



## Assessment of hoki (*Macruronus novaezelandiae*) in 2012

New Zealand Fisheries Assessment Report 2013/27

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ISSN 1179-5352 (online)

ISBN 978-0-478-41400-4 (online)

May 2013



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## EXECUTIVE SUMMARY

McKenzie, A. (2013). Assessment of hoki (*Macruronus novaezelandiae*) in 2012.

*New Zealand Fisheries Assessment Report 2013/27. 65 p.*

An updated assessment is presented for hoki that is based on the 2011 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. The biomass indices new to this assessment were a trawl survey from the Chatham Rise in January 2012, a trawl survey in Sub-Antarctic in December 2011, and an acoustic survey of spawning hoki in Cook Strait in winter 2011. New proportions-at-age data came from the four fisheries and the two trawl surveys.

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 Chatham Rise and Sub-Antarctic survey series. However, no model runs were able to mimic the changes in the last four biomass estimates from the Sub-Antarctic survey series, and it was concluded that the increase in the biomass indices was probably due to a change in catchability.

The Hoki Working Group agreed on a single base run, with four 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. In the final sensitivity model run natal fidelity was not assumed, in contrast to the other model runs.

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 41–60% $B_0$  and the eastern stock 47–52% $B_0$ . The western stock experienced an extended period of poor recruitment from 1995 to 2001 inclusive. However, recruitment has been near or above average in the last five years, except for 2010 where it was below average.

Five-year projections were carried out for each final run with two alternative recruitment scenarios: ‘long-term’ (future recruitment selected from estimated levels in 1975–2010) and ‘recent’ (recruitment selected from 1995–2010). Future catches for each fishery were assumed to be equal to those assumed for 2012. All projections with long-term recruitment suggest that continued fishing at current levels is likely to allow the biomass of both stocks to remain stable or increase. Under recent recruitment, the biomass for the western stock declines from 2014, but remains stable for the eastern stock (except when a domed selectivity is used for the spawning stocks).

## 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). Before 2003–04, the TACC 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 consequently the TACC stepped up, with the last increase being to 130 000 t for 2011–12.

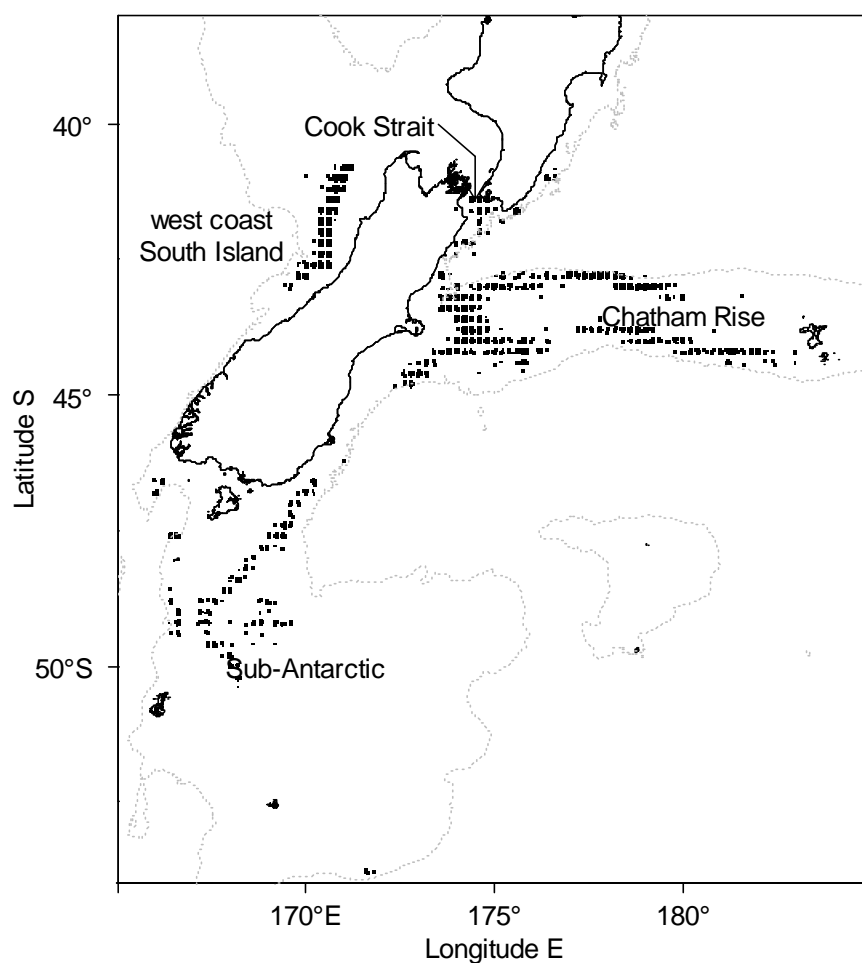
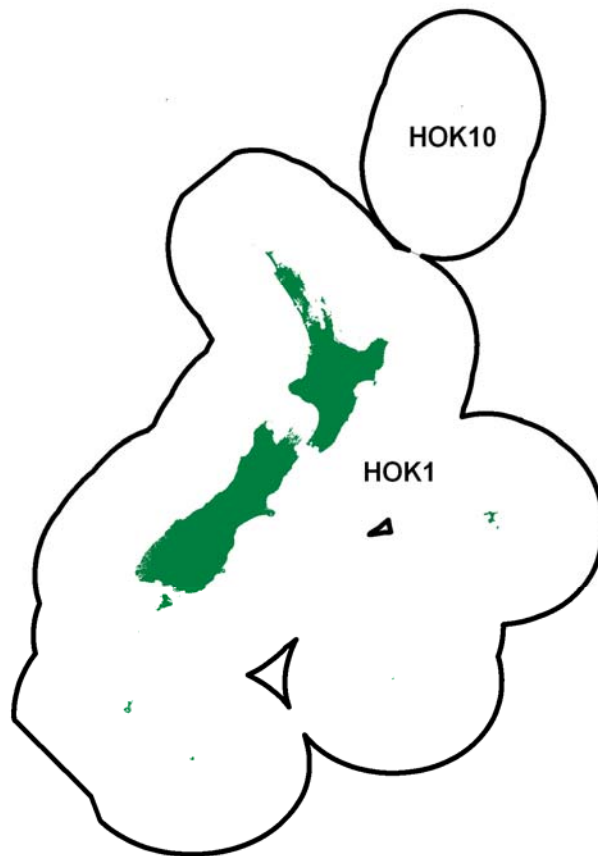


Figure 1: Southern New Zealand showing the main hoki fishing grounds, the 1000 m contour (broken grey line), and the position of all 2010–11 tows from TCEPRs (Trawl Catch and Effort Processing Returns) in which at least 10 t of hoki was caught (dots). Positions are rounded to the nearest 0.2 degrees and jittered.



**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 2012 assessment of HOK 1, which is the eleventh hoki assessment to use NIWA’s general-purpose stock-assessment model CASAL (Bull et al. 2012). Since the last assessment (McKenzie 2011b) there has been another trawl survey in Chatham Rise in January 2012 (Stevens et al. 2012), a trawl survey in Sub-Antarctic in December 2011 (Bagley & O’Driscoll 2012), and an acoustic survey of spawning hoki in Cook Strait in winter 2011 (O’Driscoll 2012).

The work reported here addresses objective 1 for the 2012 year of the Ministry for Primary Industries project DEE201002HOKA: *To update the stock assessment of hoki in the years 2012, 2013, 2014 and 2015 including estimates of biomass, risk and yields.*

## 2. MODEL ASSUMPTIONS AND INPUTS FOR 2012

This section provides a summary of all model assumptions and inputs for the 2012 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. 2012). Changes in model structure and data inputs since the first CASAL stock assessment in 2002 are documented in Appendix 2. Changes from the 2011 assessment are: (1) a reweighting of the at-age data (it is down-weighted), and (2) the re-introduction of a sensitivity model run without natal fidelity.

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 2011 is referred to as the 2012 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 EnspOLF, WnspOLF	proportions at age in catch from given fishery (from otoliths) proportions at age in catch from given fishery (from OLF <sup>1</sup> )
Migrations	Ertn, Wrtn	return migrations of E and W fish from spawning
	Whome	migration of juvenile fish from CR to SA
	Espmg, Wspmg	spawning migrations of E and W fish
Selectivity	Epsl, Wpsl, Enspsl, Wnspsl	selectivity in commercial fisheries
	CRsl, SASl	selectivity in trawl surveys

<sup>1</sup>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 the assessment two alternative assumptions concerning the juveniles are 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. There is little direct evidence of natal fidelity for hoki, though its life history characteristics would indicate that 100% natal fidelity is unlikely (Horn 2011).

The model partition divides the population into two sexes, 17 age groups (1 to 17+), four areas corresponding to the four fisheries (CR, CS, SA, and WC), and two stocks (E and W). The annual cycle (Table 2) is the same as in the 2011 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 2011 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	<i>M</i> 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	0.5
					CRsum	0.6
3	Apr-Jun	Migration Whome: CR→SA part2, non-spawning fisheries (Ensp2, Wnsp2)	0.25	0.90	SAaut pspawn	0.1
4	End Jun	Migrations Wspm: SA→WC, Espm: CR→CS	0.00	0.90	–	
5	Jul-Sep	Increment ages spawning fisheries (Esp, Wsp)	0.25	0.0	CSacous	0.5
					WCacous	0.5

As in the 2011 assessment, 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. For the current year (2012), the new TACC is 130 000 t with a catch split arrangement for 70 000 t to be taken from the western stock and 60 000 t from the eastern stock.

For the western stock it was agreed by the Hoki Working Group that the catch would be split: 15 000 t (non-spawning), 55 000 t (spawning). In the stock assessment model the non-spawning fishery is split into two parts, separated by the migration of fish from the Chatham Rise to the Sub-Antarctic. The same proportions as in 2011 were used to split the western non-spawning catch into two parts.

For the eastern stock the catch was split (Richard Wells, pers. comm.): 41 000 (non-spawning), 19 000 t (spawning). As with the western stock, the eastern non-spawning catch was split into two parts, using the same proportions as in 2011.

Figure 3 shows the distribution of the catch between eastern and western stocks, both overall and for the non-spawning and spawning catch.

The fixed biological parameters in the model are unchanged from those used in 2011 (Table 5).

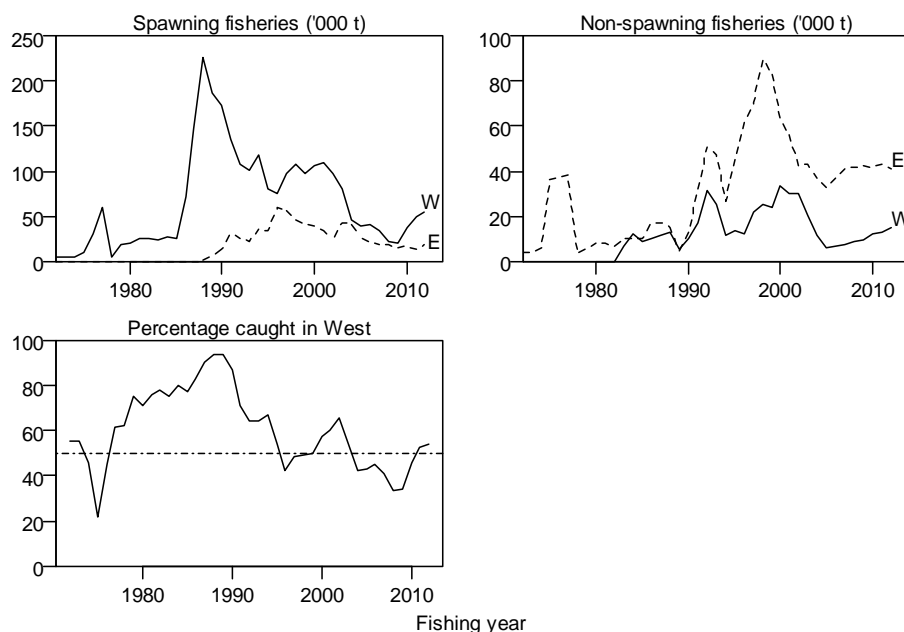
**Table 3: Catches (t) by fishery and fishing year (1972 means fishing year 1971–72), as used in the assessment.**

Year	Fishery						
	Ensp1	Ensp2	Wnsp1	Wnsp2	Esp	Wsp	Total
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	25000	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	203 500
1990	3 300	9 700	900	9 100	14 000	173 000	210 000
1991	17 400	14 900	4 400	12 700	29 700	135 900	215 000
1992	33 400	17 500	14 000	17 400	25 600	107 200	215 100
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	36 200	19 700	13 200	16 900	34 800	109 000	229 800
2002	24 600	18 100	16 800	13 400	24 600	98 000	195 500
2003	24 200	18 700	12 400	7 800	41 700	79 800	184 600
2004	17 900	19 000	6 300	5 300	41 000	46 300	135 800
2005	19 300	13 800	4 300	2 000	26 300	38 700	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	18 800	33 700	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	15 900	20 800	88 900
2010	28 500	13 500	6 700	5 600	16 400	36 600	107 300
2011	30 500	12 800	7 500	5 200	13 300	49 500	118 800
2012	28 900	12 100	8 900	6 100	19 000	55 000	130 000

**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 <sup>1</sup>	Ensp1	Ensp2	Ensp2

<sup>1</sup> 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			E stock			Source
			Male	Female	Both	Male	Female	Both	
Growth	$L_{\infty}$		92.6	104.0	102.1	89.5	101.8	100.8	a
	$k$		0.261	0.213	0.206	0.232	0.161	0.164	
	$t_0$		-0.5	-0.6	-0.96	-1.23	-2.18	-2.16	
Length-weight [W(kg)=aL(cm) <sup>b</sup> ]	$a$	$4.79 \times 10^{-6}$							b
	$b$	2.89							
Proportion by sex at birth		0.5							c

## 2.2 Ogives

The ogives used in the model are the same as in 2011: six selectivity ogives (one for each of the four fisheries — Espsl, Wpsl, Enpsl, Wnpsl — 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).

These are associated with two different ways of dealing with the problem of the lack of old fish noted in both fishery and survey observations. In the first the spawning selectivities are logistic, but natural mortality is allowed to vary with age (i.e. run 1.3). Alternatively the spawning selectivities are domed, with natural mortality the same for all ages (i.e. run 1.4).

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.

**Table 6: Ogive assumptions for two of the final runs (see section 4 for further explanation). In the ogive constraints,  $O_{7,F,E}$  refers to the ogive value at age 7 for female fish from the E stock, etc.**

Runs	Ogive type	Description	Constraints
1.3	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 <sup>1</sup>
	Survey selectivity	Length-based, double-normal	Same for M and F, must be domed <sup>1</sup>
	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
1.4	Spawning selectivity	Age-based, double-normal	Same for E and W
	Non-spawning selectivity	Age-based, double-normal	
	Survey selectivity	Age-based, double-normal	
	Spawning migration	Free, ages 1–8	$O_A = O_8$ for $A > 8$
	Home migration	Free, ages 1–7	=1 for age > 7

<sup>1</sup> 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  $Wsp_{sl}$  (the selectivity ogive for W spawning fishery). Following the recommendation of Francis (2006), these changes were restricted to years for which there were  $Wsp_{page}$  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  $Wsp_{sl}$ . The mean value was used for all years for which there was catch but no  $Wsp_{page}$  data (i.e., before 1988 and in the 2012 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	2011
309	309	308	309	307	309	310	307	301	295	298	301
Mean											
305											

### 2.3 Other structural assumptions

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

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

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),  $R_{\text{mean}}$  is the expected recruitment (ignoring the stock-recruit relationship), and  $SSB_y$  is the mid-season spawning stock biomass in year  $y$ .  $R_0$  is calculated as  $R_{\text{mean}}Y_{\text{mean}}$ , where  $Y_{\text{mean}}$  is the mean year class strength (YCS) over the years 1975 to 2006, inclusive (so  $R_0$  is the mean recruitment over those years, ignoring the effect of the stock-recruit relationship).

Thirty-six YCSs were estimated for each stock, for 1975 to 2010, inclusive. YCSs for the initial years (1970 to 1974) were fixed at 1. The E and W YCSs for 2010 were constrained (by a penalty function) to be equal for MPD runs. In previous assessments this constraint was removed for the full Bayesian runs, but was inadvertently left in for the Bayesian runs for this assessment. However, a post-assessment Bayesian run showed that this made very little difference to the results (Appendix 5).

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 (Tables 8–9), proportions at age (by sex) (Table 10, Figure 4), and proportion spawning (Table 11). Biomass indices new to this assessment are another trawl survey on Chatham Rise in January 2012 (Stevens et al. 2012), a trawl survey in Sub-Antarctic in December 2011 (Bagley & O'Driscoll 2012), and an acoustic survey of spawning hoki in Cook Strait in winter 2011 (O'Driscoll 2012).

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 2011a, 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 11) use the recommended estimates of Francis (2009).

The way the proportions-at-age data enter the model varies amongst data sets (Table 12). 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 their values to be replaced by 0.0001 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. The Cook Strait acoustic biomass estimates (CSacous) were recalculated for 2012 based on a different methodology (see Table 9).**

	<u>CRsumbio</u>	<u>SAsumbio</u>	<u>SAautbio</u>	<u>CSacous</u>	<u>WCacous</u>
1988	–	–	–	–	417 (0.22,0.60)
1989	–	–	–	–	249 (0.15,0.38)
1990	–	–	–	–	255 (0.06,0.40)
1991	–	–	–	<b>191</b> (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)	–	<b>613</b> (0.15,0.52)	550 (0.07,0.38)
1994	146 (0.10,0.22)	100 (0.09,0.22)	–	<b>597</b> (0.06,0.91)	–
1995	120 (0.08,0.21)	–	–	<b>411</b> (0.12,0.61)	–
1996	153 (0.10,0.22)	–	89 (0.09,0.22)	<b>196</b> (0.09,0.57)	–
1997	158 (0.08,0.22)	–	–	<b>302</b> (0.12,0.40)	654 (0.10,0.60)
1998	87 (0.11,0.23)	–	68 (0.11,0.23)	<b>170</b> (0.10,0.44)	–
1999	109 (0.12,0.23)	–	–	<b>245</b> (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)	–	<b>217</b> (0.12,0.30)	–
2002	74 (0.11,0.23)	38 (0.16,0.26)	–	<b>307</b> (0.13,0.35)	–
2003	53 (0.09,0.22)	40 (0.14,0.24)	–	<b>222</b> (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)	–	<b>124</b> (0.11,0.32)	–
2006	99 (0.11,0.23)	21 (0.13,0.24)	–	<b>128</b> (0.17,0.34)	–
2007	70 (0.08,0.22)	14 (0.11,0.23)	–	<b>218</b> (0.26,0.46)	–
2008	77 (0.11,0.23)	46 (0.16,0.26)	–	<b>179</b> (0.09,0.30)	–
2009	144(0.11,0.23)	47 (0.14,0.24)	–	<b>334</b> (0.14,0.39)	–
2010	98 (0.15,0.25)	65 (0.16,0.26)	–	–	–
2011	94 (0.14,0.24)	–	–	<b>269 (0.18,0.35)</b>	–
<b>2012</b>	88 (0.10,0.22)	46 (0.15,0.25)	–	–	–

**Table 9: Recalculated Cook Strait acoustic spawning biomass indices. The biomasses with “same r” are used for the assessment, with a sensitivity run using the “annual r” values (O’Driscoll 2012b).**

Year	Biomass ('000 t)		Total c.v
	“old” annual r	“new” same r	
1991	180	191	0.41
1993	583	613	0.52
1994	592	597	0.91
1995	427	411	0.61
1996	202	196	0.57
1997	295	302	0.40
1998	170	170	0.44
1999	243	245	0.36
2001	220	217	0.30
2002	320	307	0.35
2003	225	222	0.34
2005	132	124	0.32
2006	126	128	0.34
2007	216	218	0.46
2008	167	179	0.30
2009	315	334	0.39
2011	300	269	0.35

**Table 10: Description of the proportions-at-age observations used in the assessment. These data derive either from otoliths or from the length-frequency analysis program OLF (Hicks et al. 2002). Data new to this assessment are in bold type.**

Area	Label	Source of Data type	Years	age data
WC	Wspage	Catch at age	1988– <b>11</b>	otoliths
SA	WnspOLF	Catch at age	1992–94, 96, 99–00	OLF
	Wnspage	Catch at age	2001–04, 06– <b>11</b>	otoliths
	SAsumage	Trawl survey	1992–94, 2001–10, <b>12</b>	otoliths
	SAautage	Trawl survey	1992, 96, 98	otoliths
CS	Espage	Catch at age	1988– <b>11</b> *	otoliths
CR	EnspOLF	Catch at age	1992, 94, 96, 98	OLF
	Enspage	Catch at age	1999– <b>10, 11</b>	otoliths
	CRsumage	Trawl survey	1992– <b>12</b>	otoliths

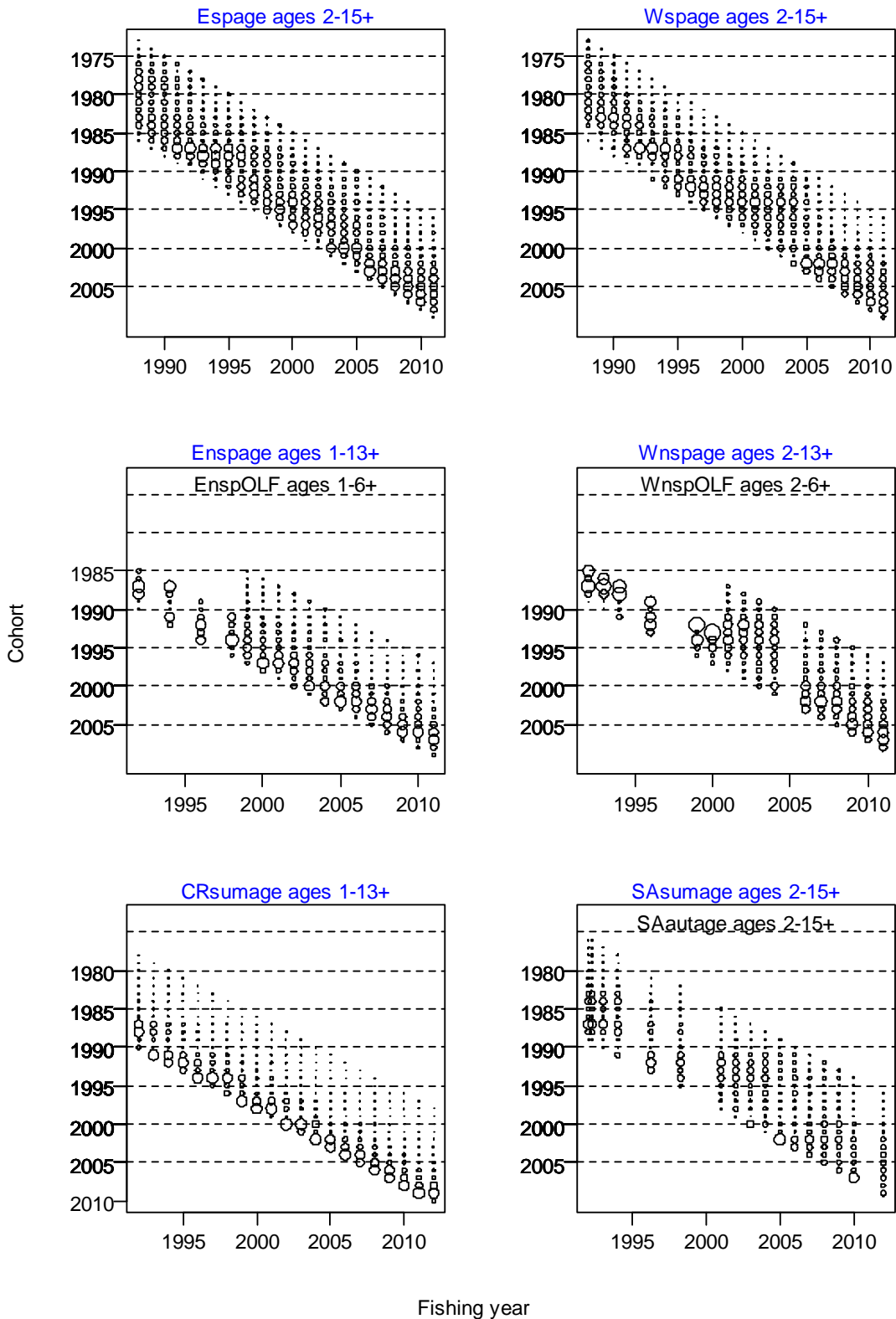
\* Not included in initial model runs, except for a sensitivity run.

