Assessment of hoki (*Macruronus novaezelandiae*) in 2011

A. McKenzie

NIWA
Private Bag 14901
Wellington 6241

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EXECUTIVE SUMMARY

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An updated assessment is presented for hoki that is based on the 2010 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) as in previous assessments. 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 a trawl survey from the Chatham Rise in January 2011, and proportions at age from three fisheries.

It was agreed 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 a single base run, with three sensitivities to the base run. In the base model run the problem of the lack of old fish in both fishery-based and survey-based observations is dealt with by allowing natural mortality to be age dependent. In one of the sensitivity runs this problem is dealt with by the alternative solution of having domed selectivities for the spawning fishery. Two other sensitivity runs were carried out in which instead of giving additional weight to the Sub-Antarctic trawl series, two catchabilities were fitted to this series instead of just one.

Both the eastern and western hoki stocks are estimated to be increasing after reaching their lowest levels in about 2005. The western stock is estimated to be 39–55%B_0 and the eastern stock 53–61%B_0. The western stock experienced an extended period of poor recruitment from 1995 to 2001, but recruitment has been near or above average in the last four years.

Five-year projections were carried out for each final run with two alternative recruitment scenarios: 'long-term' (future recruitment selected from estimated levels in 1975–2009) and 'recent' (recruitment selected from 1995–2009). Future catches for each fishery were assumed equal to those assumed for 2011. All projections, except one, suggest that continued fishing at current levels is likely to allow the biomass of both stocks to increase. The exception was the sensitivity run with a domed spawning fishery selectivity (under the recent recruitment scenario), for which the biomass remained fairly constant.

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; HOK 10 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). More recent assessments indicated that stock status had improved and the TACC was raised to 110 000 t for 2009–10, and to 120 000 t for 2010–11.
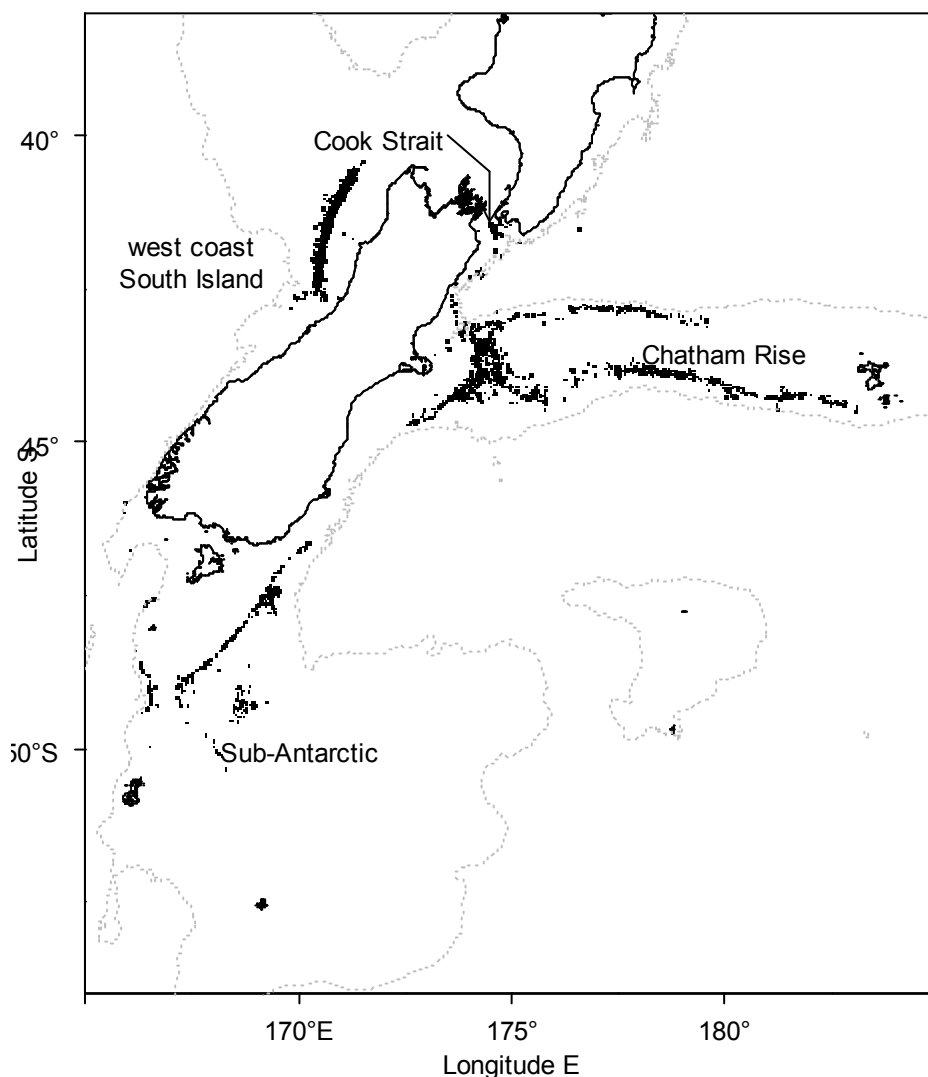

Figure 1: Southern New Zealand, showing the main hoki fishing grounds, the 1000 m contour (broken grey line), and the position of all 2009–10 tows from TCEPRs (Trawl Catch and Effort Processing Returns) in which at least 10 t of hoki was caught (dots).
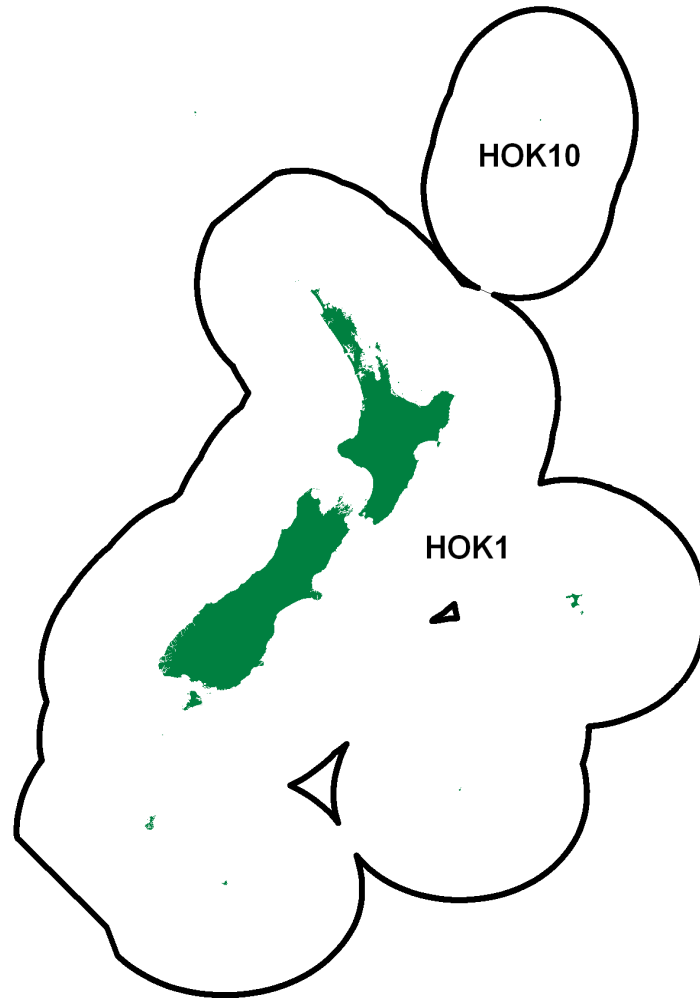
Figure 2: The Quota Management Areas for hoki.

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 2011 assessment of HOK 1, which is the tenth hoki assessment to use NIWA's general-purpose stock-assessment model CASAL (Bull et al. 2008). Since the last assessment (McKenzie 2011) there has been another trawl survey in Chatham Rise in January 2011 (Stevens et al. in press).

The work reported here addresses objective 1 of MFish project HOK200701D: *To update the stock assessment of hoki in the year 2011, including estimates of biomass, risk and yields.*

2. MODEL ASSUMPTIONS AND INPUTS FOR 2011

This section provides a summary of all model assumptions and inputs for the 2011 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). Changes in model structure and data inputs since the first CASAL stock assessment in 2002 are documented in Appendix 2.

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 starting on 1 October, 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 and proportions at age from CR summer trawl survey
	SAsumbio, SAsumage	biomass index and proportions at age from SA summer trawl survey
	SAautbio, SAautage	biomass index and 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 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 2011 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 the 2010 assessment. 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 the 2010 assessment. 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 ("Prop. 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	Prop. 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 2010, 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 2010 were slightly revised using the most recent data from MFish, and the catch for 2010 is scaled up to the MHR (Monthly Harvest Return) total of 107 200 t.

For the current year (2011), the new TACC is 120 000 t with a catch split arrangement for 60 000 t to be taken from the eastern stock and 60 000 t from the western stock. For the assumed 2011 model catch it was agreed by the Hoki Working Group that, relative to 2010, an extra 3000 t would be taken from the Sub-Antarctic non-spawning fishery and 7000 t from the west coast South Island spawning fishery. To bring the assumed catch up to the TACC of 120 000 t, with a catch split of 60 000 t each for the eastern and western stocks, an additional 2800 t was allocated. Of this additional 2800 t there was 1100 t allocated to the western stock (with 30% to the Sub-Antarctic and 70% to the west coast South Island).

The proportion of the catch taken from the western fisheries increased between 1996 and 2002, then dropped as fishers shifted effort from west coast South Island (Wsp) to Cook Strait (Esp) to reduce pressure on the W stock. The proportion increased to 50% in 2011. (Figure 3).

The fixed biological parameters in the model are unchanged from those used in 2010 (Table 5).

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

Year	Ensp1	Ensp2	Wnsp1	Wnsp2	Esp	Wsp	Total
						Fishery	
1972	1 500	2 500	0	0	0	5 000	9 000
1973	1 500	2 500	0	0	0	5 000	9 000
1974	2 200	3 800	0	0	0	5 000	11 000
1975	13 100	22 900	0	0	0	10 000	46 000
1976	13 500	23 500	0	0	0	30 000	67 000
1977	13 900	24 100	0	0	0	60 000	98 000
1978	1 100	1 900	0	0	0	5 000	8 000
1979	2 200	3 800	0	0	0	18 000	24 000
1980	2 900	5 100	0	0	0	20 000	28 000
1981	2 900	5 100	0	0	0	25 000	33 000
1982	2 600	4 400	0	0	0	25 000	32 000
1983	1 500	8 500	3 200	3 500	0	23 300	40 000
1984	3 200	6 800	6 700	5 400	0	27 900	50 000
1985	6 200	3 800	3 000	6 100	0	24 900	44 000
1986	3 700	13 300	7 200	3 300	0	71 500	99 000
1987	8 800	8 200	5 900	5 400	0	146 700	175 000
1988	9 000	6 000	5 400	7 600	600	227 000	255 600
1989	2 300	2 700	700	4 900	7 000	185 900	203500
1990	3 300	9 700	900	9 100	14 000	173 000	210000
1991	17 400	14 900	4 400	12 700	29 700	135 900	215000
1992	33 400	17 500	14 000	17 400	25 600	107 200	215100
1993	27 400	19 700	14 700	10 900	22 200	100 100	195 000
1994	16 000	10 600	5 800	5 500	35 900	117 200	191 000
1995	29 600	16 500	5 900	7 500	34 400	80 100	174 000
1996	37 900	23 900	5 700	6 800	59 700	75 900	209 900
1997	42 400	28 200	6 900	15 100	56 500	96 900	246 000
1998	55 600	34 200	10 900	14 600	46 700	107 100	269 100
1999	59 200	23 600	8 800	14 900	40 500	97 500	244 500
2000	43 100	20 500	14 300	19 500	39 000	105 600	242 000
2001	36 300	19 700	13 200	16 900	34 600	109 100	229 800
2002	24 600	18 100	16 800	13 400	24 600	98 000	195 500
2003	24 000	18 700	12 400	7 800	41 800	79 800	184 500
2004	17 900	19 000	6 400	5 300	41 000	46 300	135 900
2005	19 300	13 900	4 400	2 000	26 300	38 500	104 400
2006	22 000	14 700	2 000	4 700	20 500	40 400	104 300
2007	22 400	18 400	4 200	3 500	18 700	33 800	101 000
2008	22 100	19 400	6 500	2 200	17 900	21 200	89 300
2009	29 300	13 100	6 000	3 800	15 800	20 800	88 800
2010	28 500	13 500	6 700	5 600	16 300	36 600	107 200
2011	29 300	13 900	8 500	7 100	16 800	44 400	120 000

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 and North Island; null[1]	Ensp1	Ensp2	Ensp2

[1] no area stated
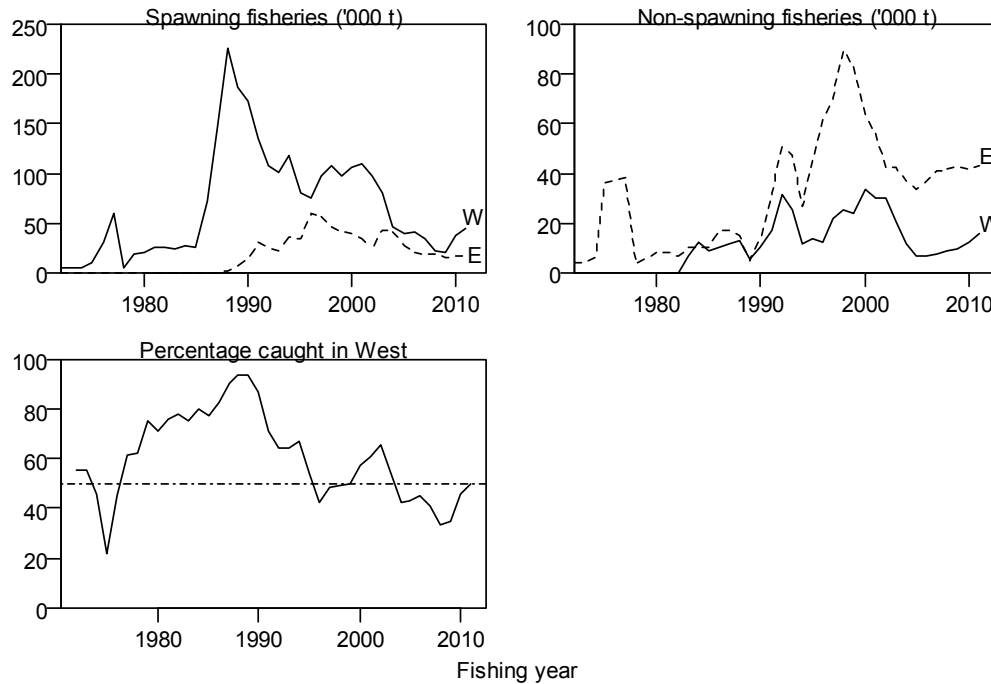
Figure 3: Annual catches by fishery for the spawning (top left panel) and non-spawning (top right panel) fisheries, and annual percentage of catch caught in western fisheries (Wsp, Wnsp1, Wnsp2) (bottom panel).

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	W stock Female	W stock Both	E stock Male	E stock Female	E stock 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 2010: 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. See section 3.1 for an explanation of the model runs.

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 $A > 8$
	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 further 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 2011 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	2010	Mean
309	309	308	309	307	309	310	307	301	295	298	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 (Francis 2008), 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

2006, inclusive (so R_0 is mean recruitment over those years, ignoring the effect of the stock-recruit relationship).

Thirty-five YCSs were estimated for each stock, for 1975 to 2009, inclusive. YCSs for the initial years (1970 to 1974) were fixed at 1. The E and W YCSs for 2009 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 (by sex) (Table 9, Figure 4), and proportion spawning (Table 10). A biomass index new to this assessment came from a trawl survey of the Chatham Rise in January 2011 (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 (McKenzie 2011, 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%.

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)	–	–	–
2011	**94 (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. Data for Wnspage in 2009 were unavailable for the 2010 assessment, but were for the 2011 assessment.

