys of the Sub-Antarctic in December 2009 (Bagley & O'Driscoll unpublished results) and Chatham Rise in January 2010 (Stevens et al. in press).

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 second group, the non-spawning otolith-based data (Enspage, Wnspage) are available only for years when 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 using 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 5). 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) use 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 remained at about 25% in 2009, much lower than the peak in 2005 (Figure 6). The proportion of older fish in the various data sets is shown in Figure 7.

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.

	CRsumbio	SAsumbio	SAautbio	CSacous	WCacous
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)	–	**315 (–,0.39)**	–
2010	**98 (0.15,0.25)**	**65 (0.16,0.26)**	–	–	

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. Data for Wnspage in 2009 were unavailable for the 2010 assessment.

Area	Label	Data type	Years	Source of age data
WC	Wspage	Catch at age	1988–**09**	otoliths
SA	WnspOLF	Catch at age	1992–94, 96, 99–00	OLF
	Wnspage	Catch at age	2001–04, 06–08	otoliths
	SAsumage	Trawl survey	1992–94, 2001–**10**	otoliths
	SAautage	Trawl survey	1992, 96, 98	otoliths
CS	Espage	Catch at age	1988–**09**	otoliths
CR	EnspOLF	Catch at age	1992, 94, 96, 98	OLF
	Enspage	Catch at age	1999–**09**	otoliths
	CRsumage	Trawl survey	1992–**10**	otoliths

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	3	4	5	6	7	8	Age 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
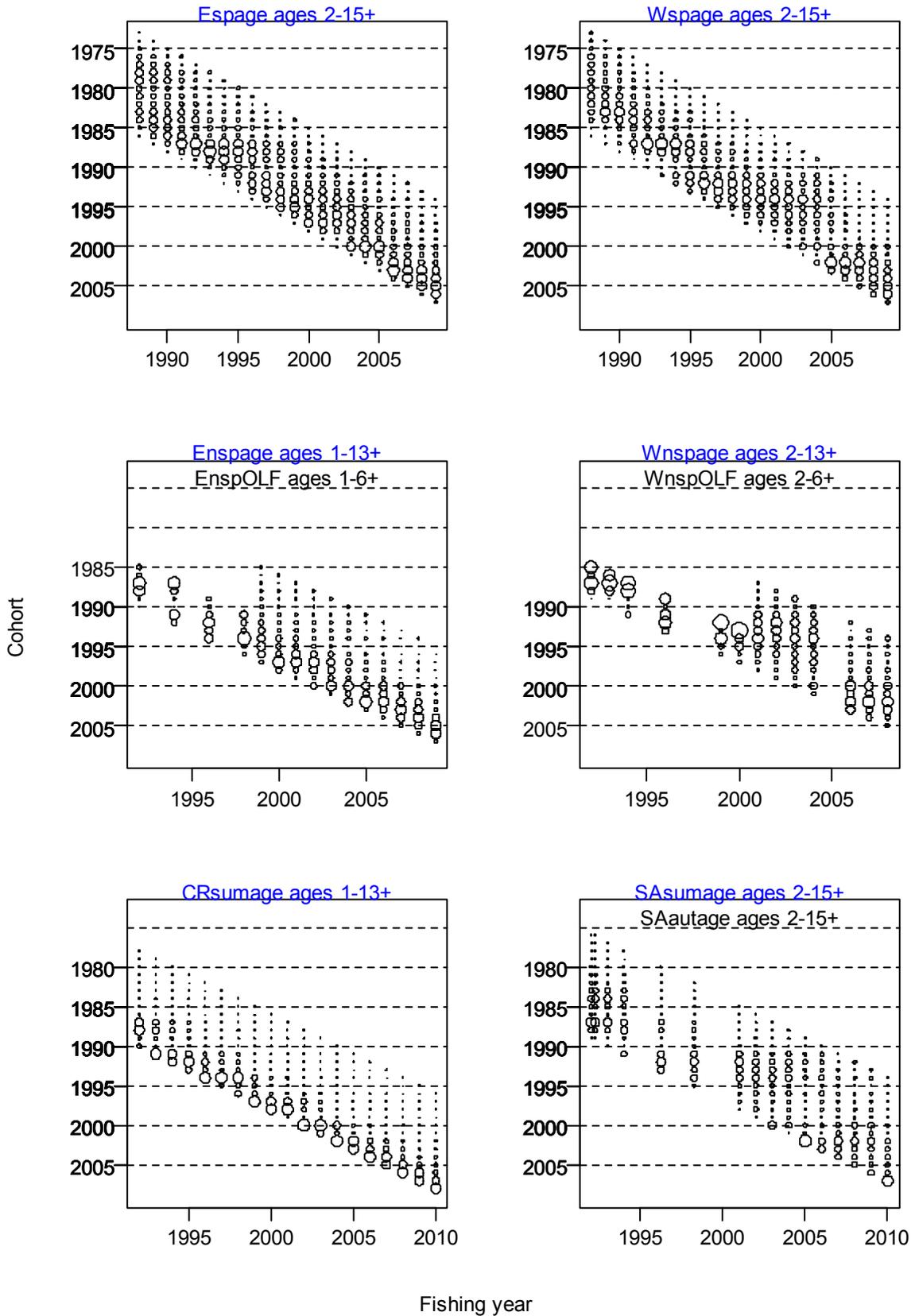
Figure 4: Proportions-at-age data, plotted by cohort and fishing year, with both sexes combined. The area of each circle is proportional to the associated proportion at age. Circle positions for the SAautage data have been offset horizontally to allow them to be plotted on the same panel as the SAsumage data. In all panels the right-most column of circles is new to this assessment.

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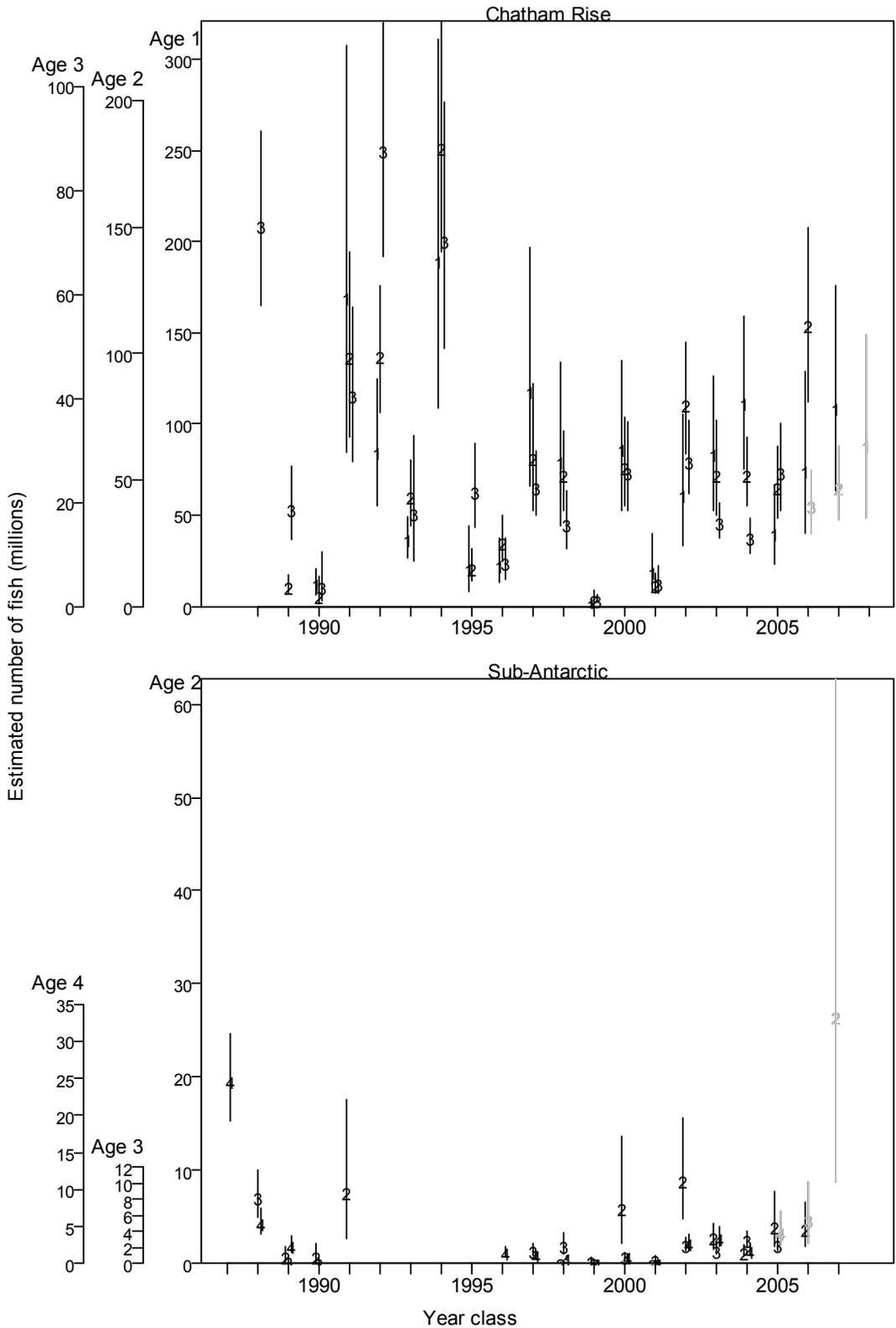
Figure 5: Estimated numbers at age for each of the three youngest ages in the two main trawl survey series. Vertical bars indicate 95% confidence intervals; data points new to this assessment are plotted in grey.

16
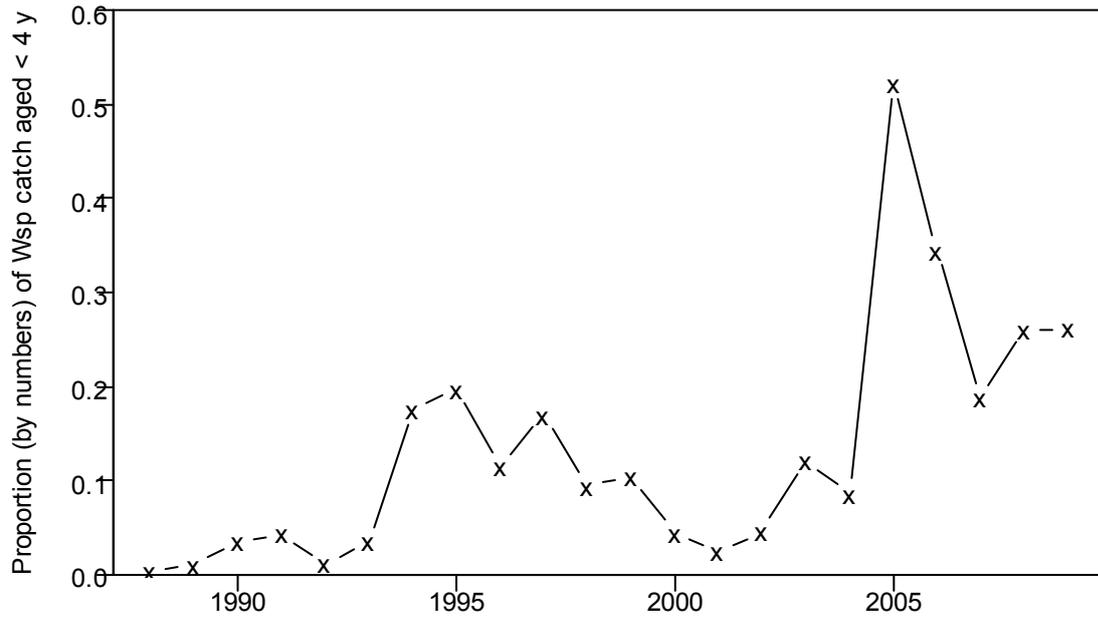
Figure 6: Annual proportion of young fish (aged less than 4 y) in the catch from the west spawning fishery. Note that all plotted proportions are based on numbers of fish; proportions based on weight would be much smaller.
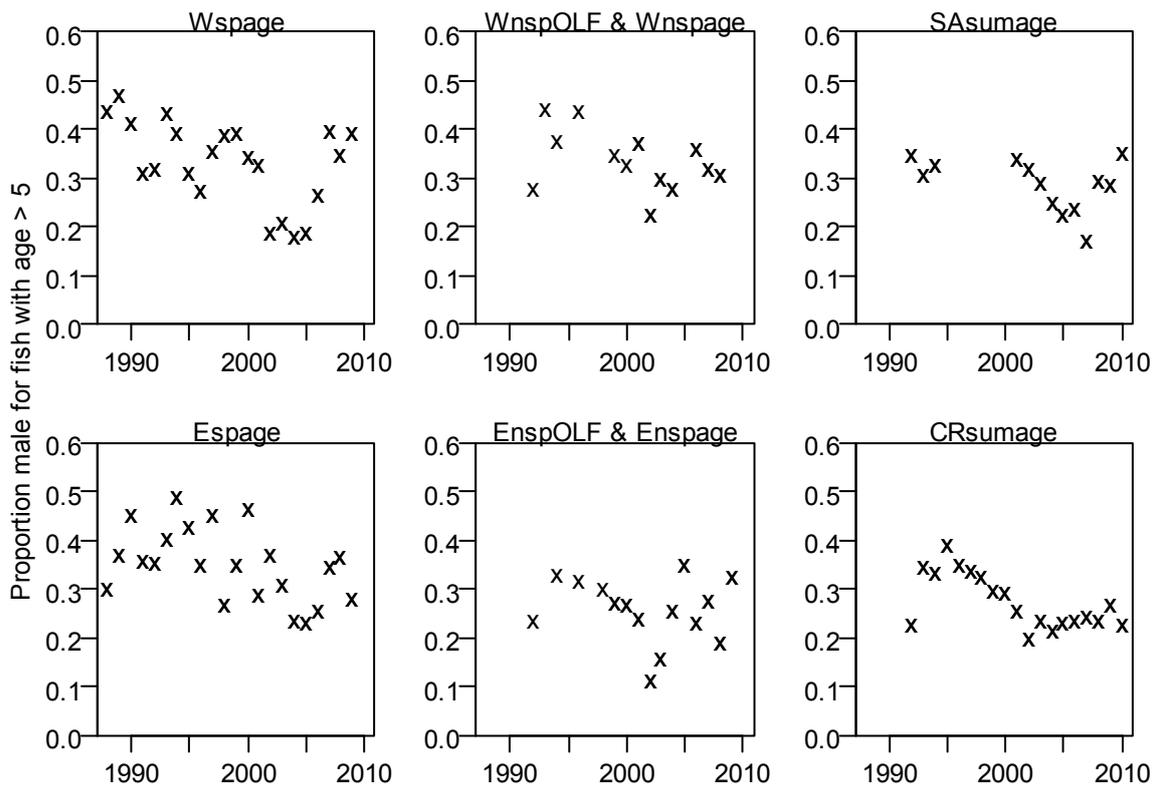
Figure 7: Observed ('x') of proportions male, by year and data set, for older fish (ages > 5 y).

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. The acoustic indices 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 8).

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).
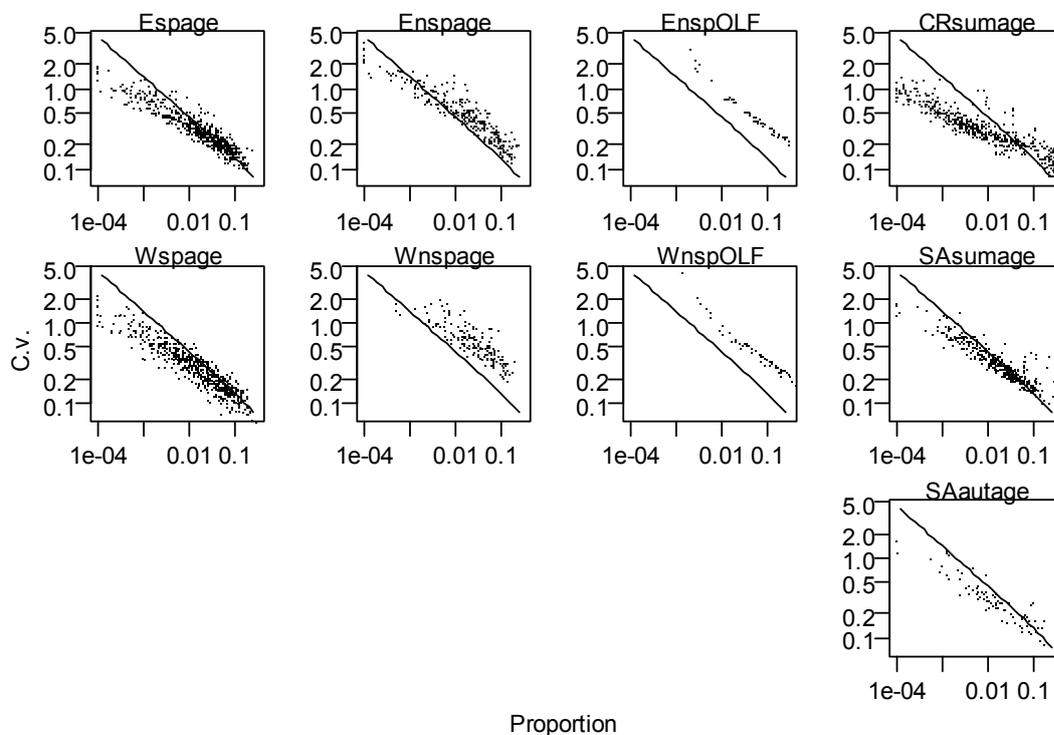

Figure 8: Observation-error c.v.s for the proportions-at-age data sets. Each point represents a proportion at a specific age and sex for a given year. The diagonal line, which is the same in each panel, is added to aid comparison between panels; it shows the relationship between proportion and c.v. that would hold with simple multinomial sampling with sample size 500.

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2.6 Parameters, priors, and penalties

The number of parameters estimated in the final model runs was 145 (for run 2.1) or 123 (for run 2.2) (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. A double exponential curve was used to parameterise the age-varying natural mortality (Bull et al. 2008).

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 2.1 and 2.2, 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. B_{mean} is the biomass associated with the Francis parameterisation of year class strengths (Bull et al. 2008).