**Table 11: 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	Age						
	3	4	5	6	7	8	9+
1992	0.13	0.44	0.48	0.54	0.67	0.61	0.66
1993	–	0.64	0.58	0.65	0.66	0.71	0.60
1998	0.27	0.46	0.39	0.42	0.49	0.44	0.54

**Table 12: 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 10.**



## 2.5 Error assumptions

In the 2011 assessment the error distributions assumed for the proportions-at-age data were robust lognormal, to which process errors estimated within the model were added. In Francis (2011a) the weighting of data in stock assessments was explored and one of the conclusions drawn was that proportions-at-age data are often over-weighted in assessments. Prior to the 2012 assessment the proportions-at-age data for the 2011 assessment were reweighted using the methods of Francis (2011a) and it was concluded that these data needed to be down-weighted (Appendix 3). Based on these results it was decided by the Hoki Working Group to reweight the proportions-at-age data for this assessment, using a multinomial error distribution. This means that the weight assigned to each proportion-at-age datum is controlled by an effective sample size, these being calculated in MPD runs, then fixed for the full Bayesian runs.

The error distributions assumed were lognormal for all other data. This means that the weight assigned to each datum was controlled by an error c.v. 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 c.v.s for 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:  $c.v.\text{total}^2 = c.v.\text{process}^2 + c.v.\text{observation}^2$ ). 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 the proportion of fish that migrate to spawn (pspawn) the error distribution was lognormal, for which an arbitrary c.v. of 0.25 was assumed following Cordue (2001).

## 2.6 Parameters, priors, and penalties

The number of parameters estimated in the final model runs was 149 (for run 1.3) or 127 (for run 1.4) (Table 13). 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 the parameter used to estimate annual changes in the selectivity ogive for the W spawning fishery ([Wspsl].shift\_a) normal priors were used with standard deviations more or less arbitrarily chosen to discourage extreme values (see section 7.1 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. 2012).

**Table 13: 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 1.3 and 1.4, respectively (see section 3 for an 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.  $B_{\text{mean}}$  is the biomass associated with the Francis parameterisation of year class strengths (Bull et al. 2012).**

Parameter(s)	Description	Type	Distribution		No. of parameters
			Parameters		
log_Bmean_total	$\log(B_{\text{mean,E}} + B_{\text{mean,W}})$	uniform	12.6 <sup>a</sup>	16.2	1
Bmean_prop_stock1 (=pE)	$B_{\text{mean,E}}/(B_{\text{mean,E}} + B_{\text{mean,W}})$	beta[0.1,0.6] <sup>b</sup>	0.344	0.072	1
recruitment.YCS	year-class strengths	lognormal	1	0.95	72
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 <sup>c</sup>	lognormal	0.17	0.61	1
q[SAAut].q	catchability, SAAutbio	lognormal	0.17	0.61	1
natural_mortality	$M_{\text{male}}$ & $M_{\text{female}}$ ages 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	Epspl,Wspsl,Enspsl,Wnspsl	uniform	various		8,9
surv. selectivities	CRsl, SAsl	uniform	various		6
					149,127

<sup>a</sup> A lower bound of 13 was used for run 1.4

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

<sup>c</sup> 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 (normally this penalty is dropped for Bayesian run, but it has little impact on results) (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).

## 2.7 No natal fidelity model structure

Under the natal fidelity assumption fish spawn on the grounds where they were spawned (Horn 2011). For this assessment a sensitivity model run is re-introduced in which natal fidelity is not assumed. Instead when a fish matures it spawns at a ground where it may or may not have been spawned, but in subsequent years returns to this same ground to spawn (so it exhibits a life history characteristic referred to as *adult fidelity*). In the no natal fidelity model there is one biological stock (i.e., genetic stock) and two spawning stocks, whereas for the natal fidelity models there are two biological stocks and these match up with the two spawning stocks.

There have been a number of attempts to implement an adult fidelity model in CASAL, the first being for the 2006 assessment. However, these CASAL models have been problematic due to difficulties defining the eastern and western spawning stock biomasses and the uncertainty in these from Bayesian runs (section 7.3 in Francis 2006, section 3.3 in Francis 2007, sections 3.2 and 3.3 in Francis 2008, section 7.1 in Francis 2009, McKenzie 2009, McKenzie 2012). Recently, the problems

appear to have been resolved, and in this section we give more detail as to how the no natal fidelity model is implemented in CASAL. The key point to remember is that the no natal fidelity model is a modification of the natal fidelity model 1.3 (see Table 6) — a sexed model with age-varying natural mortality. Apart from the obvious modification of reducing from two biological stocks to one, the two other main modifications are to the home migration ogive (Whome) and to how year class strengths are estimated.

The interpretation of the home migration ogive (Whome) differs depending on whether or not natal fidelity is assumed. With natal fidelity just those fish from the W stock migrate from CR to SA; without natal fidelity any fish in the CR can do this migration. Either way, a fish that migrates to SA will subsequently spawn on the WC and be part of the western spawning stock. Secondly, for the no natal fidelity model, Whome can vary from year to year, with this variation determining what proportion of each year class grow up to become E or W fish (see sections 7.3 in Francis 2006 for the initial implementation of this).

For the no natal fidelity model there is just a single stock, so a single vector of YCSs is estimated, this being interpreted as measuring the combined recruitment from the two spawning stocks, which is reflected in the number of juvenile fish seen in CR. For the natal fidelity model run YCSs are estimated for E and W stocks.

For the no natal fidelity model a virgin spawning stock biomass for the entire stock is well defined and calculated in the same way as for the natal fidelity models (as the spawning stock biomass under mean recruitment and no fishing pressure). To calculate east and west spawning stock biomasses 500 year projections are done with no fishing pressure and random re-sampling of year class strengths. The last 480 years of these projections are used to find the mean proportion of the spawning biomass that is in the east and west, these proportions are then applied to the virgin biomass for the entire stock to calculate virgin biomasses for east and west. Using proportions in this way ensures that the calculated eastern and western biomass match up with the total. These calculations can be done either for the MPD fit (defining MPD east and west virgin biomasses) or for each sample from the MCMC, the distribution of biomasses defined in this way determine the posterior density for the virgin biomasses.

### **3. INITIAL EXPLORATORY MODEL RUNS**

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

Two sets of initial exploratory runs were done: (1) incorporating the new data and comparing model fits to the 2011 assessment and (2) investigating whether or not to upweight the trawl surveys to improve the fit to the biomass indices.

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 2011, but used the new data (Table 14). In both these runs the three trawl surveys are upweighted (Table 15). Note that Espage for 2011 was excluded from initial model runs, except in a sensitivity model run, as it was not considered representative of the commercial catch in 2011 due to poor temporal observer coverage and the rapidly changing sex ratio (Ballara & O'Driscoll 2012).

The next MPD runs (1.3 and 1.4) are the same as 1.1 and 1.2 respectively, except that the at-age data are reweighted (Section 2.5). These two runs are the starting models for the assessment, as it was decided by the Hoki Working Group to reweight the at-age data, as long as no problems arose in doing so. Calculated weightings for these runs are used in subsequent variations on them.

The next set of runs (1.5 and 1.6) are the same as 1.3 and 1.4 respectively, except that the trawl surveys are not upweighted. The last run (1.7) is the same as run 1.3, except that the “old” CSacous biomass estimates are used (see Table 9) and the Espage 2011 age data is included.

Reweighting gives effective sample size for the data sets that ranged from 9 to 69 (taking a mean over all fishing years for each data set), with scaling down of initial effective samples sizes based on the observation error up to 83-fold but typically in the range 20–50 (Appendix 3). For model run 1.3 the effective sample sizes for the summer Chatham Rise and Sub-Antarctic trawl surveys are 83 and 9 respectively, with the fits to the associated proportions-at-age data sets little changed by reweighting for the Chatham Rise, but more altered for the Sub-Antarctic (Figures 5–6).

The biggest impact of reweighting is on the eastern stock, reducing the estimated current status (%B<sub>0</sub>) (Table 16). Removing the trawl upweighting increases the current status of both the eastern stock and western stocks. Using the old CSacous data and including Espage 2011 has a minor impact.

Upweighting the trawl surveys had little effect on the fits to the data sets SAautbio, CSacous, and WCacous (Table 17, Figures 7–10). Upweighting improves the fit for the last three years of CRsumbio (Figure 9), and for about half the years up to 2007 for SASumbio (Figure 10).

**Table 14: Relationship between initial 2012 model runs and those from the 2011 assessment. Runs labelled 1.1 and 1.2 for the 2011 assessment are two of the final model runs selected by the Hoki Working Group for the 2011 assessment. In all model runs in this table the trawl survey biomass data are upweighted.**

2012 label	2011 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

**Table 15: Relationship between initial 2012 model runs.**

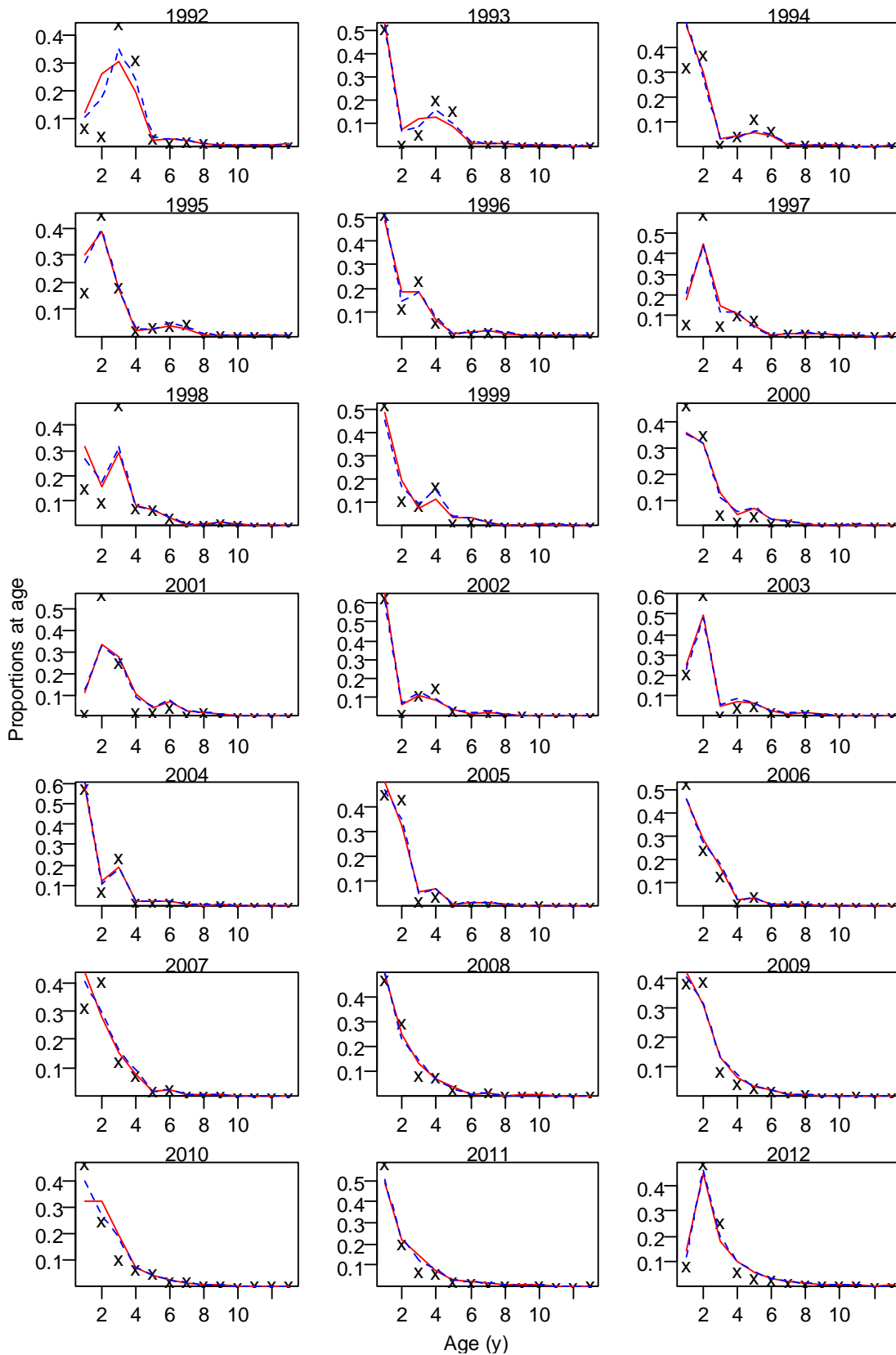
Run	Response to lack of old fish in the observations	At-age data reweighted	Trawl surveys upweighted?	Use “old” CSacous and include Espage 2011?
1.1	M dependent on age	No	Yes	No
1.2	Domed spawning selectivity	No	Yes	No
1.3	M dependent on age	Yes	Yes	No
1.4	Domed spawning selectivity	Yes	Yes	No
1.5	M dependent on age	Yes	No	No
1.6	Domed spawning selectivity	Yes	No	No
1.7	M dependent on age	Yes	Yes	Yes

**Table 16: Comparison of key aspects of all initial MPD fits. The trawl surveys are upweighted in all runs, except 1.5 and 1.6.**

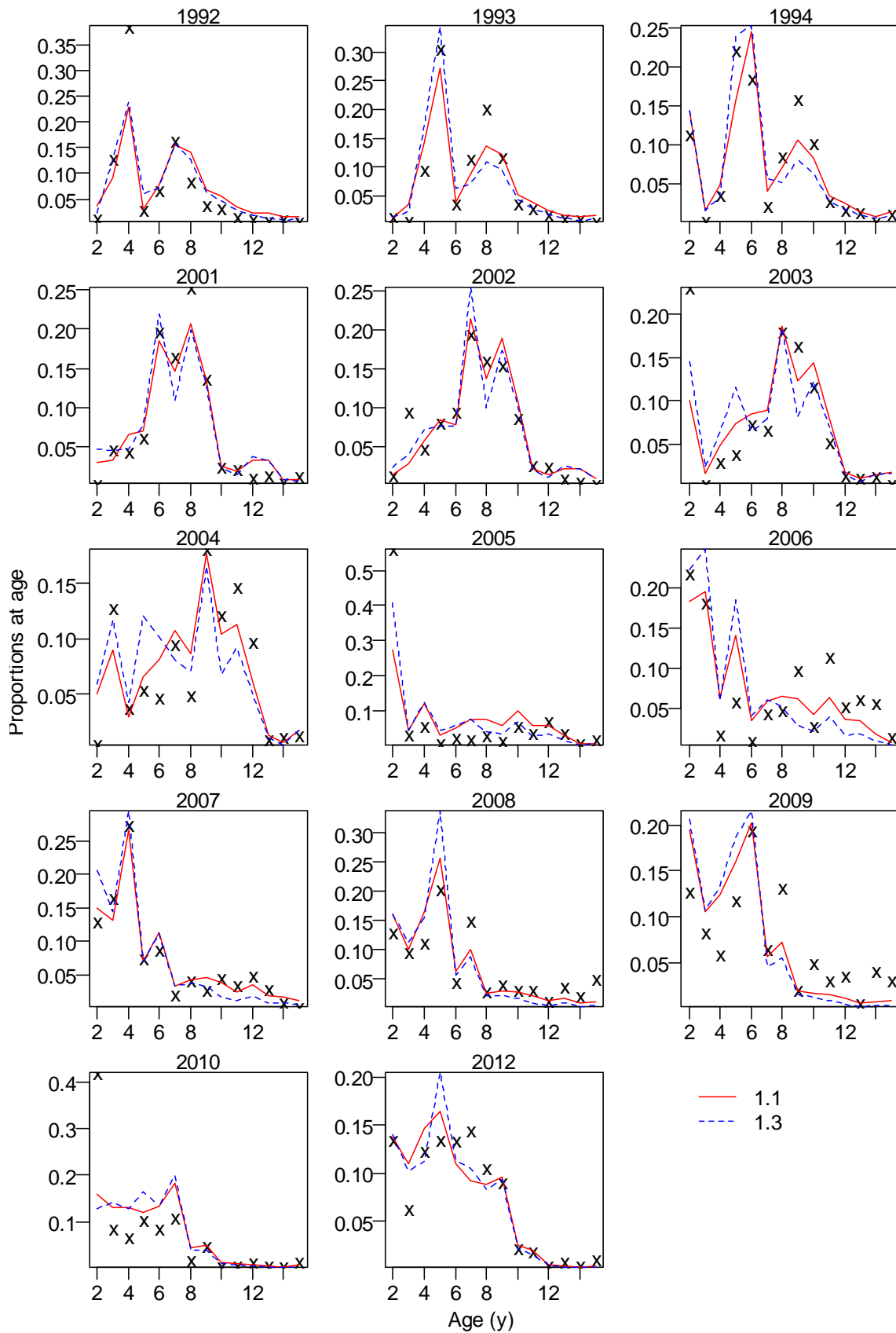
Run	Description	B <sub>current</sub> (%B <sub>0</sub> )	
		E	W
1.1	No reweighting	54	38
1.3	As in 1.1, with reweighting	50	36
1.5	As in 1.3, no trawl up weighting	54	44
1.7	As in 1.3, but “old” CS acous + CS 2011 age	48	36
1.2	No reweighting	53	51
1.4	As in 1.2, with reweighting	45	50
1.6	As in 1.4, no trawl upweighting	52	58

**Table 17: 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).**

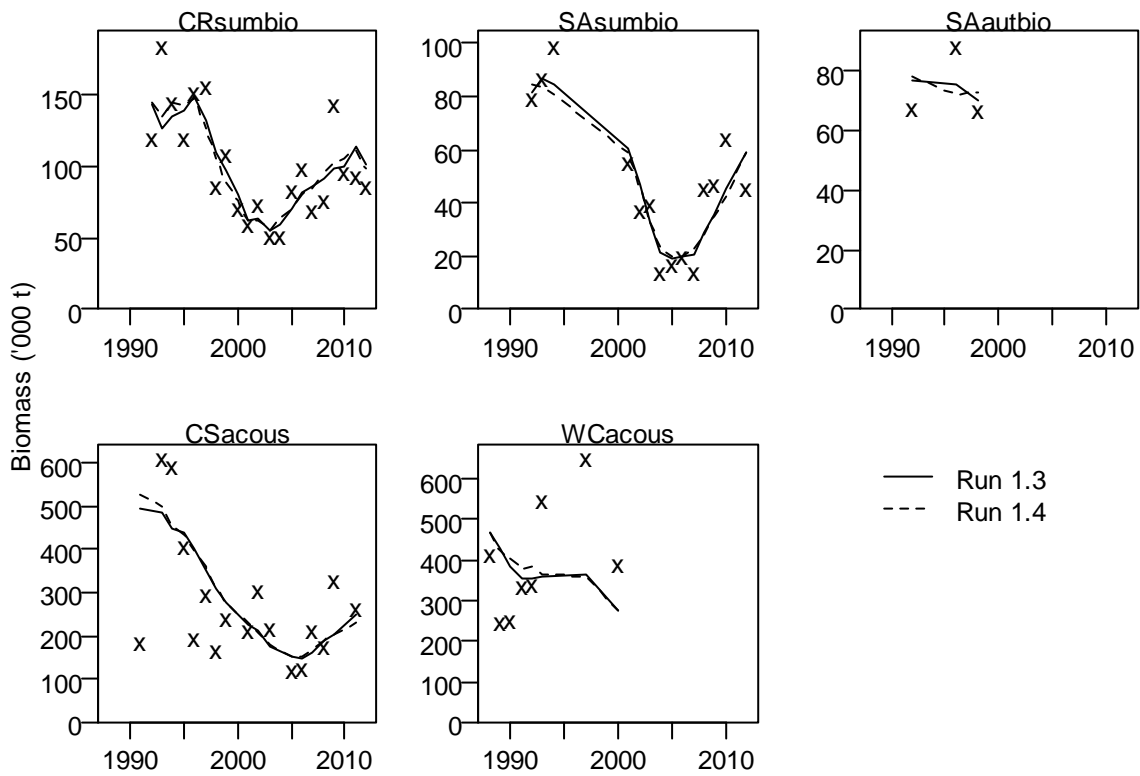
Run	Description	CRsumbio	SAsumbio	SAautbio	CSacous	WCacous
1.3		0.84	1.08	0.70	0.95	0.97
1.5	As in 1.3, no upweighting	0.93	1.35	0.72	0.94	0.99
1.4		0.83	1.24	0.86	0.99	0.98
1.6	As in 1.4, no upweighting	0.92	1.46	0.89	0.97	0.99



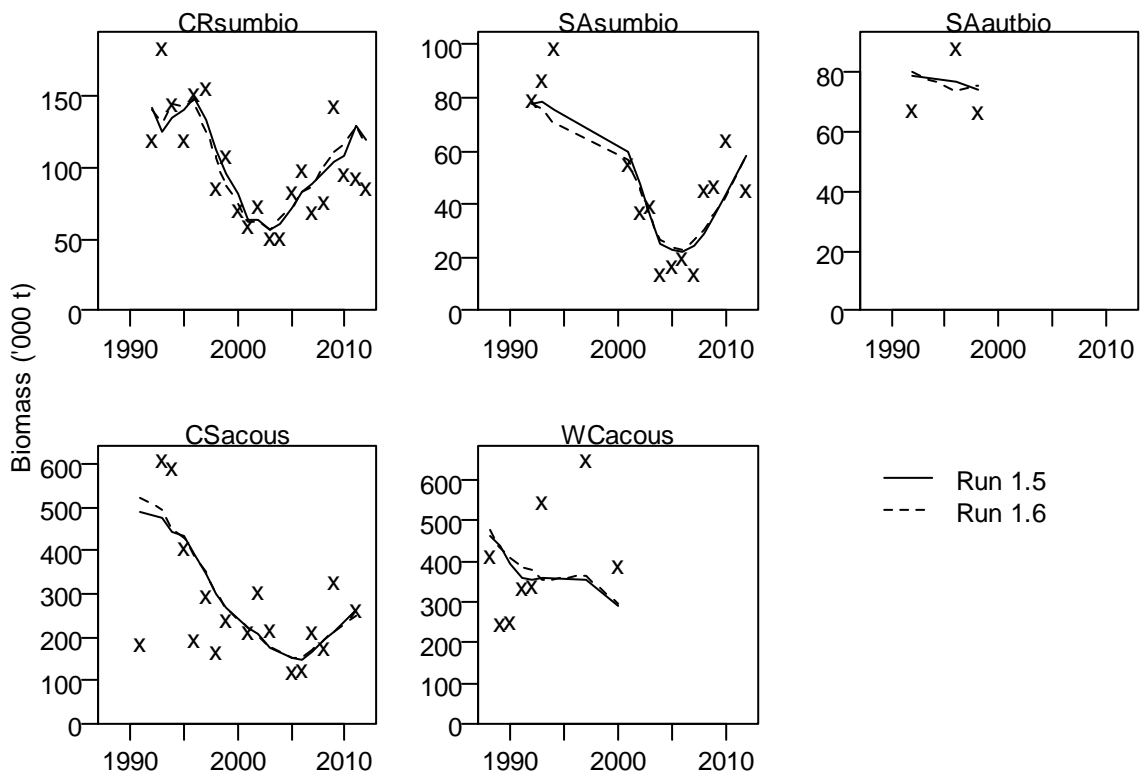
**Figure 5: The impact of reweighting on fits to the proportions-at-age in the summer Chatham Rise survey (data set CRsumage). Observed ('x') and expected (lines) for runs 1.1 (red solid line) and 1.3 (blue broken lines). Run 1.1 is not reweighted for the at-age data, while run 1.3 is reweighted. In both runs the trawl survey data are upweighted. Note that the expected value lines often overlap.**