Area	Label	Data type	Years	Source of age data
WC	Wspage	Catch at age	1988–**10**	Otoliths
SA	WnspOLF	Catch at age	1992–94, 96, 99–00	OLF
	Wnspage	Catch at age	2001–04, 06–**09, 10**	Otoliths
	SAsumage	Trawl survey	1992–94, 2001–10	Otoliths
	SAautage	Trawl survey	1992, 96, 98	Otoliths
CS	Espage	Catch at age	1988–**10**	Otoliths
CR	EnspOLF	Catch at age	1992, 94, 96, 98	OLF
	Enspage	Catch at age	1999–09	Otoliths
	CRsumage	Trawl survey	1992–**11**	Otoliths

Table 10: Proportions 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 upper 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
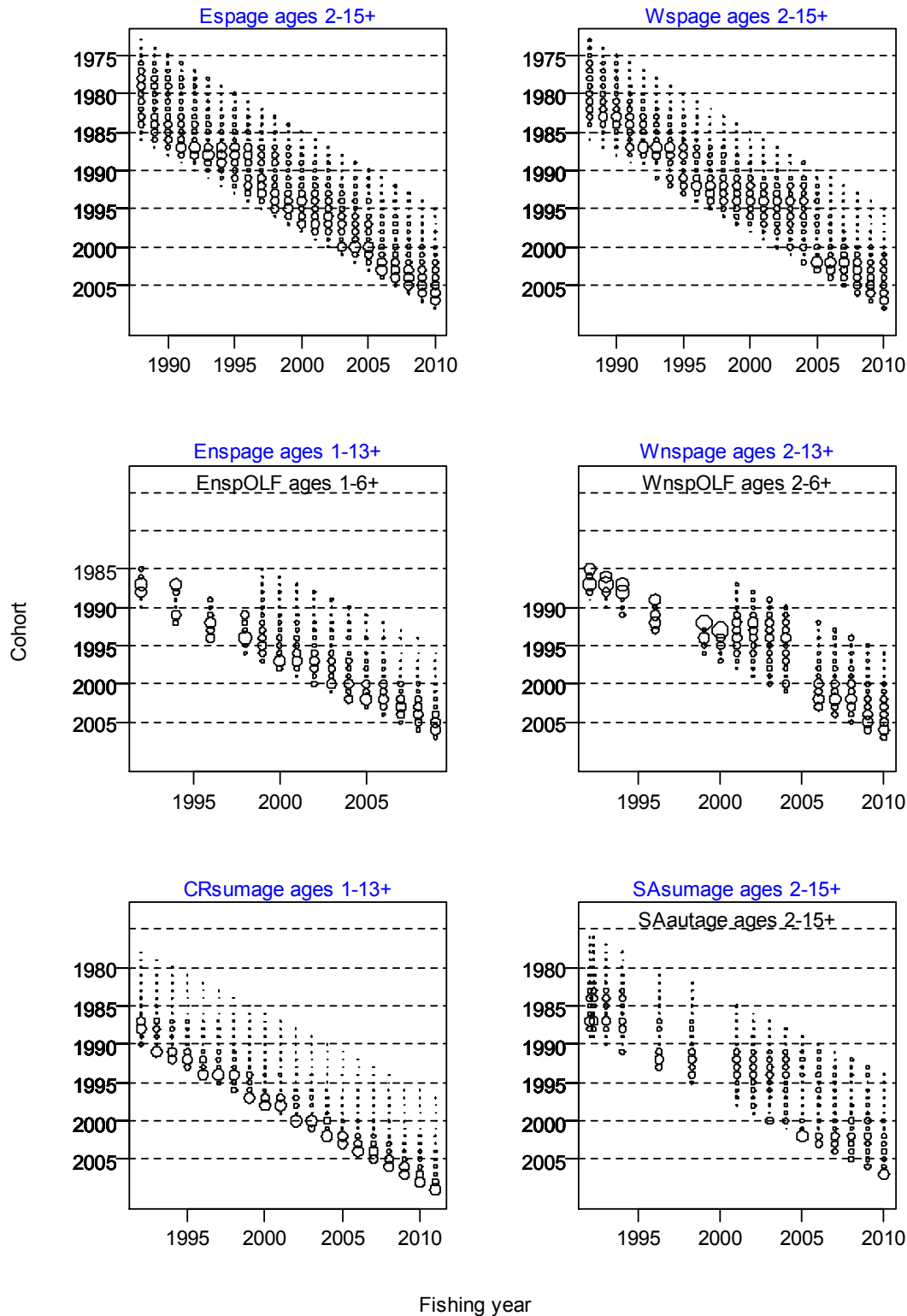
Figure 4: Proportions-at-age data, plotted by cohort and fishing year, with both sexes combined. The area of each circle is proportional to the associated proportion at age. Circle positions for the SAautage data have been offset horizontally to allow them to be plotted on the same panel as the SAsumage data. Data new to the assessment are shown in Table 9.

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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 5).

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).
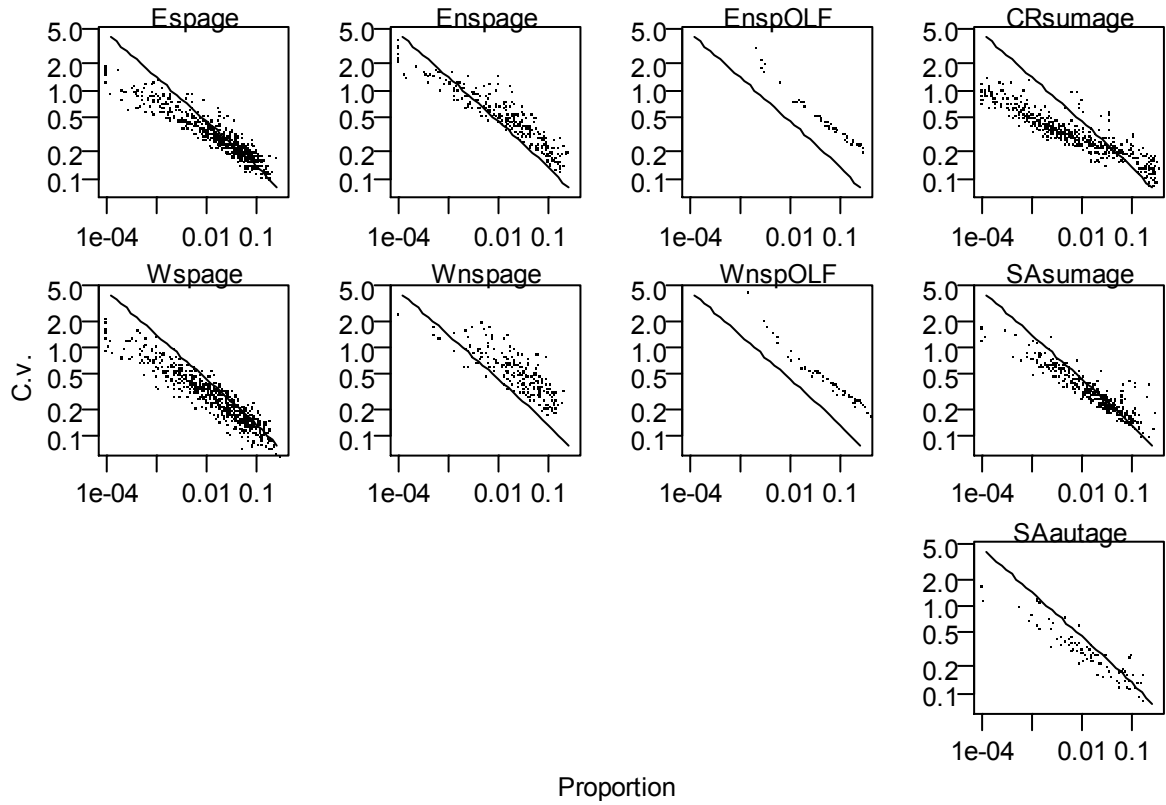
Figure 5: Observation-error c.v.s for the proportions-at-age data sets. Each point represents a proportion at a specific age and sex for a given year. The diagonal line, which is the same in each panel, is added to aid comparison between panels; it shows the relationship between proportion and c.v. that 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 147 (for run 1.1) or 125 (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. 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 1.1 and 1.2, respectively (see section 3.1 for explanation of the model runs). 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	70
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[c]	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
					147,125

[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
[c] In some sensitivity runs two catchabilities are estimated

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 2010 assessment, (2) investigating whether or not to upweight the trawl surveys to improve the fit to the biomass indices, and (3) exploring the effect of the selectivity shift parameter on the western spawning selectivity.

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 2.1 and 2.2 respectively from 2010, but used the new data (Table 13).

Table 13: Relationship between initial 2011 model runs and those from the 2010 assessment. Runs labelled 2.1 and 2.2 for 2010 are the two final model runs selected by the Hoki Working Group for the 2010 assessment. In all model runs in this table the trawl survey biomass data are upweighted.

2011 label	2010 label	Response to lack of old fish in the observations	Sex in model and selectivities length-based?
1.1	2.1	M dependent on age	Yes
1.2	2.2	Domed spawning selectivity	No

The biomass trajectory for the 2011 model runs are compared to those from last year's assessment (Table 14, Figure 6). The only significant difference is for the western stock of run 1.2: the estimated virgin biomass is about 15% less than that of the previous assessment.

Table 14: 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 2010 and the other is from 2011.

Assessment year		B_0('000 t) E	W	E+W	$B_{2010}(\%B_0)$ E	W	E+W	$B_{2011}(\%B_0)$ E	W	E+W
2010	2.1	460	777	1 237	50	37	42	–	–	–
2011	1.1	456	790	1 246	50	34	40	53	38	43
2010	2.2	671	1 001	1 672	49	40	44	–	–	–
2011	1.2	616	846	1 462	46	39	42	49	43	46

The year class strengths are very similar to those from the last assessment (Figure 7). However, as observed for the 2009 assessment, the estimate of the W stock YCS for the youngest cohort in common (2008 for the 2011 assessment) differs between assessments (McKenzie & Francis 2009). This is attributed to it having been poorly estimated compared to other year classes. An overall impression of the year class strengths is that they more closely match between model runs than they did in the previous assessment; in particular the extremes in run 1.2 are less than before.

Other graphs show exploitation rates, selectivities, migration ogives, and fitted age-varying natural mortality (Figures 8–11). The exploitation rates for the western spawning stock more closely match between the model runs than they did in the previous assessment. There are some significant changes in the selectivities for run 1.2, and the eastern spawning migration ogive has also changed for this run. However the MPD values for the newly estimated selectivities are similar to the medians of the posterior from the MCMC results from the 2010 assessment (McKenzie 2011). A likely explanation for this is that a local minimum was estimated for run 1.2 in 2010. Estimated age-varying natural mortality for run 1.1 is very similar to the previous assessment.