Parameter(s)	Description	Type	Distribution Parameters		No. of parameters
log_Bmean_total	$\log(B_{mean,E} + B_{mean,W})$	uniform	12.6[a]	16.2	1
Bmean_prop_stock1 (=pE)	$B_{mean,E}/(B_{mean,E} + B_{mean,W})$	beta[0.1,0.6][b]	0.344	0.072	1
recruitment.YCS	year-class strengths	lognormal	1	0.95	68
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_{male} & M_{female} ages 1–17	uniform	various		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, Wspmg, Espmg	uniform	various		40,24
comm. selectivities	Espsl,Wspsl,Enspsl,Wnspsl	uniform	various		8,9
surv. selectivities	CRsl, SAsl	uniform	various		6
					145,123

[a] A lower bound of 13 was used for run 2.2
[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 MPD analyses with the new data, investigate any problems that arise, and inform which runs should be used in the formal assessment (presented in Section 4).

Three sets of initial exploratory runs were done: (1) incorporating the new data and comparing model fits to the 2009 assessment, (2) investigating a time-varying catchability for the Sub-Antarctic summer trawl survey series, and (3) deciding upon final model runs.

3.1   Incorporating the new data

The first MPD runs using all the new observations were labelled 1.1 and 1.2. These runs were based on the final runs 1.1 and 1.2 respectively from 2009, but used the new data (Table 13). Note that the data set Wnspage was unavailable in time for the assessment.

Table 13: Relationship between initial 2010 model runs and those from the 2009 assessment. Runs labelled 1.1 and 1.2 for 2009 are the two final model runs selected by the Hoki Working Group for the 2009 assessment. In all model runs in this table the trawl survey biomass data is upweighted, and natal fidelity is assumed.

2010 label	2009 label	Response to lack of old fish in the observations	Sex in model and selectivities length-based?
1.1	1.1	M dependent on age	Yes
1.2	1.2	Domed spawning selectivity	No

The next MPD runs (1.3 and 1.4) are the same as 1.1 and 1.2 respectively, except the trawl survey biomass indices are not upweighted.

There was very little difference between the weighed and non-upweighted model runs regarding the fits to the data sets SAautbio, CSacous, and WCacous (Table 14, Figures 9–10). However, for the upweighted model runs the fit to CRsumbio is slightly worse (Table 14), though visually the difference is very minor and the fits in both bases are adequate (Figure 11). The fits to the associated Chatham Rise proportions-at-age have tended to become better since 2001, though in 2010 the fit worsened (Figures 12–13).

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		0.89	1.50	0.79	0.93	1.08
1.2		0.84	1.56	0.94	1.00	1.07
1.3	As in 1.1, no upweighting	0.96	1.64	0.81	0.94	1.09
1.4	As in 1.2, no upweighting	0.91	1.94	0.85	0.98	0.98

For upweighted model runs the fit to SAsumbio is better (Table 14), but the fit is not good for the last three years, with most of the improvement in the fit being in the first three years (Figure 14). In either case only one of the years 2004–2007 fits well. The fits for the proportions-at-age for 2010 have improved compared to 2009, although 2009 was the worst year ever (Figures 15–17). The catchability for the last three surveys seem similar, but higher then previous surveys (Figures 18–19).

Upweighting the trawl biomasses leads to lower current biomass estimates (as a percentage of virgin) for both east and west stock (Table 15). Retaining just the upweighted model runs, the biomass trajectory for these are compared to model runs from last year's assessment (Table 16, Figure 20). There is very little difference between them.

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

Run	Description	Objective function	$B_{current}(\%B_0)$ E	W
1.1		-244.8	50.4	37.2
1.2		-318.0	48.7	40.1
1.3	As in 1.1, no upweighting	-287.7	56.9	44.9
1.4	As in 1.2, no upweighting	-368.9	55.0	58.6

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 2009 and the other is from 2010.

Assessment year		B_0 ('000 t) E	W	E+W	$B_{2009}(\%B_0)$ E	W	E+W	$B_{2010}(\%B_0)$ E	W	E+W
2009	1.1	480	804	1284	46	36	40	–	–	–
2010	1.1	460	777	1237	48	34	39	50	37	42
2009	1.2	672	1100	1772	42	34	37	–	–	–
2010	1.2	672	1002	1674	46	36	40	49	40	44

The year class strengths are very similar compared to the last assessment (Figure 21). However, as observed for the 2009 assessment, the estimate of the W stock YCS for the youngest cohort in common (equivalent to the 2007 YCS for the 2010 assessment) differs between assessments (McKenzie & Francis 2009). This is attributed to the youngest cohort being poorly estimated compared to other cohorts.

Other graphs show exploitation rates, selectivities, migration ogives, and fitted age-varying natural mortality (Figures 22–25). These show very little difference between updated runs; for the selectivities of run 1.2 there are some slight differences from the previous assessment.
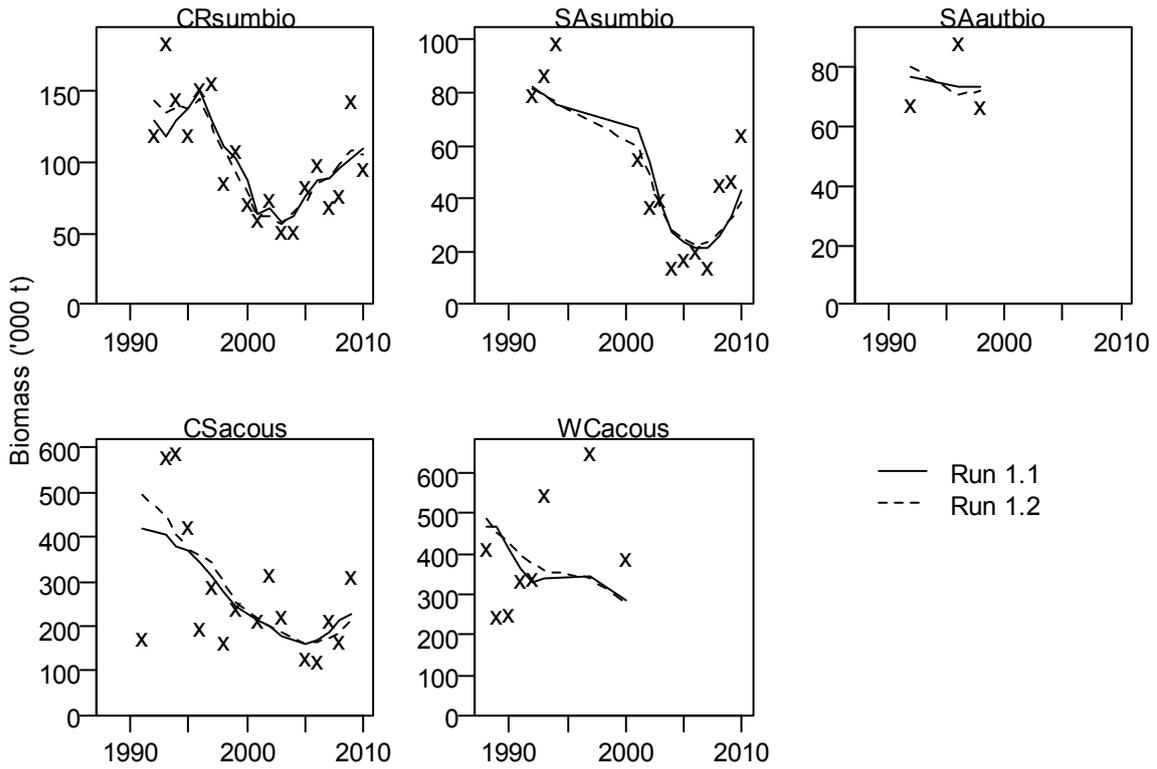
Figure 9: Fit to biomass indices for runs 1.1 and 1.2 showing observed ('x') and expected values (lines). In these model runs the trawl survey biomass data are upweighted.
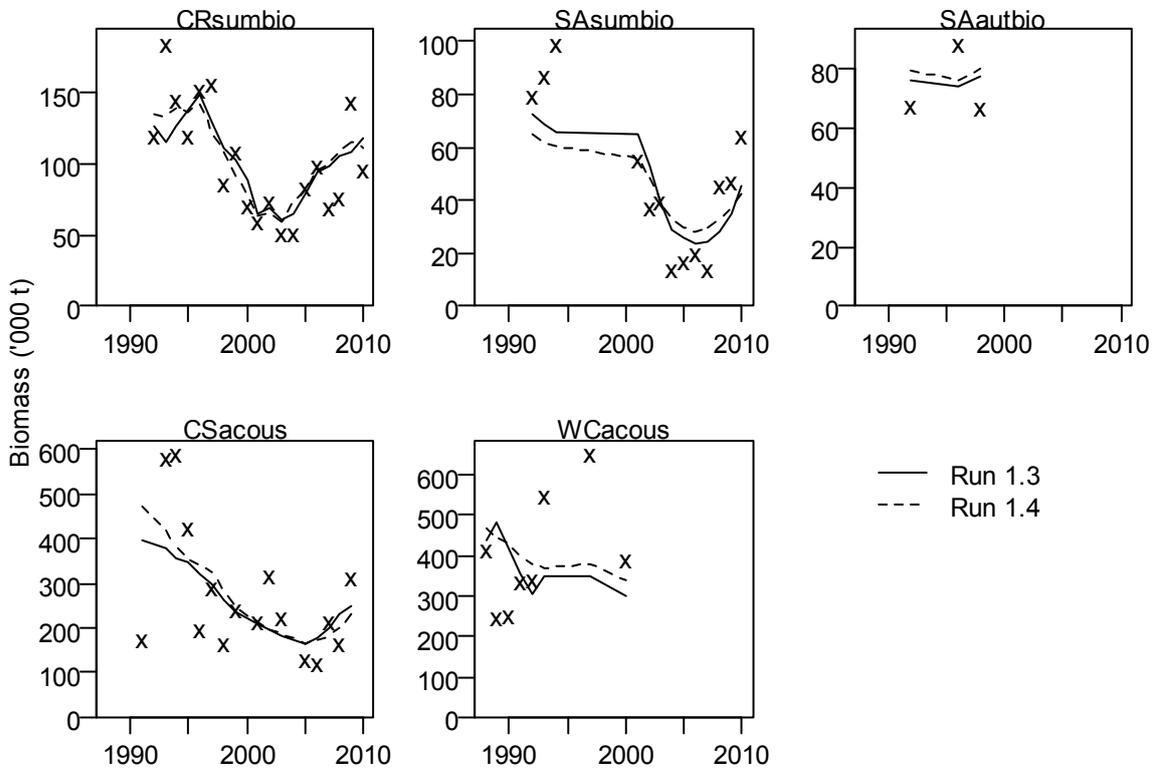
Figure 10: Fit to biomass indices for runs 1.3 and 1.4, showing observed ('x') and expected values (lines). In these model runs the trawl survey biomass data has no upweighting.
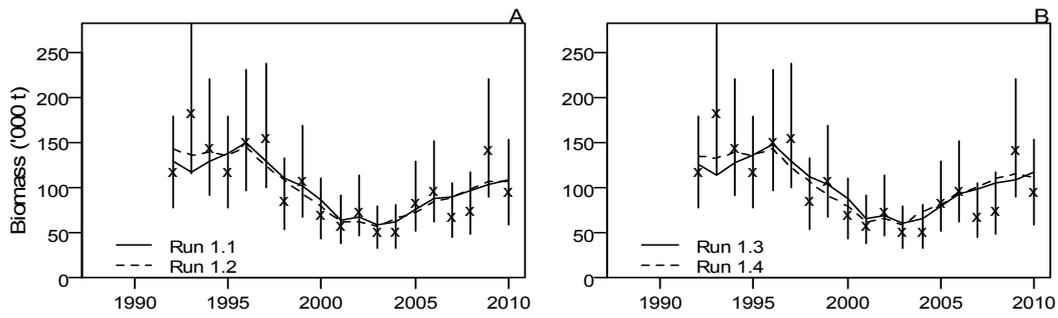
Figure 11: Fits to CRsumbio for runs 1.1 to 1.4, showing observed ('x', with vertical lines showing 95% confidence intervals) and expected values (lines). Plotted years are as in the model (so the last survey is plotted at 2010). The trawl survey indices are upweighted for the left-hand graph, and unweighted for the right-hand graph.
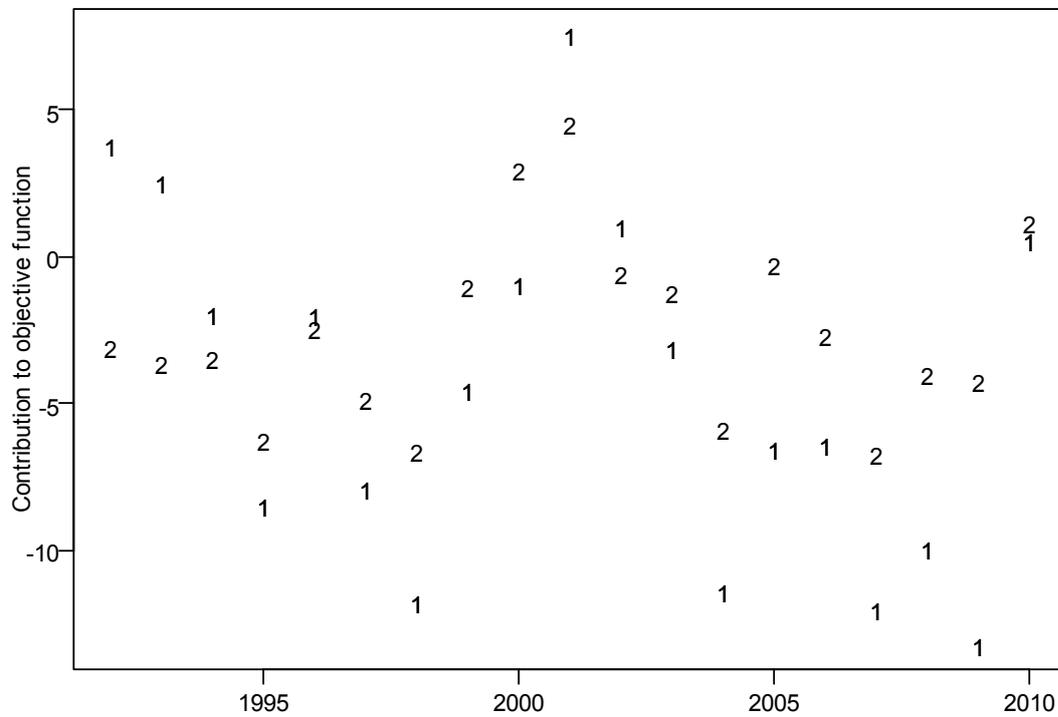
Figure 12: Goodness of fit to the CRsumage data, by year, for runs 1.1 ('1') and 1.2 ('2'). The y-value for each point indicates the contribution to the objective function from one year's CRsumage data; smaller values indicate a better fit. Plotted years are as in the model (so the last survey is plotted at 2010).
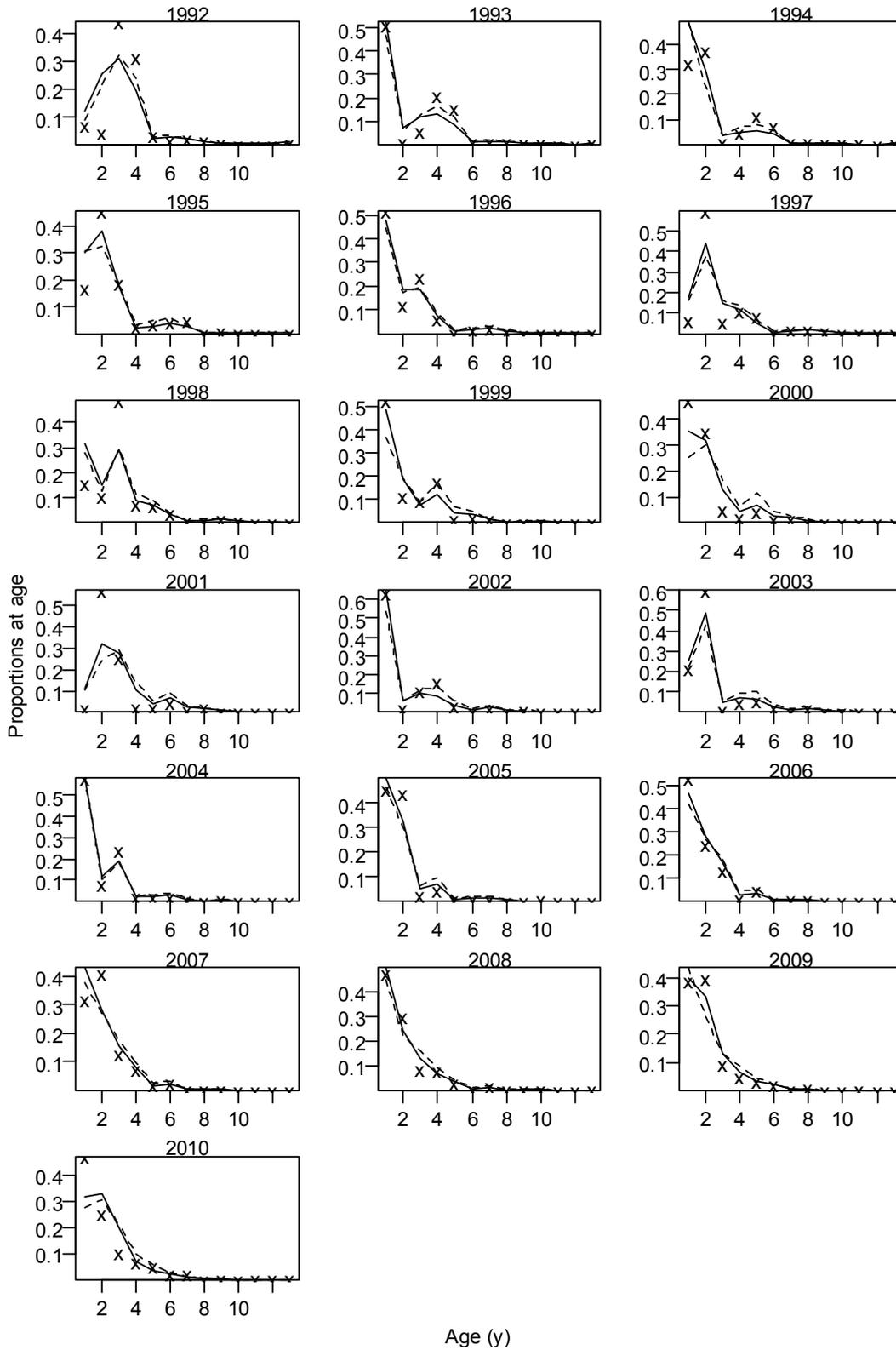
Figure 13: Observed ('x') and expected (lines) proportions at age in the summer Chatham Rise survey (data set CRsumage) for runs 1.1 (solid line) and 1.2 (broken lines).