**Figure 6: The impact of reweighting on fits to the proportions-at-age in the summer Sub-Antarctic trawl survey (data set SASumage). Observed ('x') and expected (lines) for runs 1.1 (red solid line) and 1.3 (blue broken lines). Run 1.1 is not reweighted for the at-age data, while run 1.3 is reweighted. In both runs the trawl survey data are upweighted.**

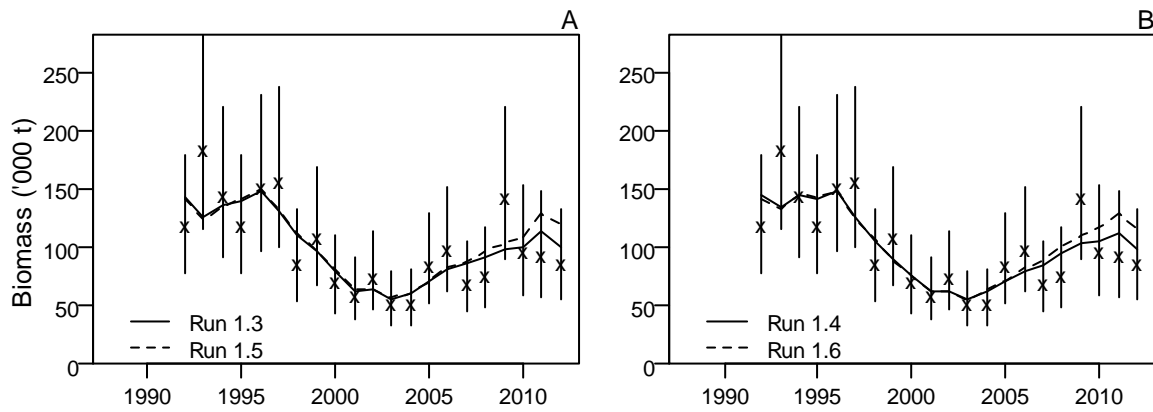


**Figure 7: Fit to biomass indices for runs 1.3 and 1.4 showing observed ('x') and expected values (lines). In these model runs the trawl survey biomass data are upweighted.**

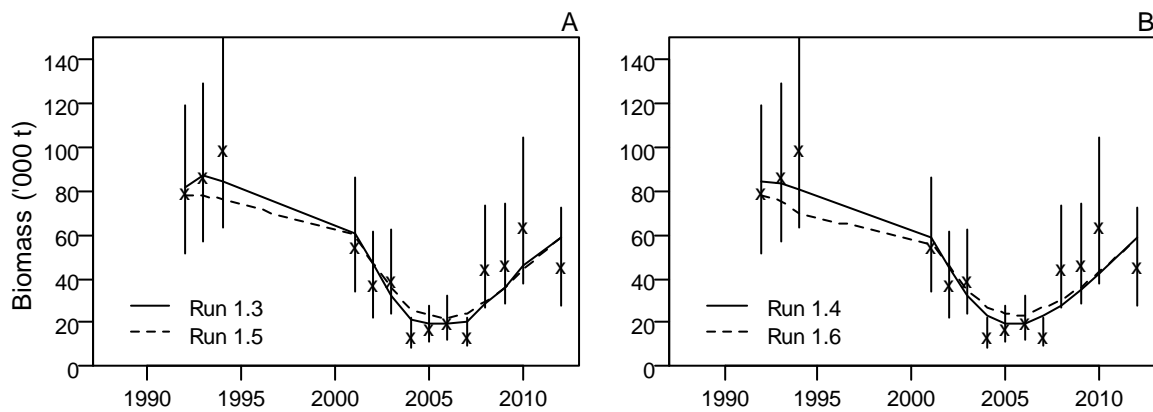


**Figure 8: Fit to biomass indices for runs 1.5 and 1.6, showing observed ('x') and expected values (lines). In these model runs the trawl survey biomass data has no upweighting.**





**Figure 9: Fits to CRsumbio for runs 1.3 to 1.6, 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 2012). The trawl survey indices are upweighted (solid lines) or non-upweighted (dashed lines).**



**Figure 10: Fits to SASumbio for runs 1.3 to 1.6, 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 (solid lines) or non-upweighted (dashed lines).**

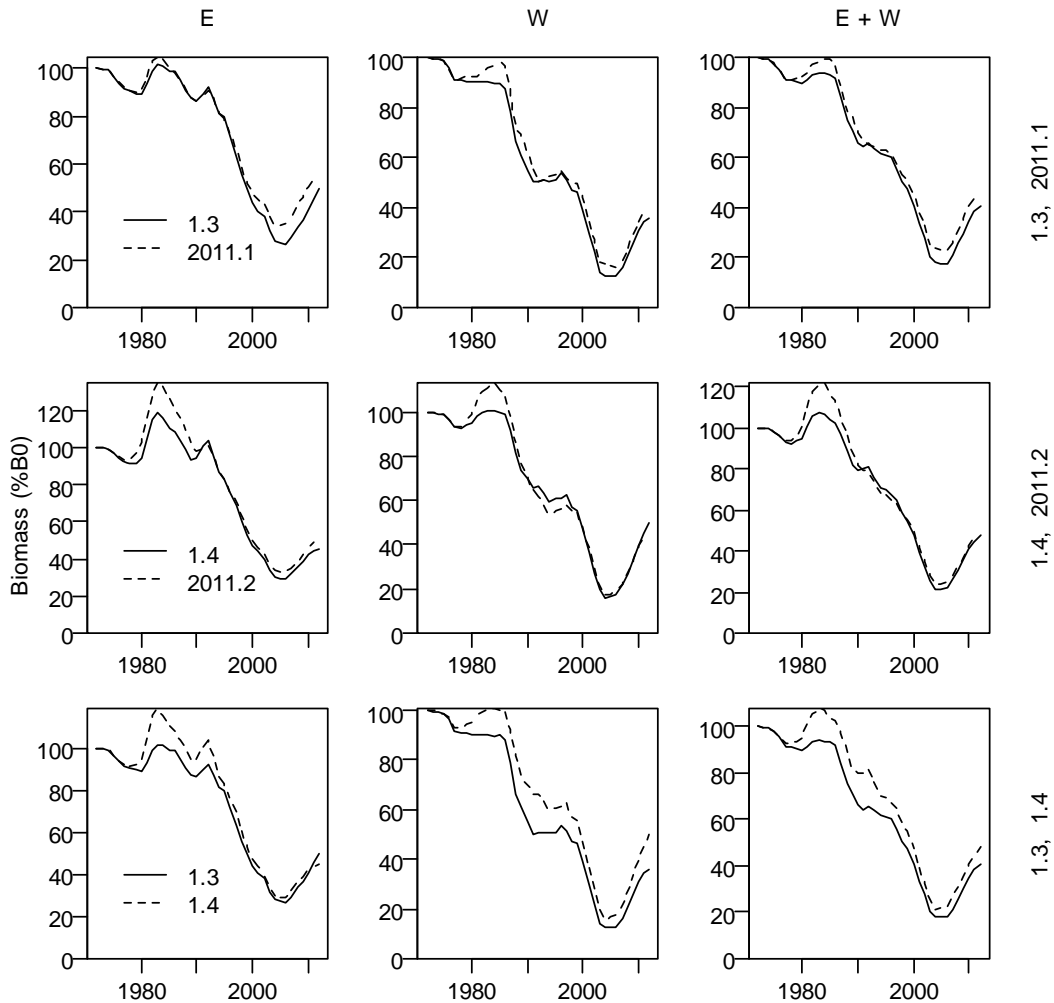
Retaining just the upweighted model runs 1.3 and 1.4, the biomass trajectory for these are compared to model runs from last year's assessment (Table 18, Figure 11). For the new assessment model runs the eastern and western virgin biomasses are estimated to be about the same or less than was estimated in 2011. Related to this is that current estimated biomass (% $B_0$ ) in 2011 for the new assessment model runs, are about the same or less than was estimated for the previous assessment. The differences are more pronounced for model 1.3.

The year class strengths are very similar between assessments and model runs with some slight differences for poorly estimated YCSs (Figures 12–13).

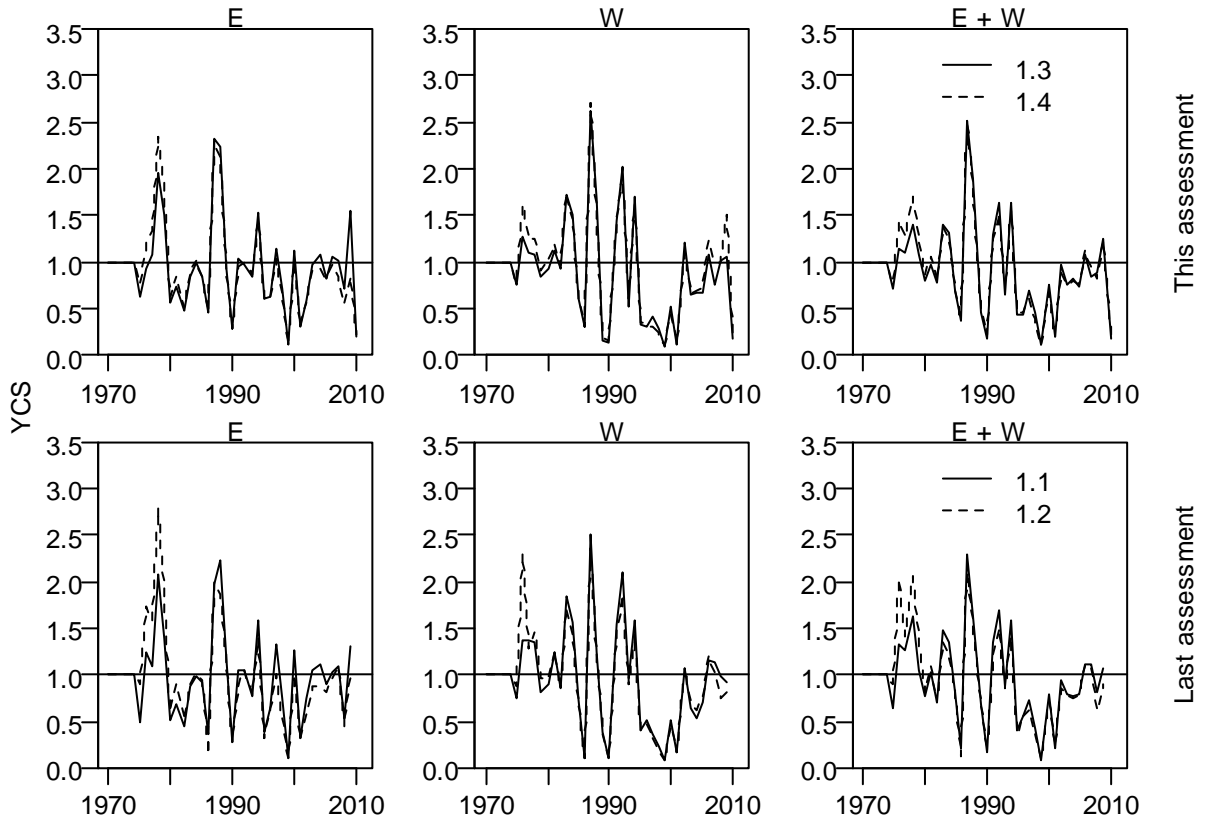
Other graphs show exploitation rates, selectivities, migration ogives, and fitted age-varying natural mortality (Figures 14–17). Exploitation rates in a period centred about 2004 are higher for the new assessment runs. There are some selectivity changes for run 1.3 involving the trawl survey selectivities (CRsl, SAsl) and the western non-spawning fishery (Wnspsl). Estimated age-varying natural mortality for run 1.3 differs from the last assessment: for younger females it is less, younger males more, and older males it is less.

**Table 18: 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 2011 and the other is from 2012.**

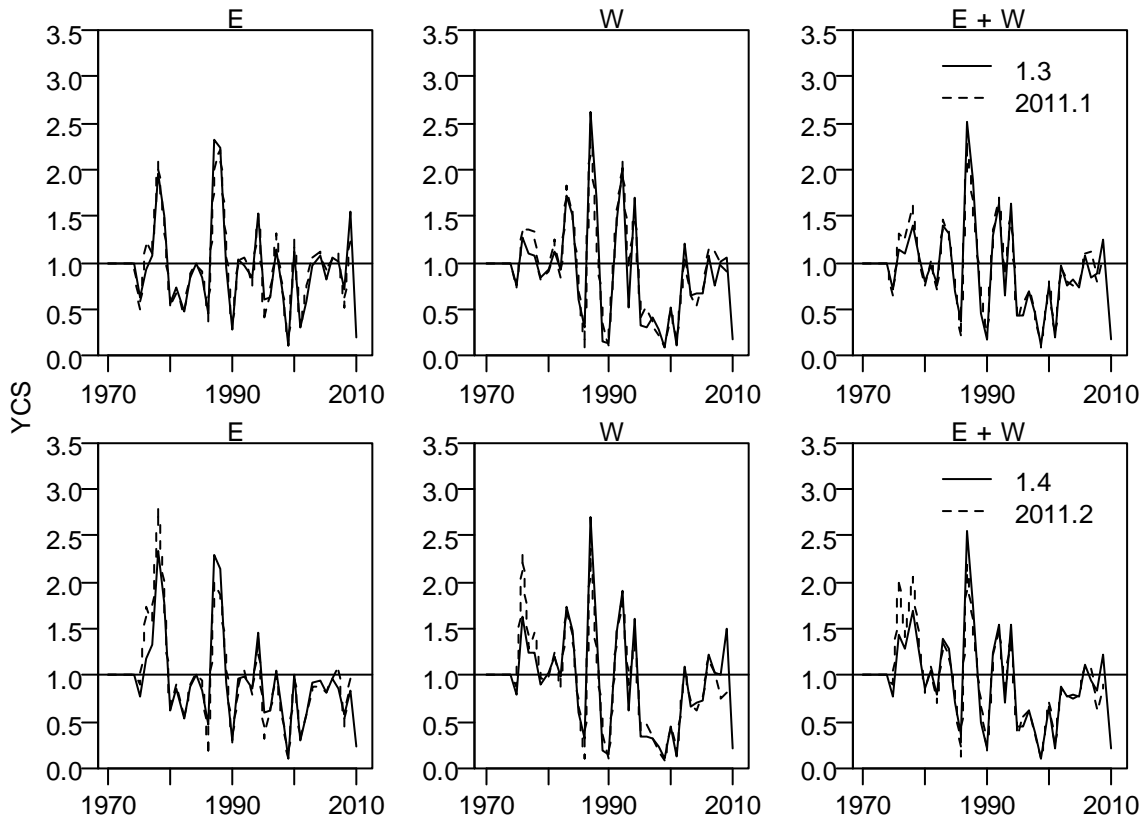
Assessment year		$B_0$ ('000 t)			$B_{2011}$ (% $B_0$ )			$B_{2012}$ (% $B_0$ )		
		E	W	E+W	E	W	E+W	E	W	E+W
2011	1.1	456	790	1246	53	38	43	–	–	–
2012	1.3	428	759	1187	45	34	38	50	36	41
2011	1.2	616	846	1462	49	43	46	–	–	–
2012	1.4	550	844	1394	44	45	45	45	50	48



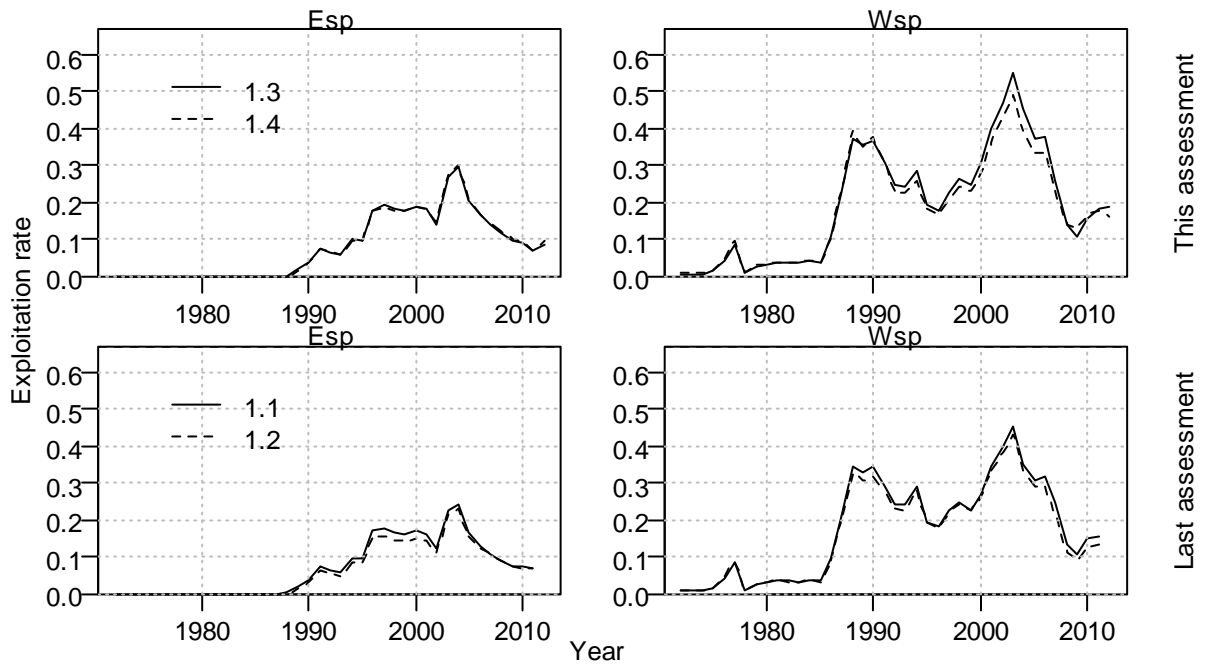
**Figure 11: Comparison of biomass trajectories from different runs: E stock (left column), W stock (middle column), and E + W stocks combined (right column). The top two rows of panels compare each new run (solid lines) with the corresponding run from 2011 (broken lines); the bottom row compares the two new runs. The label 2011.1 refers to run 1.1 from 2011, and the label 2011.2 to run 1.2 from 2011.**



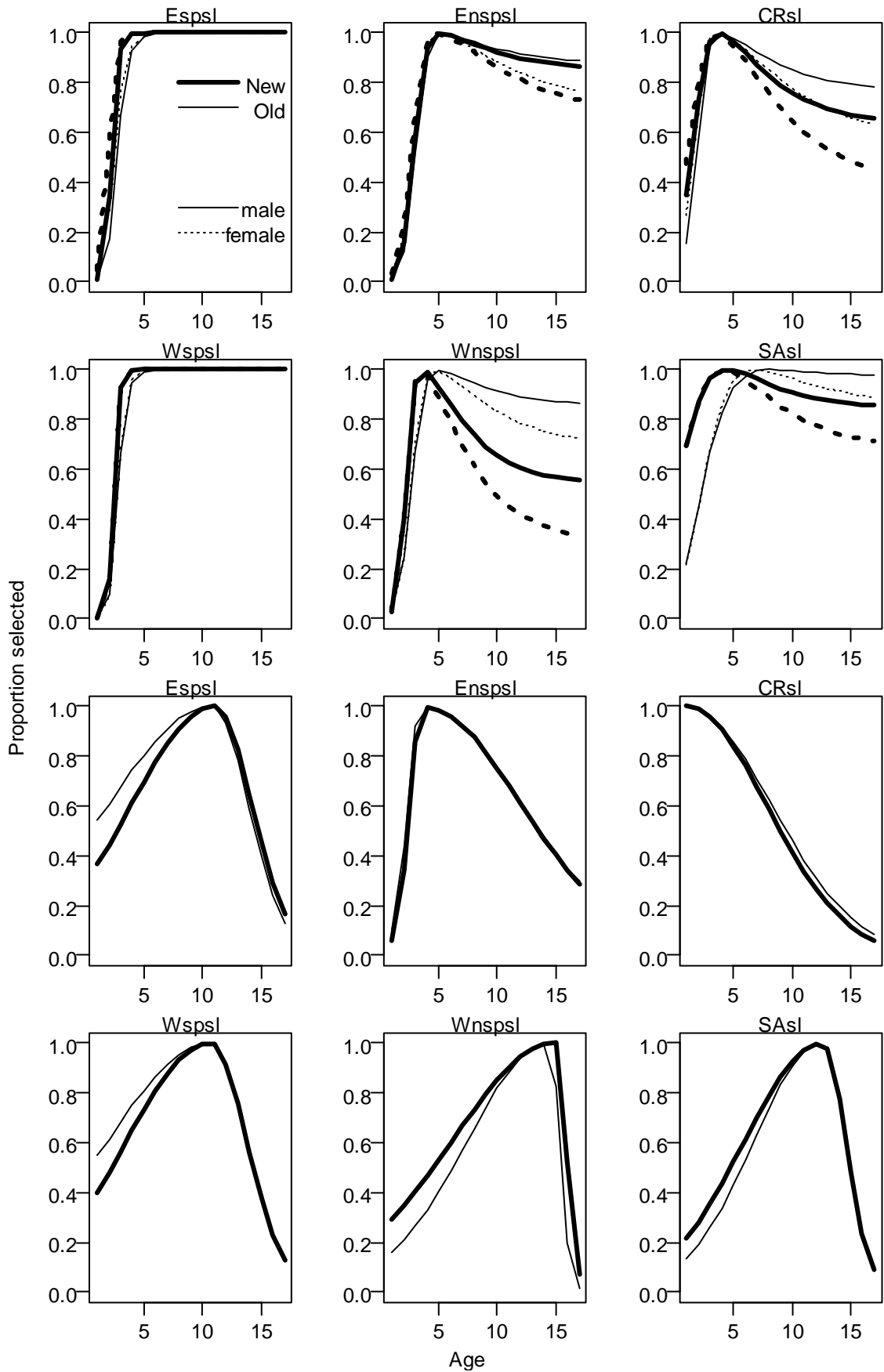
**Figure 12: YCS estimates for new runs 1.3, 1.4 (upper panels) and the runs from last year's assessment (lower panels).**