For CRsumage the fits to the proportions-at-age tended to improve from 2001 to 2009, but have worsened in the last two years (Figures 12–13). For SAsumage the fits are generally better in the last five years compared to the preceding block of six years (Figures 14–15). Here better or worse fits are assessed relative to the c.v.s associated with the data.
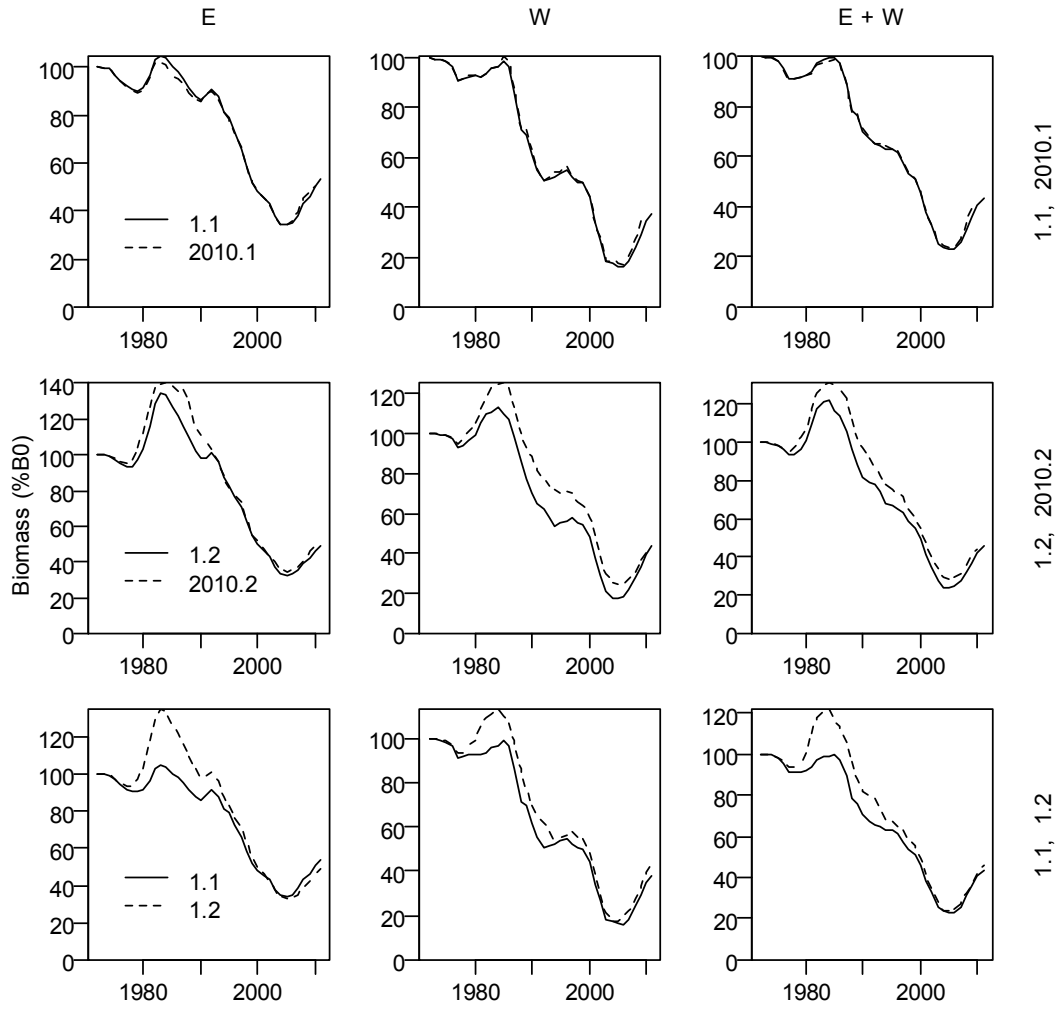
Figure 6: Comparison of biomass trajectories from different runs: E stock (left column), W stock (middle column), and E + W stocks combined (right column). The top two rows of panels compare each new run (solid lines) with the corresponding run from 2010 (broken lines); the bottom row compares the two new runs. The label 2010.1 refers to run 2.1 from 2010, and similarly for the label 2010.2.
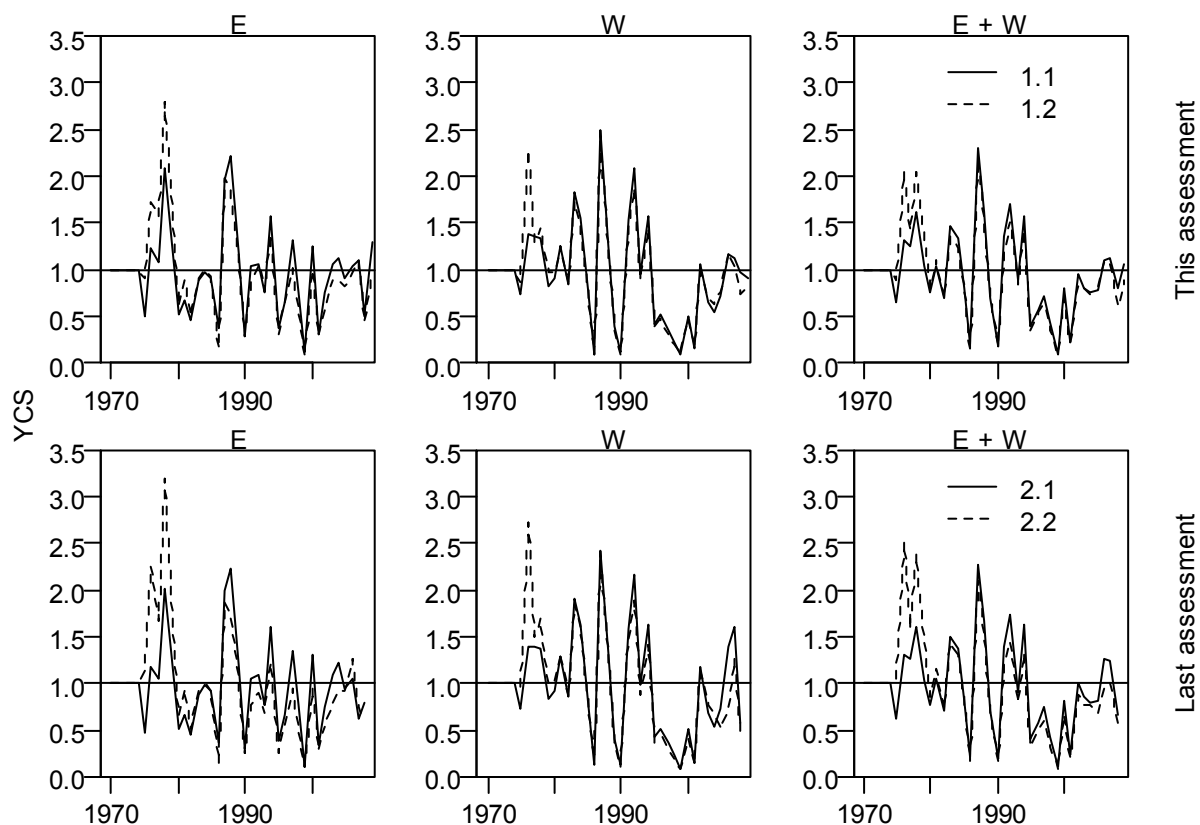
Figure 7: YCS estimates for new runs 1.1, 1.2 (upper panels) and the runs from last year's assessment (lower panels).
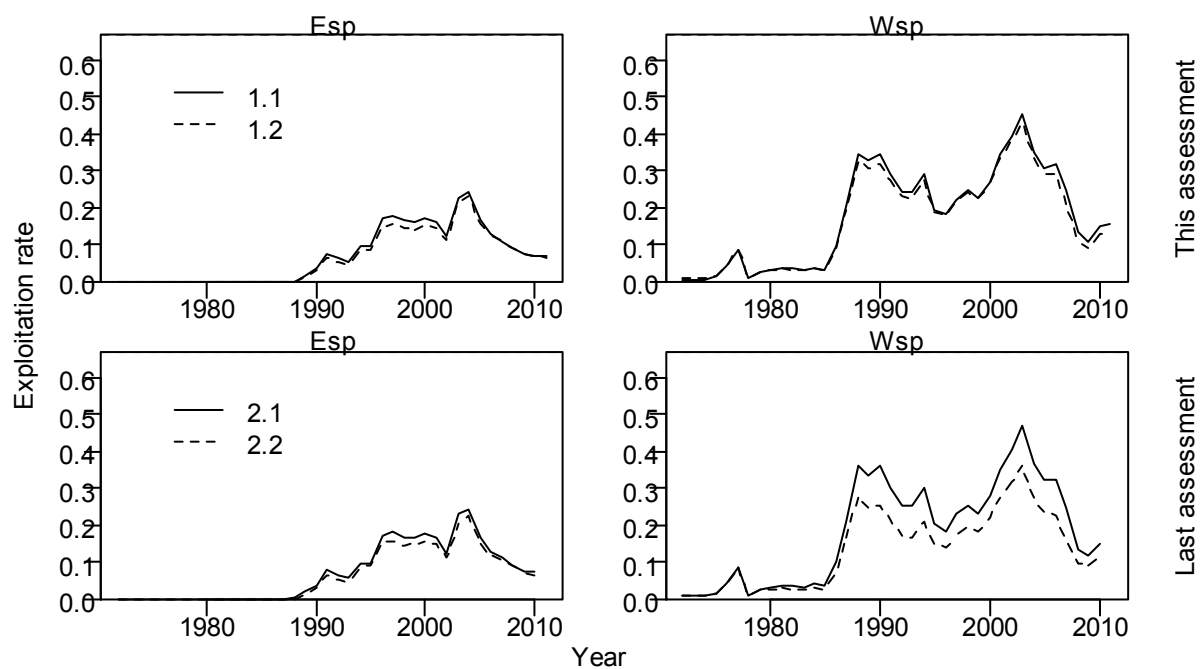
Figure 8: Estimated exploitation rates from runs 1.1 and 1.2 for this assessment (upper panels) and the main runs from last year's assessment (lower panels).
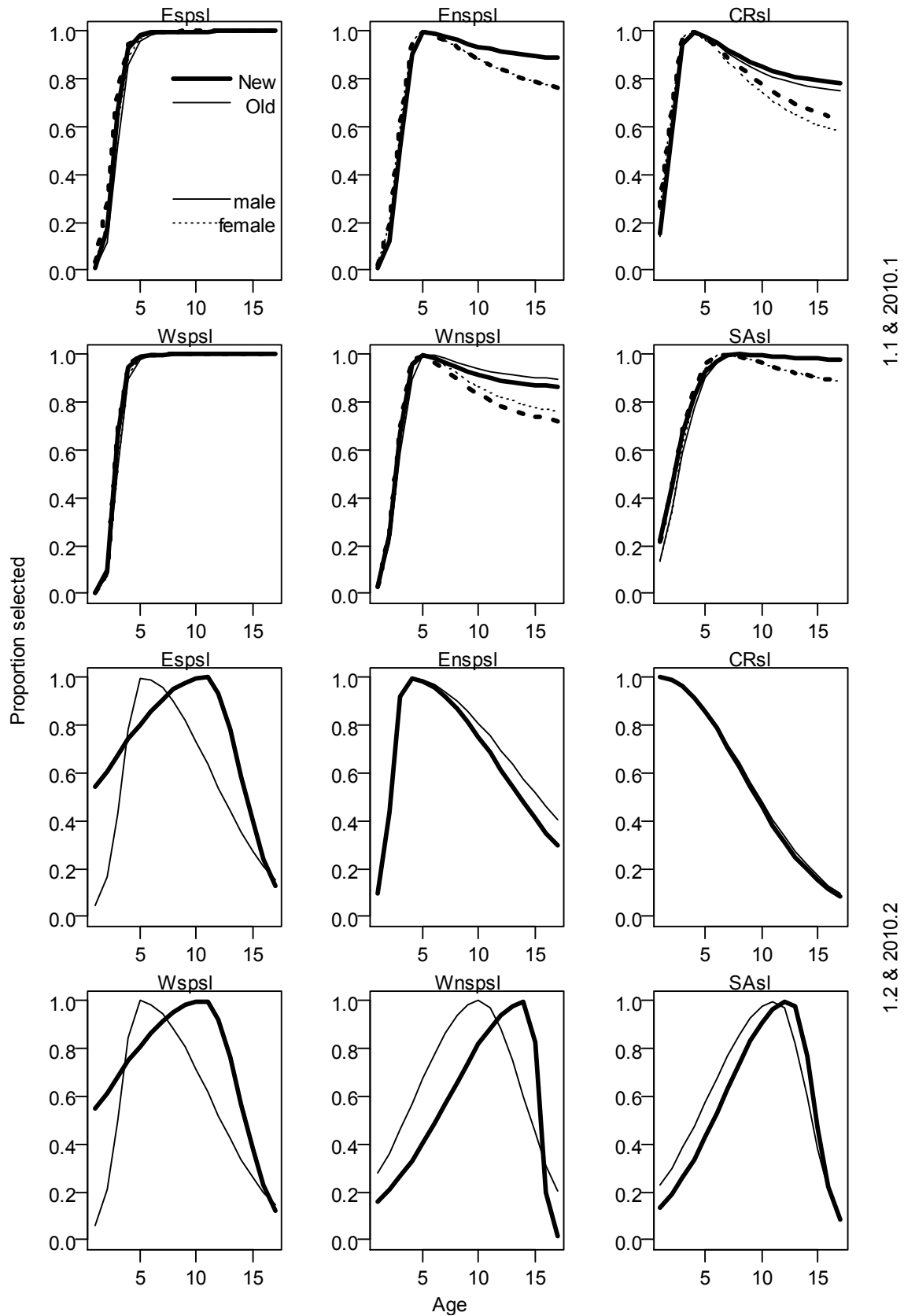
Figure 9: Estimated selectivity curves for new model runs (heavy lines) and analogous 2010 runs (light lines). Males are shown by a solid line, females by a dotted line. The label 2010.1 denotes run 2.1 for the 2010 assessment; similarly for the label 2010.2.
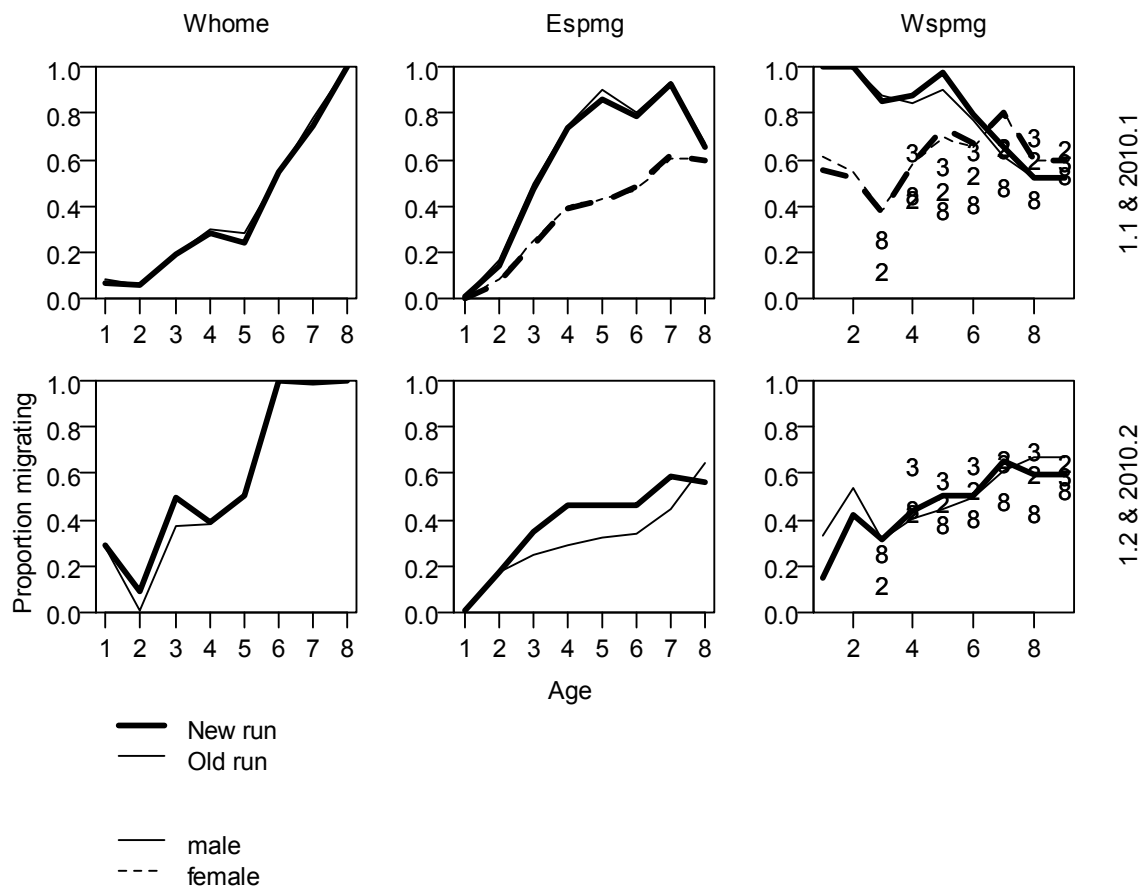
Figure 10: Estimated migration ogives for new and old runs. Each row of plots compares ogives from a new run (heavy lines) with those from the analogous 2010 runs (light lines). Where ogives differ by sex, female ogives are plotted as broken lines. The observations pspawn are also plotted in the rightmost panels, with the plotting symbol identifying the year of sampling ('2' = 1992, '3' = 1993, '8' = 1998). The label 2010.1 denotes run 2.1 for the 2010 assessment; similarly for the label 2010.2.
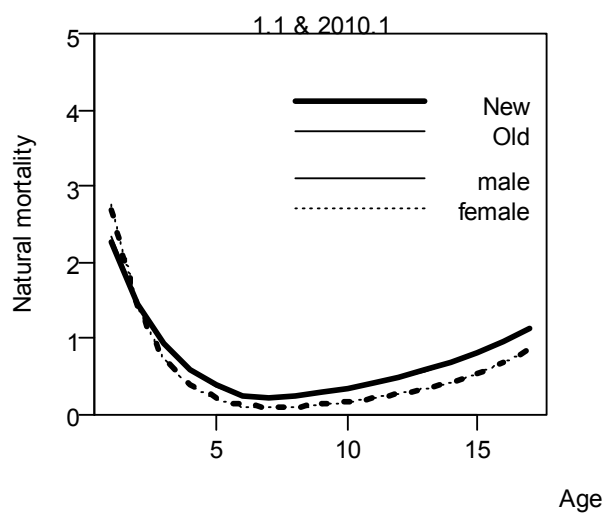
Figure 11: Comparison between age-dependent natural mortality estimated in the new run (heavy lines) and the corresponding run from 2010 (light lines). The label 2010.1 denotes run 2.1 for the 2010 assessment.
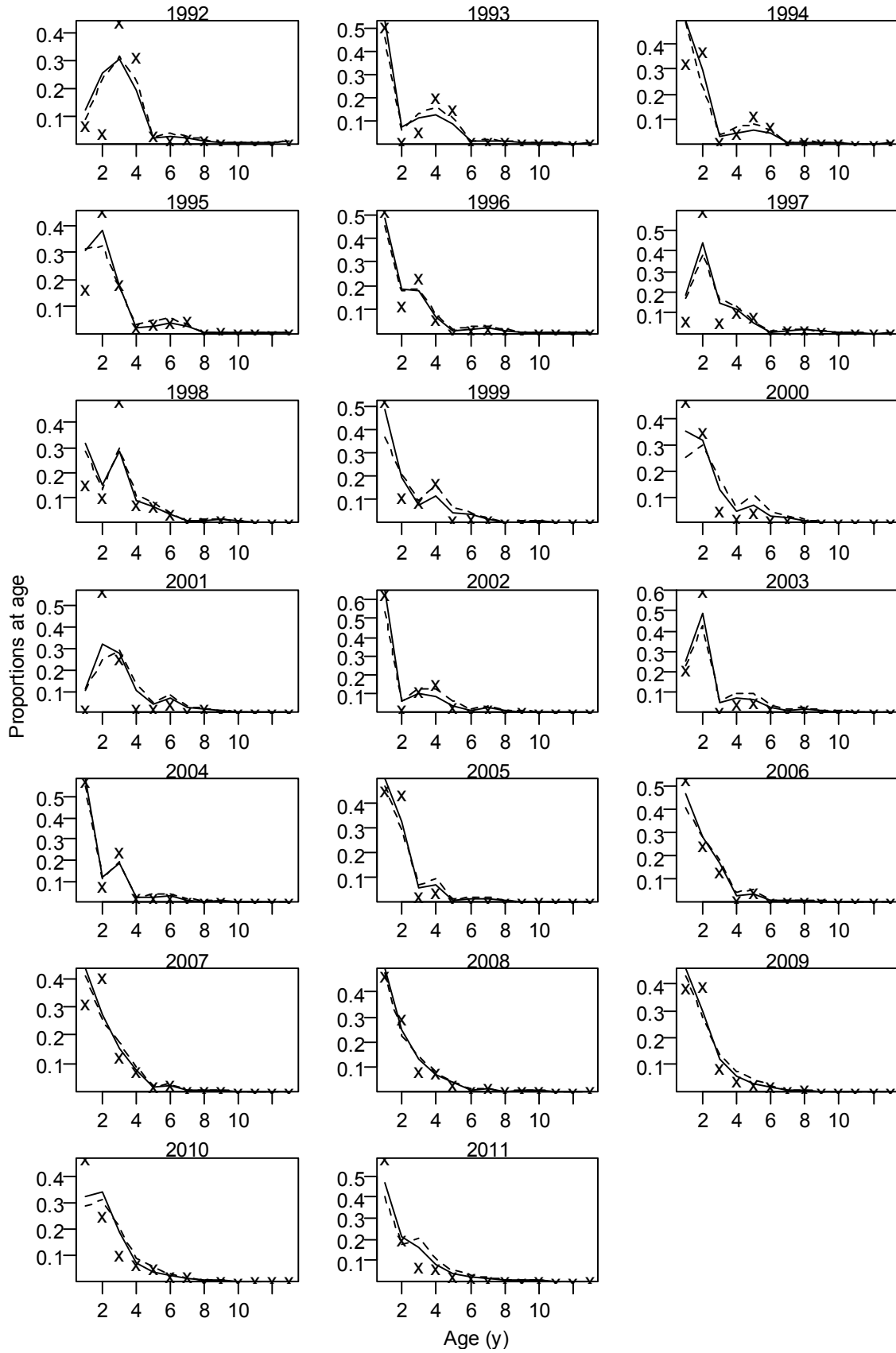
Figure 12: Observed ('x') and expected (lines) proportions at age in the summer Chatham Rise survey (data set CRsumage) for runs 1.1 (solid line) and 1.2 (broken lines).
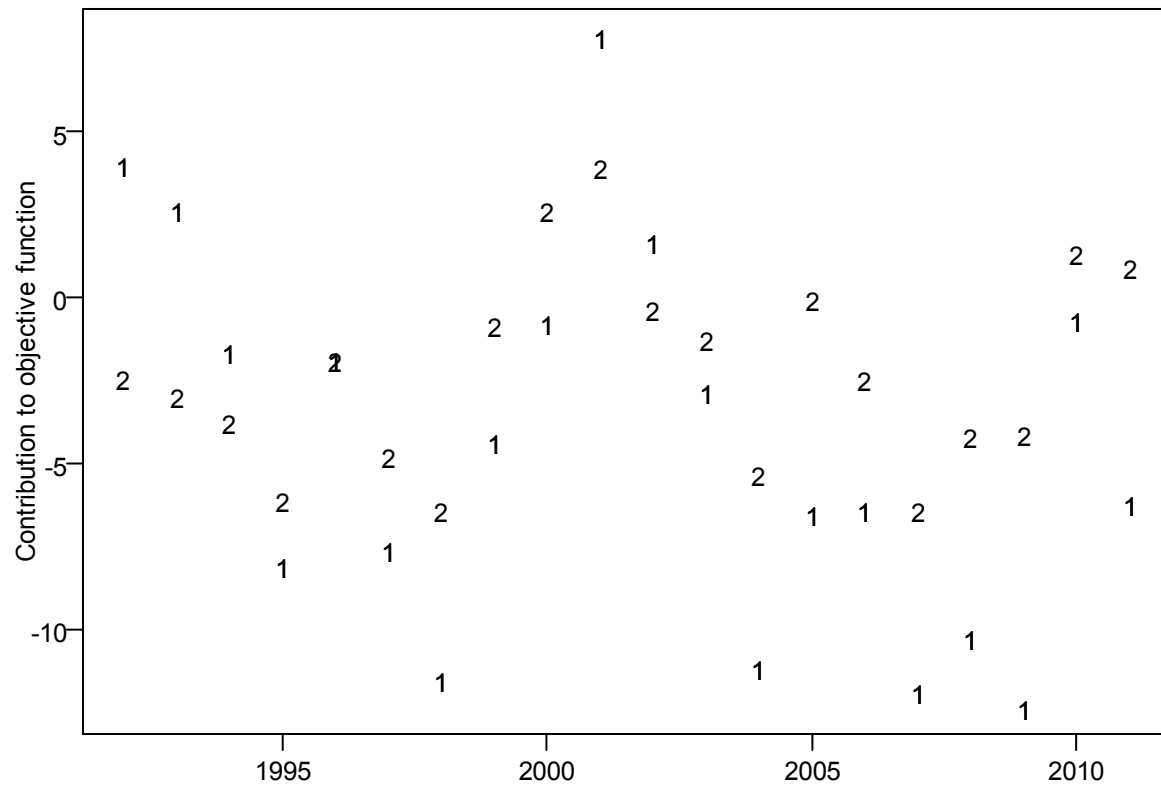
Figure 13: Goodness of fit to the CRsumage data, by year, for runs 1.1 ('1') and 1.2 ('2'). The y-value for each point indicates the contribution to the objective function from one year's CRsumage data; smaller values indicate a better fit. Plotted years are as in the model (so the last survey is plotted at 2011).
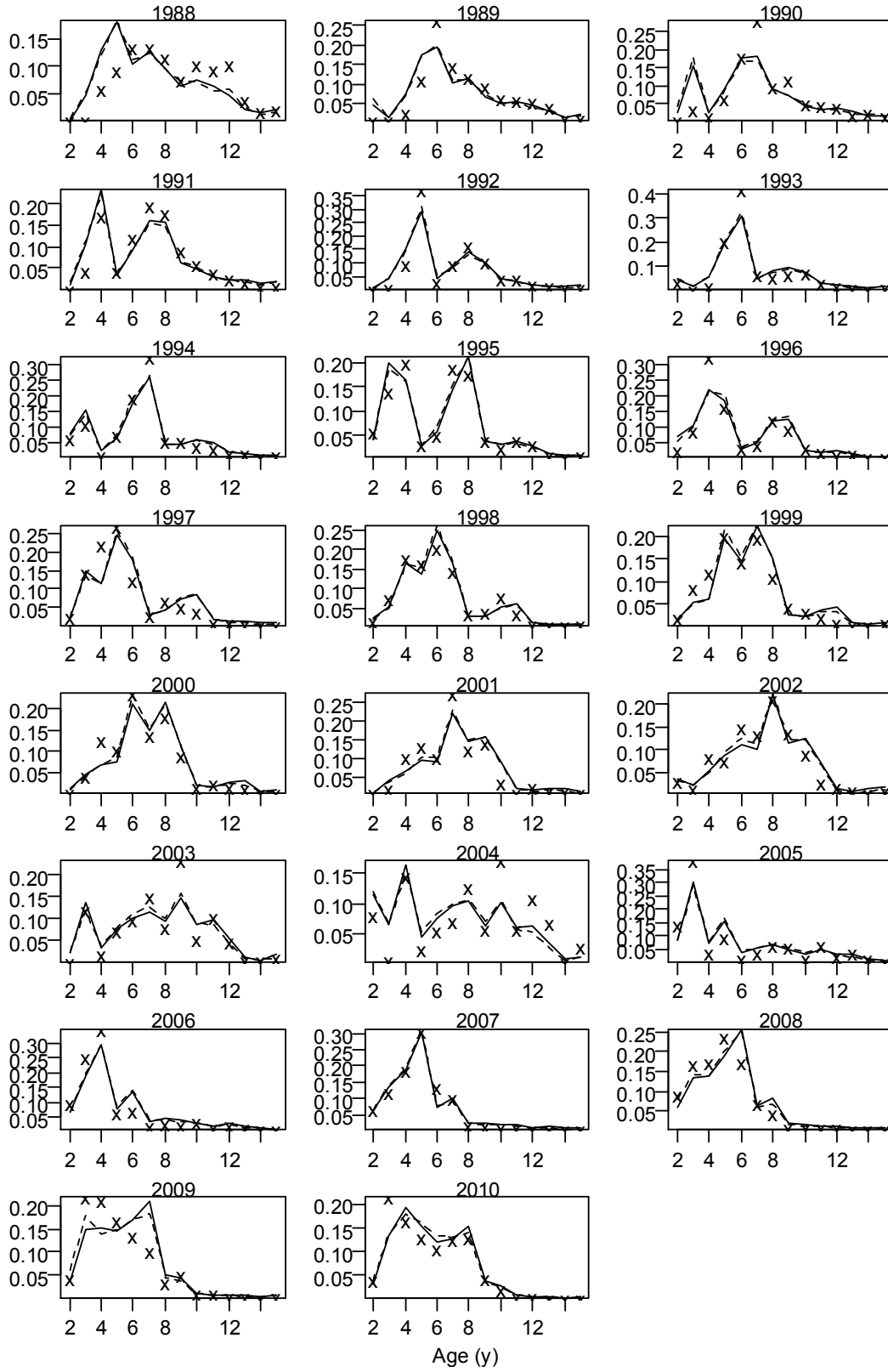
Figure 14: Goodness of fit to the SAsumage data, by year, for runs 1.1 ('1') and 1.2 ('2').
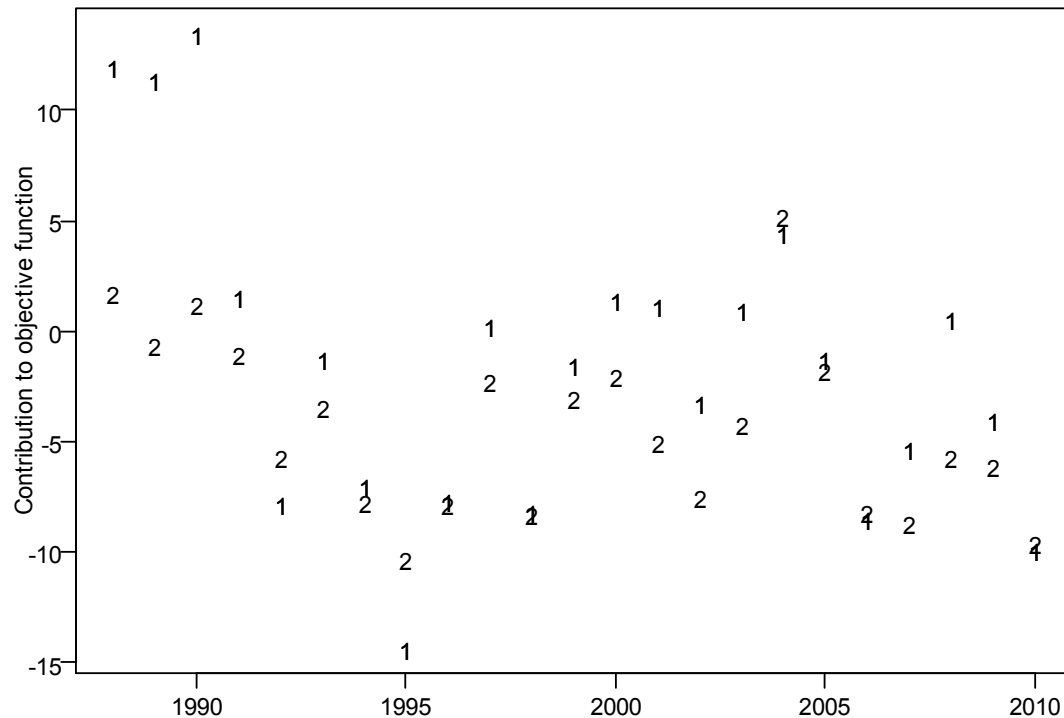
Figure 15: Goodness of fit to the SAsumage data, by year, for runs 1.1 ('1') and 1.2 ('2'). The y-value for each point indicates the contribution to the objective function from one year's SAsumage data; smaller values indicate a better fit. Plotted years are as in the model (so the last survey is plotted at 2010).