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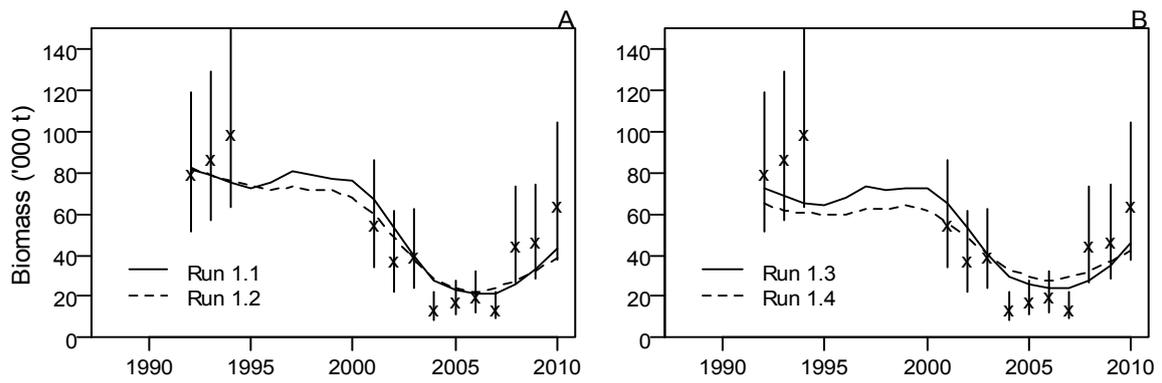
Figure 14: Fits to SAsumbio for runs 1.1 to 1.4, showing observed ('x', with vertical lines showing 95% confidence intervals) and expected values (lines). Plotted years are as in the model (so the last survey is plotted at 2010). The trawl survey indices are upweighted for the left-hand graph, and unweighted for the right-hand graph.
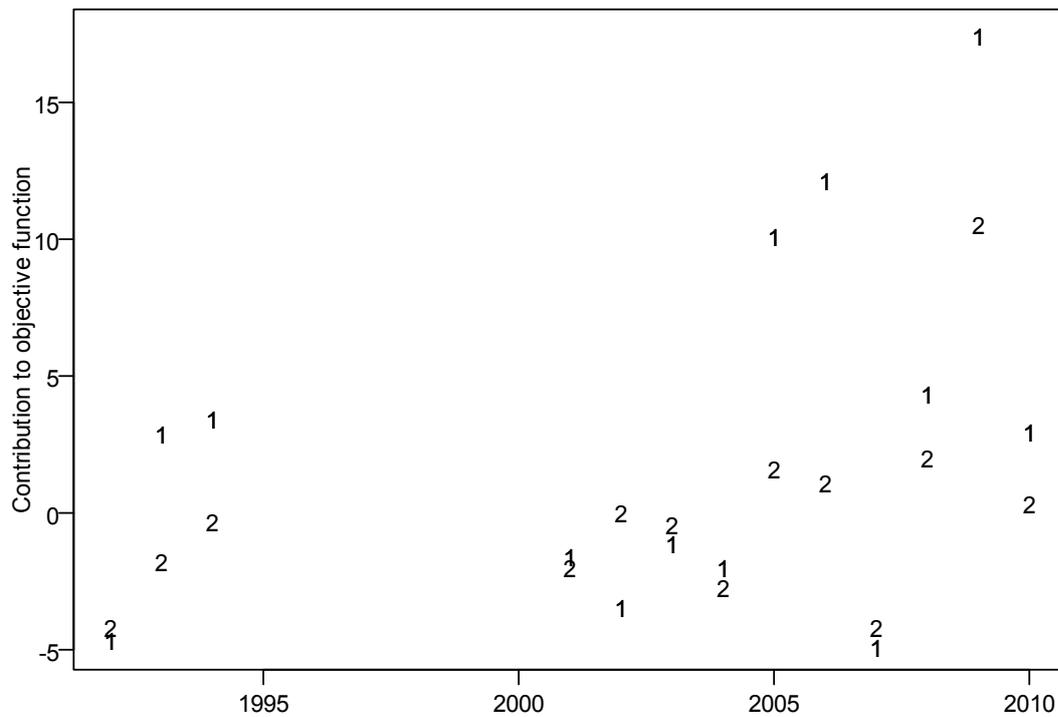
Figure 15: Goodness of fit to the SAsumage data, by year, for runs 1.1 ('1') and 1.2 ('2'). The y-value for each point indicates the contribution to the objective function from one year's SAsumage data; smaller values indicate a better fit. Plotted years are as in the model (so the last survey is plotted at 2010).

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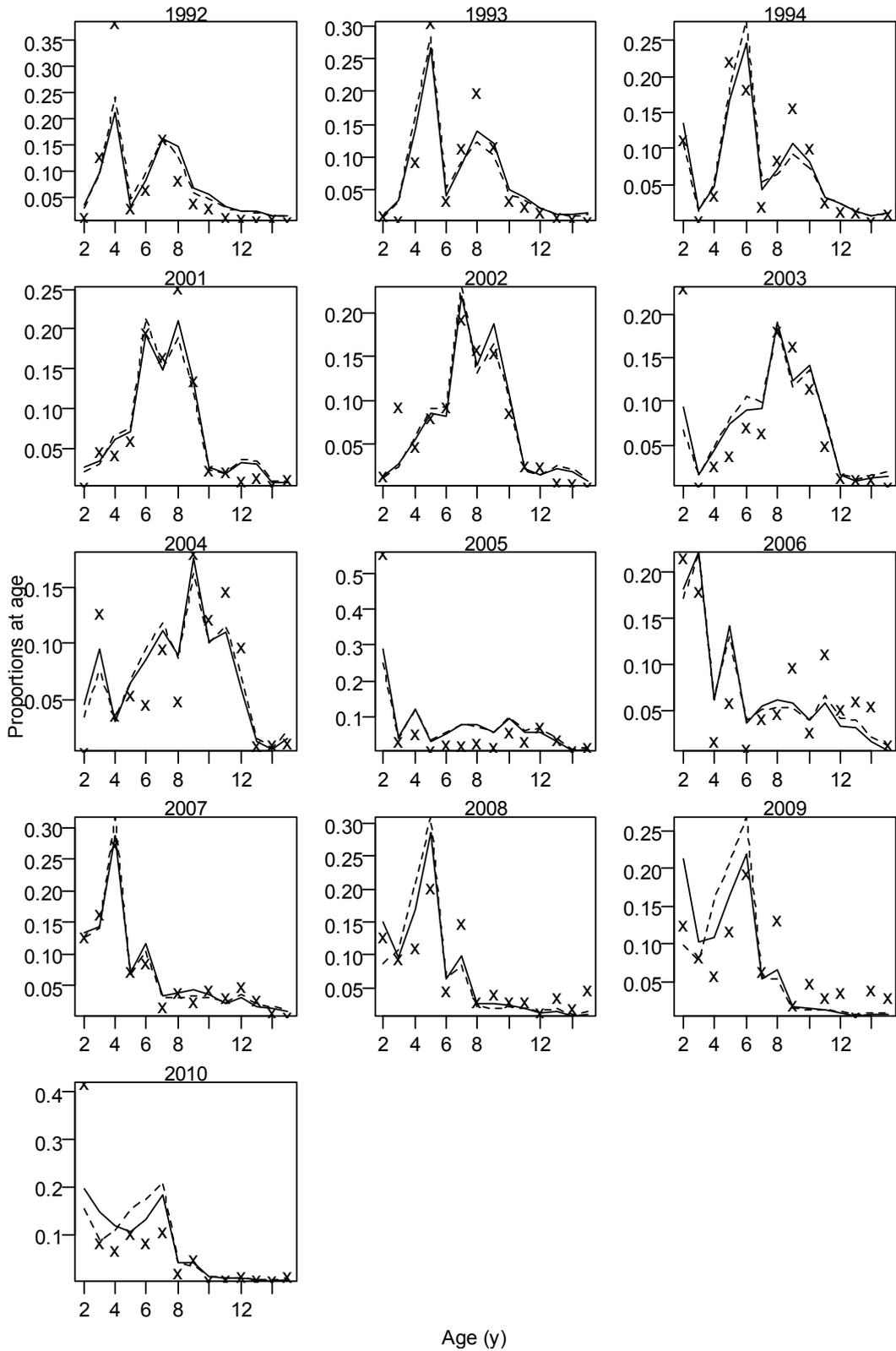
Figure 16: Observed ('x') and expected (lines) proportions at age in the summer Sub-Antarctic survey (data set SAsumage) for runs 1.1 (solid line) and 1.2 (broken lines).

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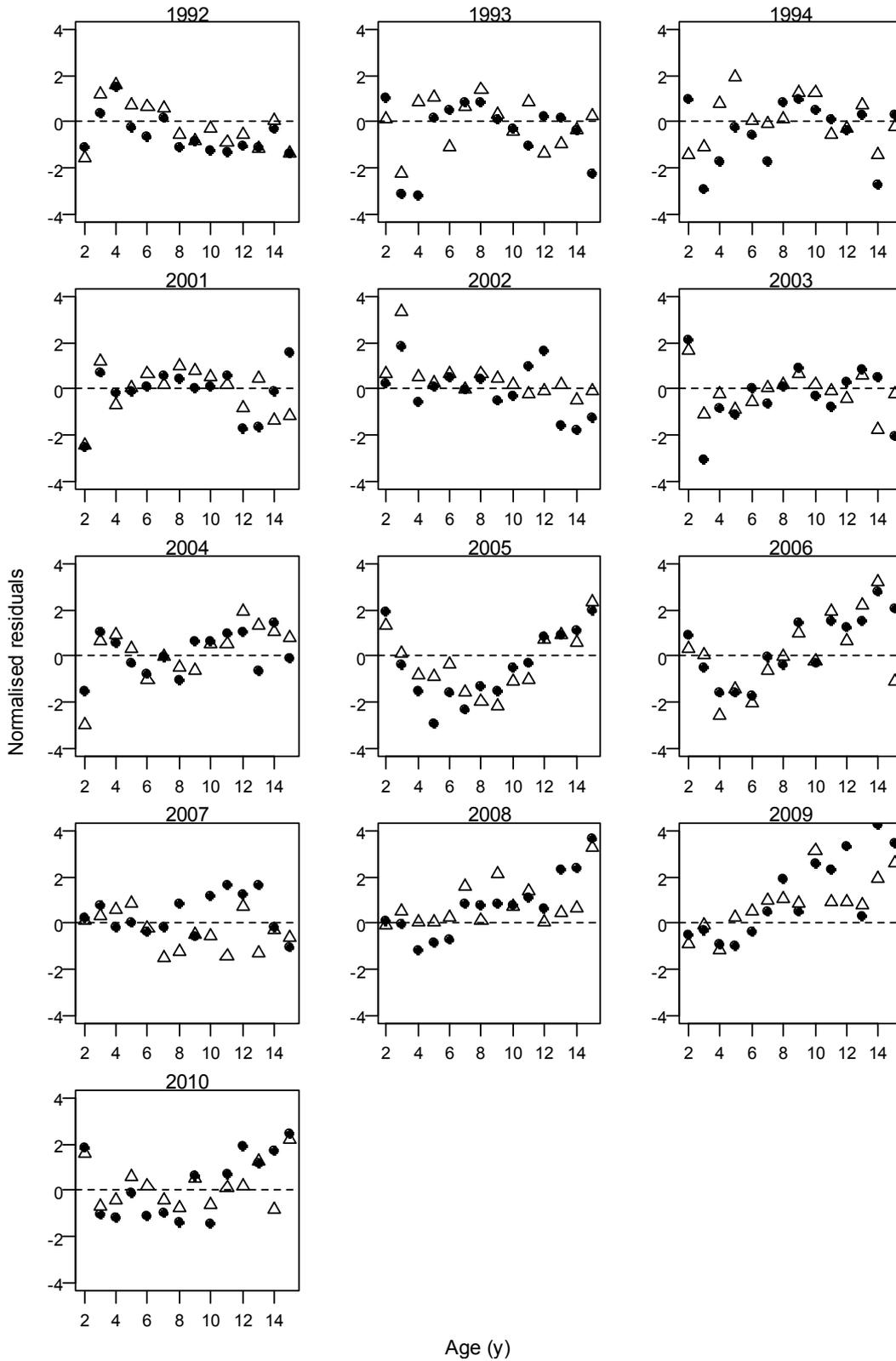
Figure 17: Normalised residuals by sex for the summer Sub-Antarctic survey (data set SAsumage) for run 1.1 (triangle, male; solid dot, female).
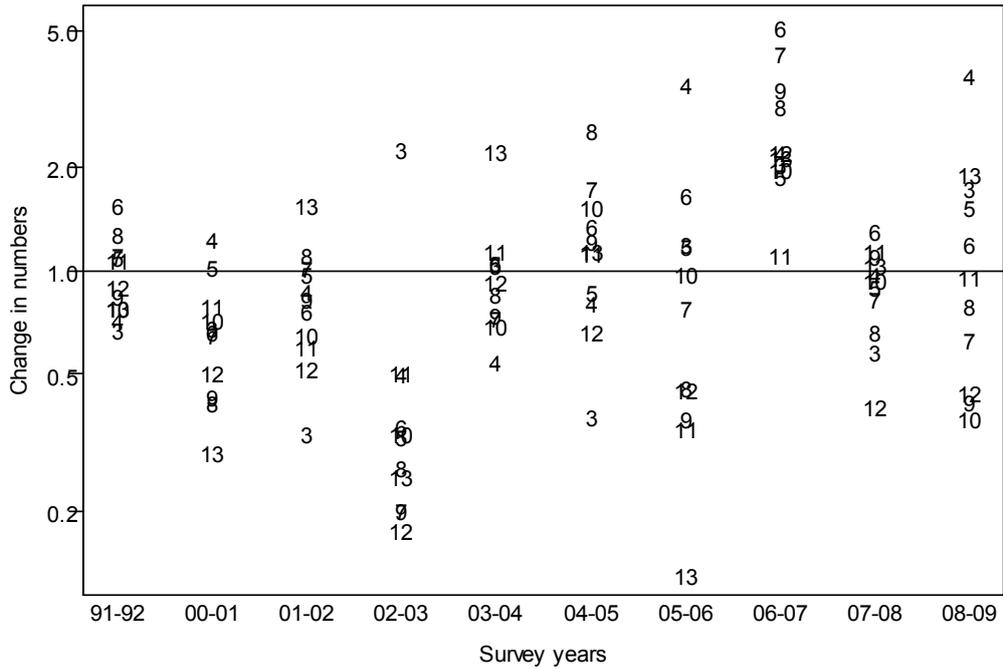
Figure 18: Changes, between surveys one year apart in the Sub-Antarctic summer series, in estimated numbers of selected cohorts. Each plotted point indicates how the estimated number in a cohort changed between the two surveys; the plotting symbol is the age of the cohort in the earlier survey. For example, 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. Note that the 2006 Sub-Antarctic summer survey is in the 2007 fishing year.
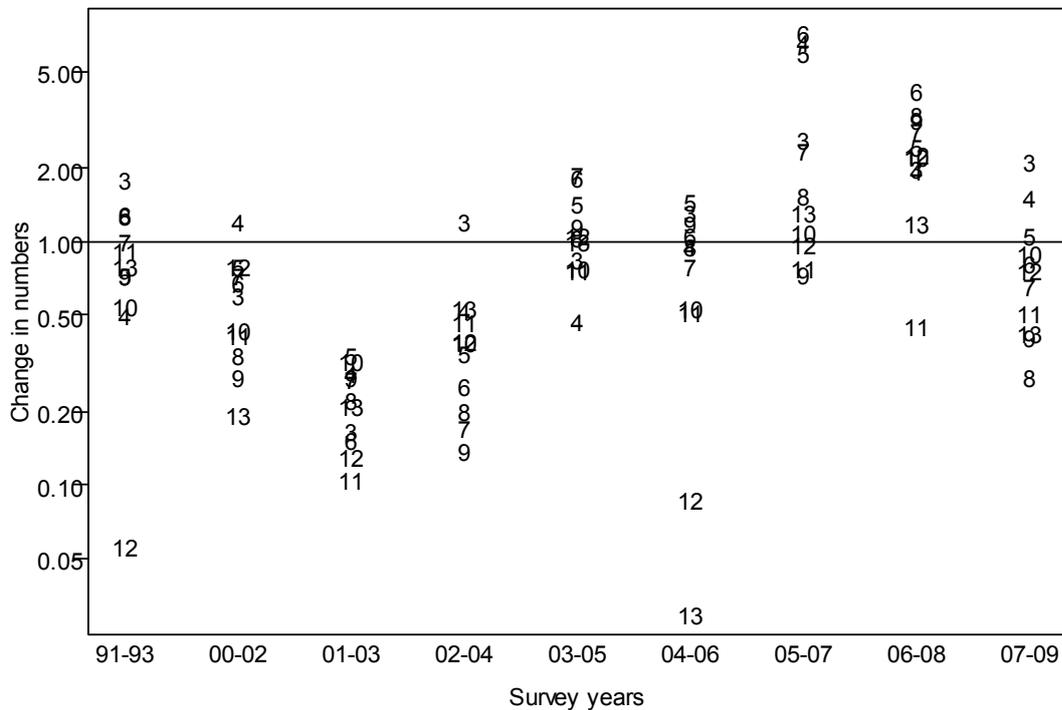
Figure 19: Changes, between surveys two years apart in the Sub-Antarctic summer series, in estimated numbers of selected cohorts. Each plotted point indicates how the estimated number in a cohort changed between the two surveys; the plotting symbol is the age of the cohort in the earlier survey. For 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. Note that the, for example 2006 Sub-Antarctic summer survey, is in the 2007 fishing year.