**Figure 13: YCS estimates for new runs 1.3, 1.4 (solid lines) compared with the runs from last year's assessment (dashed lines).**



**Figure 14: Estimated exploitation rates from runs 1.3 and 1.4 for this assessment (upper panels) and the main runs from last year's assessment (lower panels).**



1.3 & 2011.1

1.4 & 2011.2

**Figure 15: Estimated selectivity curves for new model runs (heavy lines) and analogous 2011 runs (light lines). Males are shown by a solid line, females by a dotted line. The label 2011.1 denotes run 1.1 for the 2011 assessment, and the label 2011.2 denotes run 1.2.**

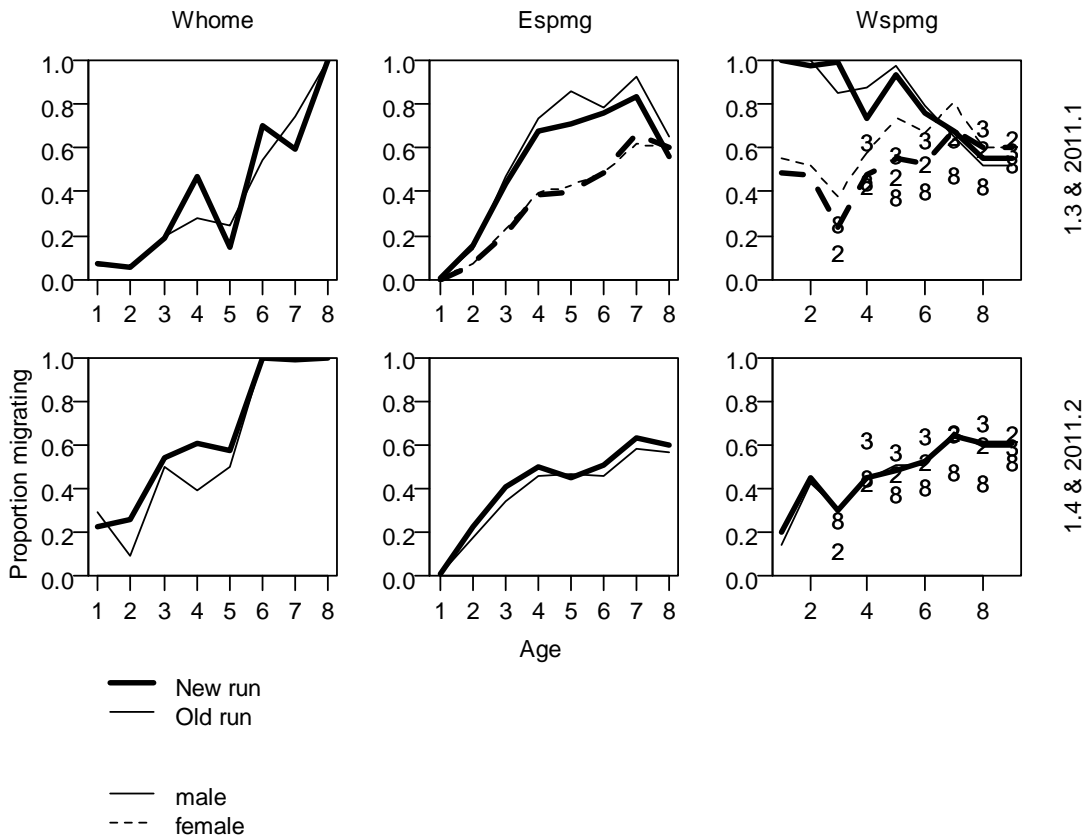


Figure 16: Estimated migration ogives for new and old runs. Each row of plots compares ogives from a new run (heavy lines) with those from the analogous 2011 runs (light lines). Where ogives differ by sex, female ogives are plotted as broken lines. The observations pspawn are also plotted in the rightmost panels, with the plotting symbol identifying the year of sampling ('2' = 1992, '3' = 1993, '8' = 1998). The label 2011.1 denotes run 1.1 for the 2011 assessment; and the label 2011.2 denotes run 1.2.

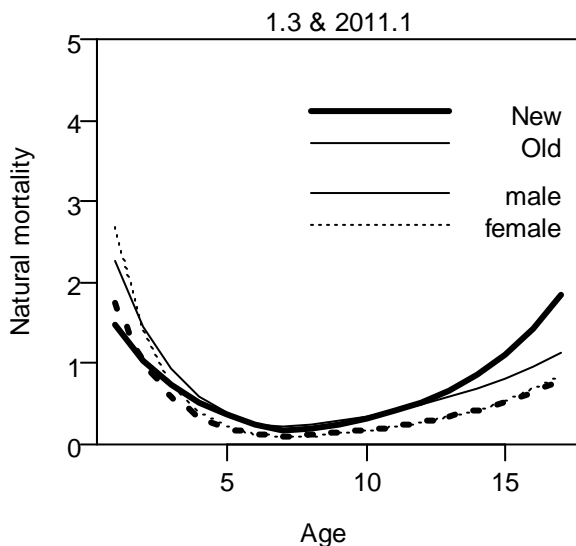


Figure 17: Comparison between age-dependent natural mortality estimated in the new run (heavy lines) and the corresponding run from 2011 (light lines). The label 2011.1 denotes run 1.1 for the 2011 assessment.

#### 4. FINAL MODEL ASSESSMENT RESULTS

It was decided by the Hoki Working Group to take five runs through to the MCMC stage. One of these runs (1.3) is considered the base case, with the other four runs being sensitivities. In all of these model runs the at-age data is reweighted (whereas no model runs were for the 2011 assessment). The five final model runs are denoted 1.3, 1.4, 1.8, 1.9, and 1.11 (Table 19).

Two of the 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 1.3 allows  $M$  (natural mortality) to be dependent on age; run 1.4 allows the spawning fishery selectivities ( $E_{sp}$ ,  $W_{sp}$ ) 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 2011 assessment (McKenzie 2011b). Two of the sensitivity runs differ from run 1.3 in that two catchabilities are fitted for the SAsumbio series instead of one, with no up-weighting of the trawl surveys (Table 19). In run 1.8 the catchability from 2008 to 2012 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.

For the last sensitivity (run 1.11) the natal fidelity assumption is dropped (see section 2.7). All of the final model runs, except this one, are updates of the final model runs from the 2011 assessment (but with reweighting of the at-age data). Reweighting of the at-age data is done for model runs 1.3, 1.4, and 1.11 (see Appendix 4); for runs 1.8 and 1.9 the same effective sample sizes are used as in run 1.3.

All final model runs, descriptions, and MPD current biomass results are shown in Table 19.

**Table 19: Comparison of key aspects of MPD runs. The base model run is 1.3, the other model runs are sensitivities. For all model runs the at-age data is reweighted, and they are all taken through to the MCMC stage.**

Run	Response to lack of old fish in the observations	Two catchabilities for SAsumbio?	Trawl surveys up-weighted?	Natal fidelity?	Objective function	$B_{current}(\%B_0)$	
						E	W
1.3	M dependent on age	N	Y	Y	2 372.2	50	36
1.8	M dependent on age	08–12 q different	N	Y	2 340.9	56	32
1.9	M dependent on age	04–07q different	N	Y	2 337.1	54	51
1.4	Domed spawning selectivity	N	Y	Y	1 566	45	50
1.11	M dependent on age	N	Y	N	2 441	45	55

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 the 2011 assessment, those migration or selectivity parameters that were found to be at a bound in the MPD run (Table 20) 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 18). 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.

The MCMC results for all runs show that the western spawning stock was originally larger than the eastern spawning stock, and is currently 37% larger than the eastern spawning stock (run 1.3) (Table 21). The western spawning stock is currently more depleted than the eastern for the base model and run 1.8, but less depleted for the other sensitivity runs (Table 21, Figures 19–22). When two

catchabilities are allowed the estimate of the current status of the western stock is more uncertain (see Figures 19–20). The no natal fidelity model run gives results for both virgin or current biomass that are similar to the sensitivity model run 1.4 with domed spawning selectivity (Figures 21–22).

Regarding estimated biomass in 2012, the new assessment is similar to that from last year, except that the base run (1.3) for the eastern stock shows a decreased 2012 biomass (% $B_0$ ) compared to the comparable run from last year (Figure 23).

All runs suggest that both the E and W stocks are increasing, both in absolute terms (Figure 24) and relative to  $B_0$  (Figure 25). For the base model run, recent W YCSs are estimated to be higher than in the seven-year period of very weak recruitment, 1995–2001, except for the last YCS in 2010 (Figure 26). The W spawning stock biomass trajectories differ more across the runs than those for the E stock, while year class strength estimates are very similar across all runs (Figures 27–28).

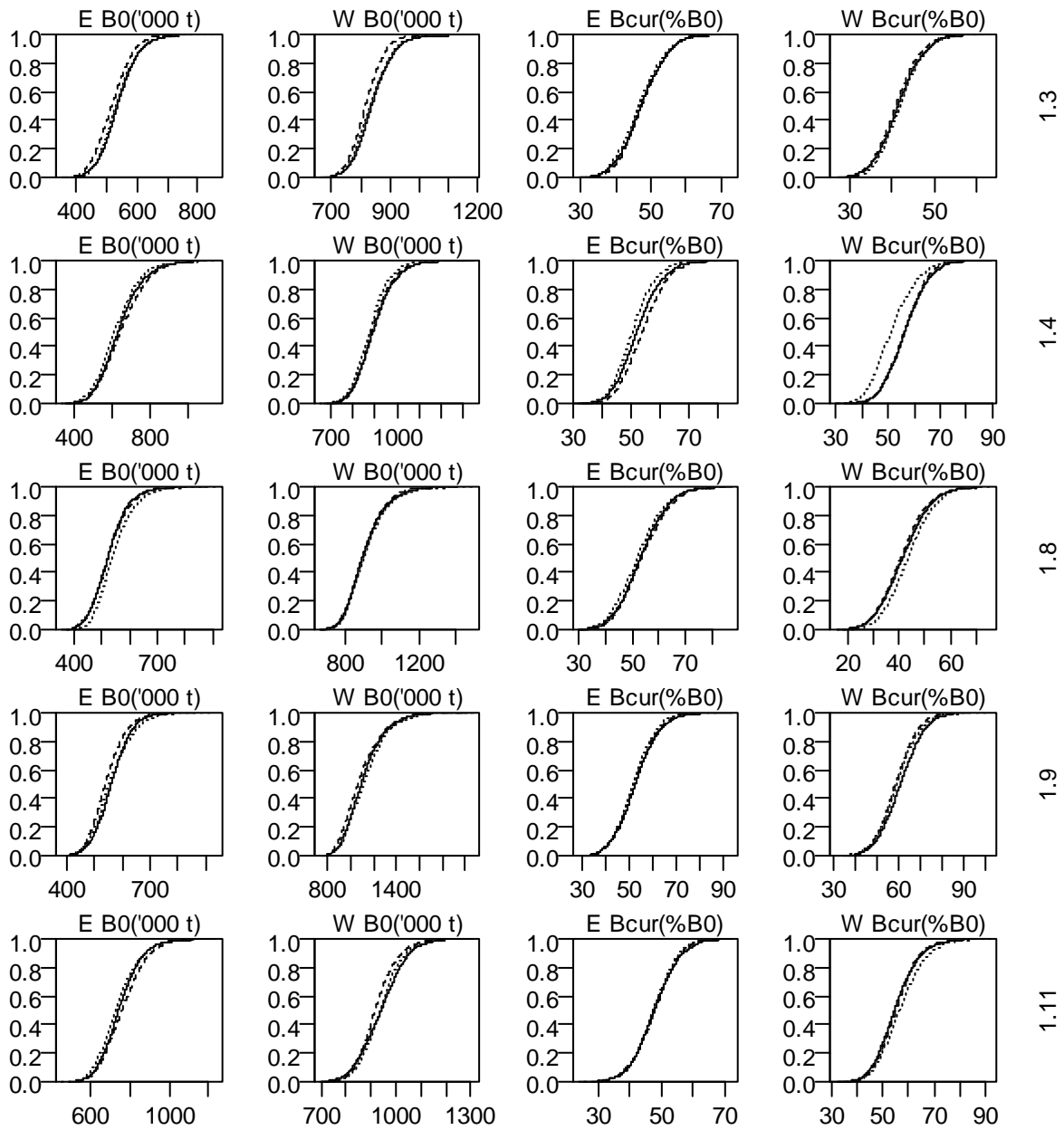
As in previous years, the selectivity ogives for the runs assuming age-dependent natural mortality (runs 1.3, 1.8, 1.9, 1.11 in the current assessment) are very different from run 1.4 without this assumption (Figures 29–30).

For all runs the migration ogives are generally similar, but with some differences for the younger ages for the western spawning migration ogive (Figure 31). The estimates of natural mortality for runs 1.3, 1.8, and 1.9 are similar to each other, but they differ from the 2011 assessment in that  $M$  is lower for the younger fish (Figures 32–33). A comparison of priors and posteriors for various parameters showed little changes from last year (Figures 34–35).

**Table 20: Migration and selectivity parameters held fixed in MCMC runs (with fixed values in parentheses). The notation M1 refers to a male of age 1, and similarly F8 refers to a female of age 8. The parameters a1, sL, sR define the parameters of a double normal selectivity (Bull et al. 2012. For the meaning of the other abbreviations refer to Table 1.**

Run	Parameters (fixed values)
1.3	WspmgM1(1), EspmgF1(0), WspmgF8(0.6), Enspsl.sR(44), Wnspsl.a1(64), CRsl.a1(64), SAsl.sL(44), SAsl.sR(44).
1.4	Whome.6(1), Wnspsl.sR(1), CRsl.a1(1), CRsl.sL(1),
1.8	As in 1.3 excluding Enspsl.SR(44), but including WhomeM7(1), SAsl.a1(84).
1.9	As in 1.3 excluding Enspsl.SR(44), but including Espsl.sL(4)
1.11	Whome.3(0), Whome.7(0), EspmgF1(0), WspmgF8(0.6), Wnspsl.sR(44), CRsl.a1(64), SAsl.a1(84), SAsl.sR(44)

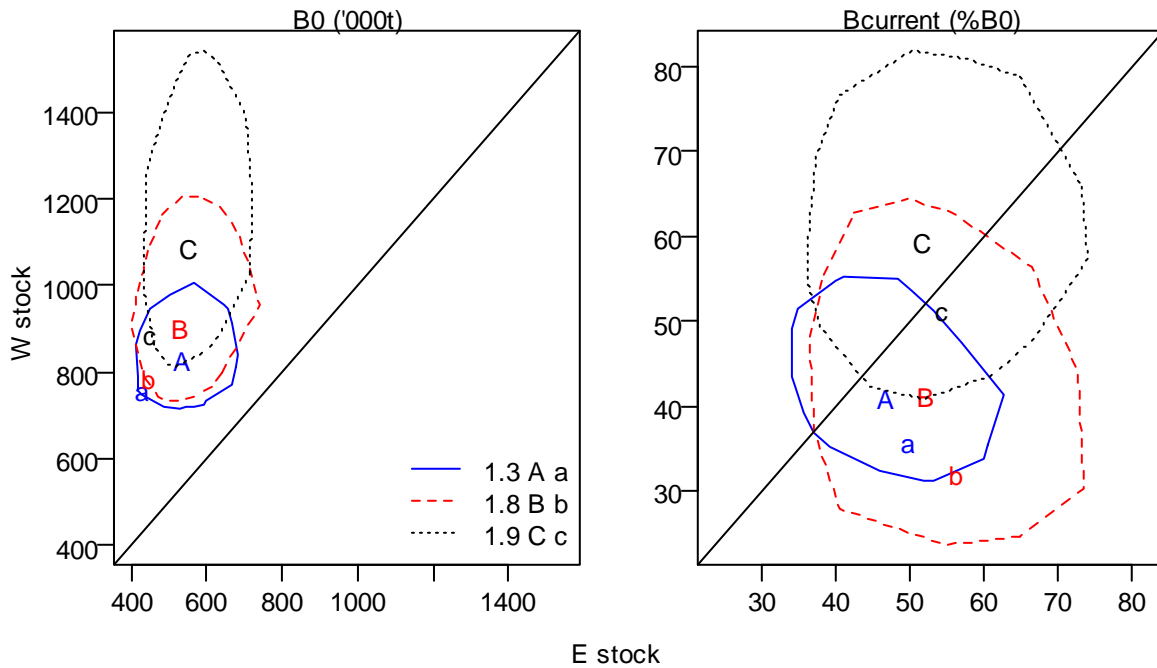




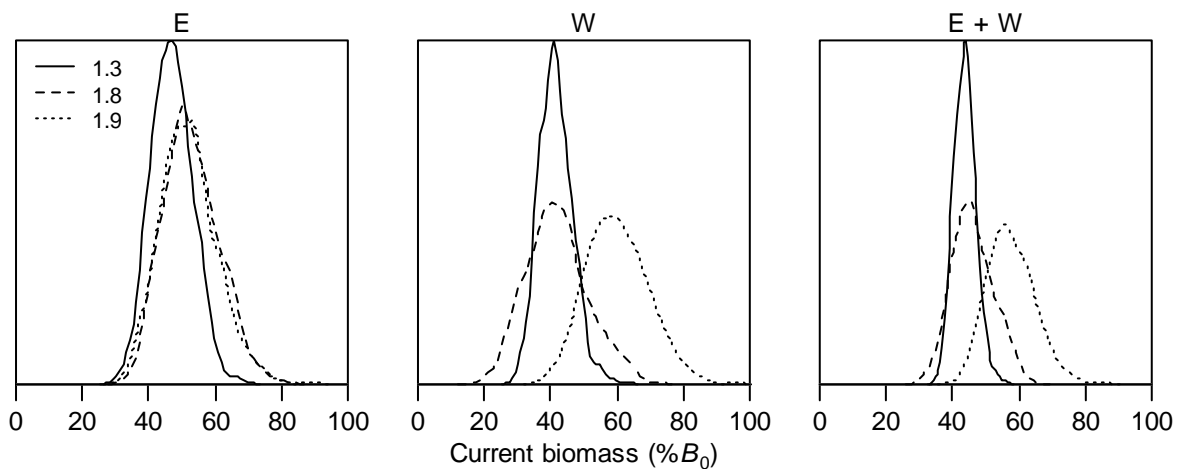
**Figure 18: Diagnostics for MCMC chains for the four runs: 1.3, 1.4, 1.8, 1.9, and 1.11. Each panel contains cumulative probability distributions, for  $B_0$  or  $B_{current}$ , for three chains from the same model run.**

**Table 21: Estimates of spawning biomass (medians of marginal posterior, with 95% confidence intervals in parentheses) for the five runs.  $B_{current}$  is the biomass in mid-season 2012.**

Run	$B_0$ ('000 t)		$B_{current}$ ('000 t)				$B_{current}$ (% $B_0$ )	
	E	W	E	W	E	W	E+W	
1.3	532(427,659)	831(727,966)	250(170,352)	342(252,478)	47(35,59)	41(32,52)	44(38,50)	
1.8	530(424,682)	905(756,1166)	280(186,420)	377(211,691)	52(39,70)	41(26,62)	46(35,59)	
1.9	549(445,691)	1094(847,1485)	282(186,439)	659(398,1073)	52(37,70)	60(44,79)	57(46,72)	
1.11	745(578,981)	932(774,1099)	354(226,532)	516(348,746)	48(35,61)	55(43,73)	52(45,62)	
1.4	616(447,893)	886(755,1070)	325(208,501)	486(331,700)	52(40,68)	55(41,71)	54(43,65)	



**Figure 19: Estimates and approximate 95% confidence intervals for virgin ( $B_0$ ) and current ( $B_{\text{current}}$  as  $\%B_0$ ) biomass by stock for the two runs 1.3, 1.8, and 1.9. 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 20: Estimated posterior distributions of current (spawning) biomass ( $B_{2011-12}$ ), expressed as  $\%B_0$ , for the E (left panel), W (middle panel) and E + W stocks (right panel) from the base case model (Run 1.3) and the two catchability sensitivities (Runs 1.8, 1.9).**

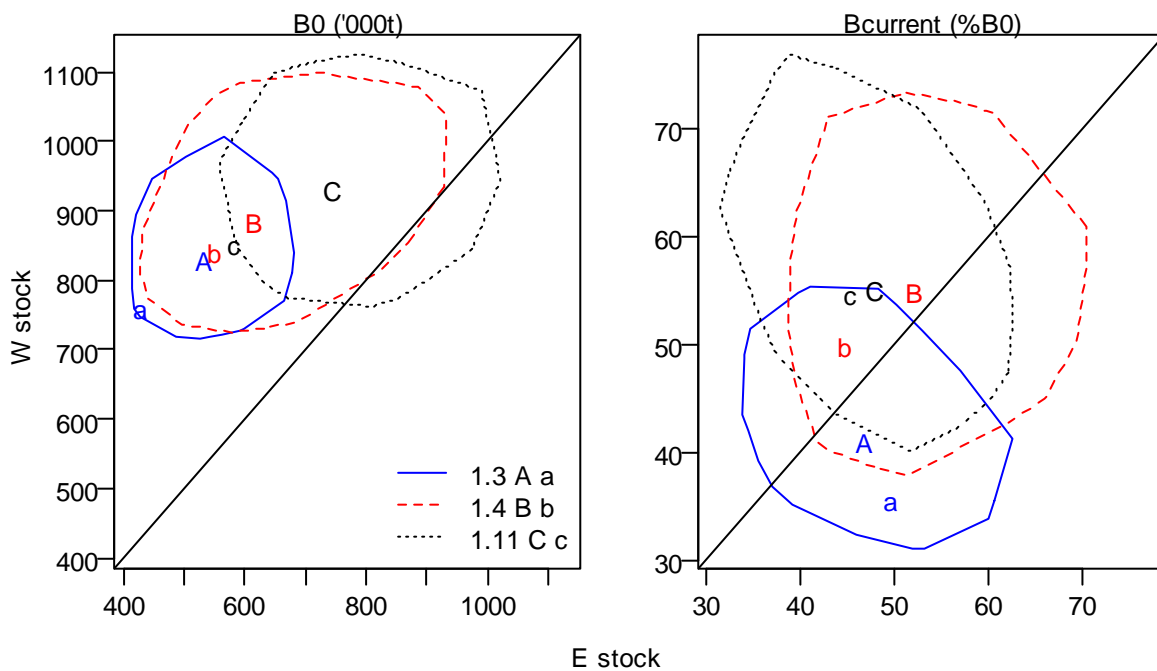


Figure 21: As in Figure 19 for but for the runs 1.3, 1.4, and 1.11.