3.2 Upweighting the trawl surveys

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 upweighted and non-upweighted model runs regarding the fits to the data sets SAautbio, CSacous, and WCacous (Table 15, Figures 16–17).

However, for the upweighted model runs the fit to CRsumbio is slightly better (Table 15), mostly in the last two years (Figure 18). For SAsumbio the fits to the upweighted model runs are better by the SDNRs criterion (Table 15). However visually there is little difference between model 1.1 and its unweighted version 1.3; and for model 1.2 the fits are better in the first three years compared to its unweighted version, but worse in the last three years (Figure 19). For SAsumbio only one of the years 2004–2007 fits well.

Upweighting the trawl biomasses leads to lower current biomass estimates (as a percentage of virgin) for both eastern and western stocks (Table 16).

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Table 15: 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		0.86	1.56	0.74	0.93	1.06
1.2		0.83	1.49	0.97	0.98	1.07
1.3	As in 1.1, no upweighting	0.92	1.68	0.77	0.93	1.08
1.4	As in 1.2, no upweighting	0.88	1.76	0.94	0.95	1.02

Table 16: Comparison of key aspects of all initial MPD fits.

Run	Description	Objective function	$B_{current}(\%B_0)$ E	$B_{current}(\%B_0)$ W
1.1		-266.1	53.3	37.6
1.2		-359.4	48.9	43.3
1.3	As in 1.1, no upweighting	-308.0	59.6	44.3
1.4	As in 1.2, no upweighting	-405.5	56.1	60.2
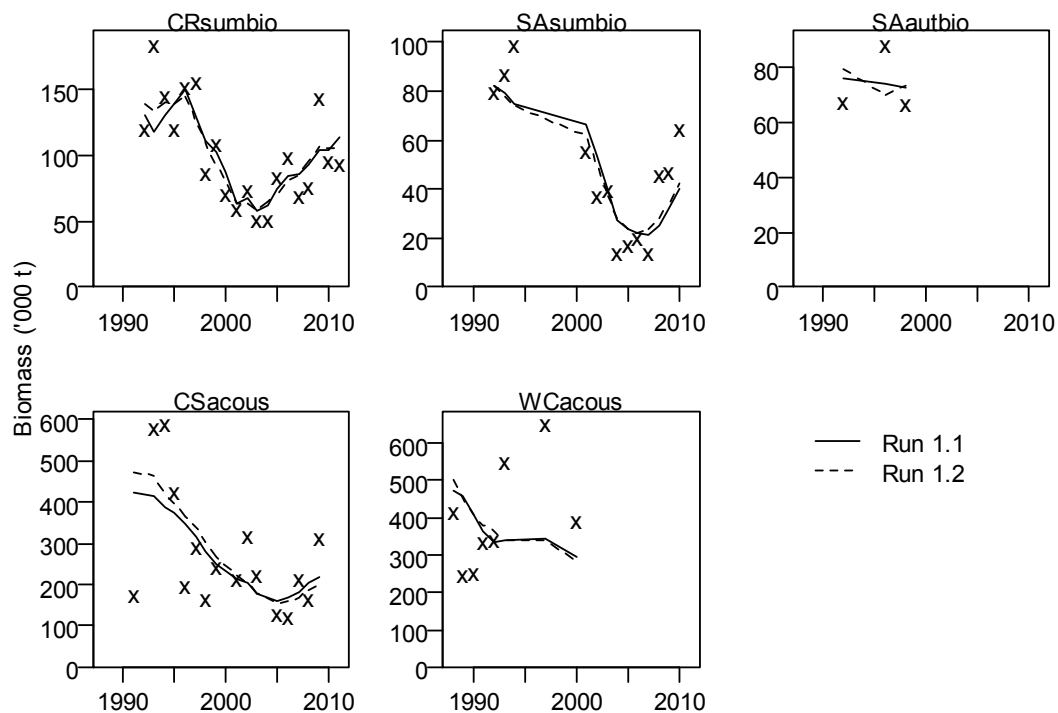
Figure 16: Fit to biomass indices for runs 1.1 and 1.2 showing observed ('x') and expected values (lines). In these model runs the trawl survey biomass data are upweighted.
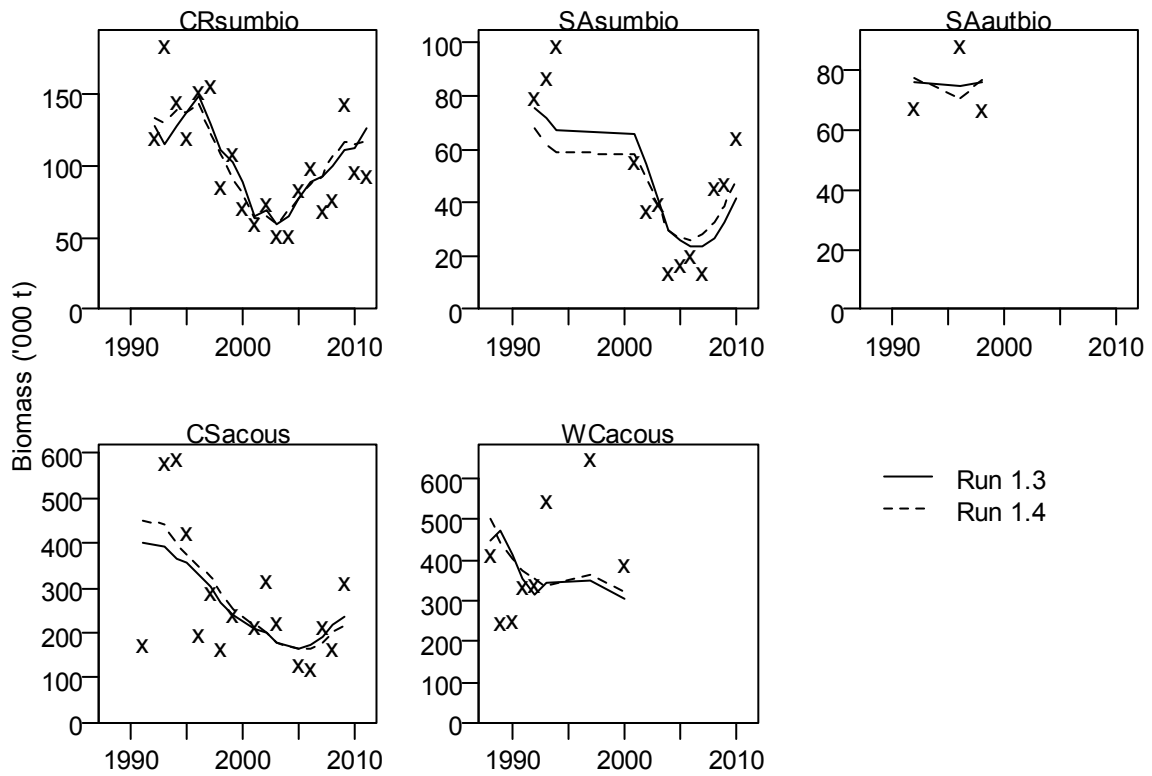
Figure 17: Fit to biomass indices for runs 1.3 and 1.4, showing observed ('x') and expected values (lines). In these model runs the trawl survey biomass data has no upweighting.
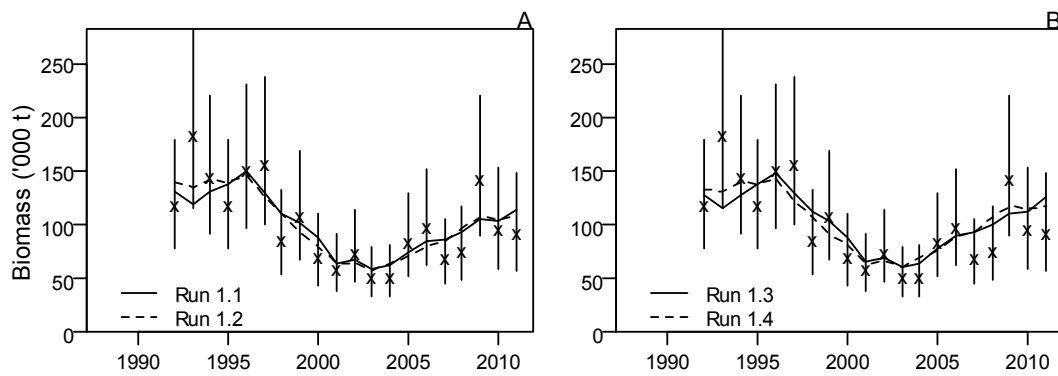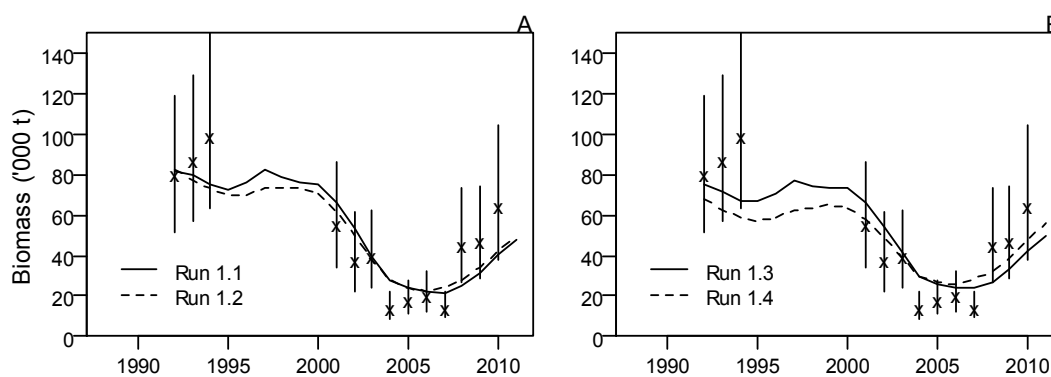

Figure 18: Fits to CRsumbio for runs 1.1 to 1.4, showing observed ('x', with vertical lines showing 95% confidence intervals) and expected values (lines). Plotted years are as in the model (so the last survey is plotted at 2011). The trawl survey indices are upweighted for the left-hand graph, and unweighted for the right-hand graph.

Figure 19: 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.

3.3 Effect of the selectivity shift parameter on the spawning selectivity

For model 1.1 a length based logistic selectivity is used for the western spawning fishery, whereas for model 1.2 an age-based double normal selectivity is used. The position of these selectivities may be shifted left or right annually depending on the median catch day (Table 7). In both models a shift parameter is estimated that scales the shift depending on how much the median catch day differs from the mean median catch day. The Hoki Working Group was interested in how much the spawning selectivity is shifted in recent years for models 1.1 and 1.2.