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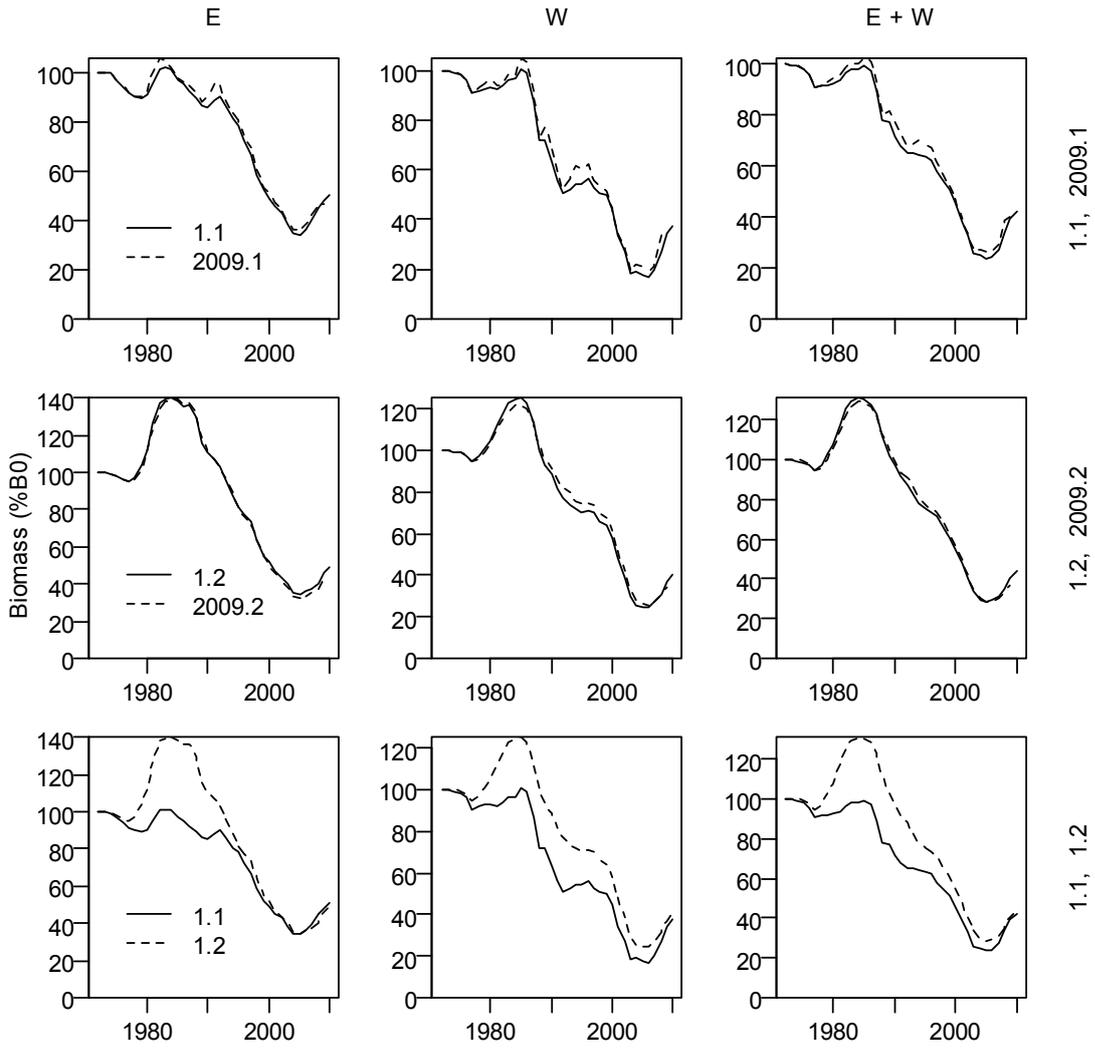
Figure 20: Comparison of biomass trajectories from different runs: E stock (left column), W stock (middle column), and E + W stocks combined (right column). The top two rows of panels compare each new run (solid lines) with the corresponding run from 2009 (broken lines); the bottom row compares the two new runs. The label 2009.1 refers to run 1.1 from 2009, and likewise for the label 2009.2.
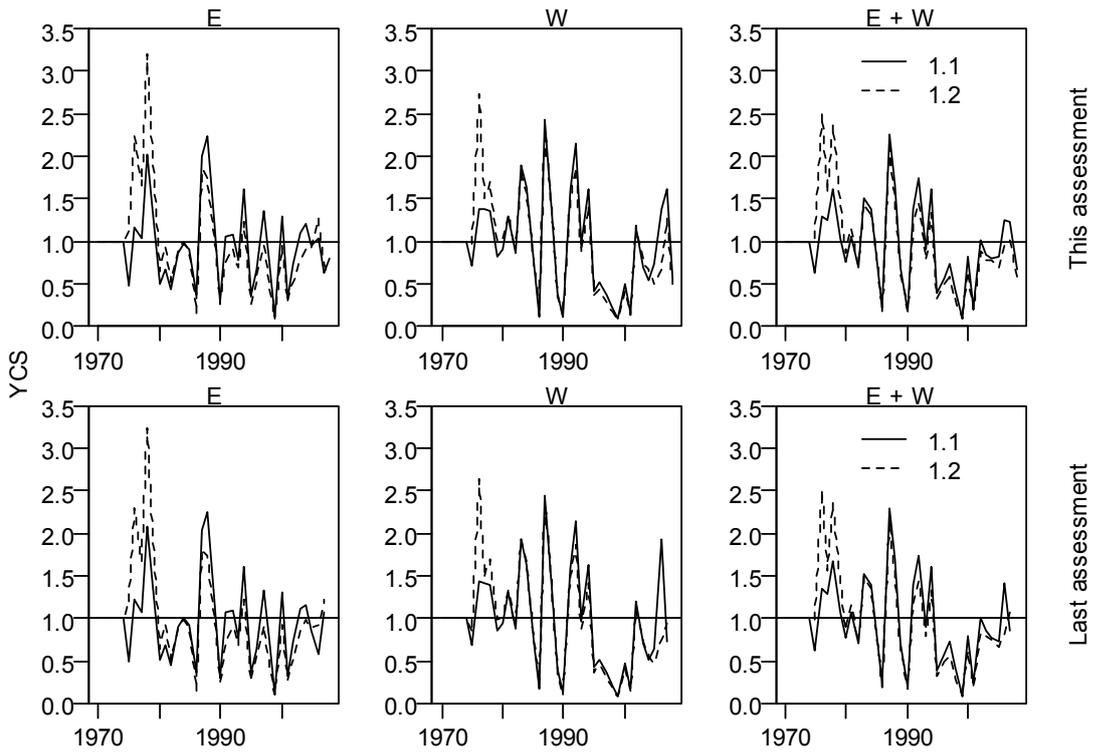
Figure 21: YCS estimates for new runs 1.1, 1.2 (upper panels) and the runs from last year's assessment (lower panels).
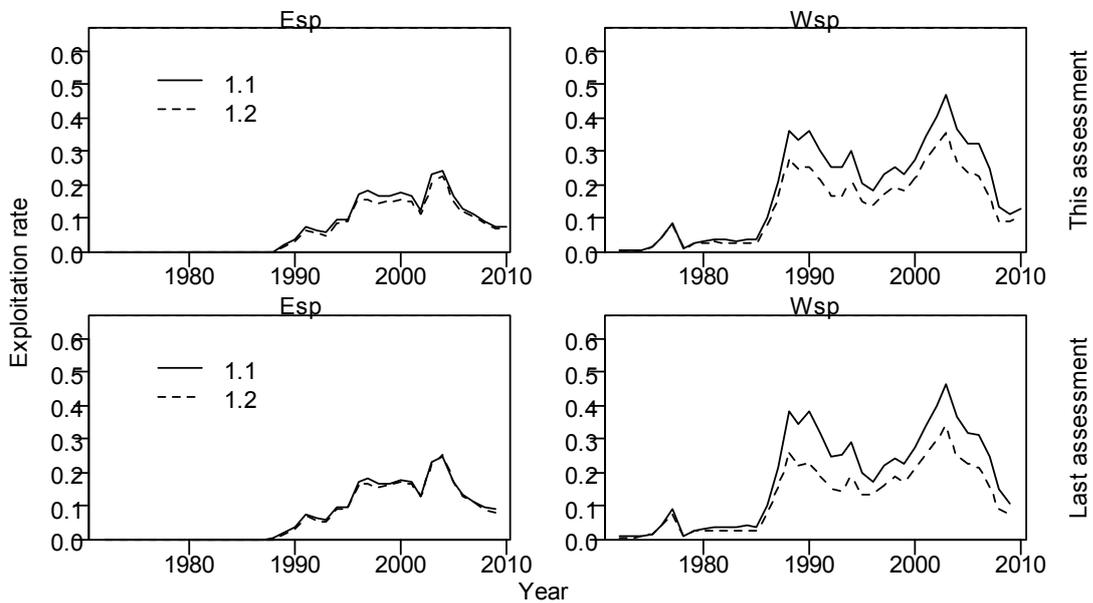
Figure 22: Estimated exploitation rates from runs 1.1 and 1.2 for this assessment (upper panels) and the main runs from last year's assessment (lower panels).
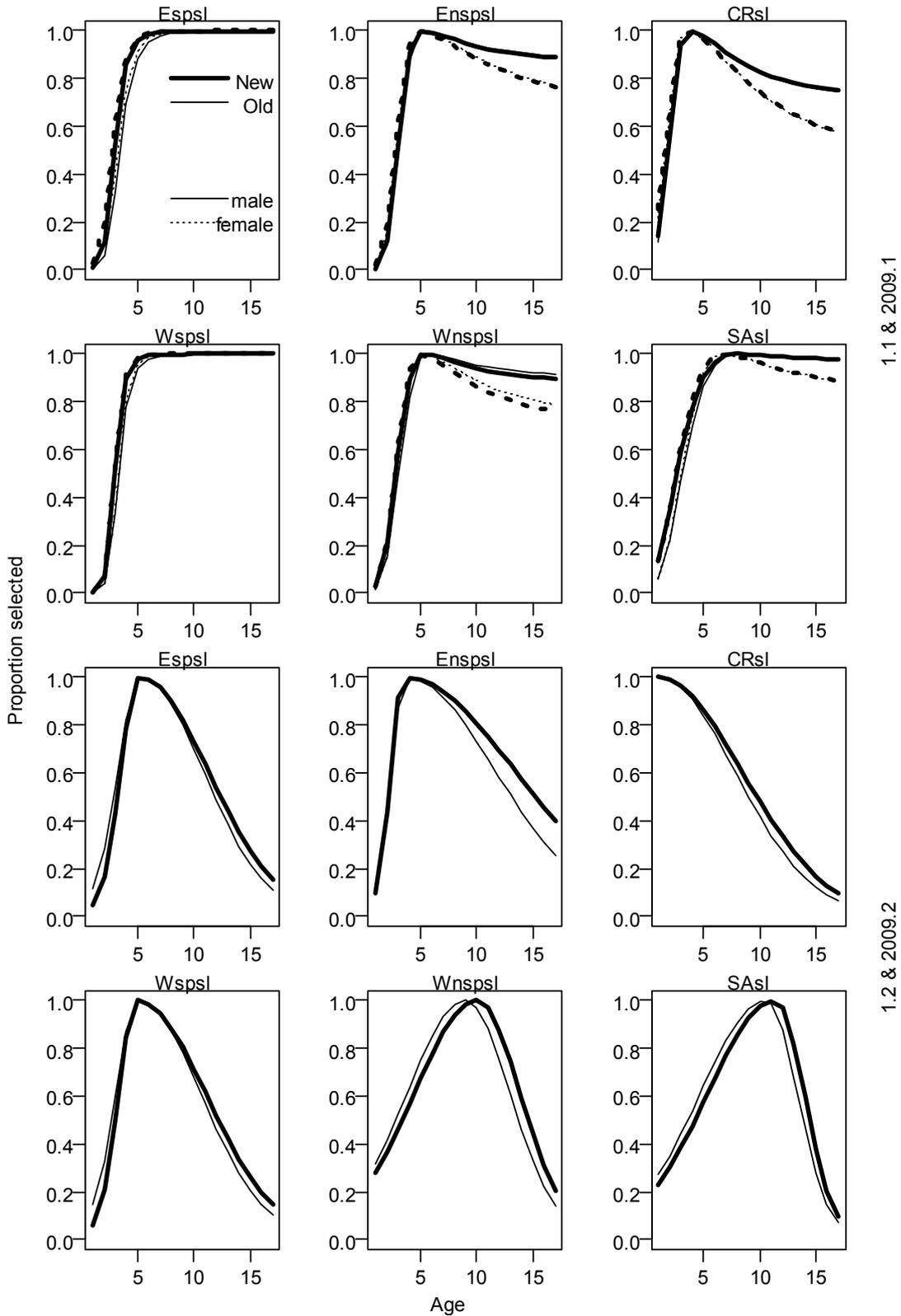
Figure 23: Estimated selectivity curves for new model runs (heavy lines) and analogous 2009 runs (light lines). Males are shown by a solid line, females by a dotted line.
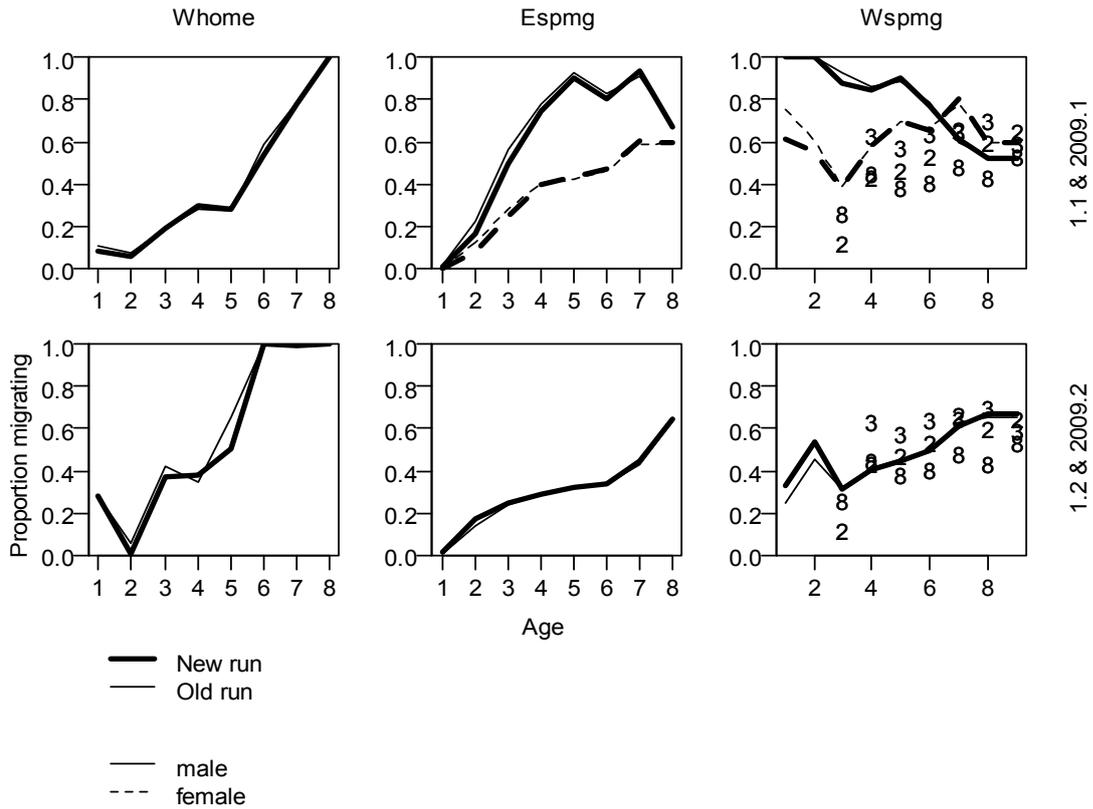
Figure 24: Estimated migration ogives for new and old runs. Each row of plots compares ogives from a new run (heavy lines) with those from the analogous 2009 runs (light lines). Where ogives differ by sex, female ogives are plotted as broken lines. The observations pspawn are also plotted in the rightmost panels, with the plotting symbol identifying the year of sampling ('2' = 1992, '3' = 1993, '8' = 1998). The label 2009.1 denotes run 1.1 for the 2009 assessment; likewise for the label 2009.2.
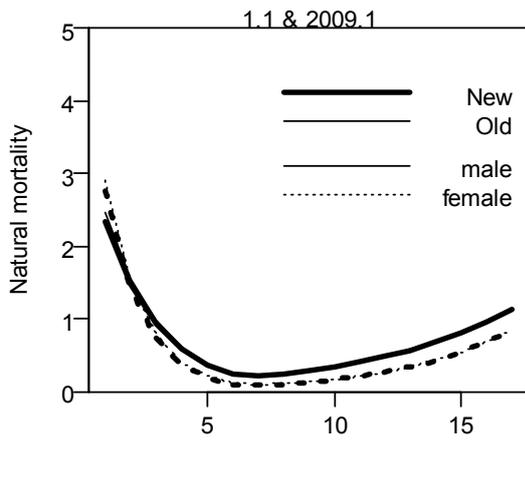
Figure 25: Comparison between age-dependent natural mortality estimated in the new run (heavy lines) and the corresponding run from 2009 (light lines).

3.2   Time-varying catchability for the Sub-Antarctic summer trawl survey series

From the numbers-at-age data for the Sub-Antarctic summer trawl there appears to have been a change in catchability in the 2004 and 2008 fishing years, as evidenced by the abrupt change in numbers-at-age across all age groups in the 2003 and 2007 survey years (see Figure 18). The change in 2004 (and slight downward trend in previous years) may partly be explained by the rapid decline in abundance of the western stock over this time (see Figure 20). However, the large increase in numbers for all age groups in 2008 cannot be explained in this way. Further evidence for a change in catchability is the inability of model runs to fit the low biomass indices from 2004–07 and the last three high biomass indices from 2008–10 (see Figure 14).

The Hoki Working Group decided that the sensitivity of the model results to changes in catchability should be looked at, basing this investigation on initial model run 1.1.

Two sensitivity model runs were done for model run 1.1 (age-varying natural mortality with trawl surveys up-weighted):

- Run 1.5. The catchability for the 2008–2010 fishing years inclusive is estimated separately from the other years. The hypothesis for this model run is that the catchability for these years is unusually high.

- Run 1.6. The catchability for the 2004–2007 fishing years inclusive is estimated separately from the other years. The hypothesis for this model run is that the catchability over this period was particularly low relative to the other years. The advantage of this hypothesis over that modelled in run 1.5 is that it could explain both the large changes in 2004 and 2008 in numbers-at-age, not just the change in 2008. And furthermore, as with run 1.5, the addition of just one more parameter in the model.