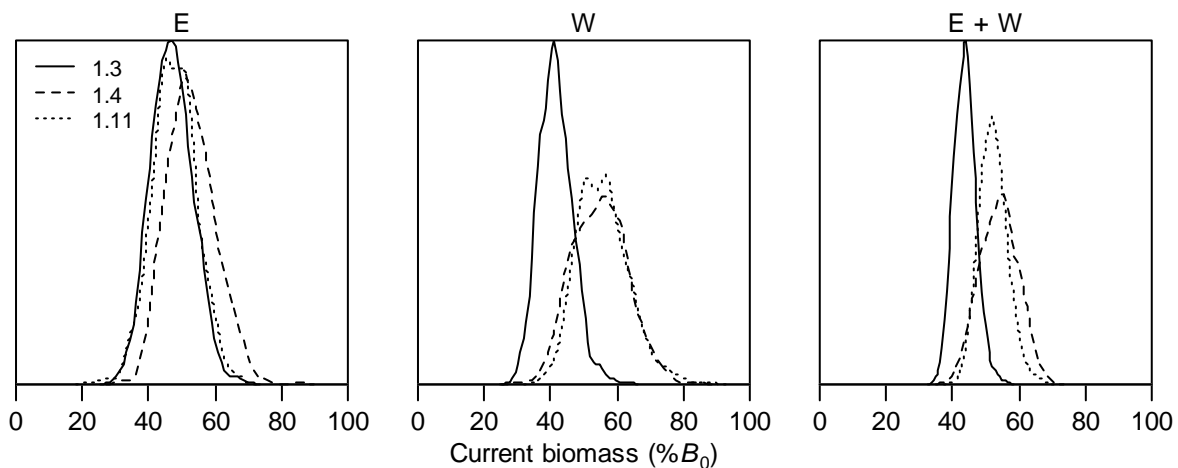
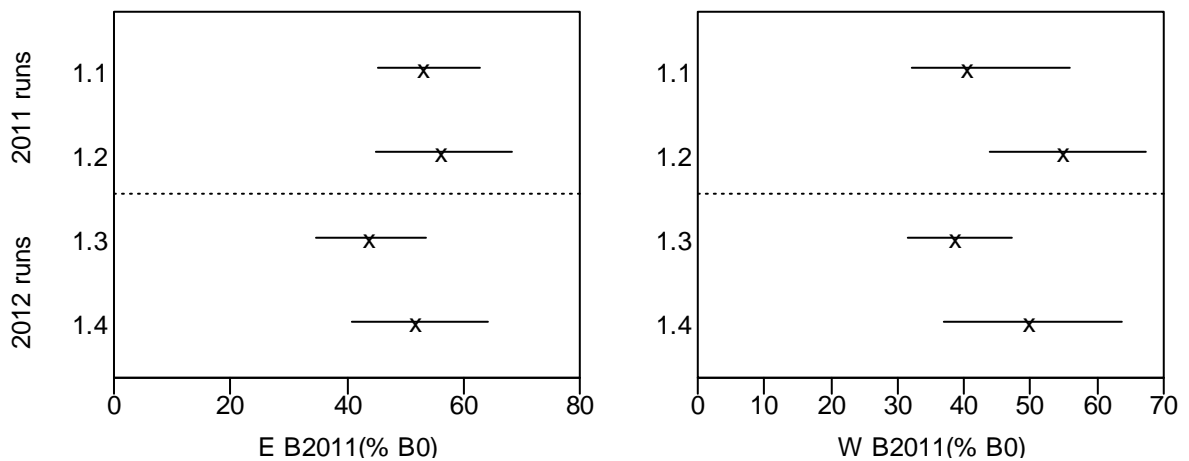
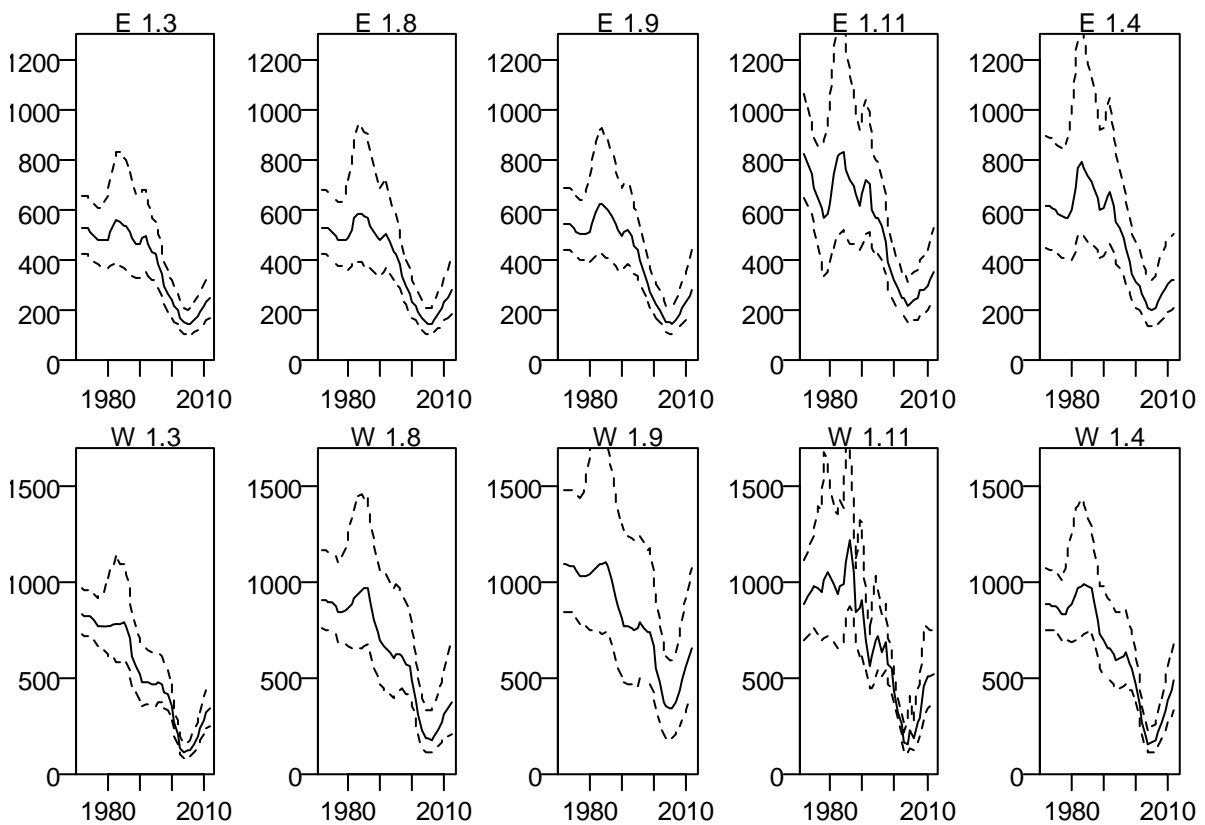


Figure 22: Estimated posterior distributions of current (spawning) biomass ( $B_{2011-12}$ ), expressed as % $B_0$ , for the E (left panel), W (middle panel) and E + W stocks (right panel) from the base case model (Run 1.3) and two sensitivity runs (Runs 1.4 and 1.11).



**Figure 23: Comparison of 2012 runs (1.3, 1.4) with the comparable runs from 2011 (1.1, 1.2): estimates of stock status in 2011 ( $B_{2011}$  as  $\%B_0$ ), with 95% confidence intervals shown as horizontal lines.**



**Figure 24: 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).**

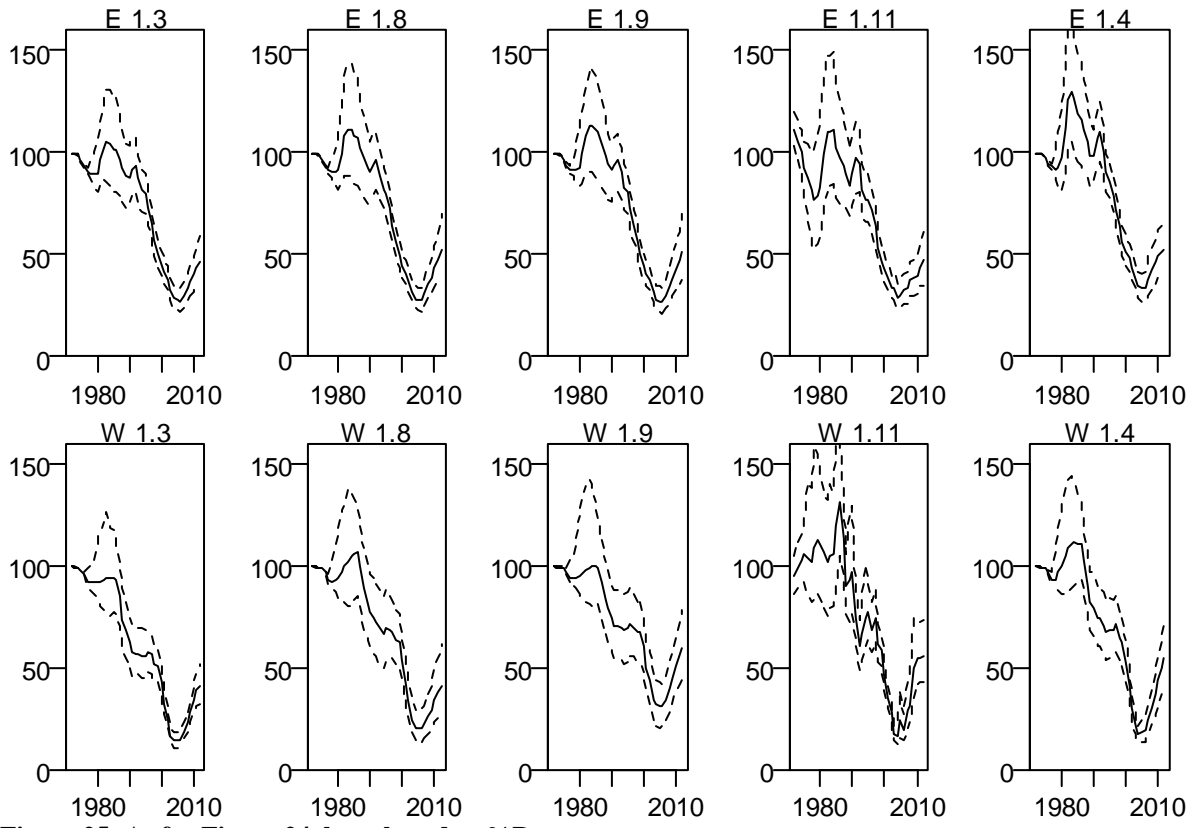
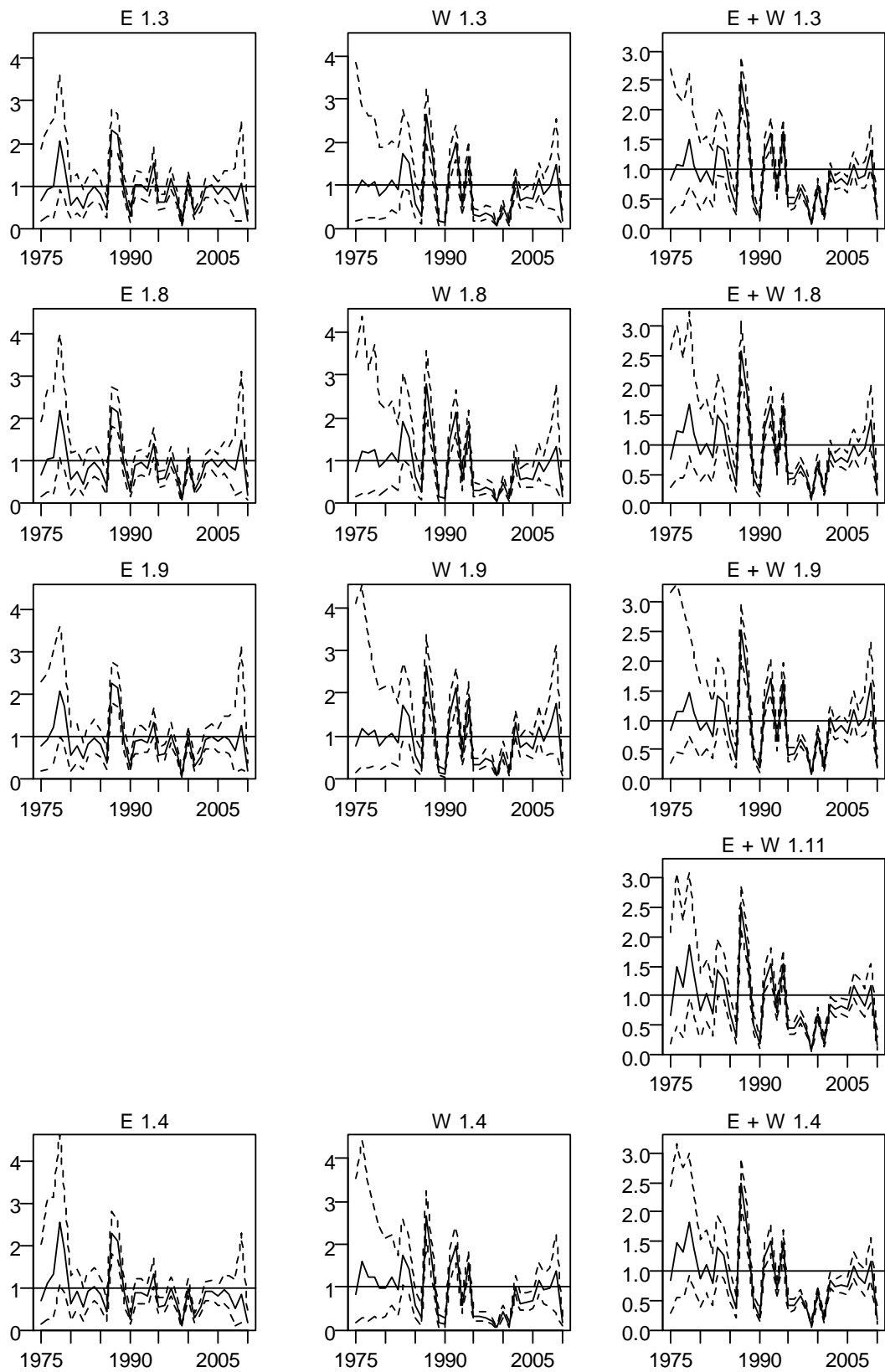
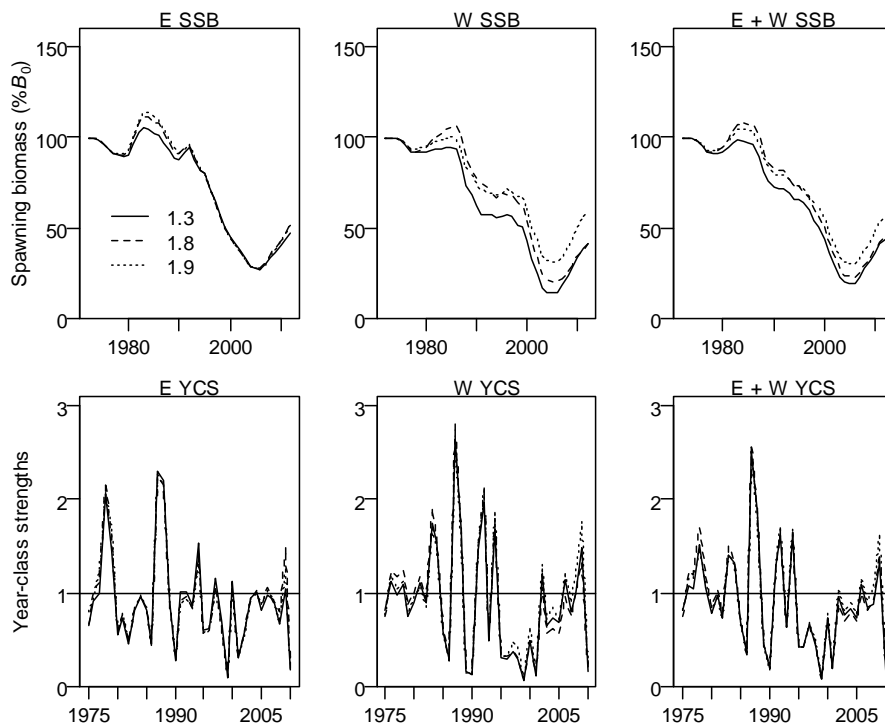


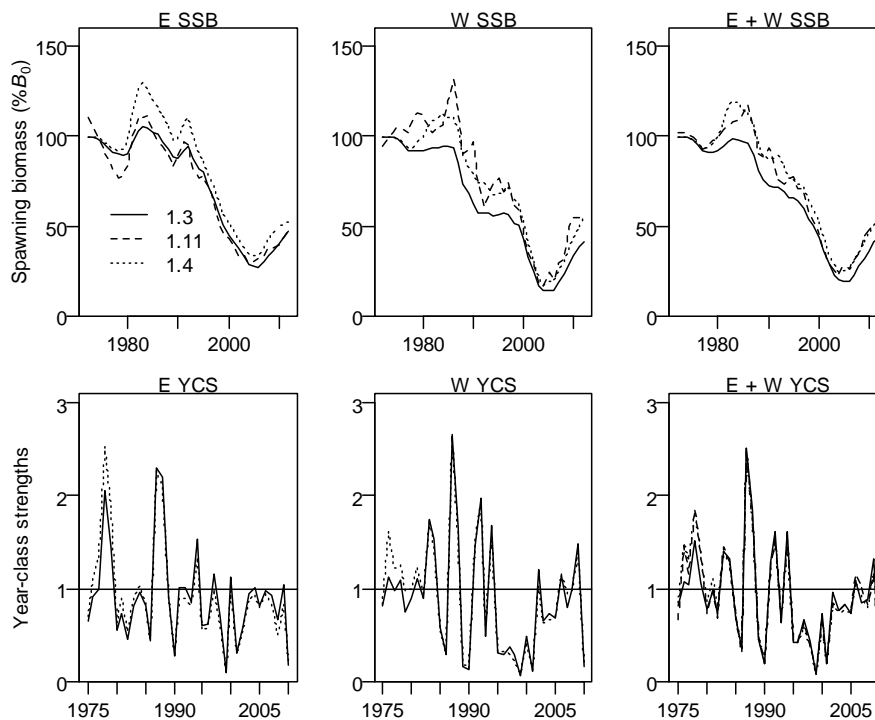
Figure 25: As for Figure 24, but plotted as %B<sub>0</sub>.



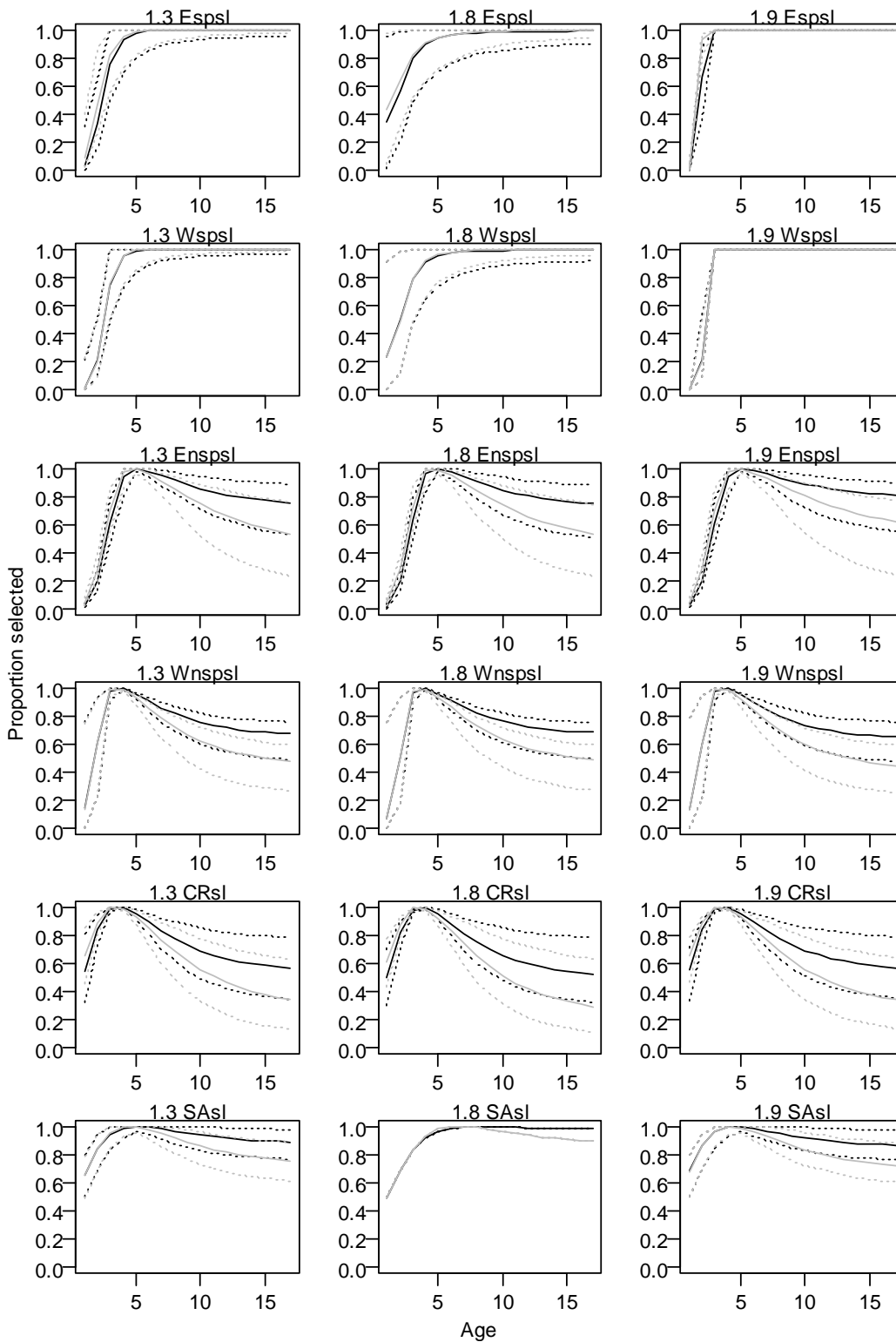
**Figure 26: Estimated year-class strengths (YCSs) from the runs 1.3, 1.8, 1.9, 1.11, and 1.4 showing medians (solid lines) and 95% confidence intervals (broken lines) by run for E (left panels), W (middle panels) and E + W (right panels).**



**Figure 27: 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 case model (Run 1.3) and the two catchability sensitivity runs (Runs 1.8, 1.9). Plotted values are medians of marginal posterior distributions. Years are fishing years (1990 is 1989–90).**