The shift in the selectivities for the last five years of the models are shown in Figures 20–21. The lower the median catch day, the more the shift is to the right.
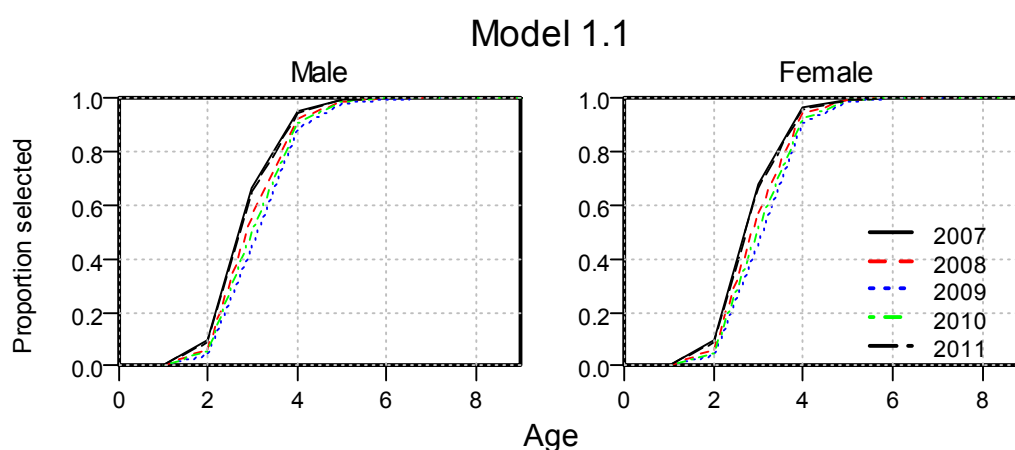
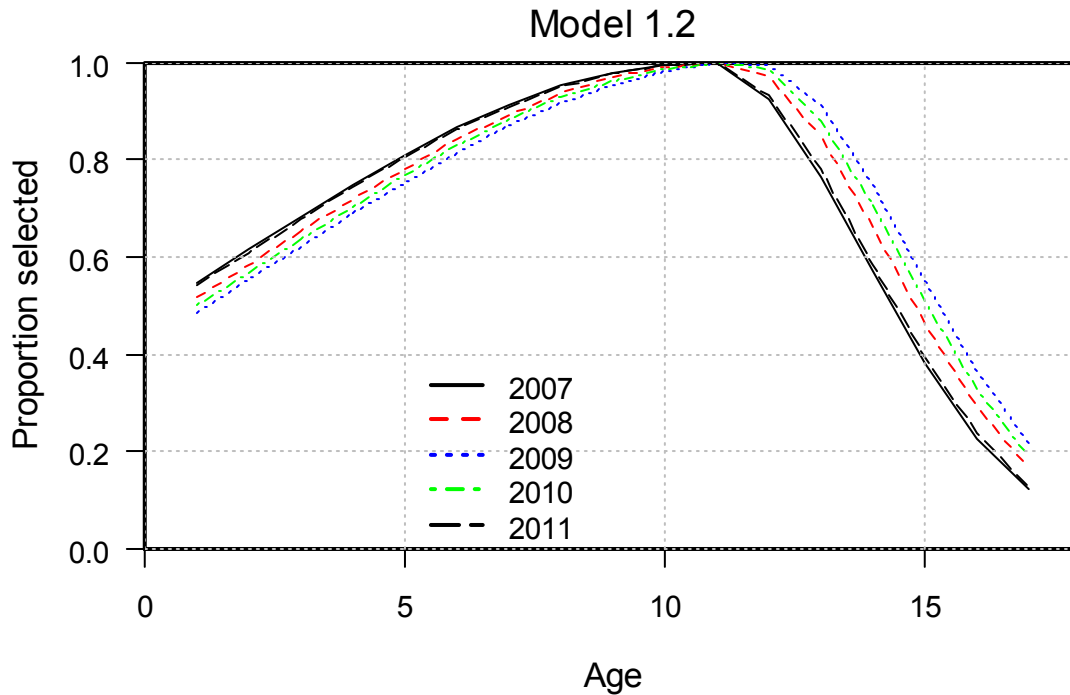**Figure 20: Wspsl selectivity from 2007 to 2011 (model 1.1). The ages go to 17+ but are truncated at 9.**

Figure 21: Wspsl selectivity from 2007 to 2011 (model 1.2)

3.4 Final runs

It was decided by the Hoki Working Group to take four runs through to the MCMC stage. One of these runs is considered a base case (1.1) and is an update of one of the final model runs from the 2010 assessment; the other three runs are sensitivities to the base model run. The runs taken through to the MCMC stage are denoted 1.1, 1.2, 1.8, and 1.9 (Table 17).

The first two 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 1.1 allows *M* (natural mortality) to be dependent on age; run 1.2 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.

To improve the fit to the SAsumbio series, an alternative approach to upweighting is to assume that the catchability has changed over time, as was done for some of the final runs for the 2010 assessment (McKenzie 2011). The two other sensitivity runs differ from run 1.1 in that two catchabilities are fitted for the SAsumbio series instead of one, with no up-weighting of the trawl surveys (Table 17). In run 1.8 the catchability from 2008 to 2010 inclusive is estimated separately from the other years in the series, whereas for run 1.9 the catchability from 2004 to 2007 inclusive is estimated separately. An alternative model run in which three catchabilities were used was also investigated, but this was not taken as a final model run for the assessment (Appendix 3).

All model runs, descriptions, and MPD biomass results are shown in Table 17. For runs 1.8 and 1.9 the current biomass (%B_0) for both the western and eastern stocks is estimated to be higher than in run 1.1, except for the western stock of run 1.8.

Table 17: Comparison of key aspects of MPD runs. The base model run is 1.1. The other model runs are all sensitivities to the base model. All of these model runs are taken through to the MCMC stage.

Run	Two catchabilities for SAsumbio?	Trawl surveys up-weighted	Objective function	B_0('000 t)			B_{2011}(%B_0)		
				E	W	E+W	E	W	E+W
1.1	N	Y	-266.1	456	790	1246	53	38	43
1.2	N	Y	-359.4	616	846	1462	49	43	46
1.8	08–10 q different	N	-317.9	467	799	1266	57	36	44
1.9	04–07 q different	N	-320.0	475	846	1321	61	50	54

4. FINAL MODEL ASSESSMENT RESULTS

The Hoki Working Group decided to take the base run 1.1 and the sensitivities 1.2, 1.8, and 1.9 through to the MCMC stage. The model runs 1.1 and 1.2 are are updates of the final model runs from the 2010 assessment (McKenzie 2011). The other two model runs are sensitivities to the 1.1 model run, and involve using two catchabilities for the Sub-Antarctic summer trawl survey, with no up-weighting of the trawl surveys (Section 3.4).

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 2010, 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 22). 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).

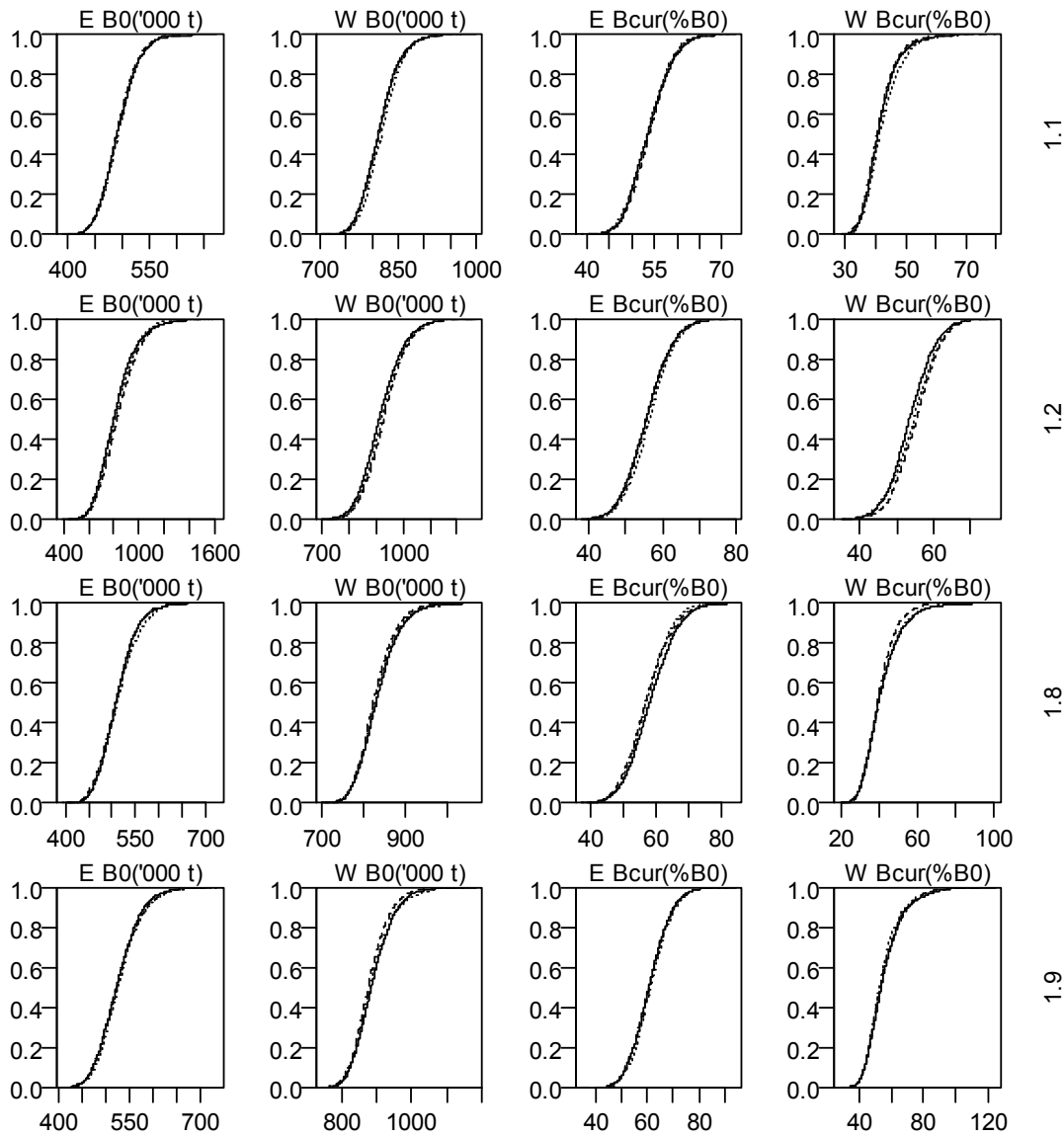|	
1.1	WspmgM1(1), WspmgM2(1), EspmgF8(0.6), WspmgF8(0.6), Enspsl.sR(44), Wnspsl.sR(44), CRsl.a1(64), SAsl.a1(84), SAsl.sR(44)
1.2	Whome.6(1), Wnspsl.sR(1), CRsl.sL(1), CRsl.a1(1)
1.8	As in 1.1
1.9	As in 1.1, except for WspmgM2(1)

Figure 22: Diagnostics for MCMC chains for the four runs: base cases 1.1 (top row) and the three sensitivities 1.2, 1.8, and 1.9 (bottom three 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 run 1.1 and sensitivity 1.2 show, as in 2010, that the western spawning stock was originally much larger than the eastern spawning stock, and is currently about 30% larger than the eastern spawning stock (run 1.1) or about the same size (run 1.2) (Table 19, Figure 23). In terms of current spawning biomass the western spawning stock is more depleted then the eastern (Figures 23–24). In terms of estimated biomass in 2010, the new assessment is similar to that from last year, except that run 1.1 for the western stock shows a decreased 2010 biomass (%B_0) compared to the comparable run from last year (Figure 25).

The other sensitivity runs to 1.1 where two catchabilities are used (1.8, 1.9) show that compared to the base run (i) the eastern stock is larger, and (ii) the western stock is about the same size or larger (Figures 26–27, Table 19). The estimate of the current status of the western stock is more uncertain when two catchabilities are allowed (see Figures 26–27, Table 19).

All runs suggest both the eastern and western stocks are rebuilding, both in absolute terms (Figure 28) and relative to B_0 (Figure 29). For the all base runs, recent western YCSs are estimated to be higher than in the seven-year period of very weak recruitment, 1995–2001 (Figure 30). Biomass trajectories differ most for runs 1.1 and 1.2, while year class strength estimates are very similar across all runs (Figures 31–32).

As in previous years, the selectivity and migration ogives for the runs assuming age-dependent natural mortality (runs 1.1, 1.8, 1.9 in the current assessment) are very different from run 1.2 without this assumption (Figures 33–35). The estimates of natural mortality for run 1.1 show the same pattern as the 2010 assessment with, except for the very young fish, a higher natural mortality for males (Figure 36, Table 20). A comparison of priors and posteriors for various parameters showed no substantial changes from last year (Figure 37).

Table 19: 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 2011.

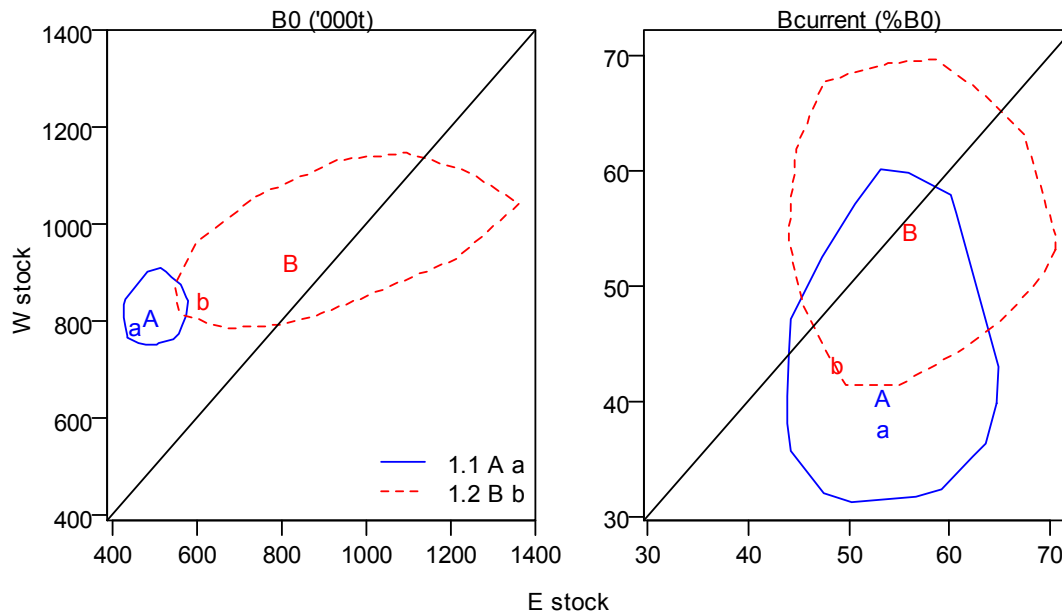|	B_0('000 t)		$B_{current}$('000 t)		$B_{current}$(%B_0)		
Run	E	W	E	W	E	W	E+W
1.1	491(433,563)	814(757,890)	263(206,333)	330(254,471)	53(45,63)	41(32,56)	46(39,56)
1.2	821(597,1170)	926(806,1096)	462(310,666)	507(371,687)	56(45,68)	55(44,67)	56(48,64)
1.8	511(444,606)	830(756,950)	290(205,405)	326(209,550)	57(44,72)	39(27,62)	46(36,62)
1.9	524(453,633)	879(792,1011)	320(232,455)	466(325,769)	61(48,77)	52(39,81)	56(45,76)

Figure 23: Estimates and approximate 95% confidence intervals for virgin (B_0) and current ($B_{current}$ as %B_0) biomass by stock for the base case runs 1.1 and the sensitivity 1.2. 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 and broken lines, respectively) enclose approximate 95% confidence intervals. Diagonal lines indicate equality (y = x).
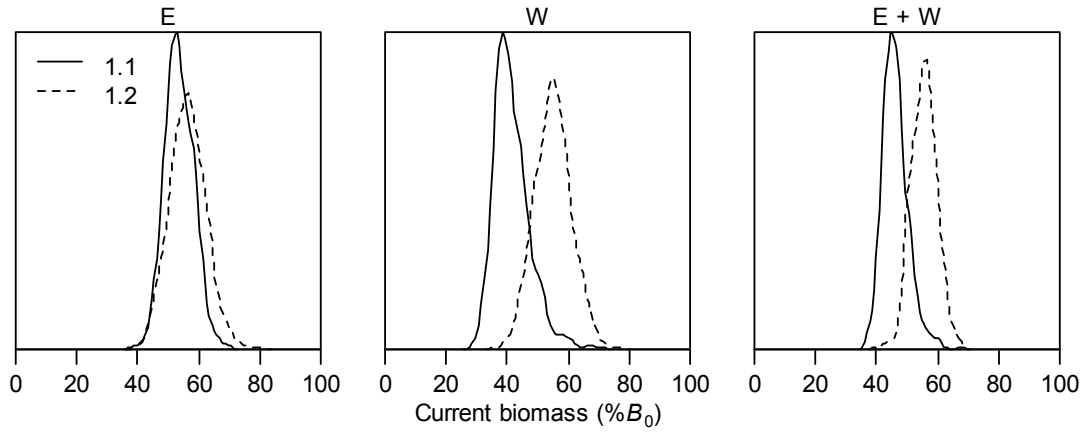
Figure 24: Estimated posterior distributions of current (spawning) biomass (B_{2011}), expressed as %B_0, for the E (left panel), W (middle panel) and E + W stocks (right panel) from the base final model run and one of its sensitivities.
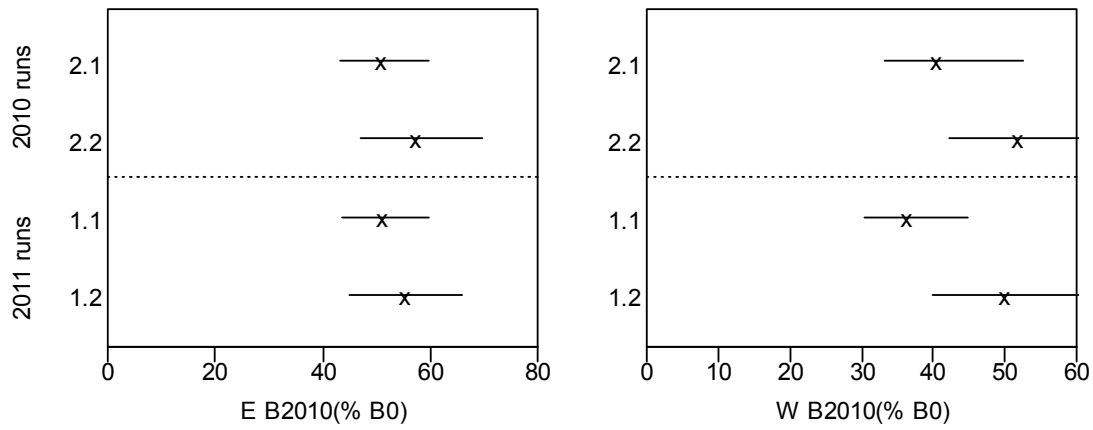