Allowing for a step change in the catchability had a significant impact on the biomass trajectory for the western stock (Table 17, Figure 26). For run 1.5 the catchability in the last three years is estimated to be a bit more than double that of the other years, and current biomass (%B_0) lowers from 37% to 27% (Table 18). For run 1.6 the catchability for 2004–07 is estimated to be half that of the other years and current biomass increases from 37% to 46%.

The fits to the trawl survey data are substantially better for both runs 1.5 and 1.6 (Figure 27). The change in the objective function is about 25–35 for the addition of one more parameter, with the fit to run 1.6 a bit better then run 1.5 (Table 17). However, a year remains poorly fitted in both runs (2004 for run 1.5, and 2002 for run 1.6).

The trawl survey biomass indices were first upweighted in the 2004 assessment to help fit the 2004 Sub-Antarctic summer trawl survey biomass (Francis 2005). With a change in catchability assumed for 2004–2007 this may not be needed. A further model run 1.7 was done, which is the same as run 1.6 except the trawl surveys are not upweighted, and the fits to SAsumbio are very similar for both runs (Figure 28).

Table 17: Comparison of key aspects of MPD fits.

Run	Description	Objective function	B_0('000 t) E	W	E+W	B_{2010}(%B0) E	W	E+W
1.1	q constant	-244.8	460	777	1237	50	37	42
1.5	08–10 q different	-270.4	468	768	1236	54	27	37
1.6	04–07 q different	-279.1	473	840	1313	50	46	47

Table 18: Estimated catchability for the model runs.

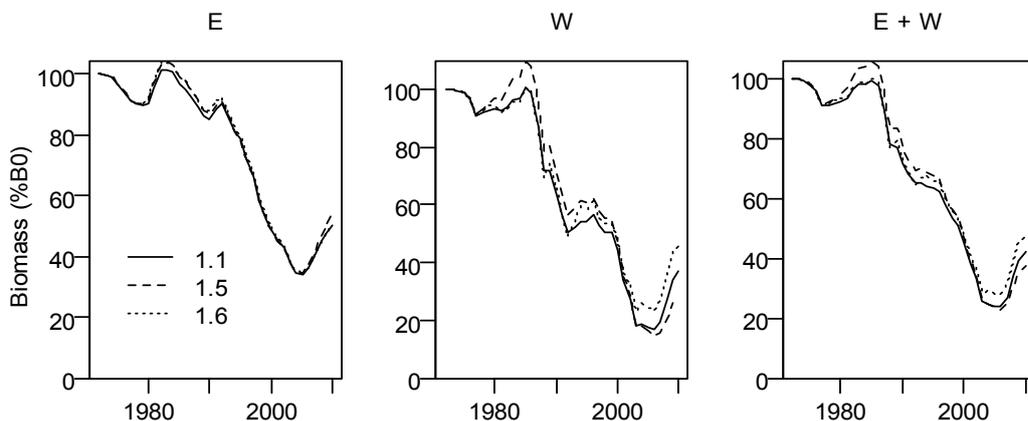|	catchability		
Run	1992-2003	2004-2007	2008-10
1.1	0.16	0.16	0.16
1.5	0.14	0.14	0.33
1.6	0.16	0.08	0.16

Figure 26: Comparison of biomass trajectories from different runs: E stock (left column), W stock (middle column), and E + W stocks combined (right column).
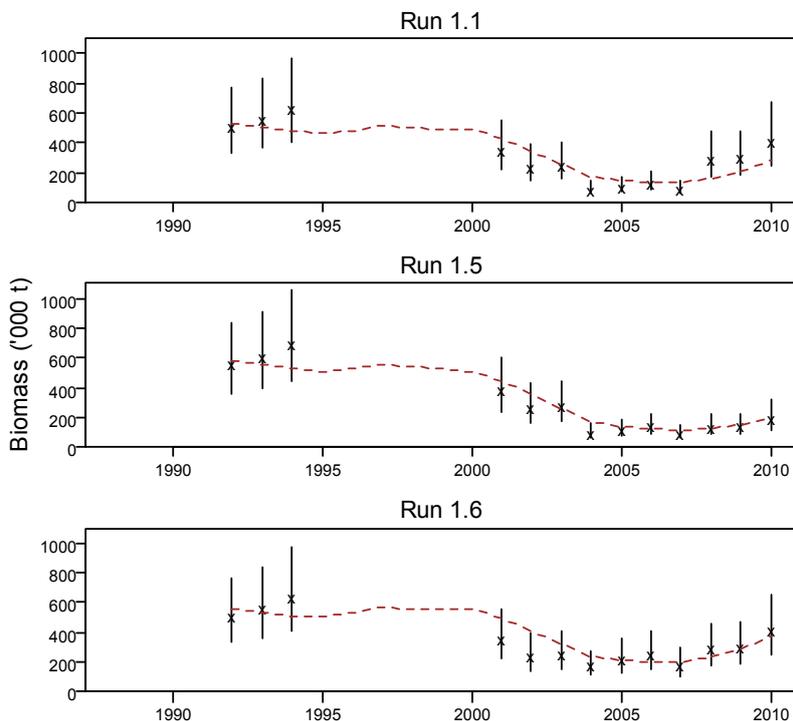

Figure 27: Fits to SAsumbio for runs 1.1, 1.5, and 1.6, showing observed ('x', with vertical lines showing 95% confidence intervals) and expected values (dashed lines). Plotted years are as in the model (so the last survey is plotted at 2010). The trawl survey indices are upweighted in all model runs. In run 1.5 the years 2008–10 inclusive have a separate catchability from other years; for run 1.6 the years 2004–2007 inclusive have a separate catchability from other years.
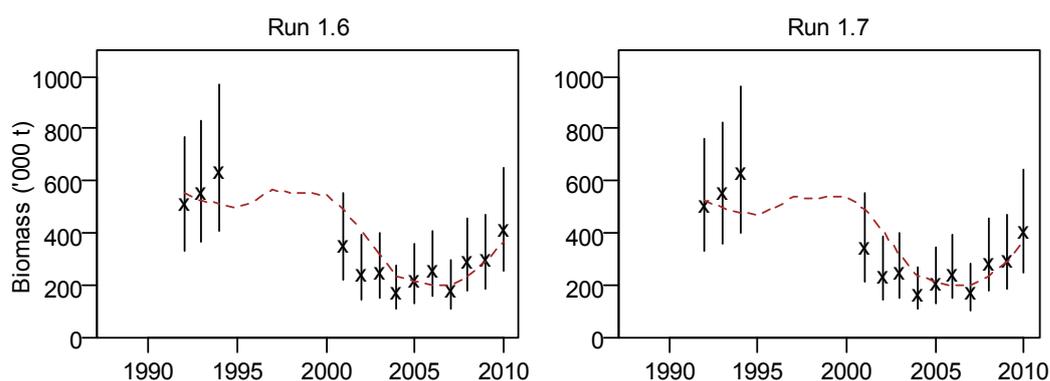
Figure 28: Fits to SAsumbio for runs 1.6 and 1.7, showing observed ('x', with vertical lines showing 95% confidence intervals) and expected values (dashed lines). Plotted years are as in the model (so the last survey is plotted at 2010). The trawl survey indices are upweighted for run 1.6 and not upweighted for run 1.7. In both runs 2004–2007 inclusive have a separate catchability from other years.

3.3   Final runs

For the current year (2010), the new TACC is 110 000 t with a catch split arrangement for 60 000 t to be taken from the eastern stock and 50 000 t from the western stock. For the first two sets of initial model runs (1.x) an assumed 2010 catch was used based on this, with the fishery catches from 2009 scaled up to the eastern and western stock totals. In the last set of initial model runs (2.x) it was decided by the Hoki Working Group to use a slightly adjusted 2010 catch split in which more of the TACC is taken from the western spawning fishery, keeping the same totals for the eastern and western stock (Tables 3 and 19). The impact of this change on the model run biomass trajectories is miniscule.

Table 19: Assumed 2010 catch: initial and adjusted.

	Ensp1	Ensp2	Wnsp1	Wnsp2	Esp	Wsp
Initial	30100	13500	9800	6200	16400	34000
Adjusted	29700	13300	6100	3900	17000	40000

It was decided by the Hoki Working Group to take four runs through to the MCMC stage. Two of these runs are considered base cases and are updates of the final model runs from the 2009 assessment (McKenzie & Francis 2009); the other two runs are sensitivities to one of the base model runs. The runs taken through to the MCMC stage are denoted 2.1–2.4 (Table 20).

The two base runs are distinguished by the mechanism they used to deal with the problem of the lack of old fish in both fishery-based and survey-based observations. Run 2.1 allows *M* (natural mortality) to be dependent on age; run 2.2 allows the spawning fishery selectivities (Espsl, Wspsl) to be domed. When the domed selectivities were used it was also necessary to combine sexes in the model and make the selectivities age-based (Francis 2005). As in the previous assessment, the trawl biomass indices were upweighted to improve the fit to them. Runs 2.1 and 2.2 differ from the earlier initial runs 1.1 and 1.2 only in the slightly different assumed 2010 catch (see above).

To improve the fit to the SAsumbio series, an alternative approach to upweighting is to assume that the catchability has changed over time. The two sensitivity runs differ from run 2.1 in that two catchabilities are fitted for the SAsumbio series instead of one, with no up-weighting of the trawl sureveys (Table 20). In run 2.3 the catchability from 2004 to 2007 inclusive is estimated separately from the other years in the series, whereas for run 2.4 the catchability from 2008 to 2010 inclusive is estimated separately.

For completeness, two additional runs 2.5 and 2.6 are presented in this section, but not taken through to the MCMC stage. They are same as runs 2.3 and 2.4, except the trawl surveys are up-weighted.

MPD results are given for all six model runs. For runs 2.3–2.6 the current biomass (%B_0) for both the western and eastern stocks is estimated to be the same or higher than in run 2.1, except for the western stock of run 2.6 (Table 20). Up-weighting make little difference to the fit for the model runs with a separately estimated 2004–2007 catchability, but more so in the early years for the model runs with separately estimated 2008–10 catchability (Figure 29).

Table 20: Comparison of key aspects of MPD runs. The base model runs are 2.1 and 2.2. Runs 2.3–2.6 are all sensitivities to the base model 2.1. Runs 2.1–2.4 are the final models runs taken through to the MCMC stage.

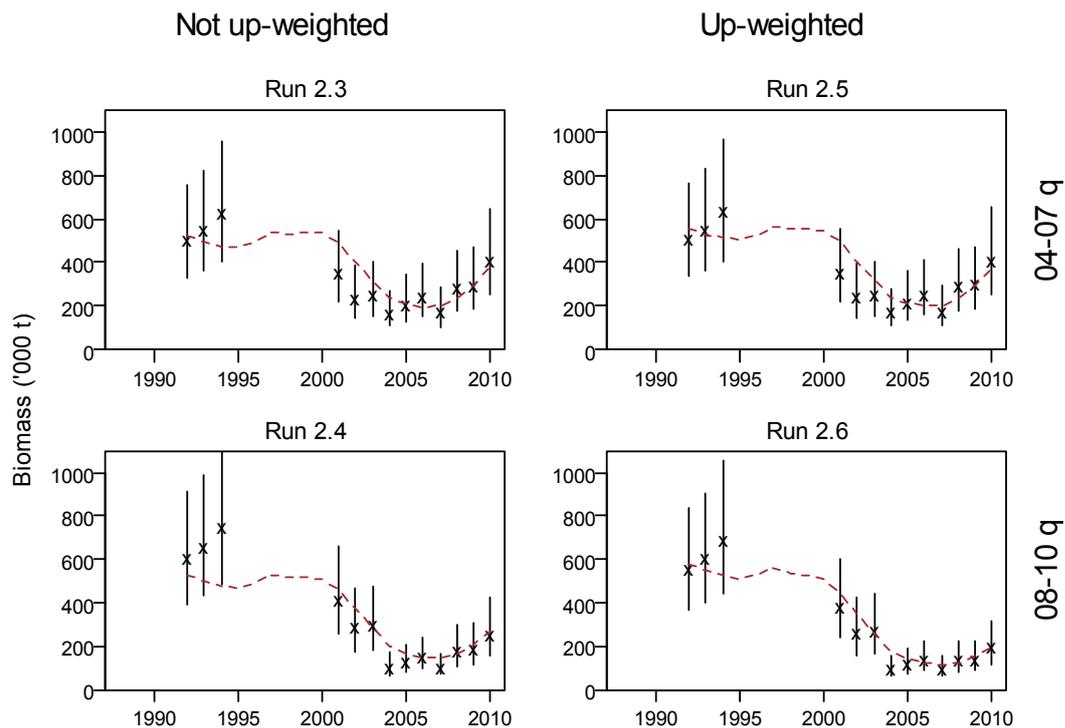| Run	Two catchabilities for SAsumbio?	Trawl surveys up-weighted?	Objective function	B_0 ('000 t)			B_{2010}(%B0)		
				E	W	E+W	E	W	E+W
2.1	N	Y	-244.8	460	777	1237	50	37	42
2.2	N	Y	-318.1	671	1001	1672	49	40	44
2.3	04–07 q different	N	-300.0	484	852	1336	58	50	53
2.4	08–10 q different	N	-295.7	471	805	1276	55	38	44
2.5	04–07 q different	Y	-279.1	473	840	1313	50	46	47
2.6	08–10 q different	Y	-270.4	468	769	1236	54	27	37

Figure 29: Fits to SAsumbio for runs 2.3 to 2.6, showing observed ('x', with vertical lines showing 95% confidence intervals) and expected values (dashed lines). Plotted years are as in the model (so the last survey is plotted at 2010). All model runs are sensitivities to the base model run 2.1.

4. FINAL MODEL ASSESSMENT RESULTS

The Hoki Working Group decided to take the runs 2.1–2.4 through to the MCMC stage. The model runs 2.1 and 2.2 are considered base cases and are updates of the final model runs from the 2009 assessment (McKenzie & Francis 2009). The other two model runs are sensitivities to the 2.1 model run, and involve using two catchabilities for the Sub-Antarctic summer trawl survey, with no up-weighting of the trawl surveys (Section 3.3).

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 2009, those migration or selectivity parameters that were found to be at a bound in the MPD run (Table 21) 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 30). 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 21: Migration and selectivity parameters held fixed in MCMC runs (with fixed values in parentheses).

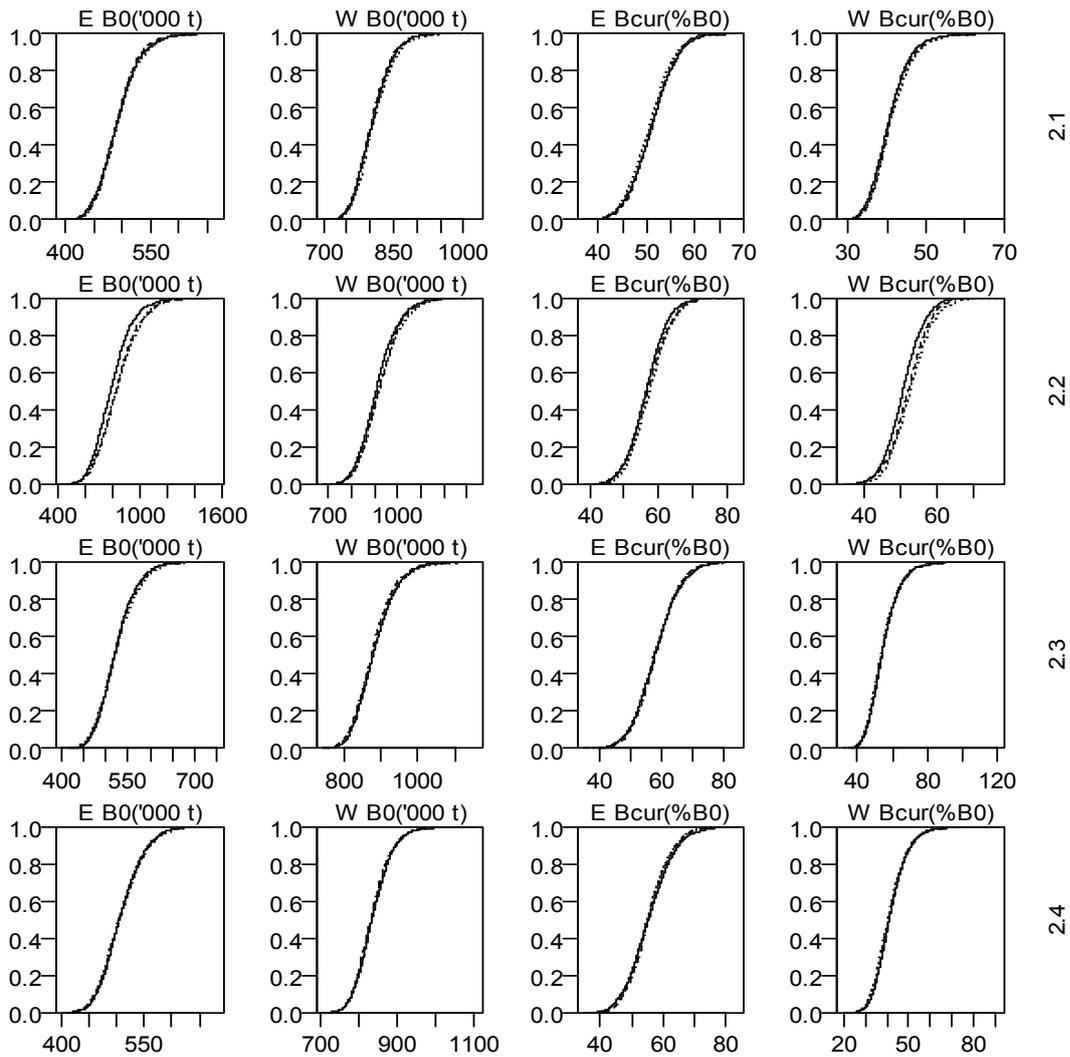| Run	Parameters (fixed values)
2.1	WspmgM1(1), WspmgM2(1), EspmgF8(0.6), WspmgF8(0.6), Enspsl.sR(44), Wnspsl.sR(44), CRsl.a1(64), SAsl.a1(84), SAsl.sR(44)
2.2	Whome.2(0.01), Whome.6(1), CRsl.sL(1), CRsl.a1(1)
2.3	As in 2.1
2.4	As in 2.1

Figure 30: Diagnostics for MCMC chains for the four runs: base cases 2.1 and 2.2 (top two rows) and sensitivity runs 2.3 and 2.4 (bottom two rows). Each panel contains cumulative probability distributions, for B_0 or $B_{current}$, for three chains from the same model run.