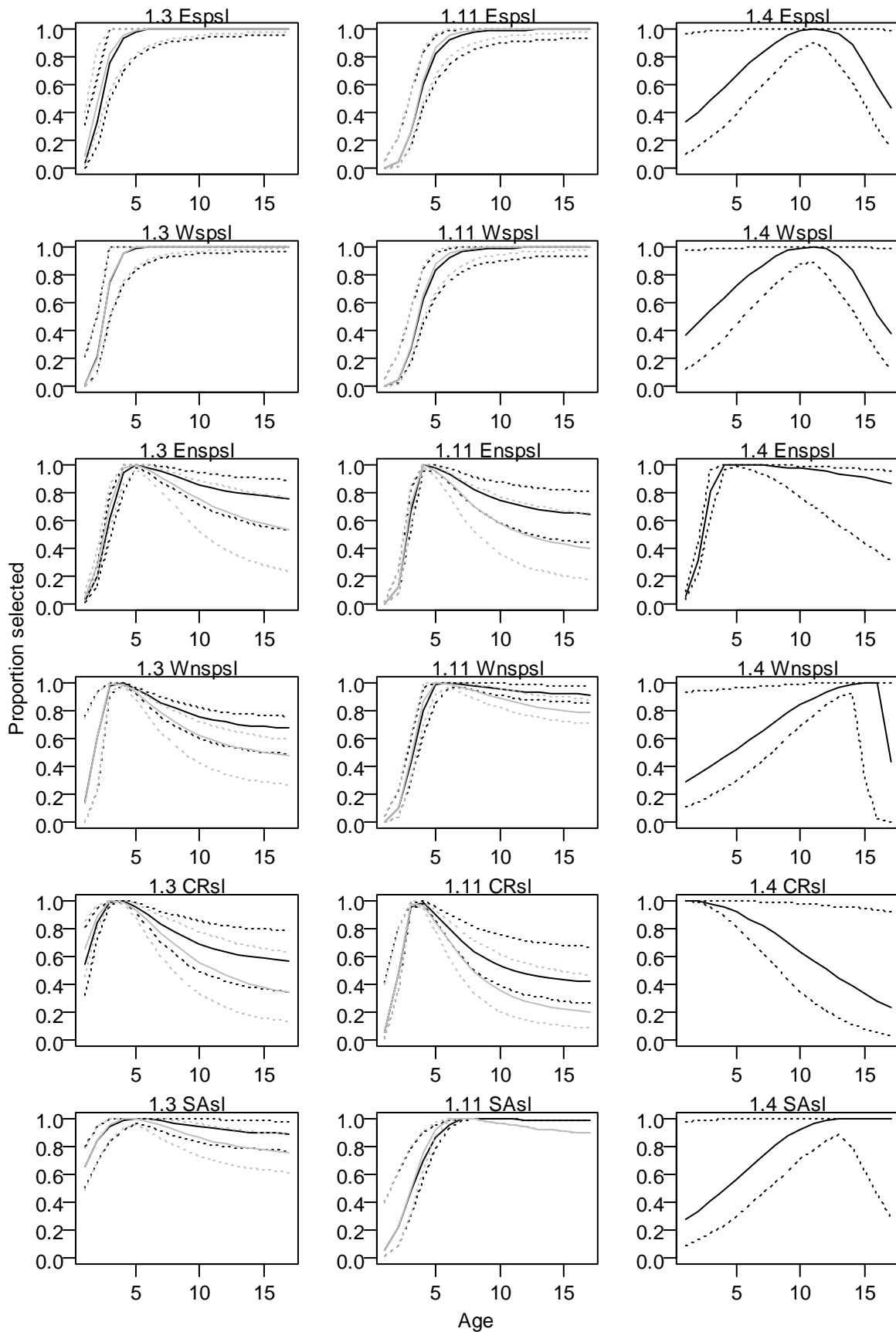


**Figure 28: Estimated spawning biomass trajectories (SSB, upper panels) and year-class strengths (YCS, lower panels) for the E (left panels), W (middle panels) and E + W stocks (right panels) from the base case model (Run 1.1) and the two sensitivity runs (Runs 1.4 and 1.11). Plotted values are medians of marginal posterior distributions. Years are fishing years (1990 is 1989–90).**

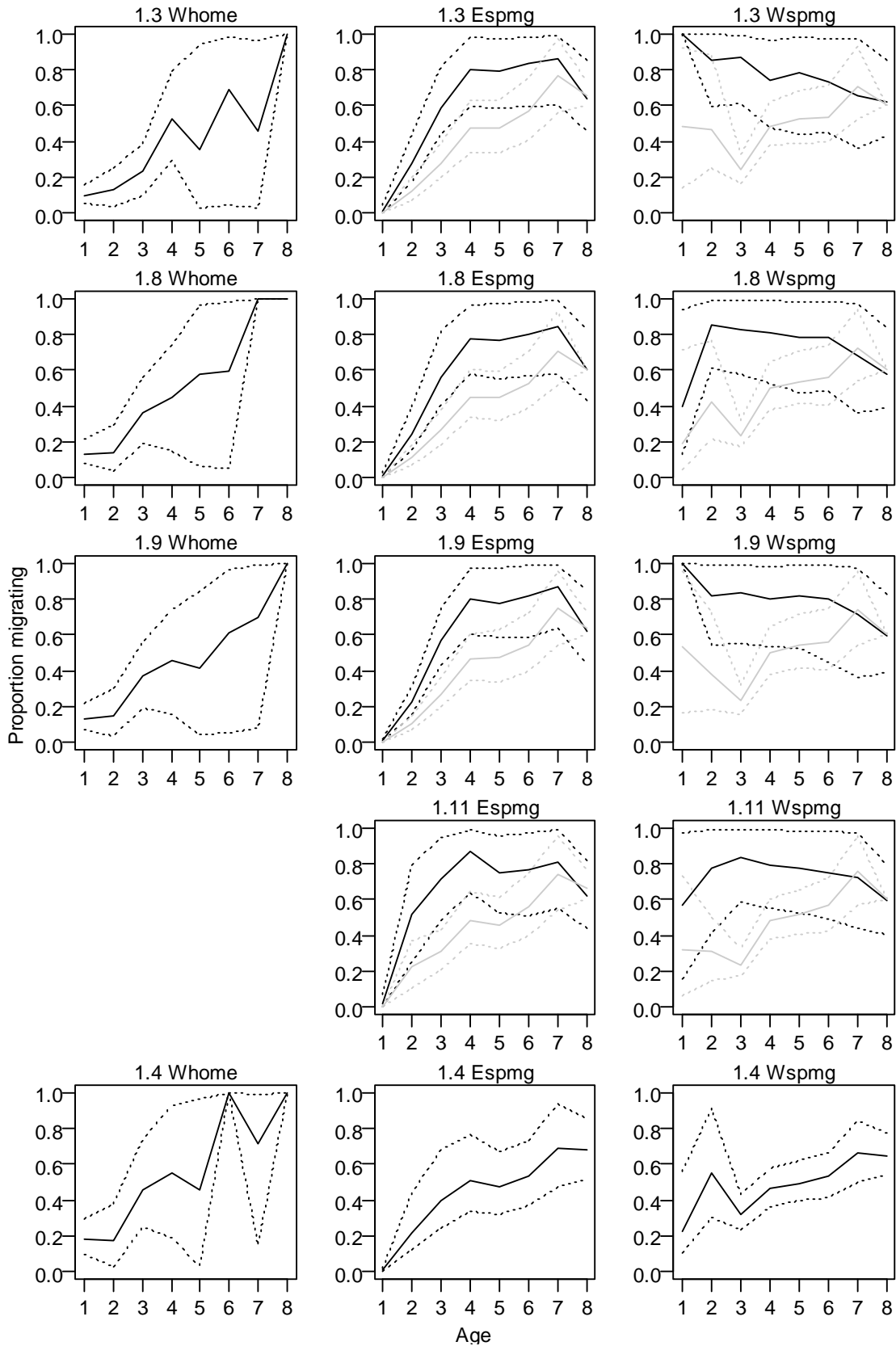


**Figure 29: Posterior estimates of selectivity ogives for each for the three MCMC runs 1.3, 1.8 and 1.9. Solid lines are medians; broken lines show 95% confidence intervals. Where ogives differ by sex they are plotted as black for males and grey for females. Where they differ by stock or time step the plotted curves are for one selected combination (E step 2 for Enpsl and CRsl, W step 2 for Wnpsl and SAsl).**

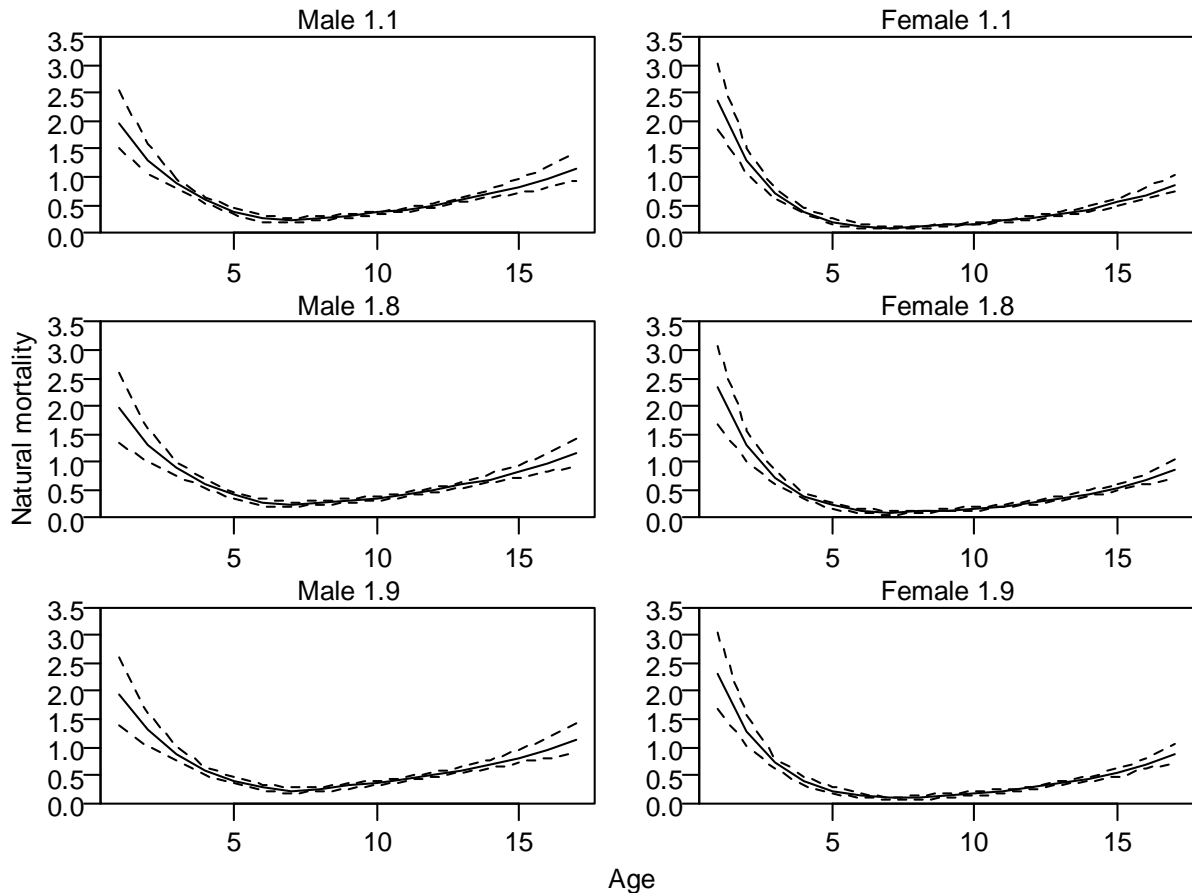




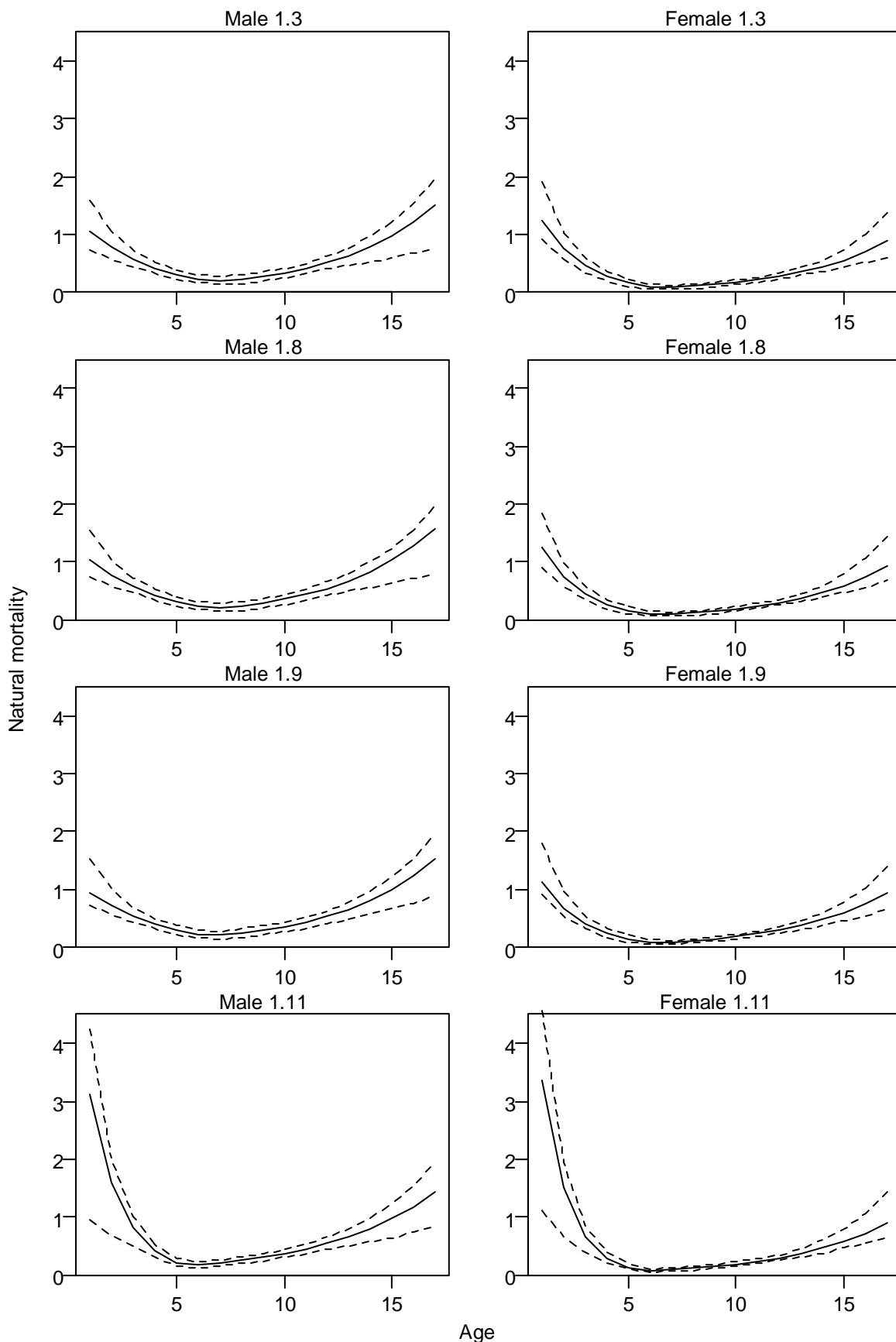
**Figure 30: As in Figure 29, but for the MCMC runs 1.3, 1.11, and 1.4.**



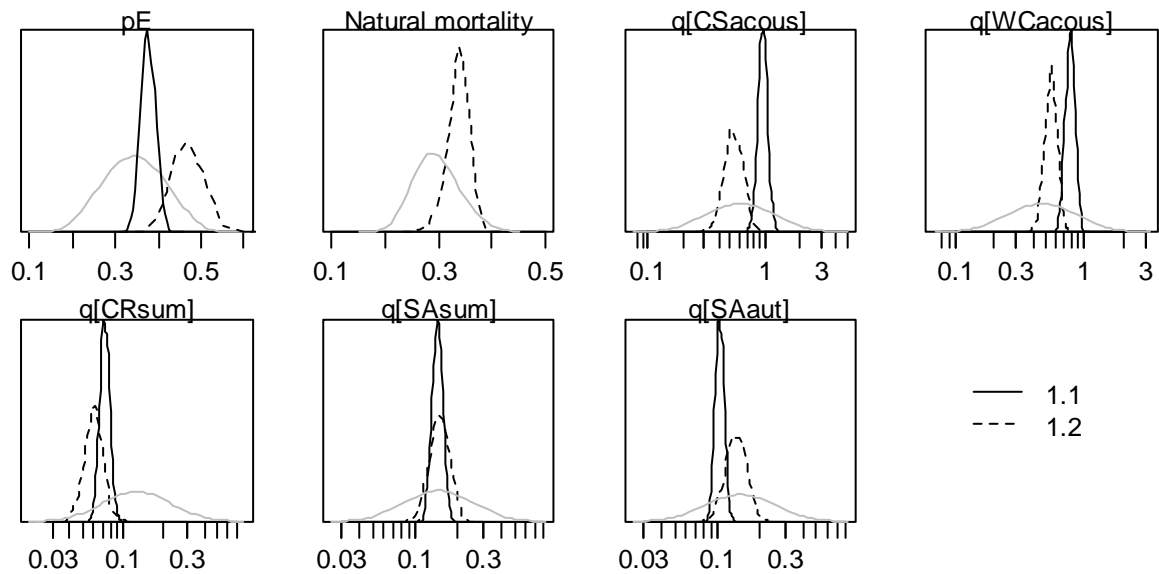
**Figure 31: Migration ogives estimated in each of the five MCMC runs. Solid lines are medians, broken lines show 95% confidence intervals. Where ogives differ by sex they are plotted as black for males and grey for females.**



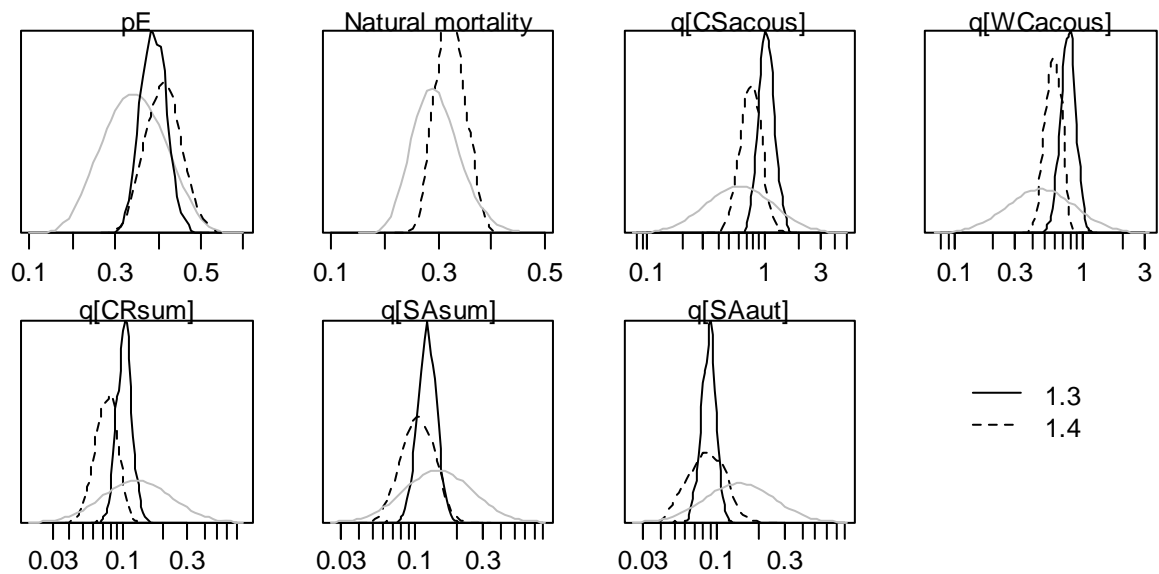
**Figure 32: 2011 assessment estimates of age-dependent natural mortality ogives for runs 1.1, 1.8, and 1.9 from 2011 showing median estimates (solid lines) and 95% confidence intervals (broken lines) for each sex. In the 2012 assessment the equivalent models runs are 1.3, 1.8, and 1.9 respectively (see Figure 33).**



**Figure 33: 2012 assessment estimates of age-dependent natural mortality ogives for run 1.3, 1.8, 1.9, and 1.11 showing median estimates (solid lines) and 95% confidence intervals (broken lines) for each sex.**



**Figure 34: 2011 assessment 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).**



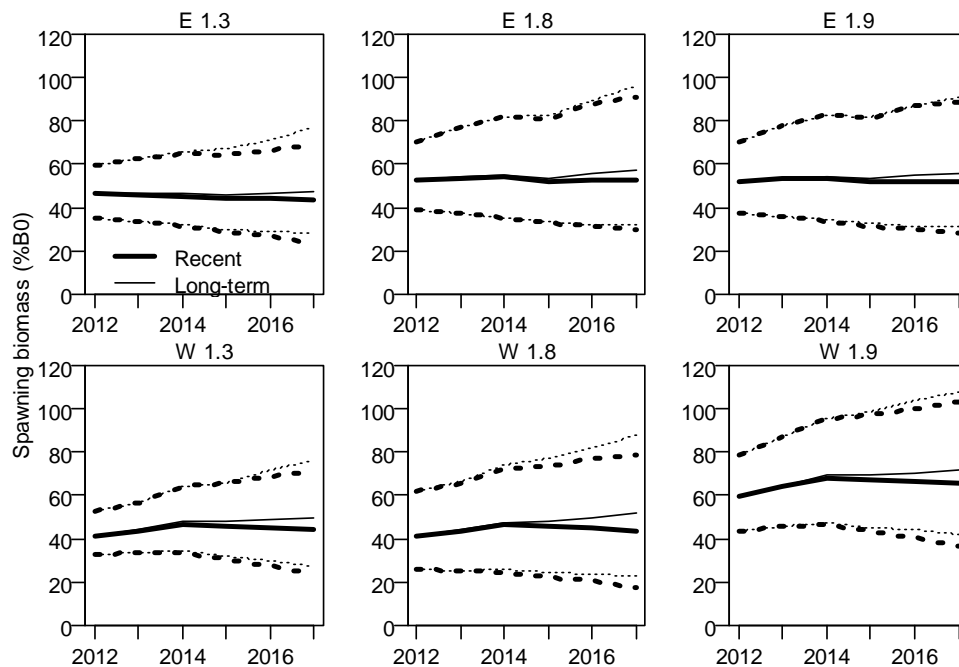
**Figure 35: 2012 assessment prior (grey lines) and estimated posterior (black lines) distributions from the two MCMC runs for 1.3 and 1.4 for the following parameters: pE (proportion of  $B_0$  in E stock), natural mortality (independent of age, run 1.4 only), and survey catchabilities (acoustic and trawl).**

## 5. PROJECTIONS

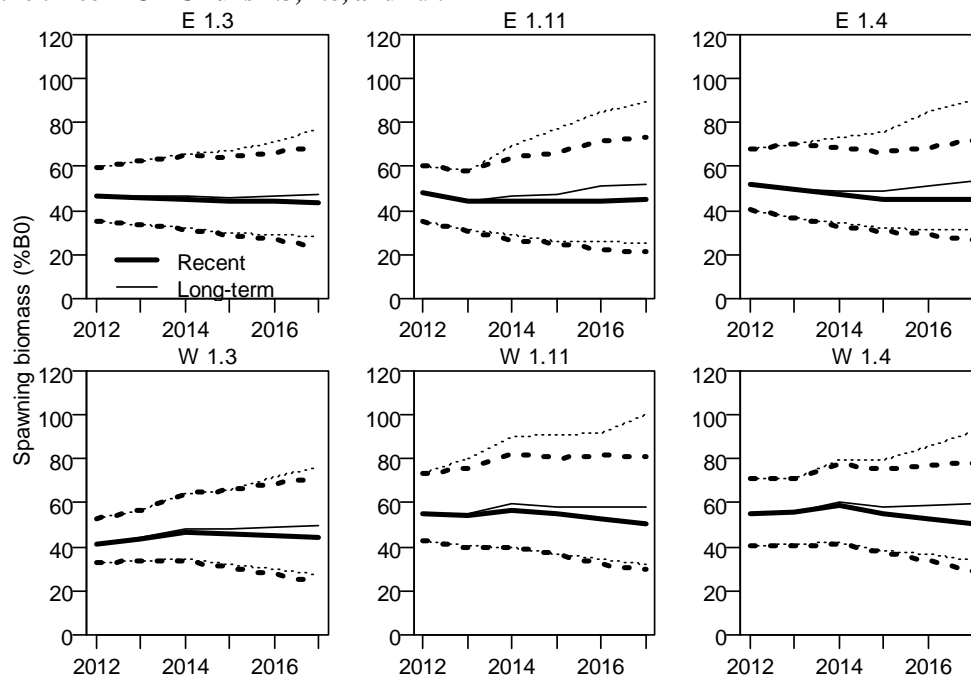
Five-year projections were carried out for each run with alternative recruitment scenarios: ‘long-term’ (future recruitment selected from estimated levels in 1975–2010) and ‘recent’ (recruitment selected from 1995–2010). Future catches for each fishery were assumed equal to those assumed for 2012.