Figure 25: Comparison of 2011 runs (1.1, 1.2) with the comparable runs from 2010 (2.1, 2.2): estimates of stock status in 2010 (B_{2010} as %B_0), with 95% confidence intervals shown as horizontal lines.
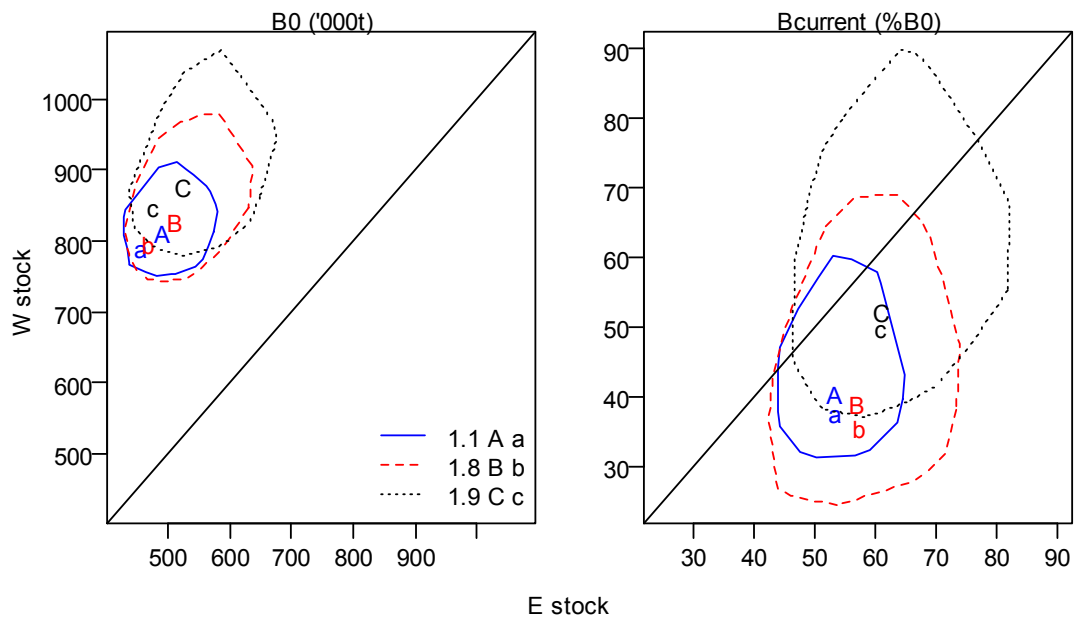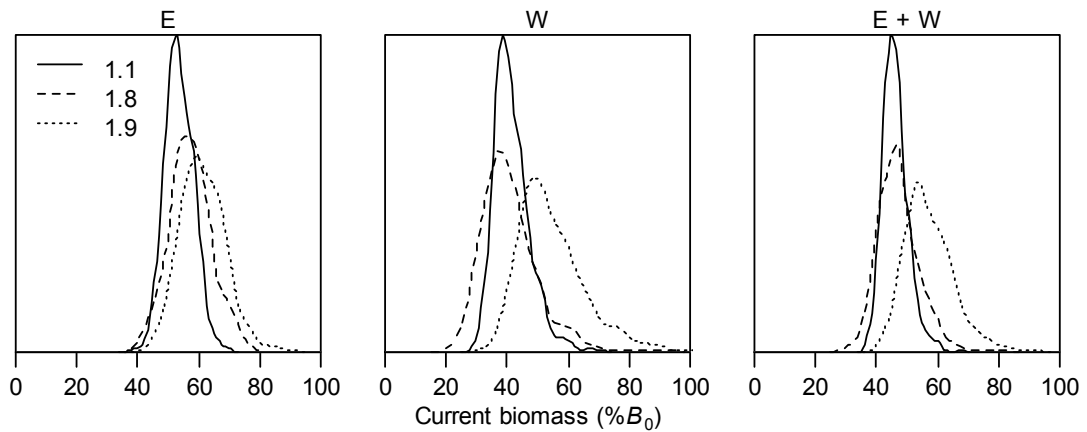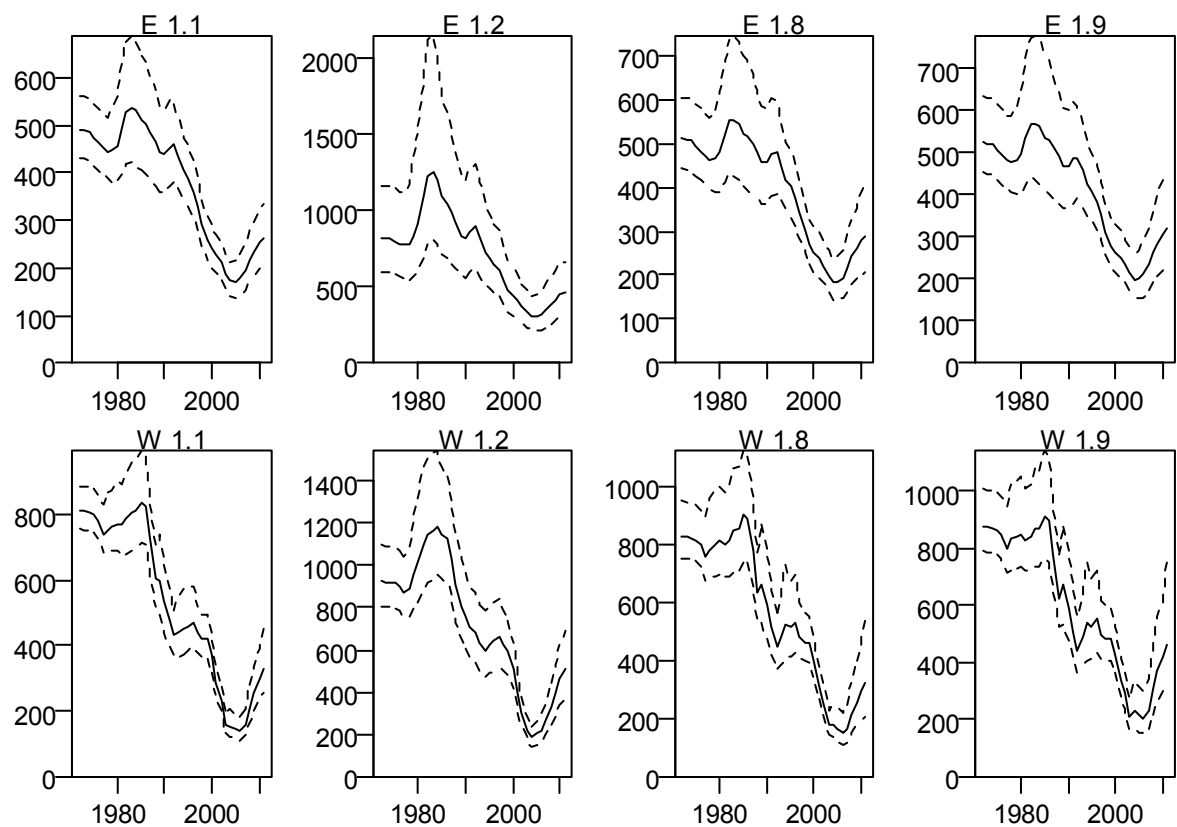
Figure 26: As for Figure 23 but for the runs 1.1, 1.8, and 1.9.

Figure 27: Estimated posterior distributions of current (spawning) biomass (B_{2011}), expressed as %B_0, for the E (left panel), W (middle panel) and E + W stocks (right panel) from the base final model runs and the two catchability sensitivity runs.

Figure 28: 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).
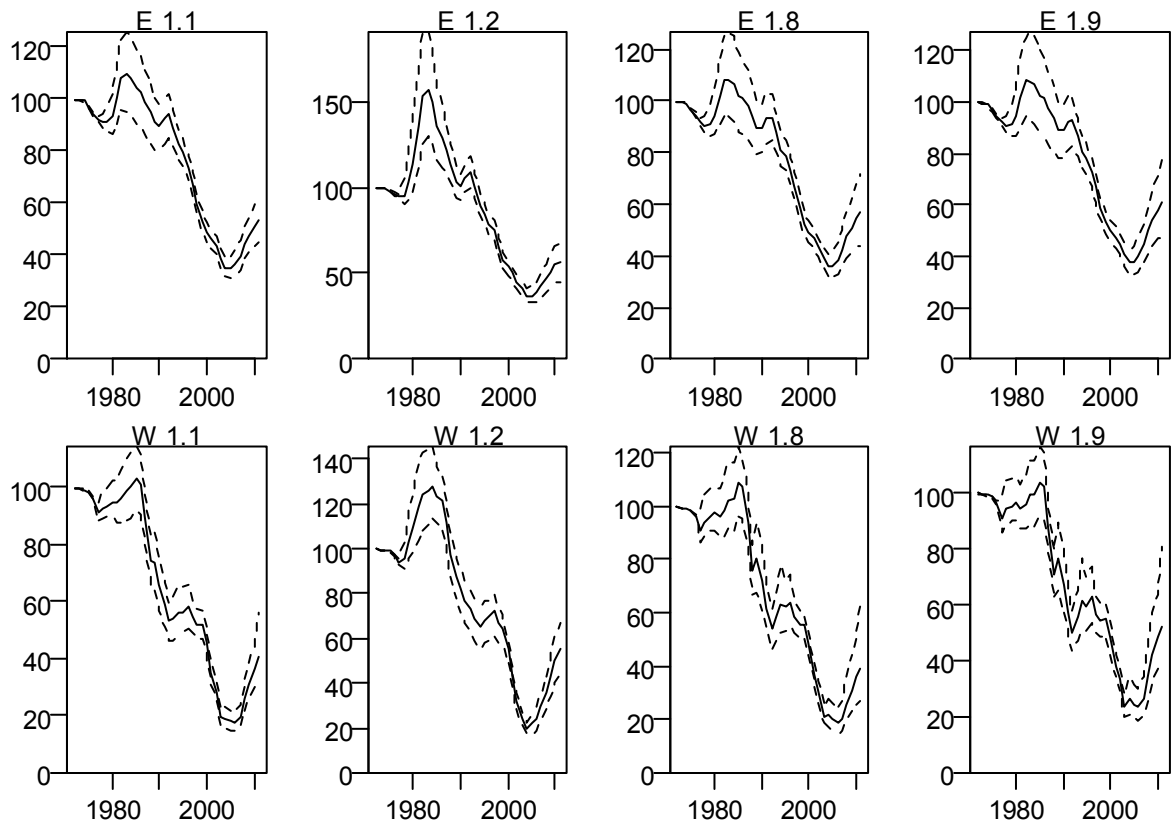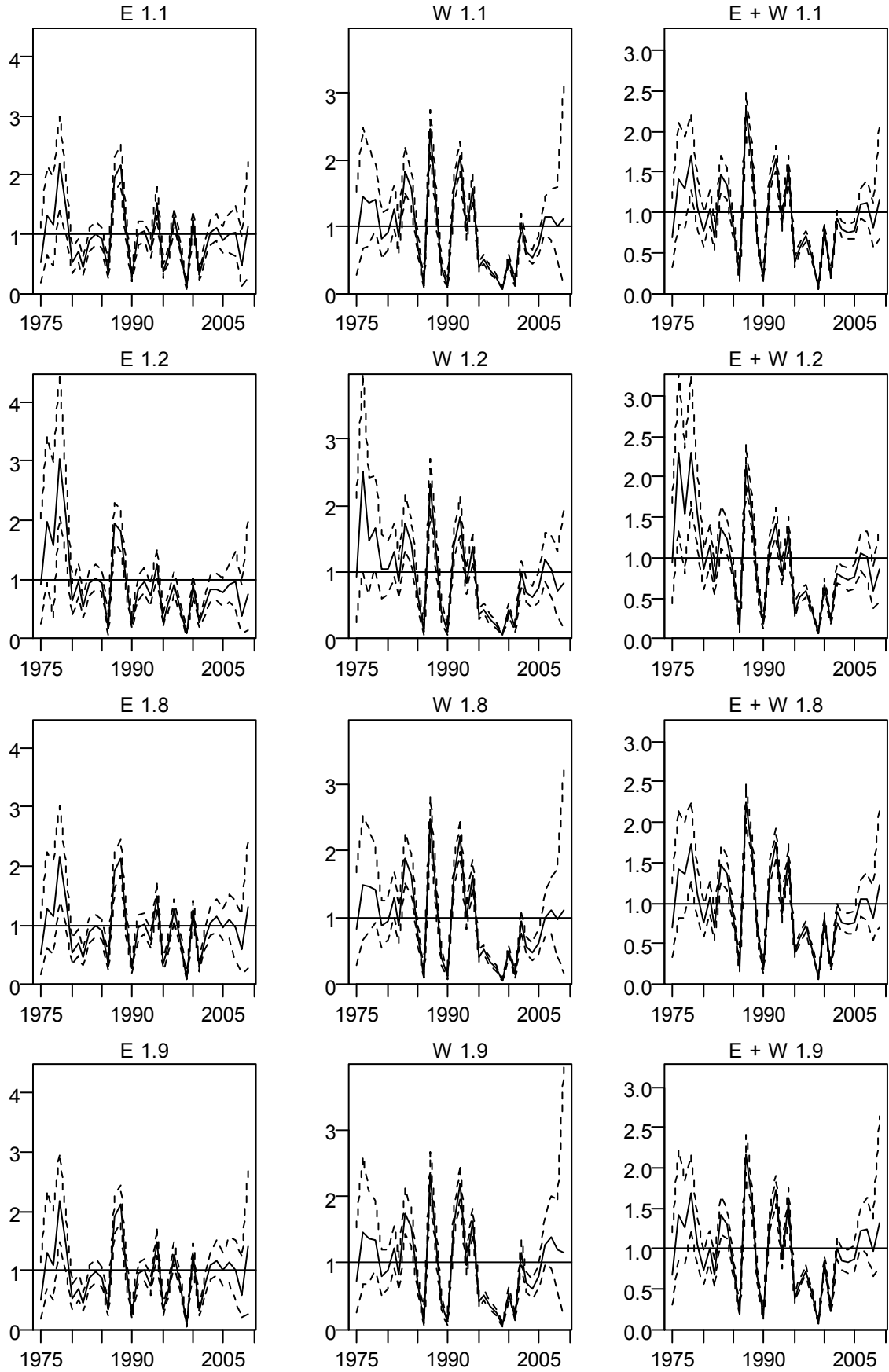
Figure 29: As for Figure 28, but plotted as %B$_0$.

Figure 30: 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).
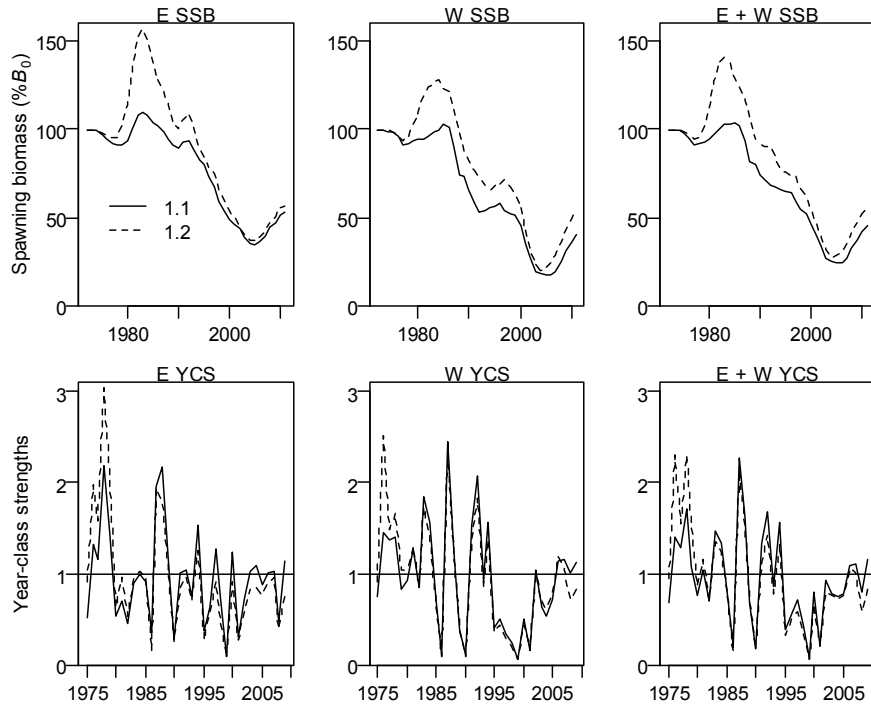
Figure 31: Estimated spawning biomass trajectories (SSB, upper panels) and year-class strengths (YCS, lower panels) for the E (left panels), W (middle panels) and E + W stocks (right panels) from the base final model run and one of the sensitivities. Plotted values are medians of marginal posterior distributions.
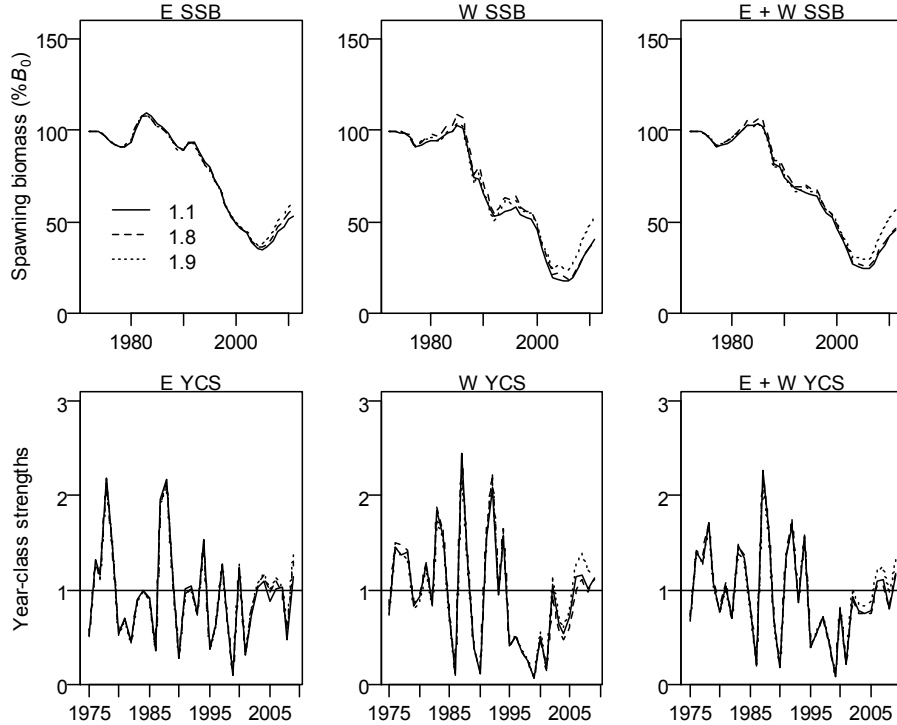