The MCMC results for the base runs 2.1 and 2.2 show, as in 2009, that the western spawning stock was originally much larger than the eastern spawning stock, and is currently about 30% larger then the eastern spawning stock (run 2.1) or about the same size (run 2.2) (Table 22, Figure 31). In terms of current spawning biomass the western spawning stock is more depleted then the eastern (Figure 31). In terms of estimated biomass in 2009, the new assessment is similar to that from last year, except run 2.1 shows an increased current biomass (%B_0) compared to the comparable run from last year (Figure 32).

The sensitivity results to run 2.1 show either (i) that both the western and eastern stocks are larger (run 2.3), or (ii) little difference in the current estimated biomass status for the western stock and an increase for the eastern stock (run 2.4) (Figure 33, Table 22). The estimate of the current status of the western stock is more uncertain when two catchabilities are allowed (Figure 33).

All runs suggest both the E and W stocks are rebuilding, both in absolute terms (Figure 34) and relative to B_0 (Figure 35). For the base runs, recent W YCSs are estimated to be higher than in the seven-year period of very weak recruitment, 1995–2001 (Figure 36). As in previous years, the selectivity and migration ogives for the runs assuming age-dependent natural mortality (run 2.1 in the current assessment) are very different from the run without this assumption (Figures 37–38).

For the base run 2.1 and its sensitivities (2.3, 2.4) there is very little difference in the estimated year class strengths, and selectivity and migration ogives (Figures 39–41).

The estimates of natural mortality for run 2.1. show the same pattern as the 2009 assessment with, except for the very young fish, a higher natural mortality for males (Figure 42). A comparison of priors and posteriors for various parameters showed no substantial changes from last year (Figure 43).

Table 22: Estimates of spawning biomass (medians of marginal posterior, with 95% confidence intervals in parentheses) for the four runs. $B_{current}$ is the biomass in mid-season 2010.

	B_0('000 t)		$B_{current}$('000 t)		$B_{current}$(%B_0)		
Run	E	W	E	W	E	W	E+W
2.1	493(433,576)	808(748,893)	250(198,317)	326(254,454)	51(43,60)	40(33,53)	44(39,53)
2.2	807(568,1168)	912(780,1115)	461(312,682)	477(357,654)	57(47,70)	52(42,63)	54(48,62)
2.3	524(454,618)	880(793,1009)	303(220,413)	478(334,716)	58(45,71)	54(41,76)	56(45,71)
2.4	507(439,591)	835(764,940)	280(204,392)	342(230,522)	55(43,70)	41(29,58)	47(37,60)
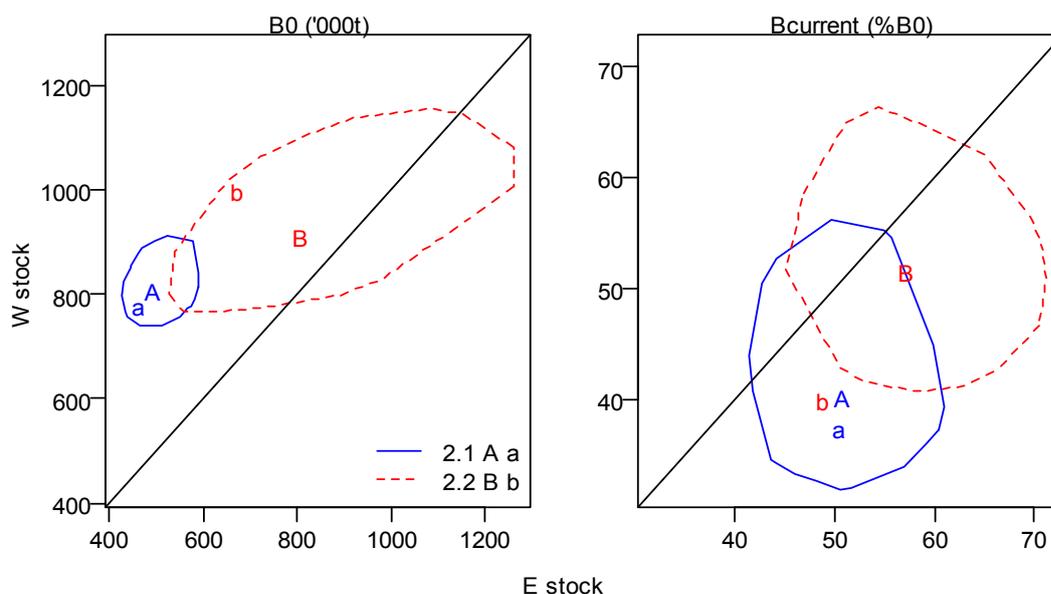
Figure 31: Estimates and approximate 95% confidence intervals for virgin (B_0) and current ($B_{current}$ as %B_0) biomass by stock for the two base case runs 2.1 and 2.2. In each panel the points 'A', 'B' indicate best estimates (median of the posterior distribution) for these three runs, 'a','b', are the MPD estimates, and the polygons (with solid, broken and dotted lines, respectively) enclose approximate 95% confidence intervals. Diagonal lines indicate equality (y = x).
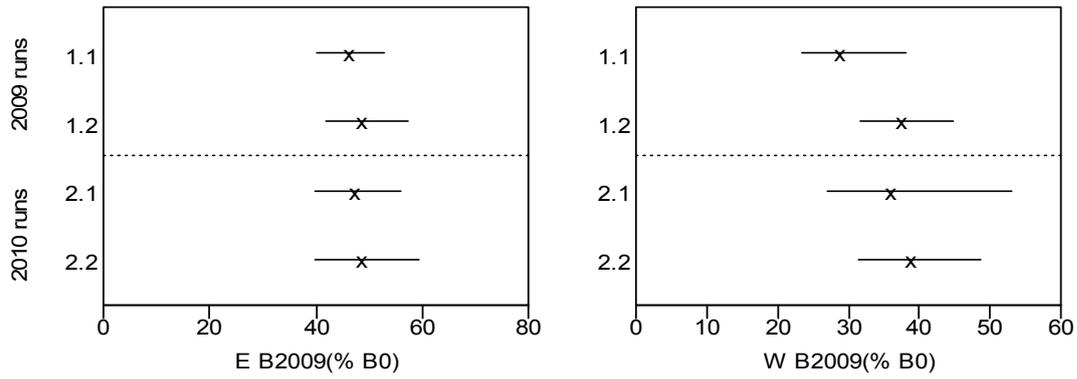
Figure 32: Comparison of 2010 base case runs (2.1, 2.2) with those from 2009 (1.1, 1.2): estimates of stock status in 2009 (B2009 as %B0), with 95% confidence intervals shown as horizontal lines.
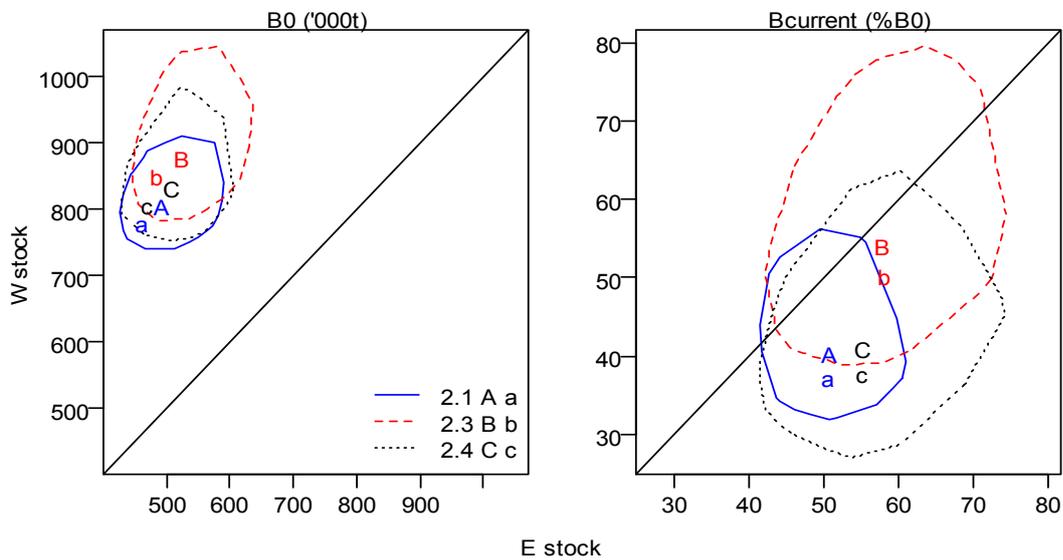

Figure 33: Estimates and approximate 95% confidence intervals for virgin (B_0) and current ($B_{current}$ as %B_0) biomass by stock for run 2.1 and sensitivity runs 2.2, 2.3. In each panel the points 'A', 'B', 'C' indicate best estimates (median of the posterior distribution) for these three runs, 'a','b', 'c' are the MPD estimates, and the polygons (with solid, broken and dotted lines, respectively) enclose approximate 95% confidence intervals. Diagonal lines indicate equality (Eastern stock = Western stock).

40
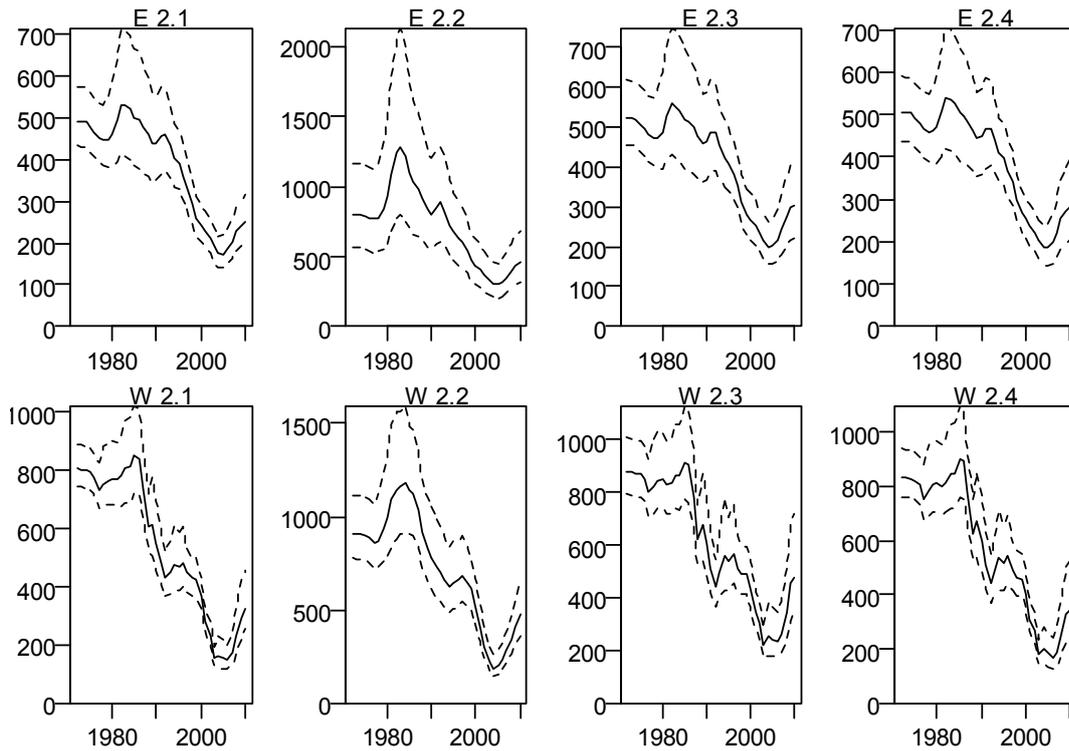
Figure 34: Estimated spawning-biomass trajectories from the MCMC runs, showing medians (solid lines) and 95% confidence intervals (broken lines) by run for E (upper panels) and W (lower panels).
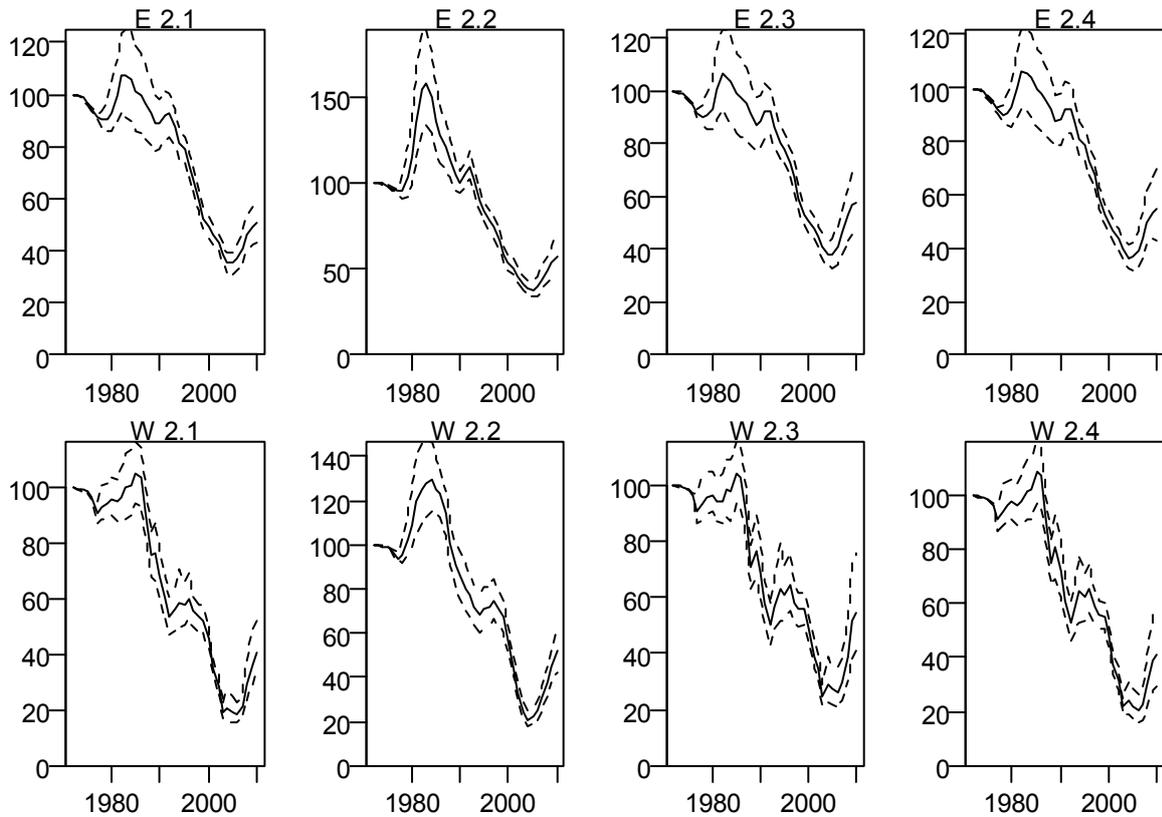
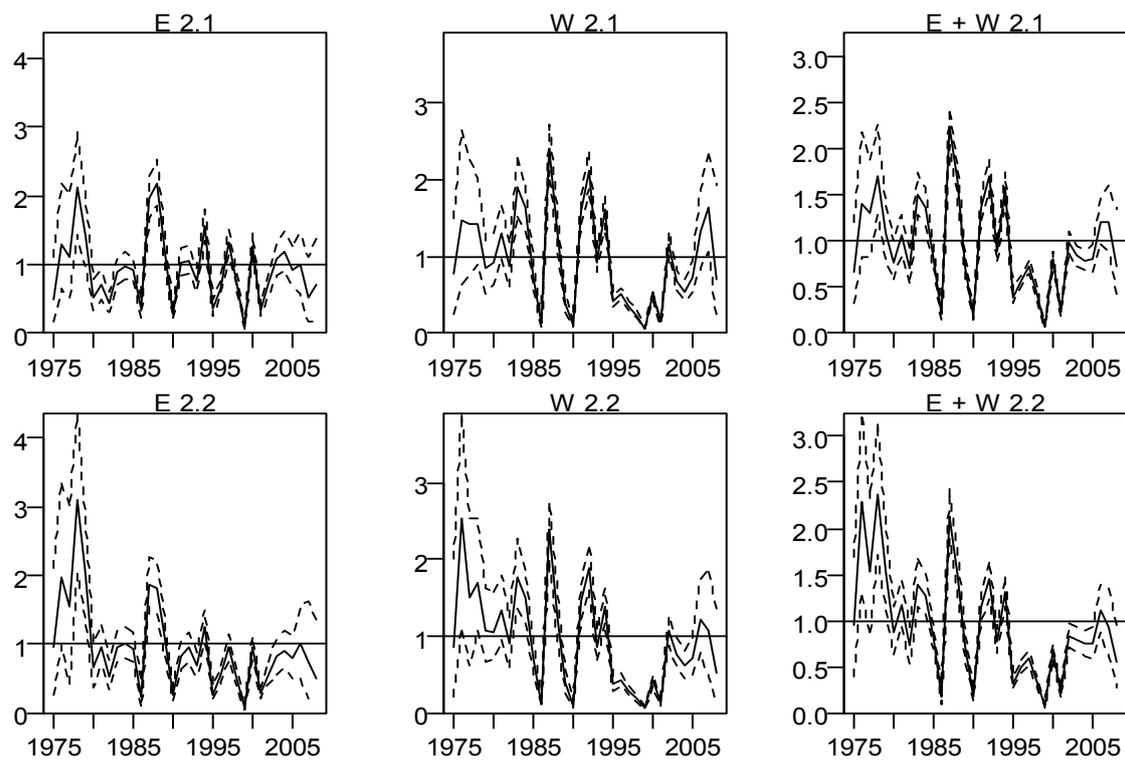**Figure 35: As for Figure 34, but plotted as %B_0.**