In all runs with long-term recruitment, median spawning biomass remained flat or increased for both stocks in all years (Figures 36–37). Under recent recruitment, the biomass for the western stock declines from 2014, but remains stable for the eastern stock (except when a domed selectivity is used for the spawning stocks – run 1.4).

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 probabilities of falling below the soft limit, hard limit, and lower and upper ends of the interim management target range are given in Table 22. For either recruitment scenario, the biomass is very unlikely to fall below the soft or 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 0.30.



**Figure 36:** 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 three MCMC runs 1.3, 1.8, and 1.9.



**Figure 37:** 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 three MCMC runs 1.3, 1.4, and 1.11.

**Table 22: Probabilities (rounded to two decimal places) associated with projections for SSB (%B<sub>0</sub>) in Figure 36–37.**

	2012					2017: Recent recruitment					2017: Long-term recruitment				
	1.3	1.8	1.9	1.11	1.4	1.3	1.8	1.9	1.11	1.4	1.3	1.8	1.9	1.11	1.4
<b>EAST</b>															
P(SSB<10%B <sub>0</sub> )	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
P(SSB<20%B <sub>0</sub> )	0	0	0	0	0	0.01	0	0	0.02	0	0	0	0	0.01	0
P(SSB<35%B <sub>0</sub> )	0.02	0	0.01	0.03	0	0.21	0.08	0.10	0.22	0.17	0.14	0.04	0.05	0.13	0.06
P(SSB<50%B <sub>0</sub> )	0.68	0.38	0.42	0.63	0.36	0.70	0.42	0.44	0.65	0.67	0.58	0.32	0.34	0.45	0.41
<b>WEST</b>															
P(SSB<10%B <sub>0</sub> )	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
P(SSB<20%B <sub>0</sub> )	0	0	0	0	0	0.01	0.05	0	0	0	0	0.01	0	0	0
P(SSB<35%B <sub>0</sub> )	0.08	0.22	0	0	0	0.19	0.30	0.02	0.09	0.09	0.10	0.16	0.01	0.04	0.03
P(SSB<50%B <sub>0</sub> )	0.95	0.81	0.13	0.24	0.30	0.68	0.66	0.16	0.47	0.49	0.50	0.47	0.08	0.29	0.24

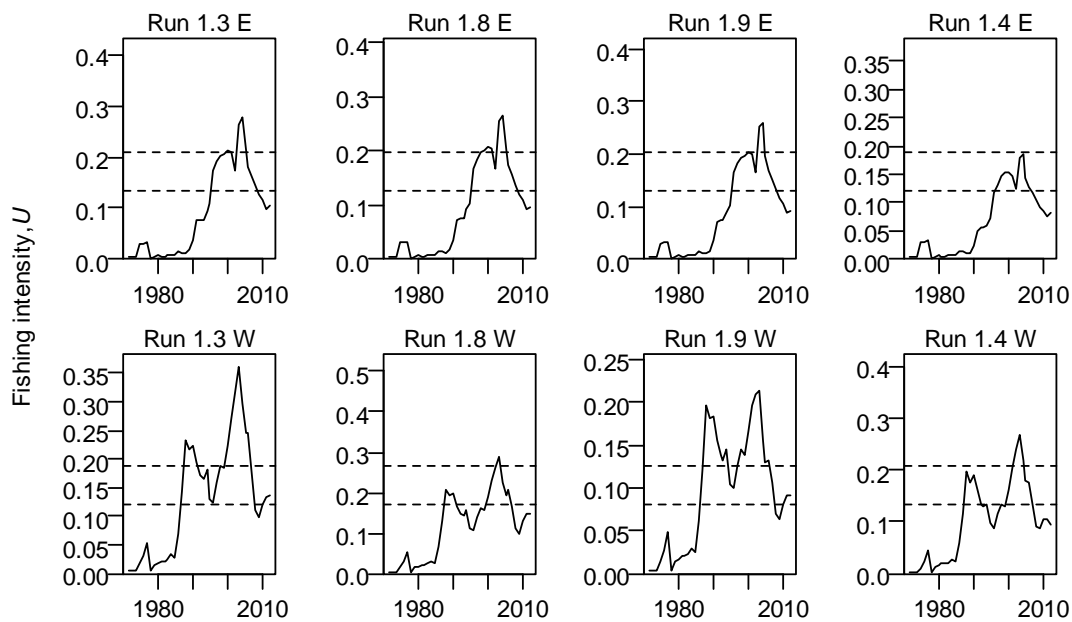
## 6. FISHING PRESSURE

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 it is 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<sub>0</sub> or 50%B<sub>0</sub>, 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 38).



**Figure 38: Fishing intensity,  $U$  (from MPDs), 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 1.3, assuming a harvest strategy in which the exploitation rate for fishery  $f$  was  $mU_{f,2012}$ , where  $U_{f,2012}$  is the estimated 2012 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  $B_{MSY}$  for the base case run (run 1.3) were 25% for both the E stock and W stocks.

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. For the base model run, the western stock is estimated to be more depleted ( $41\%B_0$ ), than the eastern stock ( $47\%B_0$ ), but only for one of the four sensitivity runs. 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 five years, except for 2010 where it was below average. All projections with long-term recruitment, suggest that continued fishing at current levels is likely to allow the biomass of both stocks to remain stable or increase. Under recent recruitment, the biomass for the western stock declines from 2014, but remains stable for the eastern stock (except when a domed selectivity is used for the spawning stocks – run 1.4).

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

I am grateful to Sira Ballara, Dan Fu, Richard O’Driscoll, and Darren Stevens for providing data, and to members of the Hoki Working Group for suggestions during the assessment process. This work was funded under Ministry for Primary Industries project DEE201002HOKA. Thank you to Peter Horn, Chris Francis, and Kevin O’Sullivan for reviewing the manuscript. Marianne Vignaux did a fine job of editing the manuscript.

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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. 2012), by two input files — population.csl and estimation.csl — and, for runs with an age varying natural mortality, a user.prior\_penalty.cpp file. These files may be obtained as a pdf, from the Science Officer at Ministry for Primary Industries ([science.officer@mpi.govt.nz](mailto:science.officer@mpi.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.**

Year	Changes
2003	<ul style="list-style-type: none"> <li>Changed timing of spawning migrations from the middle to the end of the non-spawning fisheries (and after the autumn SA surveys)</li> <li>Earliest estimated YCS changed to 1977 from 1980</li> <li>Assumed Beverton-Holt stock-recruit relationship</li> <li>Disallowed annual variation in selectivities for Wnsp fishery</li> <li>Allowed for ageing error (expected to reduce bias in estimates of YCSs)</li> <li>Process errors for at-age data sets estimated within the model</li> <li>Non-uniform prior on pE</li> <li>Max. age of otolith-based at-age data increased from 10 (plus group) to 12 (no plus group)</li> <li>First use of otolith-based at-age data for non-spawning fisheries (Enspage &amp; Wnspage)</li> <li>Forced equality of recent W and E YCSs extended from 2 y to 3 y</li> <li>Improvements in methods of converting ogives from size-based to age-based and implementing annual variation in selectivities</li> </ul>
2004	<ul style="list-style-type: none"> <li>First use of age-dependent natural mortality and domed spawning selectivities to cope with lack of old fish</li> <li>Maximum age in partition increased from 13 y to 17 y</li> <li>New parameterisation for YCSs</li> <li>Earliest estimated YCS changed to 1975 from 1977</li> <li>Change in priors for CSacous catchability and pE</li> <li>Max. age of otolith-based at-age data increased from 12 (no plus group) to 13/15 (plus group)</li> </ul>

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 W <sub>sp</sub> 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)
2012	Re-weight the proportions-at-age data (the procedure giving them a substantial down-weighting) Re-introduce a sensitivity model run without natal fidelity

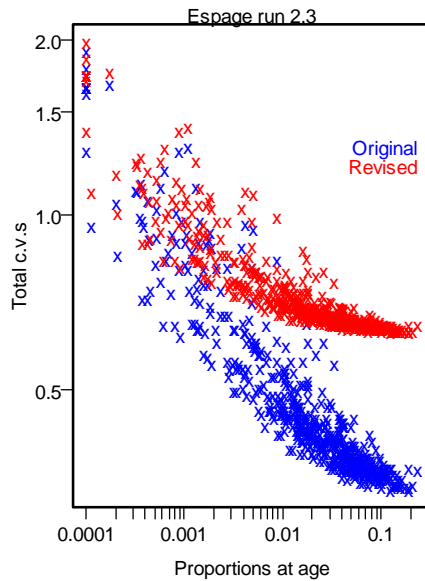
### Appendix 3: Reweighting the at-age data for the base hoki model from 2011

#### Introduction

In Francis (2011a) the weighting of data in stock assessments was explored and one of the conclusions drawn was that at-age data are often over-weighted in assessments. Using methods in this paper the at-age data for the 2008 hoki stock assessment were reweighted, with revised process errors estimated to be about double what they originally were (Francis 2011b).

However, as the hoki assessment uses lognormal error distributions, then adding on the revised process errors led to total c.v.s for which there is little contrast between low and high proportions (Figure A1). An alternative distribution to use instead, which automatically gives contrast, is the multinomial, and reweighting under this error distribution is investigated in this appendix for the base hoki model from 2011.

In the base hoki model from 2011 the three trawl surveys are upweighted. With reweighting of the at-age data the trawl surveys may not need upweighting. In this appendix MPD results are given under reweighting with the trawl surveys both upweighted and not upweighted: spawning stock biomass and year class strengths. For the MCMC results the trawl surveys are not upweighted, and this is compared to the base hoki model from 2011 (no reweighting, robustified lognormal distributions for the at-age data, trawl surveys upweighted).



**Figure A1: Total c.v.s for model 2.3 from the 2008 hoki assessment. Shown is the Espace at-age data set with original total c.v.s and those under reweighting.**

## Methods

For the 2011 assessment there was one base model run with three sensitivities (Table A2). The base model run 1.1 is used for the reweighting with a multinomial error distribution.

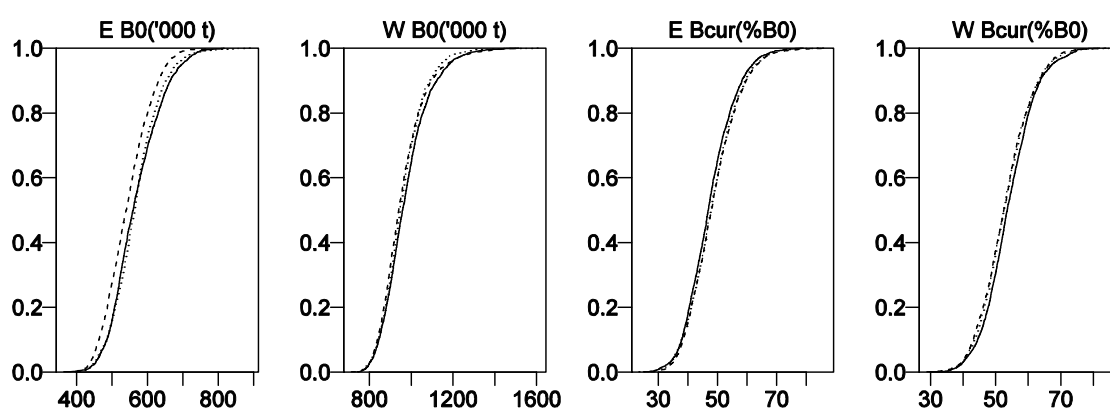
**Table A2: Distinguishing characteristics for the four final model runs for the 2011 assessment. The base model is run 1.1, the other three model runs are sensitivities.**

Label	Trawl surveys up-weighted?	Two catchabilities for SAsumbio?	Response to lack of old fish in the observations	Sex in model and selectivities length-based?
1.1	Y	N	<i>M</i> dependent on age	Yes
1.2	Y	N	Domed spawning selectivity	No
1.8	N	Y 08–10 separate	<i>M</i> dependent on age	Yes
1.9	N	Y 04–07 separate	<i>M</i> dependent on age	Yes

Reweighting was done using method T1.8 of Francis (2011a). This method compares mean observed ages from a year to expected ages from the model, relative to the confidence interval for the mean. For a given data set (e.g. the western spawning stock at-age set) the weighting is changed depending on how close the mean and expected values are for the data set. The aim of the weighting, which is parameterised by the multinomial sample size, is to make the standard deviation of the normalised residuals for the mean and expected values close to one (for a given at-age data set).

To start the reweighting process, initial multinomial sample sizes need to be assigned for each year of observational data in the at-age data sets. This was done by fitting equivalent multinomial sample sizes based on the observational error c.v.s in the original model (i.e., process error is not included).

For the reweighted model without the trawl surveys upweighted, the standard procedure for generating the MCMC was followed (McKenzie 2011b). 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. Those migration or selectivity parameters that were found to be at a bound in the MPD run 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 A2). 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.



**Figure A2: Diagnostics for the MCMC chains for reweighted model 1.1 with the trawl surveys not upweighted: Each panel contains cumulative probability distributions, for  $B_0$  or  $B_{\text{current}}$ , for three chains from the same model.**

## Results

Equivalent multinomial sample sizes for the at-age data sets are shown in Figure A3. For simplicity a single initial multinomial sample size could be assigned to each at-age data set. However, there is a good amount of variation in sample sizes across years, so it was decided to assign an initial multinomial sample size for each year in a data set. The reweighting process keeps the same relative weights across years for each data set, but scales them all up or down.

Starting with these initial sample sizes the reweighting process was carried out with results (for mean values of a data set) shown in Table A3. About four or five iterations were required for the process to converge with final values 2–75 times less than initial values.

Mean and expected values using the final weights are shown in Figure A4. Fits for the mean values under the revised weighting are mostly good, with no strong trends in residuals. Some exceptions are the first two-thirds of Wspage and the last five years of SASumage.

The original model run used lognormal error and had no reweighting. The total c.v.s (observation and process) for the original model are compared to that under reweighting with a multinomial error distribution (Figure A5). They are much larger under reweighting, and unlike when lognormal errors were used shown contrast for low and high proportions (see Figure A1).

Differences are not large for the biomass of the original and reweighted model, though the reweighted model shows a steeper decline in biomass up to about the 2005 fishing year (Figure A6). MCMC results show an increase in the confidence intervals with reweighting, but the differences are not large (Figure A7).

Results for YCSs are shown Figures A8–A9. Estimates are very similar with reweighting, except for the poorly estimated YCSs up to about 1985 and in the last few years. Confidence intervals for these poorly estimated YCSs are much larger for the earlier years, but similar for the last few years. For intermediate years the confidence intervals are larger, but not substantially.

**Table A3: Iterative reweighting for multinomial sample sizes using method TA1.8. Shown are the mean values of N for the at age data sets.**

Stage	Espage	Wspage	EnspOLF	Enspage	WnspOLF	Wnspage	CRsumage	SAsumage	SAautage
Initial	650	902	89	305	80	161	1325	575	829
2	58	33	13	45	83	32	74	10	24
3	63	25	12	47	42	22	72	8	13
4	66	23	12	45	36	20	72	8	12
5	69	22	12	44	34	20	72	8	12
Final	70	22	12	43	34	20	72	8	11
Initial/Final	9	41	7	7	2	8	18	72	75

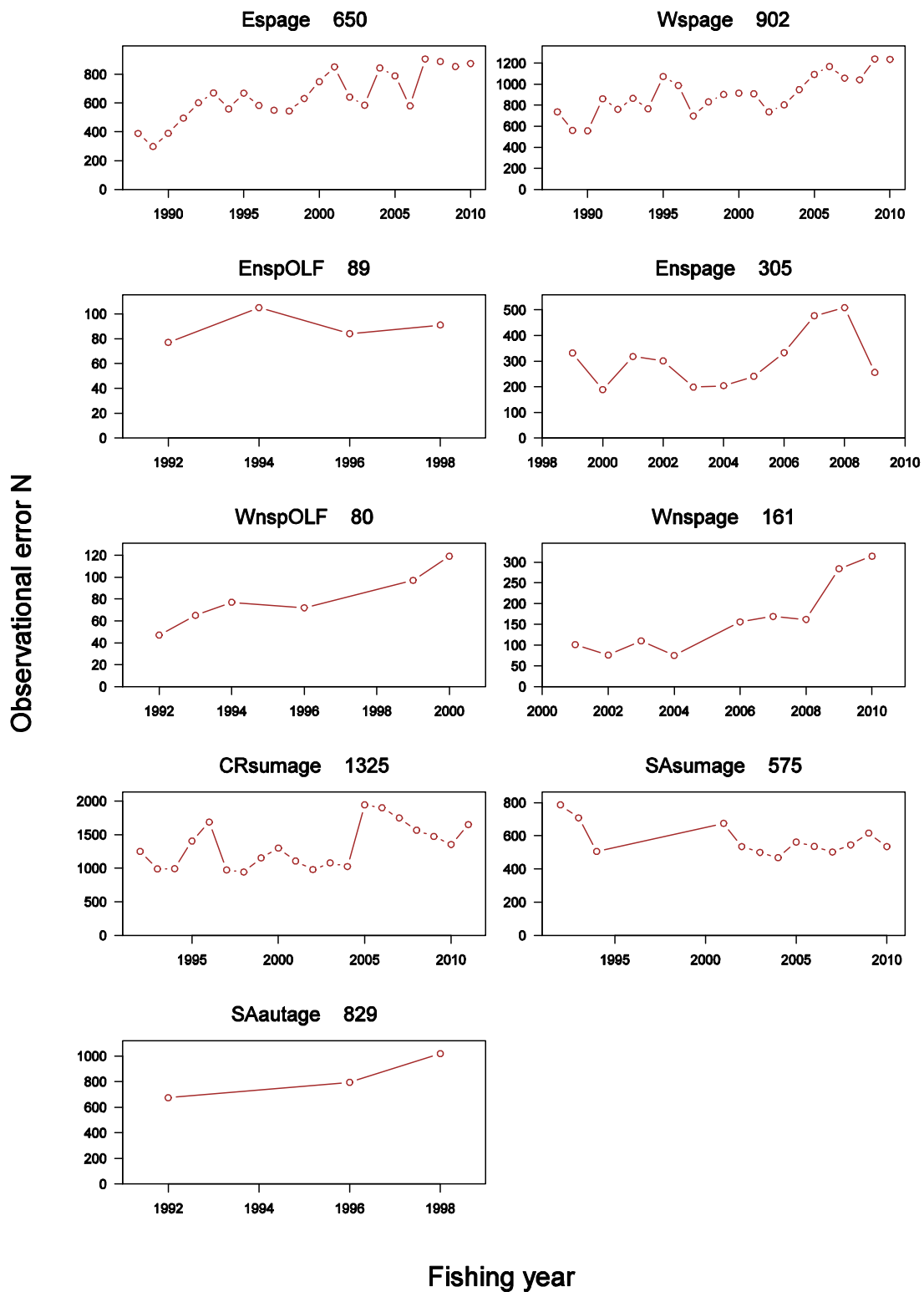
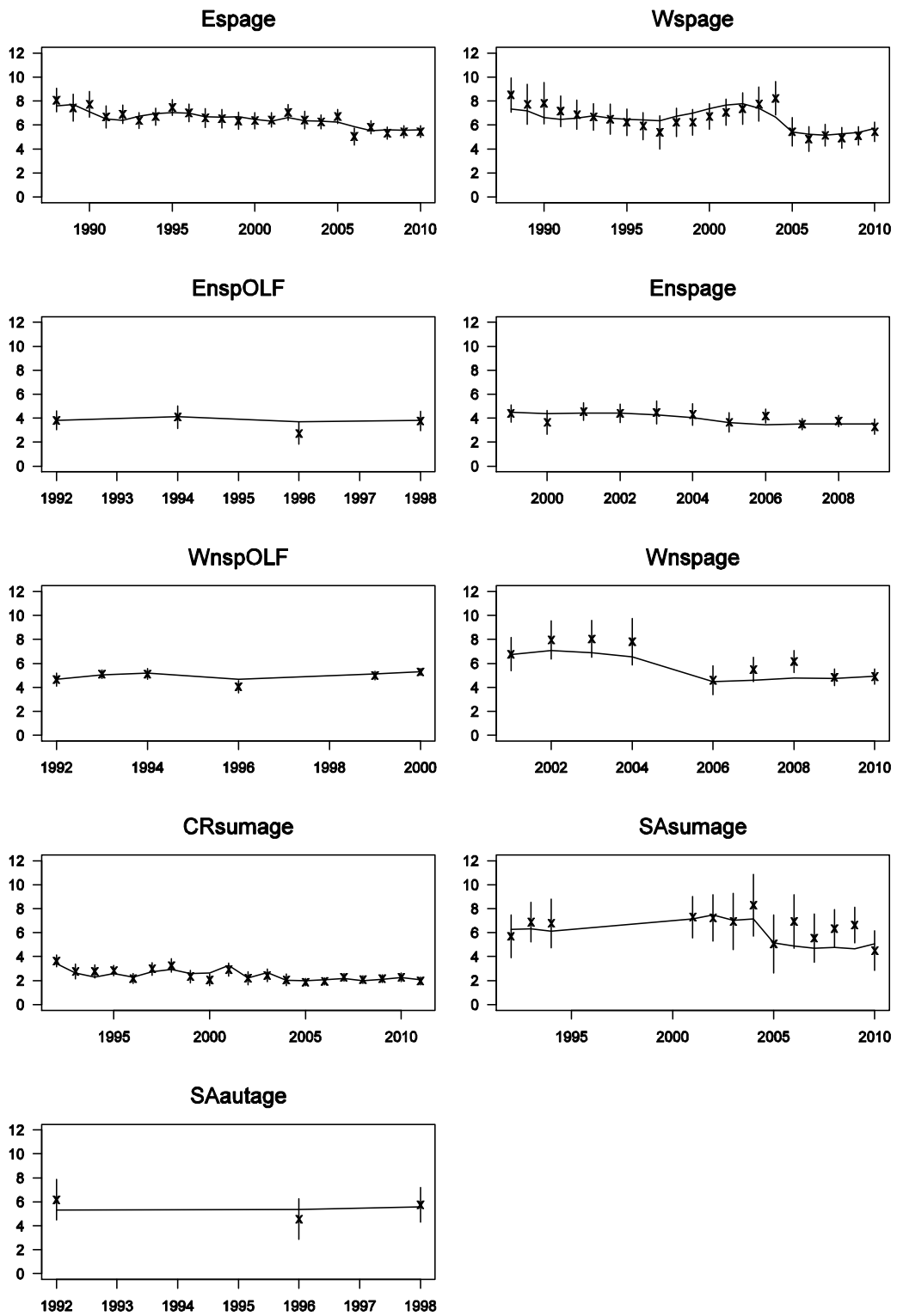


Figure A3: Equivalent multinomial N values for the observational error. The number above each panel is the mean value over the fishing years.