Figure 32: Estimated spawning biomass trajectories (SSB, upper panels) and year-class strengths (YCS, lower panels) for the E (left panels), W (middle panels) and E + W stocks (right panels) from the base final model run and the two catchability sensitivity runs. Plotted values are medians of marginal posterior distributions.
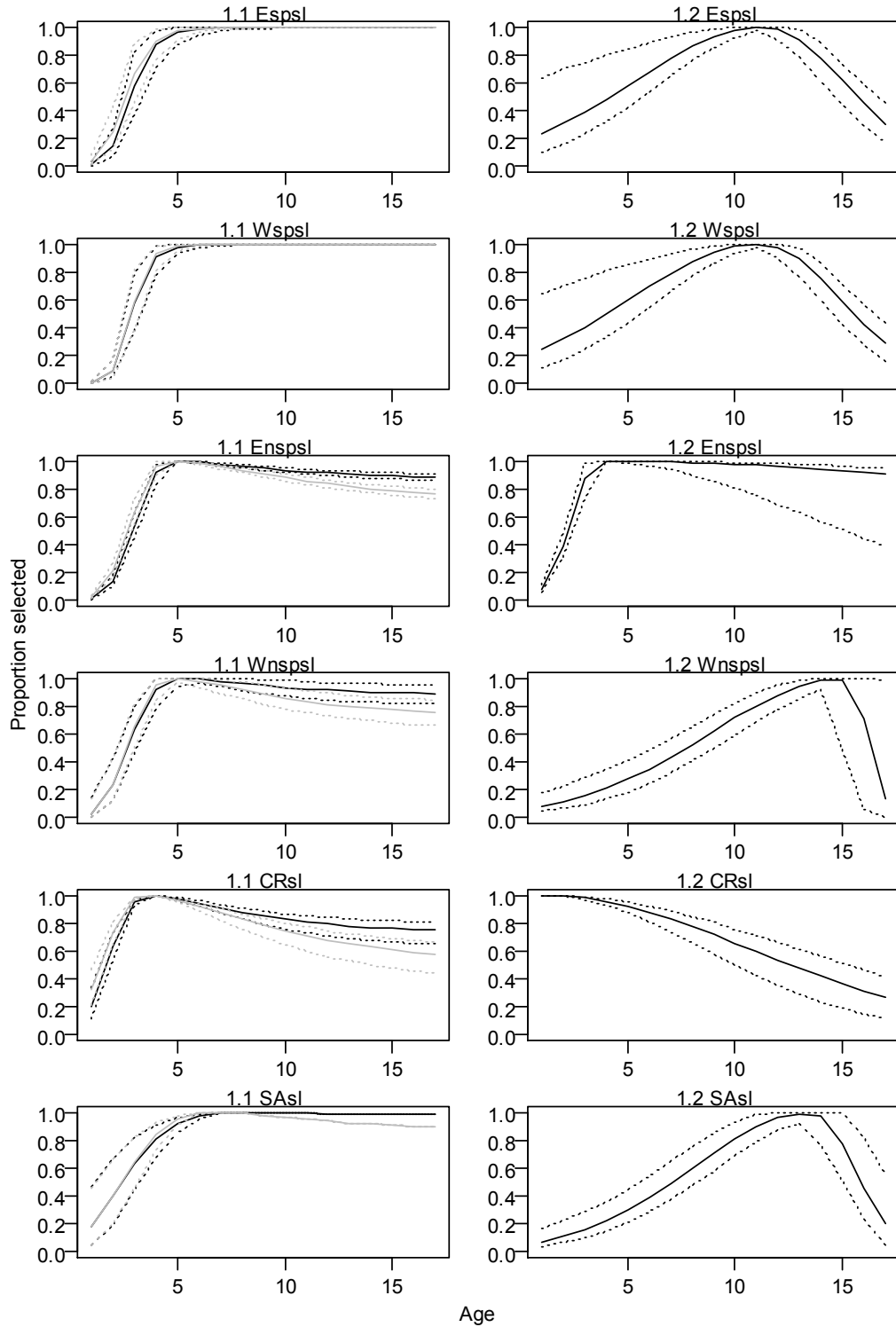
Figure 33: Posterior estimates of selectivity ogives for each for the base MCMC runs 1.1 and the sensitivity 1.2. Solid lines are medians; broken lines show 95% confidence intervals. Where ogives differ by sex they are plotted as black for males and grey for females. Where they differ by stock or time step the plotted curves are for one selected combination (E step 2 for Enspsl and CRsl, W step 2 for Wnspsl and SAsl).
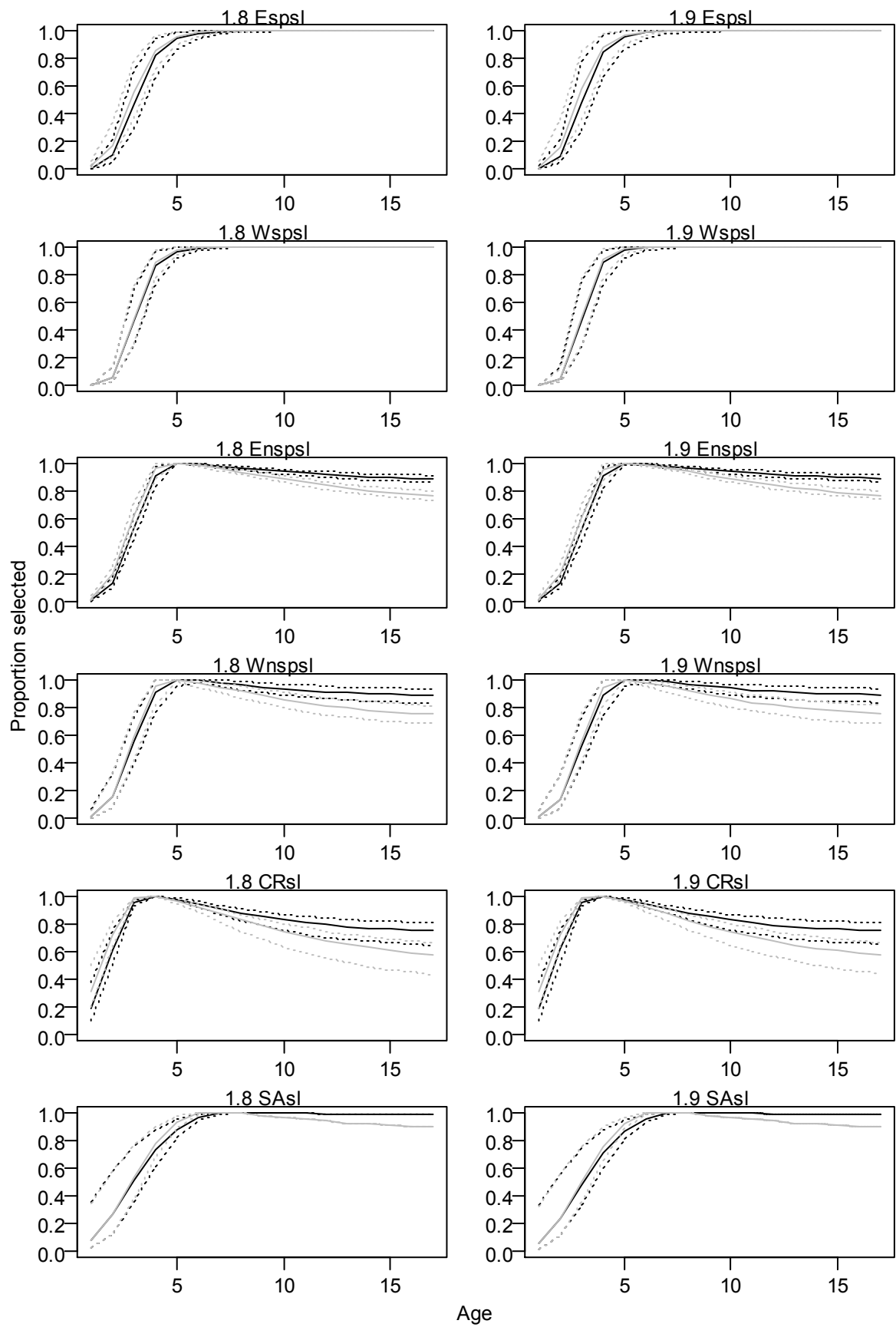
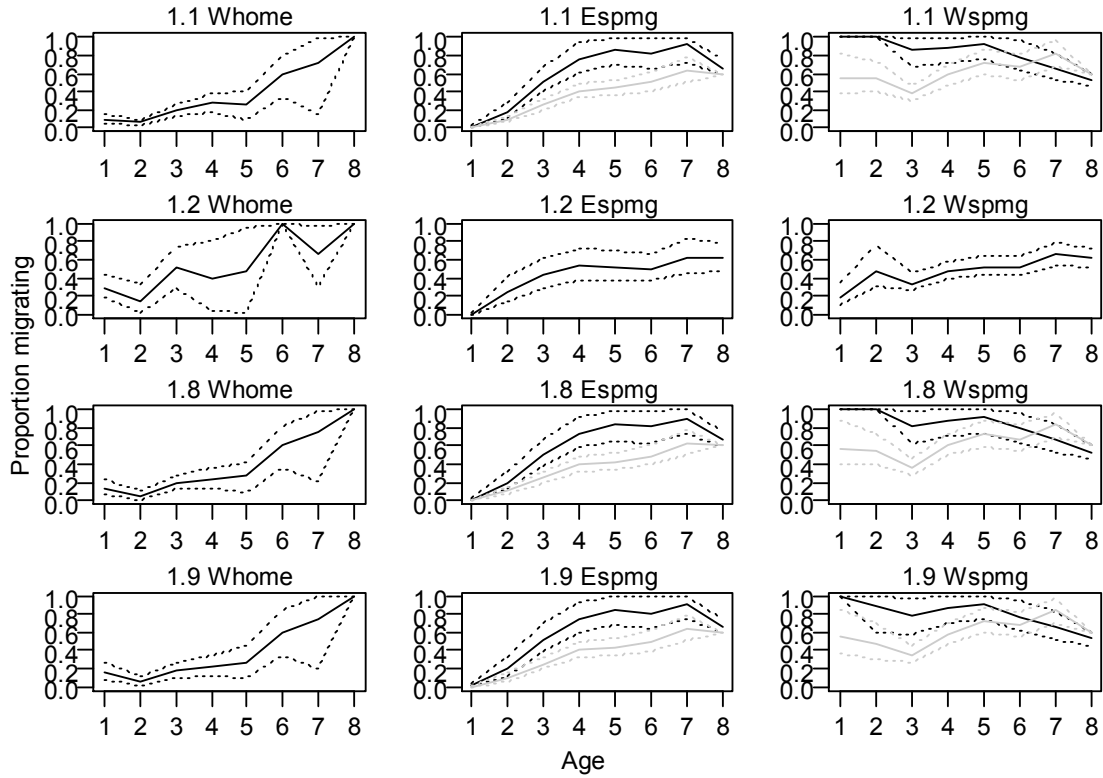**Figure 34: As in Figure 33 but for the MCMC runs 1.8 and 1.9**

Figure 35: Migration ogives estimated in each of the four 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.
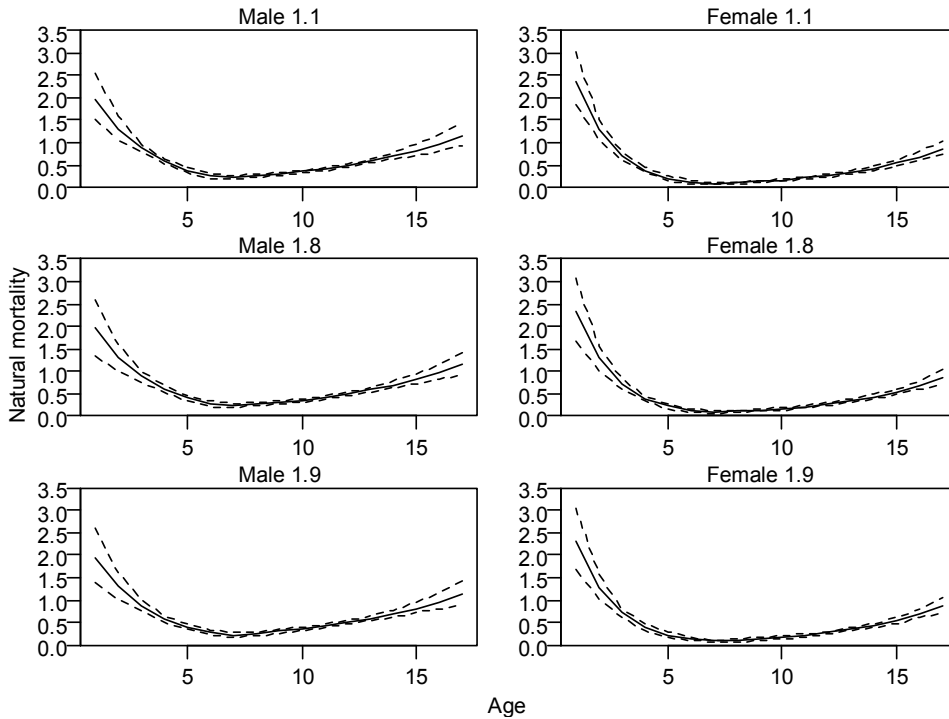

Figure 36: Estimates of age-dependent natural mortality ogives for run 1.1, 1.8, and 1.9 showing median estimates (solid lines) and 95% confidence intervals (broken lines) for each sex.

Table 20: Estimates of age-dependent natural mortality ogives for run 1.1 showing median estimates for each sex.

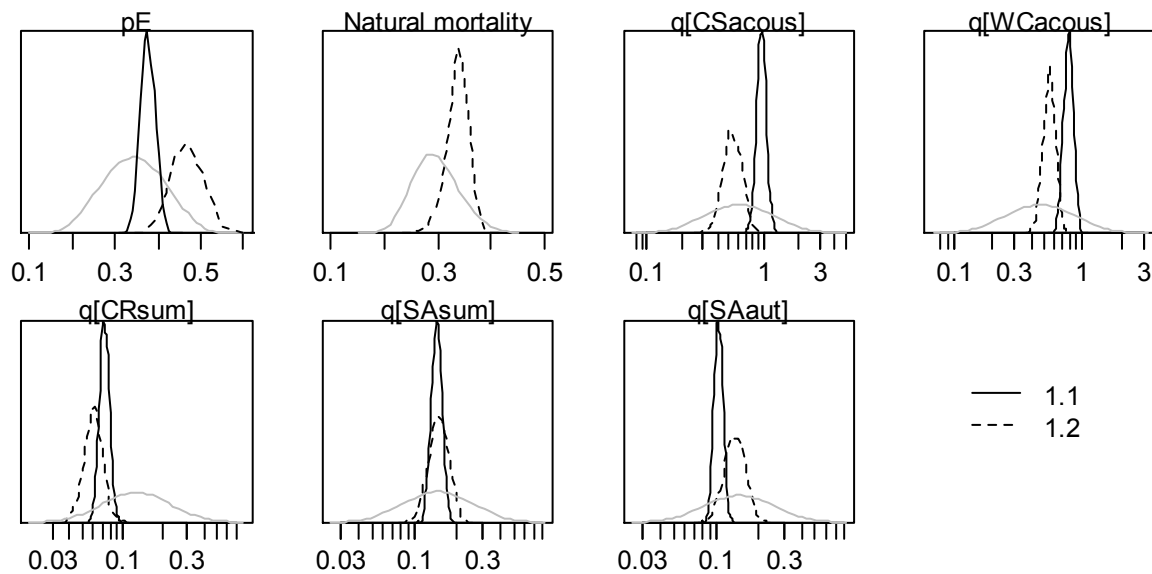| Age Group	Male	Female
1+	1.98	2.36
2+	1.31	1.28
3+	0.87	0.69
4+	0.58	0.38
5+	0.39	0.20
6+	0.26	0.11
7+	0.22	0.09
8+	0.26	0.11
9+	0.30	0.14
10+	0.36	0.17
11+	0.42	0.22
12+	0.50	0.27
13+	0.59	0.34
14+	0.69	0.43
15+	0.82	0.54
16+	0.97	0.68
17+	1.14	0.86

Figure 37: Prior (grey lines) and estimated posterior (black lines) distributions from the two MCMC runs for 1.1 and 1.2 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 1975–2009) and 'recent' (recruitment selected from 1995–2009). Future catches for each fishery were assumed equal to those assumed for 2011.

In all models with long-term recruitment, median spawning biomass increased for both stocks in all years. The same was found for all models with recent recruitment, except for model 1.2 where it remained fairly constant under the recent recruitment scenario (Figures 38–39).