Figure 36: Estimated year-class strengths (YCSs) from the base 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).
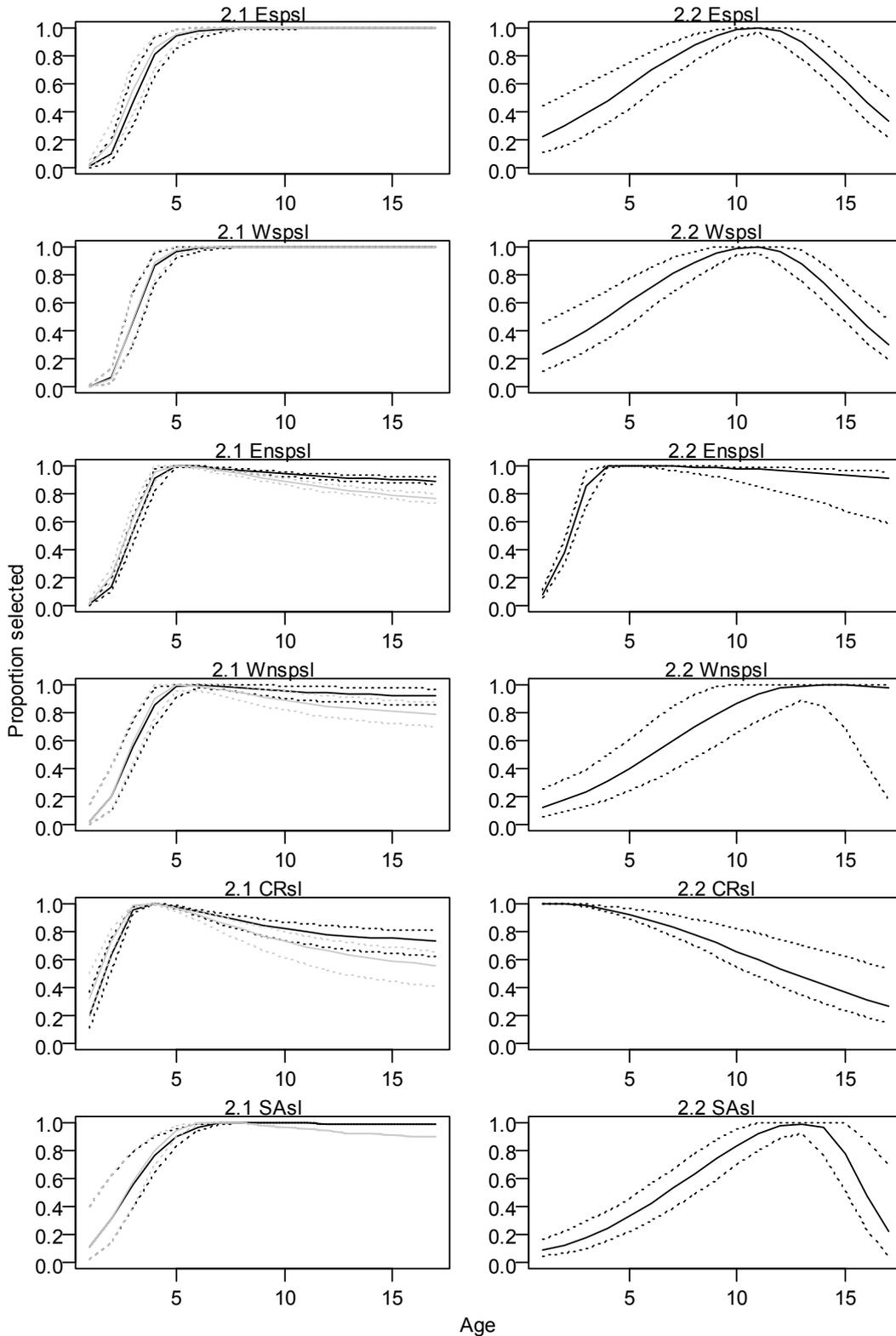
Figure 37: Posterior estimates of selectivity ogives for each for the two MCMC runs. Solid lines are medians; broken lines show 95% confidence intervals. Where ogives differ by sex they are plotted as black for males and grey for females. Where they differ by stock or time step the plotted curves are for one selected combination (E step 2 for Enspsl and CRsl, W step 2 for Wnspsl and SAsl).
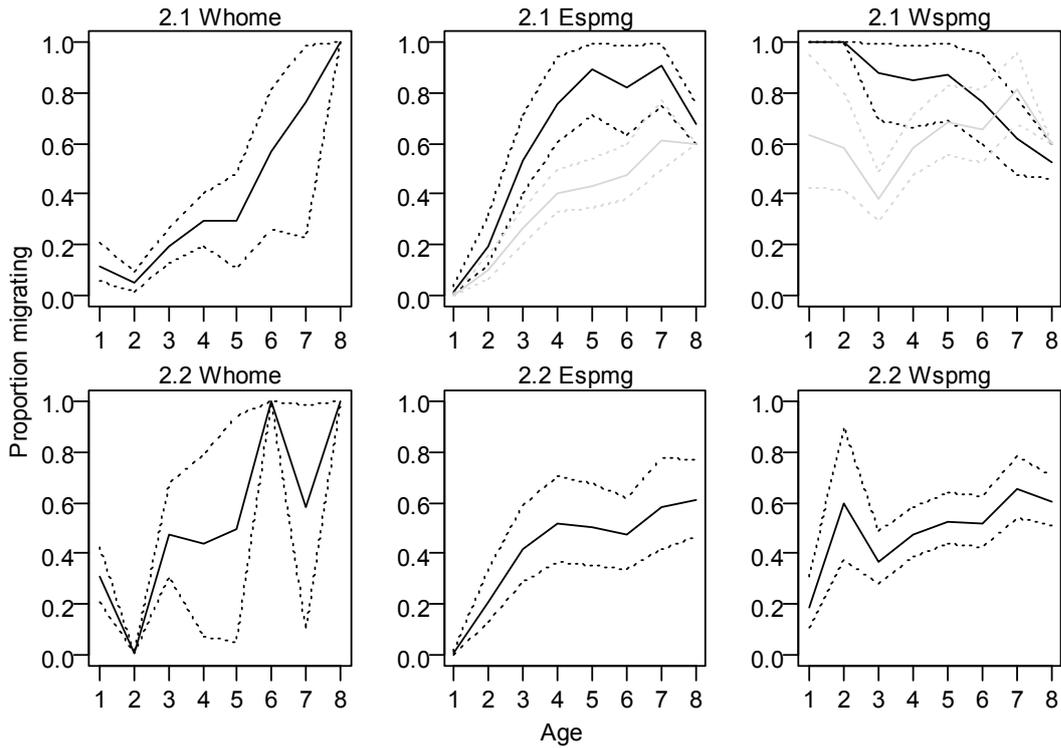
Figure 38: Migration ogives estimated in each of the two MCMC runs. Solid lines are medians, broken lines show 95% confidence intervals. Where ogives differ by sex they are plotted as black for males and grey for females (2.1 Espmg and 2.1 Wspmg).
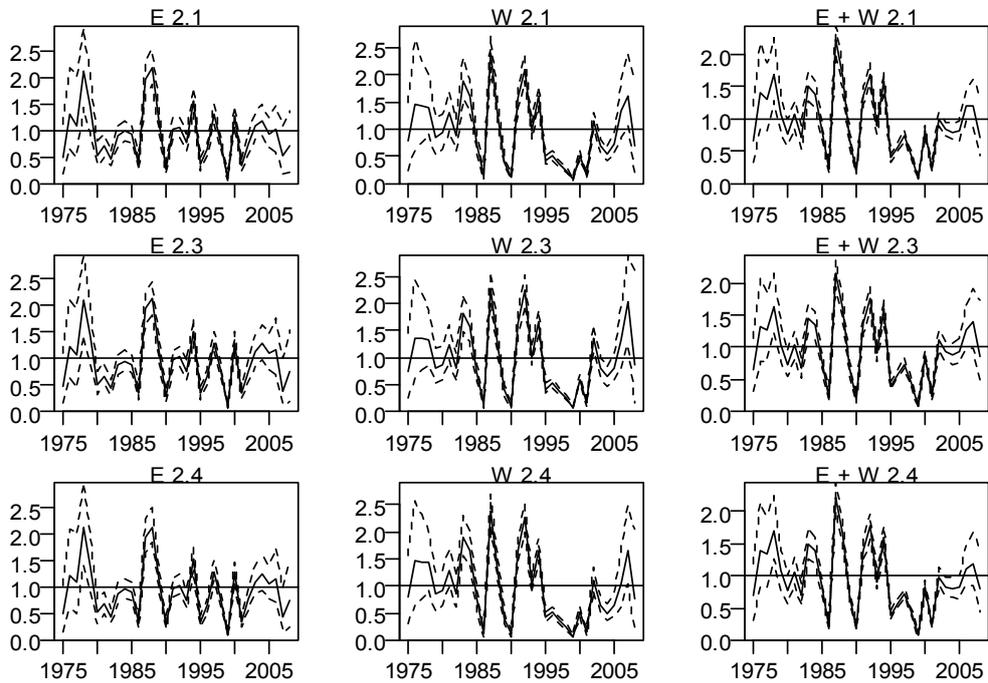

Figure 39: Estimated year-class strengths (YCSs) for one of the base MCMC runs (2.1) and its two sensitivty runs (2.3, 2.4), showing medians (solid lines) and 95% confidence intervals (broken lines) by run for E (left panels), W (middle panels) and E + W (right panels).
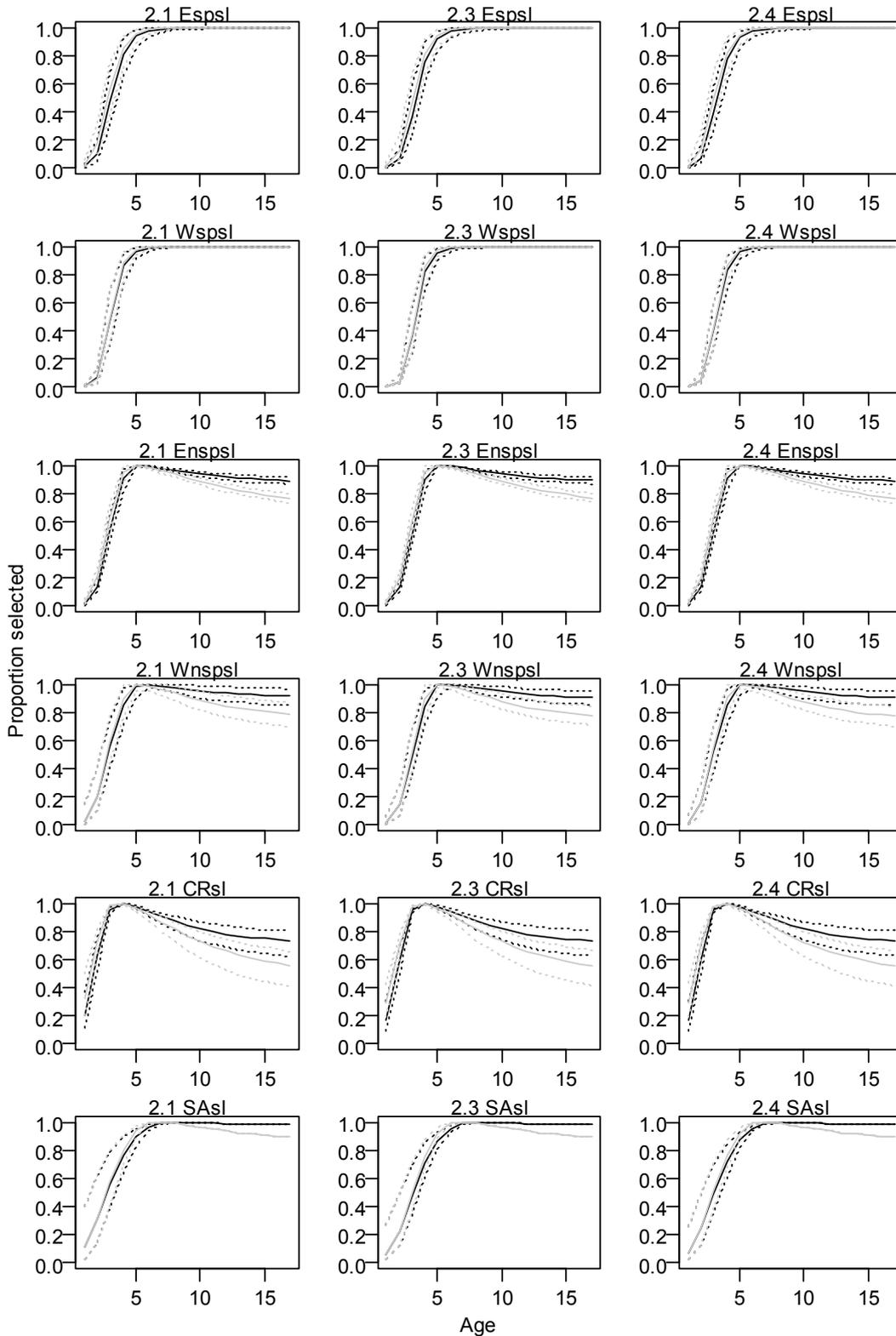
Figure 40: Posterior estimates of selectivity ogives for one of the base MCMC runs (2.1) and its two sensitivities (2.3, 2.4). Solid lines are medians; broken lines show 95% confidence intervals. Where ogives differ by sex they are plotted as black for males and grey for females. Where they differ by stock or time step the plotted curves are for one selected combination (E step 2 for Enspsl and CRsl, W step 2 for Wnspsl and SAsl).
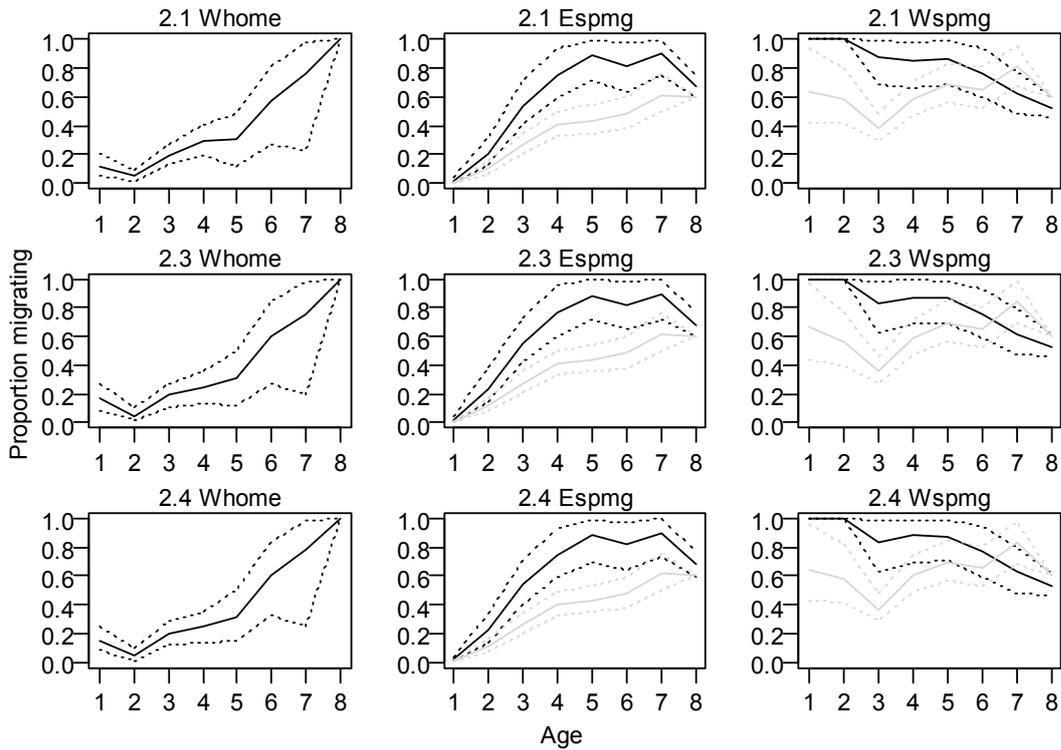
Figure 41: Migration ogives estimated in one of the base MCMC runs (2.1) and its two sensitivities (2.3, 2.4). Solid lines are medians, broken lines show 95% confidence intervals. Where ogives differ by sex they are plotted as black for males and grey for females (Espmg and Wspmg)
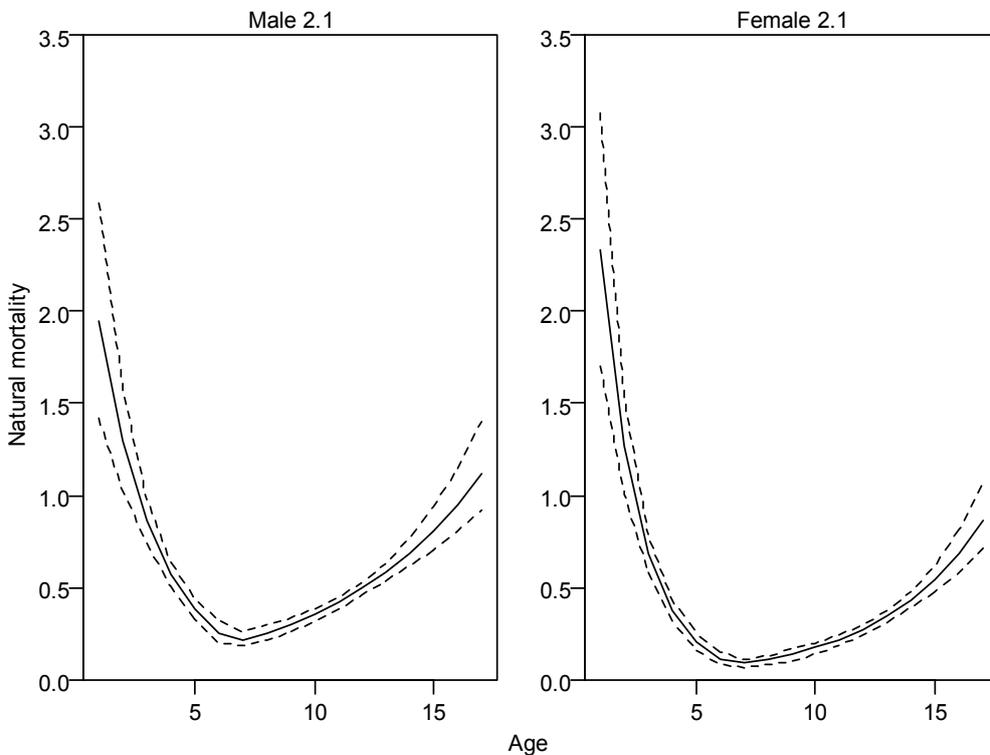

Figure 42: Estimates of age-dependent natural mortality ogives for run 2.1, showing median estimates (solid lines) and 95% confidence intervals (broken lines) for each sex.
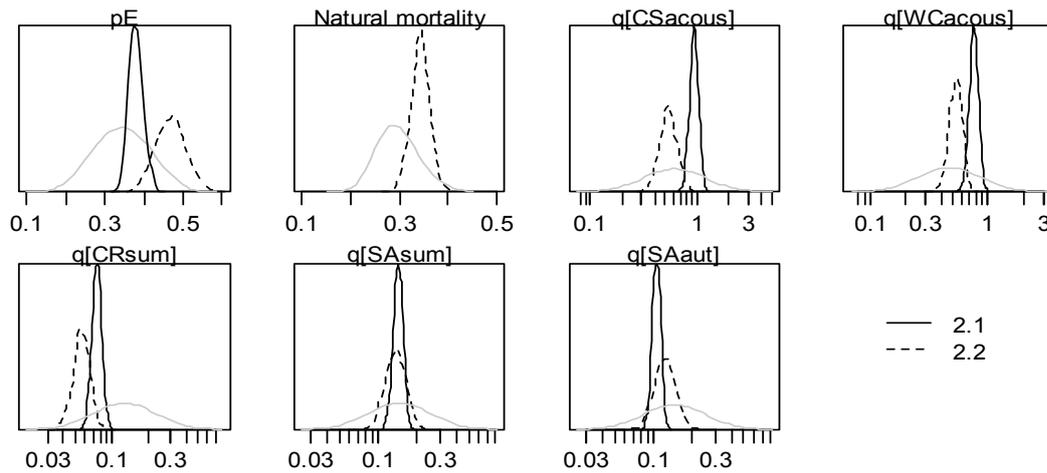
Figure 43: Prior (grey lines) and estimated posterior (black lines) distributions from the two base MCMC runs for the following parameters: pE (proportion of B_0 in E stock), natural mortality (independent of age, run 2.2 only), and survey catchabilities (acoustic and trawl).