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 21. 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 0.14.
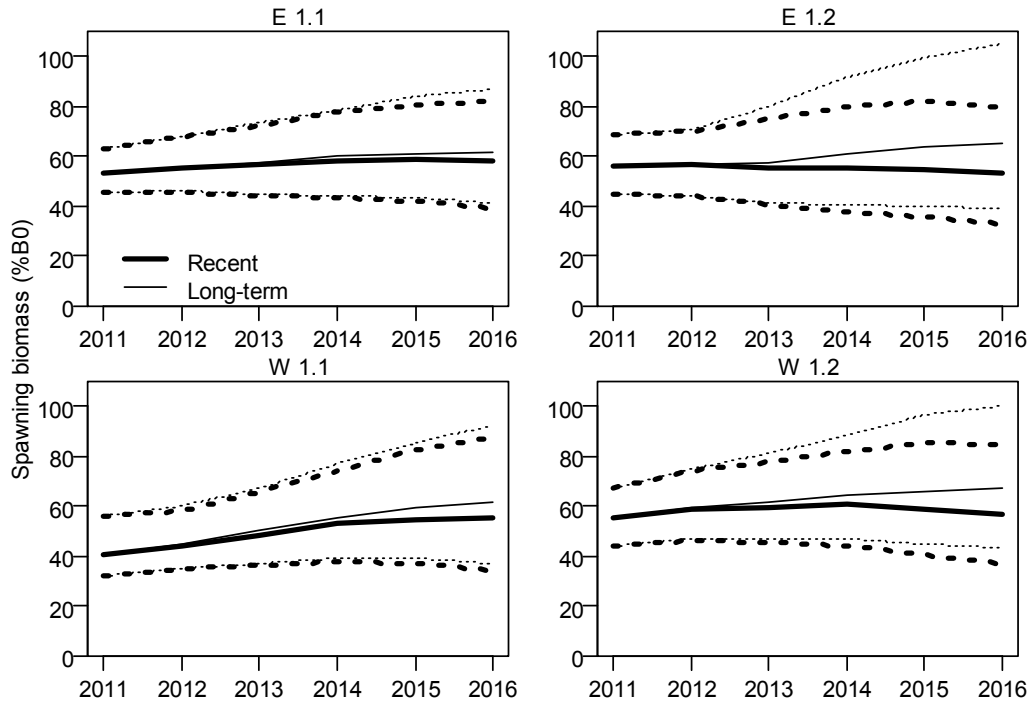

Figure 38: Trajectories of median spawning biomass (as %B_0) from the projections (solid lines) together with lower and upper bounds of a 95% confidence interval (broken lines) assuming 'long-term' (light lines) or 'recent' recruitment (heavy lines). Each panel shows results for one stock (E or W) from one of the two MCMC runs 1.1 and 1.2.
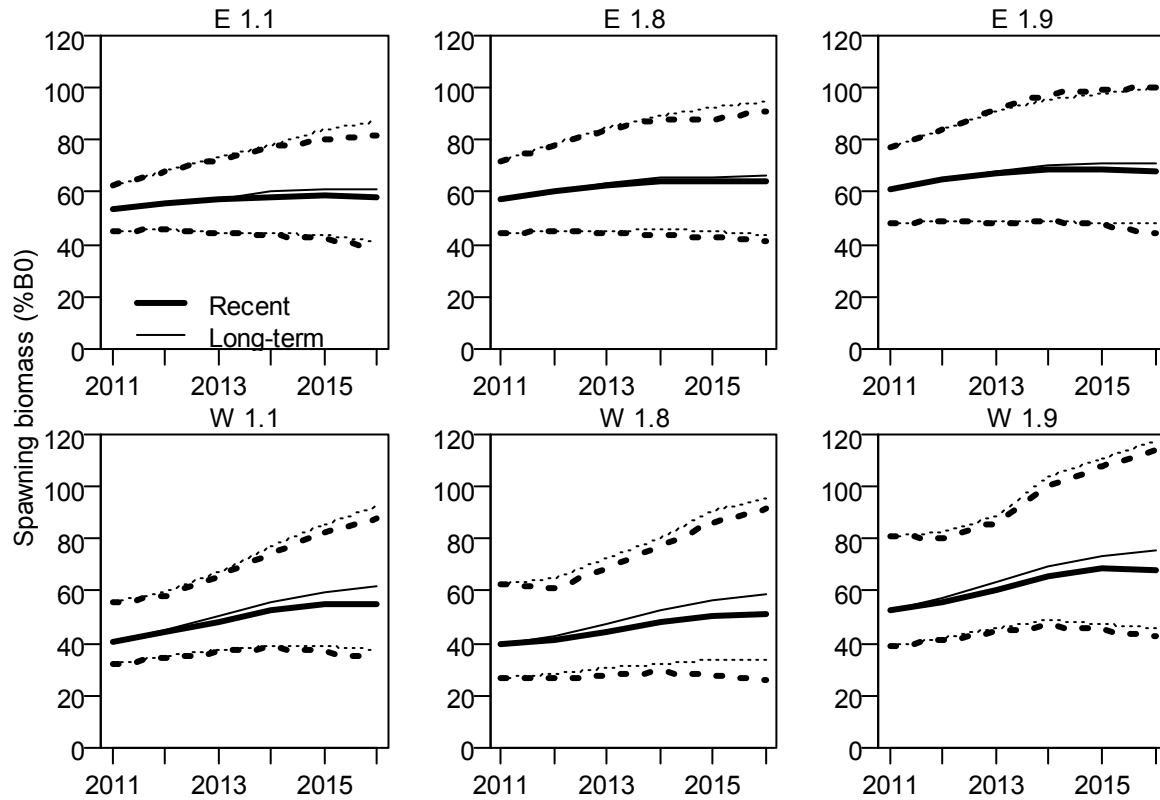
Figure 39: As in figure 38, but for MCMC runs 1.1, 1.8, and 1.9.

Table 21: Probabilities (rounded to two decimal places) associated with projections for SSB (%B$_0$) in Figures 38–39.

	2011				2016: Recent recruitment				2016: Long-term recruitment			
	1.1	1.2	1.8	1.9	1.1	1.2	1.8	1.9	1.1	1.2	1.8	1.9
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	0.01	0.04	0.01	0	0	0.01	0	0
P(SSB<50%B$_0$)	0.21	0.14	0.13	0.05	0.21	0.38	0.15	0.07	0.12	0.14	0.09	0.04
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$_0$)	0.09	0	0.27	0	0.03	0.01	0.14	0	0.01	0	0.03	0
P(SSB<50%B$_0$)	0.91	0.21	0.86	0.39	0.35	0.29	0.47	0.11	0.17	0.1	0.25	0.04

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

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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 $mU_{f,\text{current}}$, where $U_{f,\text{current}}$ 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 $m_{x\%}U_{\text{current}}$, 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 40).
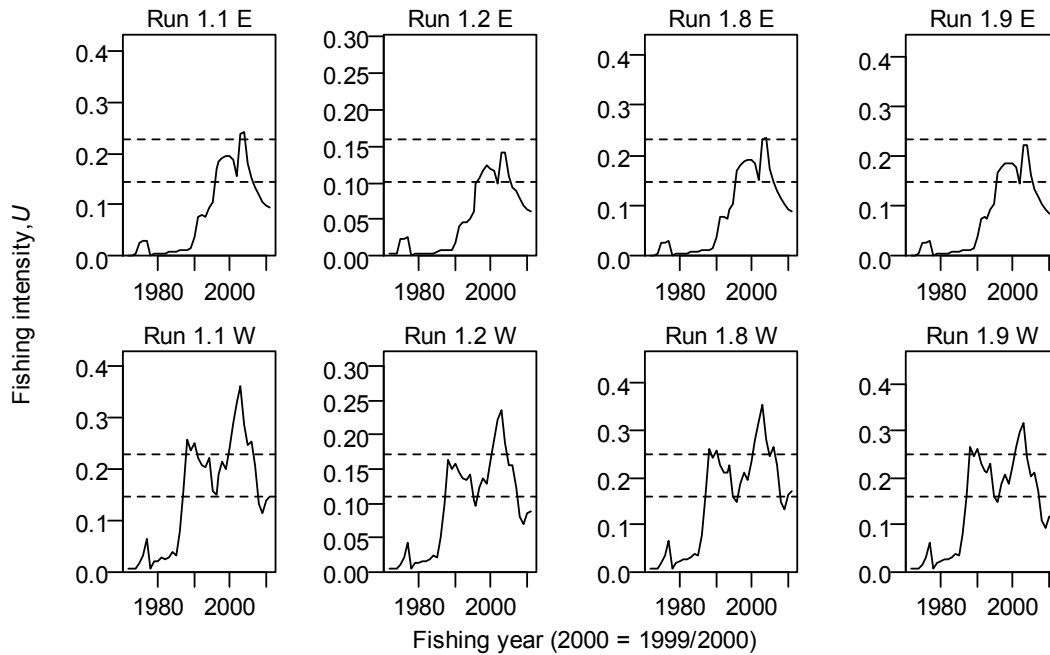

Figure 40: Fishing intensity, U, plotted by run and stock. Also shown (as broken lines) are the reference levels $U_{35\%}$ (upper line) and $U_{50\%}$ (lower line), which are the fishing intensities that would cause the spawning biomass to tend to $35\%B_0$ and $50\%B_0$, respectively. The y-axes are 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 from the base model 1.1, assuming a harvest strategy in which the exploitation rate for fishery f was $mU_{f,2011}$, where $U_{f,2011}$ is the estimated 2011 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 24% for the E stock and 26% for the W stock.

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 western stock is more depleted (39–55%B_0), than the eastern stock (53–61%B_0). The western stock experienced an extended period of poor recruitment from 1995 to 2001, but recruitment appears to have been near or above average in the last four years. The projections suggest that continued fishing at current levels is likely to allow the biomass of both stocks to increase, or remain fairly constant under the recent recruitment for the sensitivity run with a domed spawning fishery selectivity.

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 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).

Appendix 2: Changes in stock-assessment model assumptions

Table A1: Changes in stock-assessment model assumptions and input data for each year since the first CASAL assessment of hoki in 2002. Adapted from table 31 in Francis (2008).

Year	Changes
2003	Changed timing of spawning migrations from the middle to the end of the non-spawning fisheries (and after the autumn SA surveys)
	Earliest estimated YCS changed to 1977 from 1980
	Assumed Beverton-Holt stock-recruit relationship
	Disallowed annual variation in selectivities for Wnsp fishery
	Allowed for ageing error (expected to reduce bias in estimates of YCSs)
	Process errors for at-age data sets estimated within the model
	Non-uniform prior on pE
	Max. age of otolith-based at-age data increased from 10 (plus group) to 12 (no plus group)
	First use of otolith-based at-age data for non-spawning fisheries (Enspage & Wnspage)
	Forced equality of recent W and E YCSs extended from 2 y to 3 y
	Improvements in methods of converting ogives from size-based to age-based and implementing annual variation in selectivities
2004	First use of age-dependent natural mortality and domed spawning selectivities to cope with lack of old fish
	Maximum age in partition increased from 13 y to 17 y
	New parameterisation for YCSs
	Earliest estimated YCS changed to 1975 from 1977
	Change in priors for CSacous catchability and pE
	Max. age of otolith-based at-age data increased from 12 (no plus group) to 13/15 (plus group)
2005	For runs with domed spawning selectivities, spawning selectivities (rather than migrations) constrained to be equal
	Some at-age data revised
2006	Annual variation in Wsp selectivity restricted to years with significant data and constrained by non-uniform prior on controlling parameter
	Forced equality of recent W and E YCSs reduced from 3 y to 1 y
	Added smoothing penalty for age-dependent natural mortality
	First model run without the assumption of natal fidelity
2007	New parameterisation (double-exponential) and prior for age-dependent natural mortality
2008	Models runs without natal fidelity dropped
	Stock recruitment steepness reduced from 0.90 to 0.75
	1998 proportions spawning data re-analysed
2009	Median catch day re-calculated using a new first year
	1992 and 1993 proportions spawning data re-analysed
2010	Allow two catchabilities for the Sub-Antarctic trawl survey in sensitivity model runs

2011   Reduce to one base model (age-varying natural mortality) from two base models (for the other base model there were domed shaped fishing selectivities in the spawning fishery)

Appendix 3: Using three catchabilities for SAsumbio

An MCMC model run (run 1.10) was set up for which three catchabilities were allowed for SAsumbio instead of one or two (Table A2), this model run being an alternative to the base model run 1.1.

With another catchability allowed, the current status of the eastern stock remains much the same as when there are two catchabilities (Table A2, Figures A1–A2). For the western stock the current status of the stock is intermediate to the model runs with two catchabilities, with the uncertainty similar to model 1.9 (Table A3, Figures A1–A2). As the model with three catchabilities gives a current biomass that is similar or intermediate to the models with two catchabilities, it was not pursued any further by the Hoki Working Group.

Table A2: Comparison of model runs.

Run	Two catchabilities for SAsumbio?	Trawl surveys up-weighted
1.1	N	Y
1.8	08–10 q different	N
1.9	04–07 q different	N
1.10	*	N

* Three separate catchabilities: 1992–2003 (inclusive), 2004–07 (inclusive), 2008–10 (inclusive)

Table A3: 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 2011.

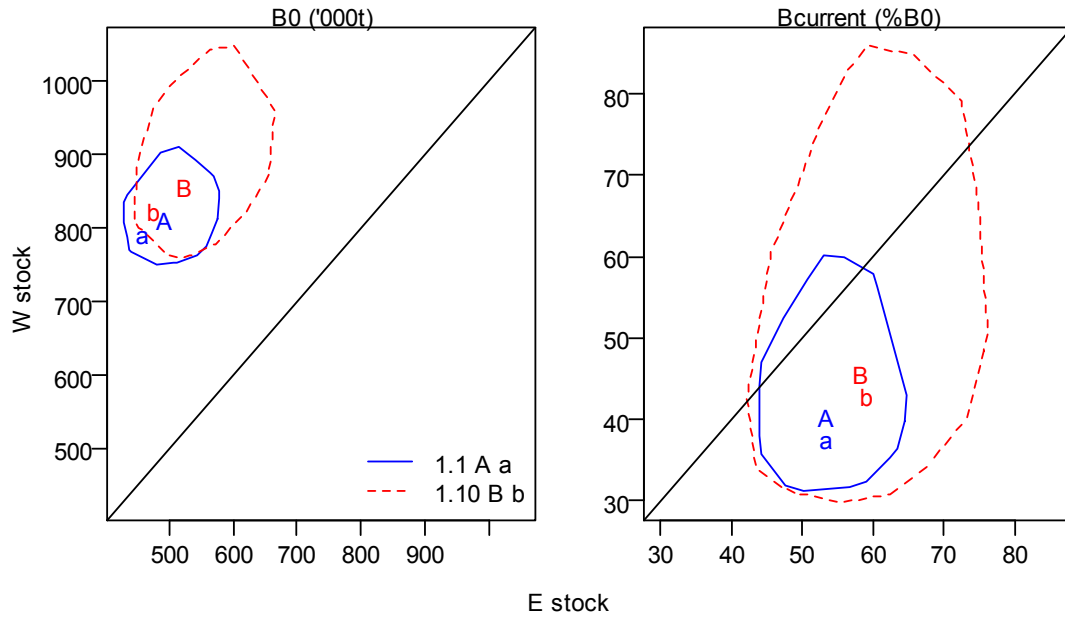| Run	B_0('000 t) E	W	$B_{current}$('000 t) E	W	$B_{current}$(%B_0) E	W	E+W
1.1	491(433,563)	814(757,890)	263(206,333)	330(254,471)	53(45,63)	41(32,56)	46(39,56)
1.8	511(444,606)	830(756,950)	290(205,405)	326(209,550)	57(44,72)	39(27,62)	46(36,62)
1.9	524(453,633)	879(792,1011)	320(232,455)	466(325,769)	61(48,77)	52(39,81)	56(45,76)
1.10	524(452,627)	860(778,1000)	304(216,429)	394(258,746)	58(45,73)	46(31,78)	51(39,73)

Figure A1: 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 1.10. 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).
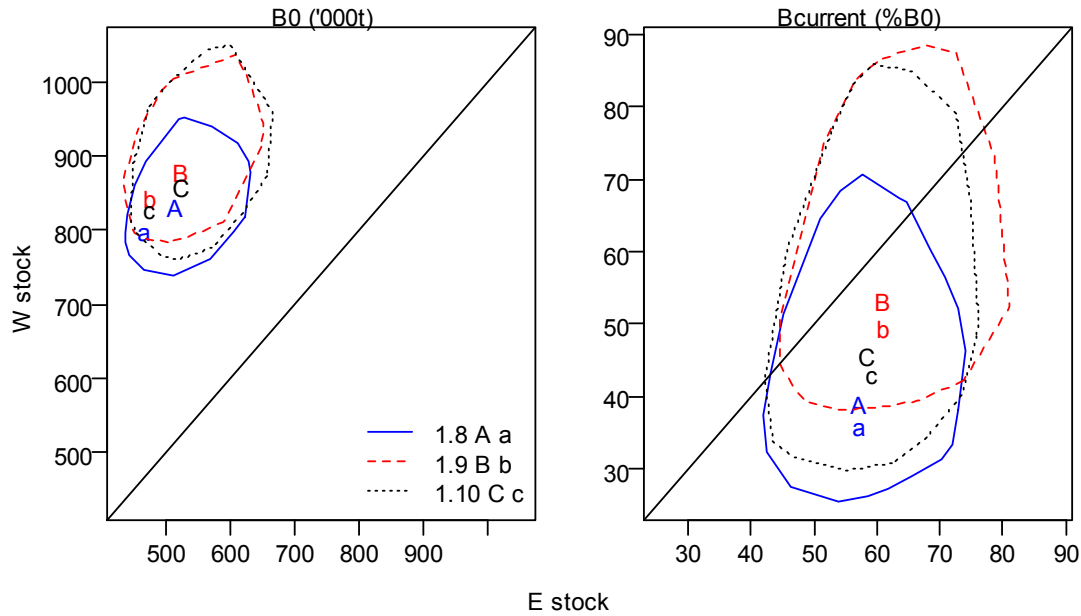

Figure A2: As in Figure A1, except for runs 1.8, 1.9, 1.10.