5. PROJECTIONS

Five-year projections were carried out for each run with alternative recruitment scenarios: 'long-term' (future recruitment selected from estimated levels in 1975–2008) and 'recent' (recruitment selected from 1995–2008). Future catches for each fishery were assumed equal to those assumed for 2010.

With long-term recruitment, median spawning biomass increased for both stocks in all years. With recent recruitment, the median spawning biomass increased for the W stock, but remained constant or decreased slightly for the E stock (Figures 44 and 45). Exploitation rates are expected to decrease for both stocks, with very little difference between the recruitment scenarios (Figures 46 and 47).

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 35–50% 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 23, with future catches assumed equal to those for 2010. 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 0.05.
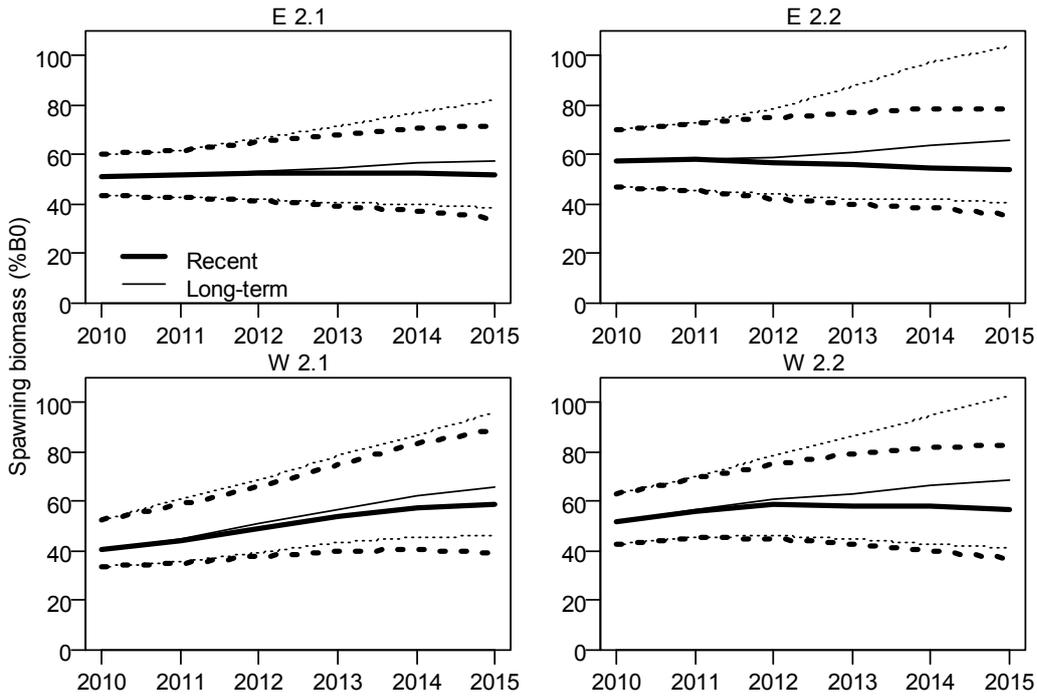
Figure 44: Trajectories of median spawning biomass (as %B₀) from the projections (solid lines) together with lower and upper bounds of a 95% confidence interval (broken lines) assuming 'long-term' (light lines) or 'recent' recruitment (heavy lines). Each panel shows results for one stock (E or W) from one of the two base MCMC runs (2.1, 2.2).
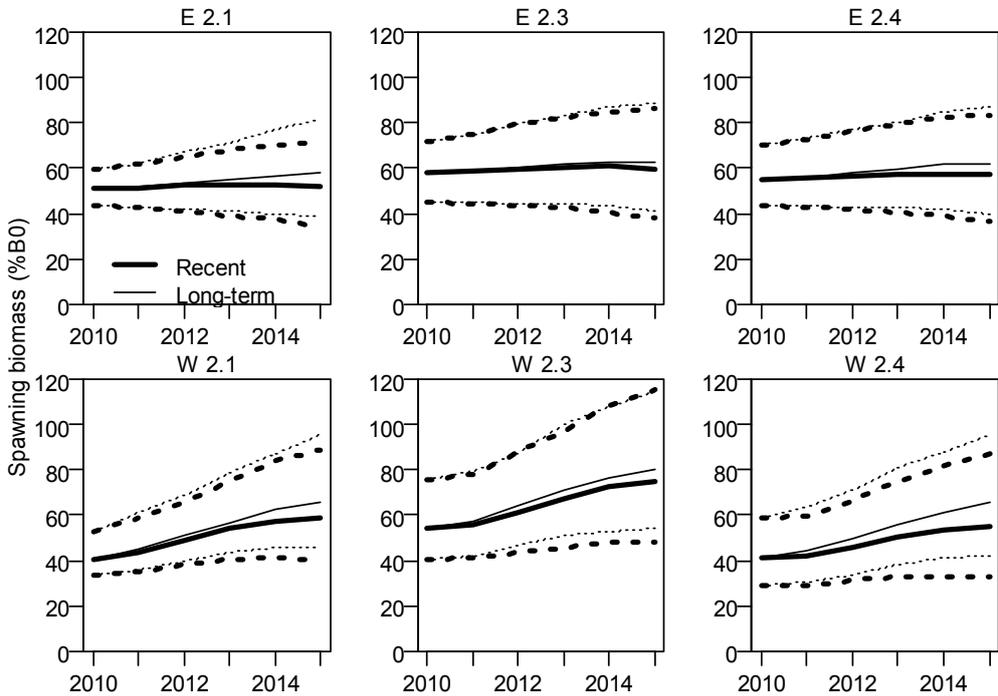

Figure 45: Trajectories of median spawning biomass (as %B₀) from the projections (solid lines) together with lower and upper bounds of a 95% confidence interval (broken lines) assuming 'long-term' (light lines) or 'recent' recruitment (heavy lines). Each panel shows results for one stock (E or W) from one of the base MCMC runs (2.1) and the two sensitivities for this (2.3, 2.4)

Figure 46: Estimated exploitation rates for 2010 and future years assuming long-term recruitment (light lines) or recent recruitment (heavy lines). Each panel shows results for one stock (E or W) from one of the two base MCMC runs (2.1, 2.2).
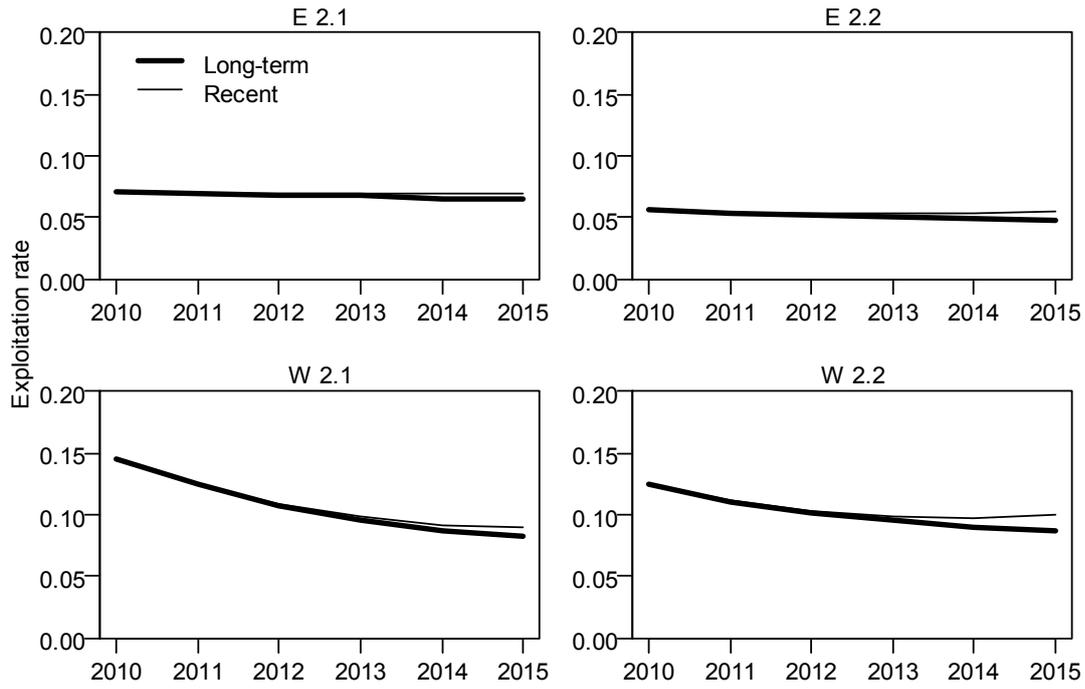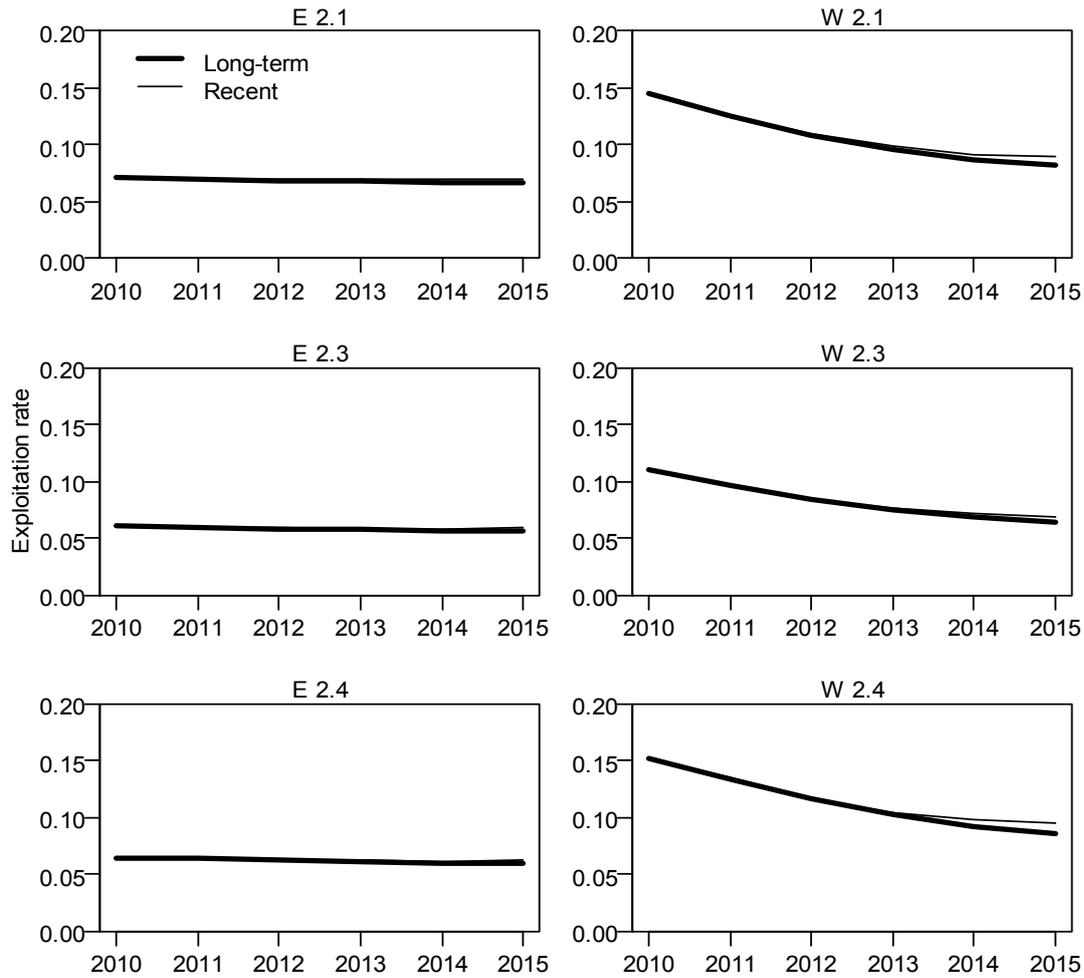
Figure 47: Estimated exploitation rates for 2010 and future years assuming long-term recruitment (light lines) or recent recruitment (heavy lines). Each panel shows results for one stock (E or W) from one of the base MCMC runs (2.1) and its two sensitivities (2.3, 2.4)

Table 23: Probabilities (rounded to two decimal places) associated with projections for SSB (%B_0) in Figures 44–45.

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

6. FISHING PRESSURE

The fishing pressure for a given stock and model run was calculated as an annual exploitation rate, $U_y = \max_{as} \left(\sum_f C_{asfy} / N_{asy} \right)$, where the subscripts a, s, f, and y index age, sex, fishery, and year, respectively, C is the catch in numbers, and N is the number of fish in the population immediately before the first fishery of the year.

This measure is deemed to be more useful than the spawning fisheries exploitation rates that have been presented in previous assessments, because it does not ignore the effect of the non-spawning fisheries, and thus represents the total fishing pressure on each stock. An alternative measure is the fishing pressure (F), which is virtually identical to U, except for the scale on which they are measured. However, as F may be less easily interpretable by non-scientists, U is preferred as a measure of fishing pressure.

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

Fishing intensity on both stocks was estimated to be at or near all-time highs in 2003 and is now substantially lower (Figure 48).
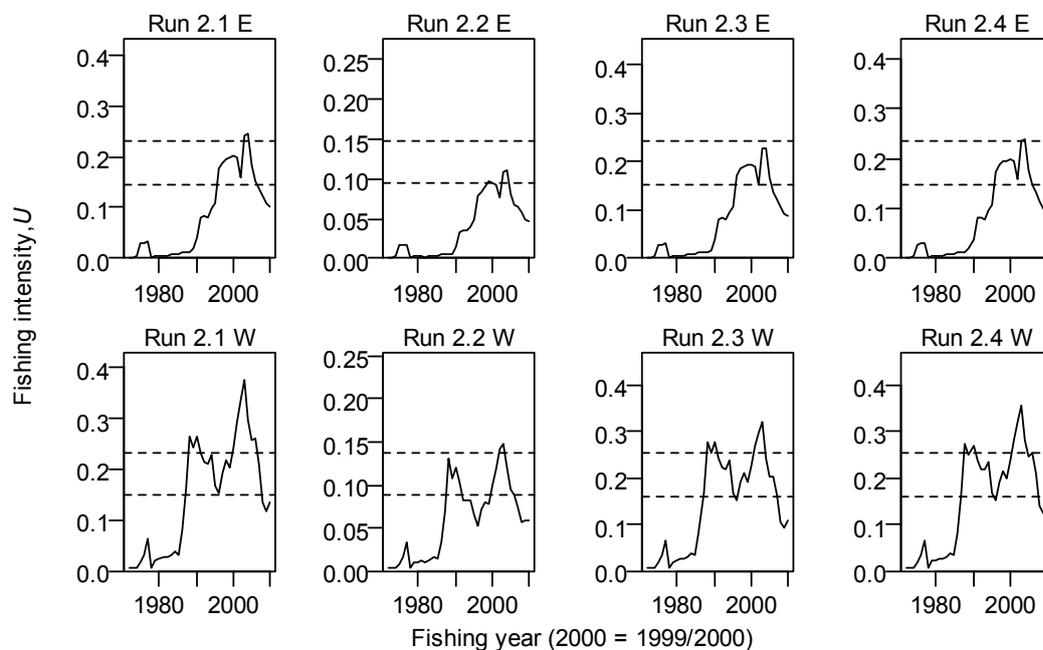

Figure 48: Fishing intensity, U, plotted by run and stock. Also shown (as broken lines) are the reference levels $U_{35\%}$ (upper line) and $U_{50\%}$ (lower line), which are the fishing intensities that would cause the spawning biomass to tend to $35\%B_0$ and $50\%B_0$, respectively. The y-axes are scaled so that the $U_{35\%}$ reference lines align horizontally (within and across the stocks).

7. CALCULATION OF B_{MSY}

B_{MSY} was calculated, for each stock and each of model runs 2.1 and 2.2, assuming a harvest strategy in which the exploitation rate for fishery f was $mU_{f,2010}$, where $U_{f,2010}$ is the estimated 2010 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 $24\%B_0$ for the E stock, and $25\%B_0$ for the W stock (Table 24). Sensitivity analyses (not presented) showed that these values changed very little (always by no more than $1\%B_0$) when the calculations were repeated using the final runs from the 2009 assessment, or when the harvest strategy was based on exploitation rates from a different year.

Table 24: Estimates of B_{MSY} (expressed as $\%B_0$) by stock for runs 2.1 and 2.2.

Run	Stock E	Stock W
2.1	24.4	26.4
2.2	22.9	24.4

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 (40–52 $\%B_0$), than the E stock (51–57 $\%B_0$). 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 (2002–08). 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 is random error in the observations, which is reasonably well dealt with in the assessment by the c.v.s that are assigned to individual observations. The second 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) and it 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 2.1, 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).