**Figure A4: Observed ('x', with 95% c.i.s. as vertical lines) and expected (lines) for the at-age data sets in run 1.1 of the 2011 hoki assessment after reweighting.**

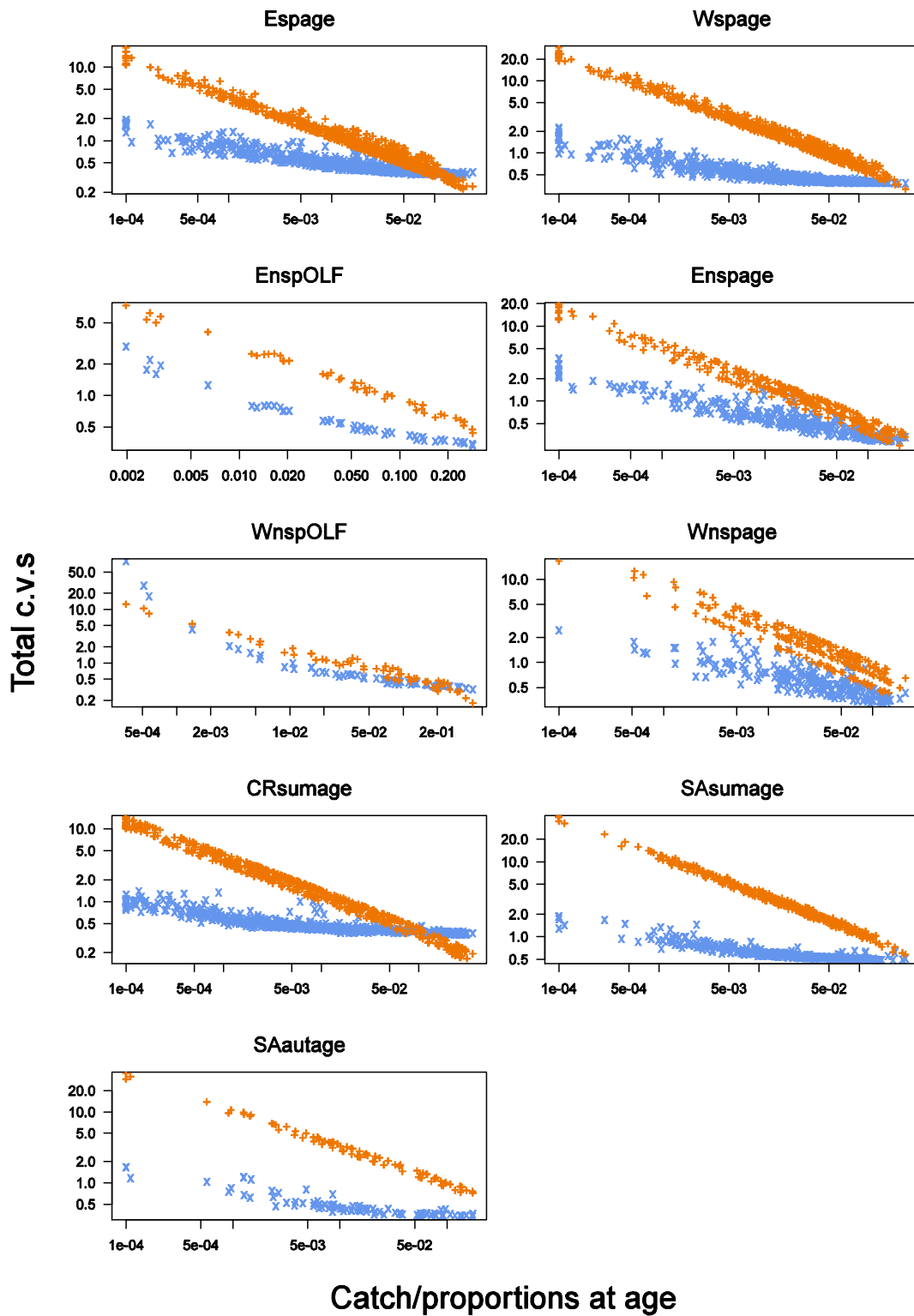


Figure A5: Total c.v.s. using the robust lognormal distribution (blue 'x') for the original model run 1.1 (no reweighting) and the reweighting with a multinomial distribution (orange '+').

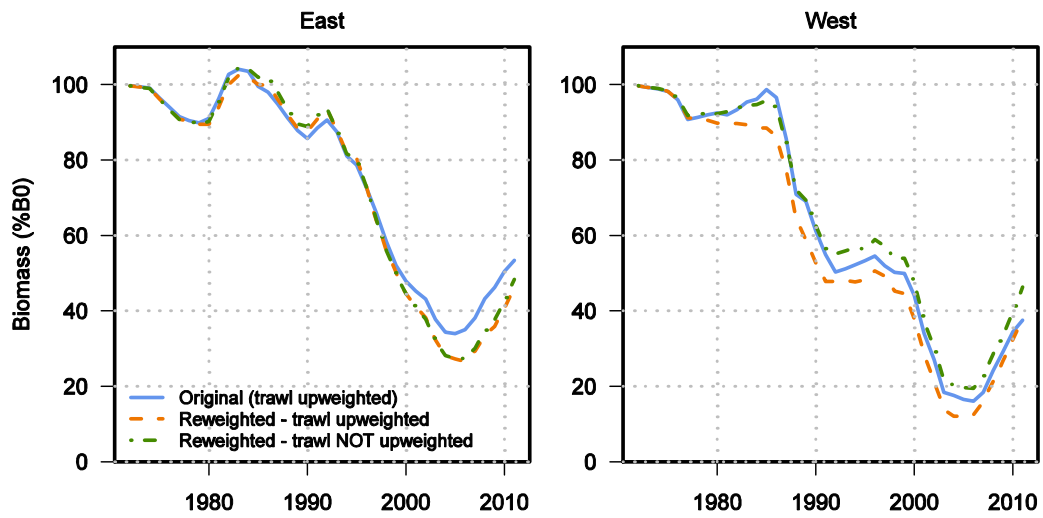


Figure A6: MPD spawning-biomass trajectory ( $\%B_0$ ) for the run 1.1 ('Original') and with reweighting ('Reweighted').

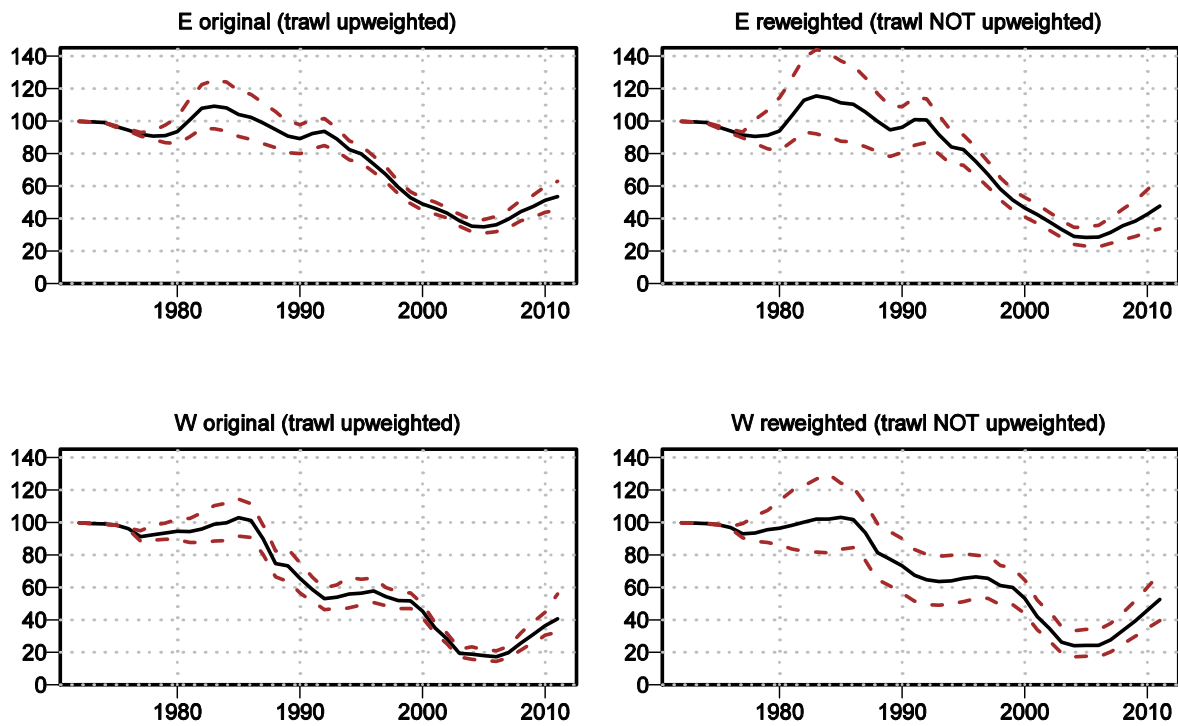


Figure A7: Estimated spawning-biomass ( $\%B_0$ ) from the MCMC runs, showing median (solid lines) and 95% confidence intervals. Split by E (top panels) and W (bottom panels).

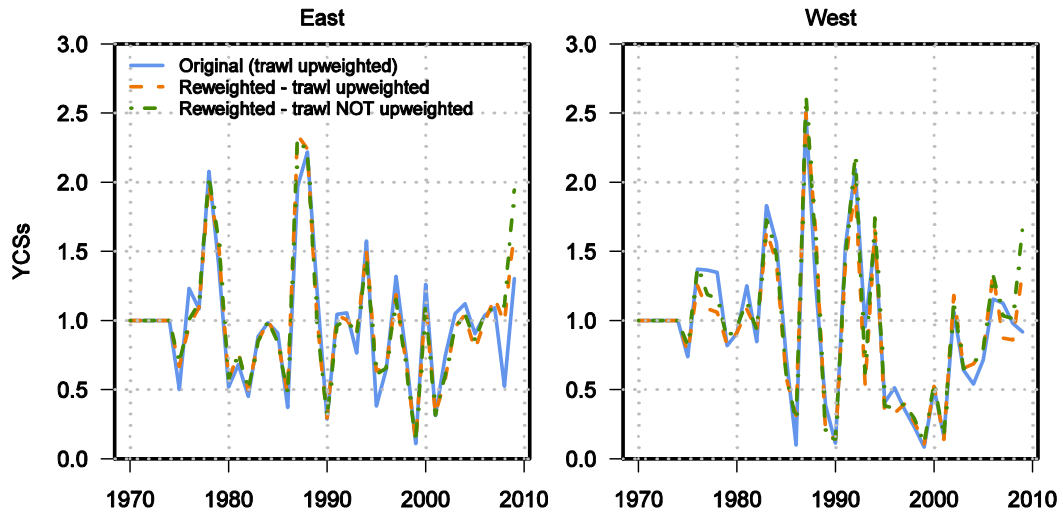


Figure A8: MPD YCSs for the run 1.1 ('Original') and with reweighting ('Reweighted').

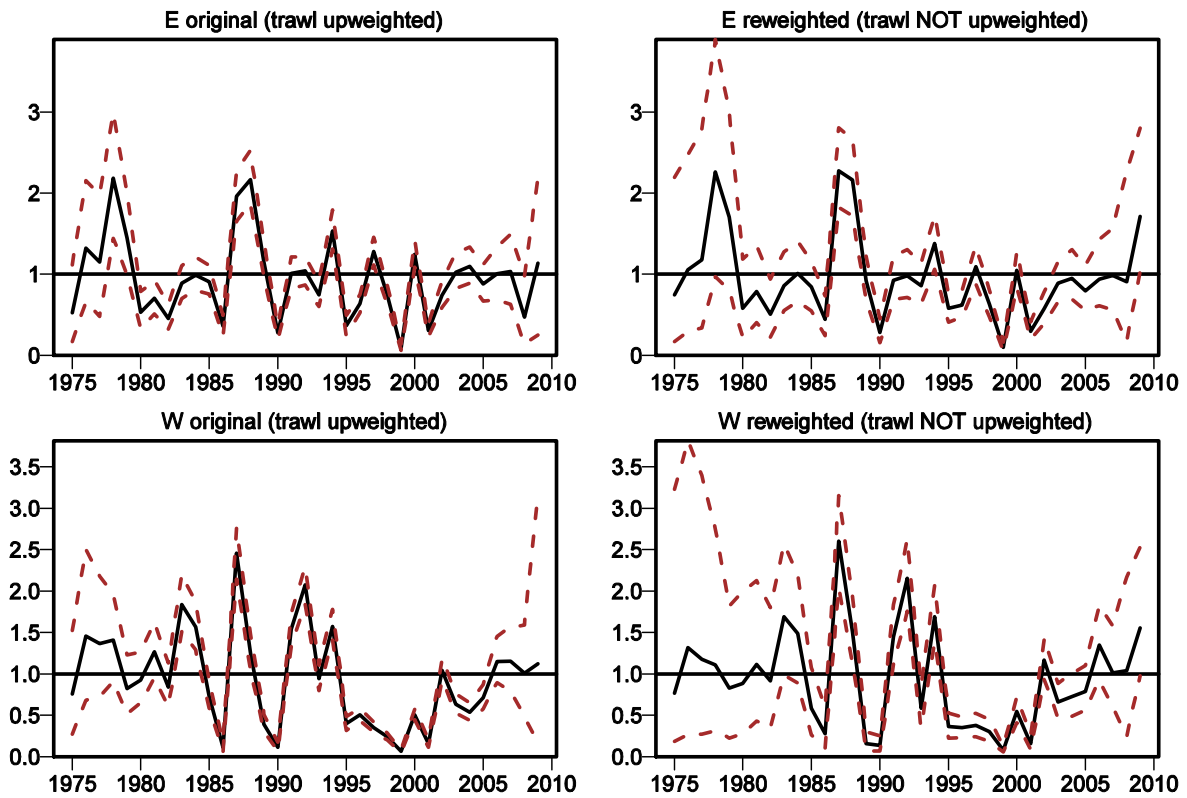


Figure A9: YCSs for the MCMC runs, show medians (solid lines) and 95% confidence intervals. Split by E (top panels) and W (bottom panels).

## Appendix 4: Reweighting the 2012 assessment at-age data

The same procedure as in Appendix 3 was used to reweight the at-age data for the model runs 1.1 and 1.2, 1.10 giving models 1.3, 1.4, and 1.11 respectively. Summary results from the reweighting are shown in the tables and figures below: initial and final effective sample sizes (Table A4–A6), initial effective sample sizes based on the observational error (Figures A10–A11), and observed and expected ages after reweighting (Figure A12–A14).

**Table A4: Model run 1.1. Iterative reweighting for multinomial sample sizes using method TA1.8. Shown are the mean values of N for the at age data sets in the model. Final/Initial values are rounded to the nearest integer.**

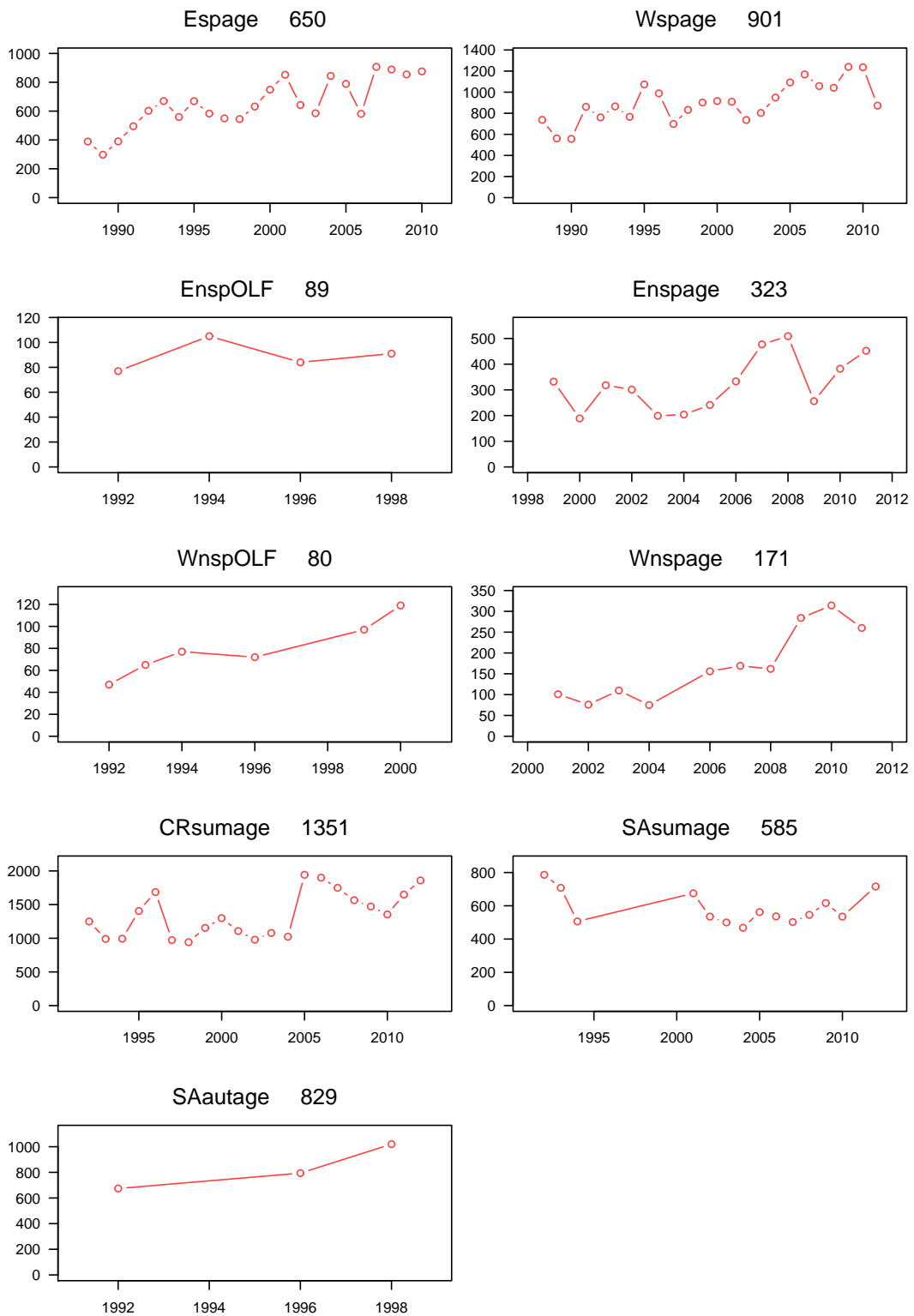
Stage	Espage	Wspage	EnspOLF	Enspage	WnspOLF	Wnspage	CRsumage	SAsumage	SAautage
Initial	650	901	89	323	80	171	1351	585	829
2	57	33	13	30	93	22	87	11	24
3	60	25	12	31	47	13	83	9	13
4	65	22	12	30	39	11	83	9	12
5	67	21	12	30	37	11	83	9	11
Final	69	21	12	30	36	10	83	9	10
Final/Initial	9	43	7	11	2	17	16	65	83

**Table A5: Model run 1.2. Iterative reweighting for multinomial sample sizes using method TA1.8. Shown are the mean values of N for the at age data sets in the model. Final/Initial values are rounded to the nearest integer.**

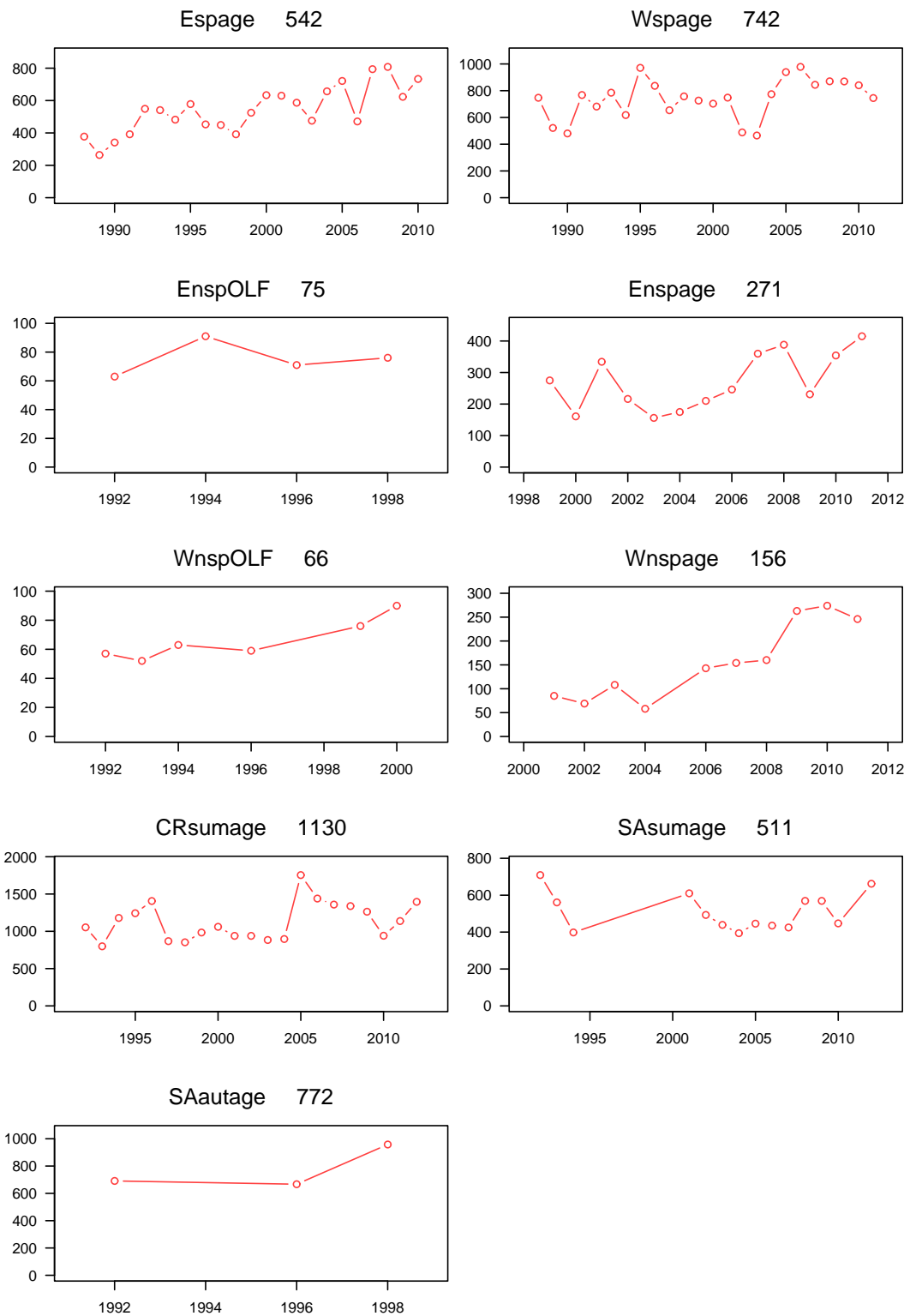
Stage	Espage	Wspage	EnspOLF	Enspage	WnspOLF	Wnspage	CRsumage	SAsumage	SAautage
Initial	542	742	75	271	66	156	1130	511	772
2	58	35	12	27	86	24	88	11	24
3	58	29	10	26	50	19	59	10	13
4	64	28	10	26	45	18	54	10	13
5	67	27	10	26	45	18	53	10	13
Final	68	27	10	26	45	18	52	10	13
Final/Initial	8	27	8	10	1	9	22	51	59

**Table A6: Model run 1.10. Iterative reweighting for multinomial sample sizes using method TA1.8. Shown are the mean values of N for the at age data sets in the model. Final/Initial values are rounded to the nearest integer.**

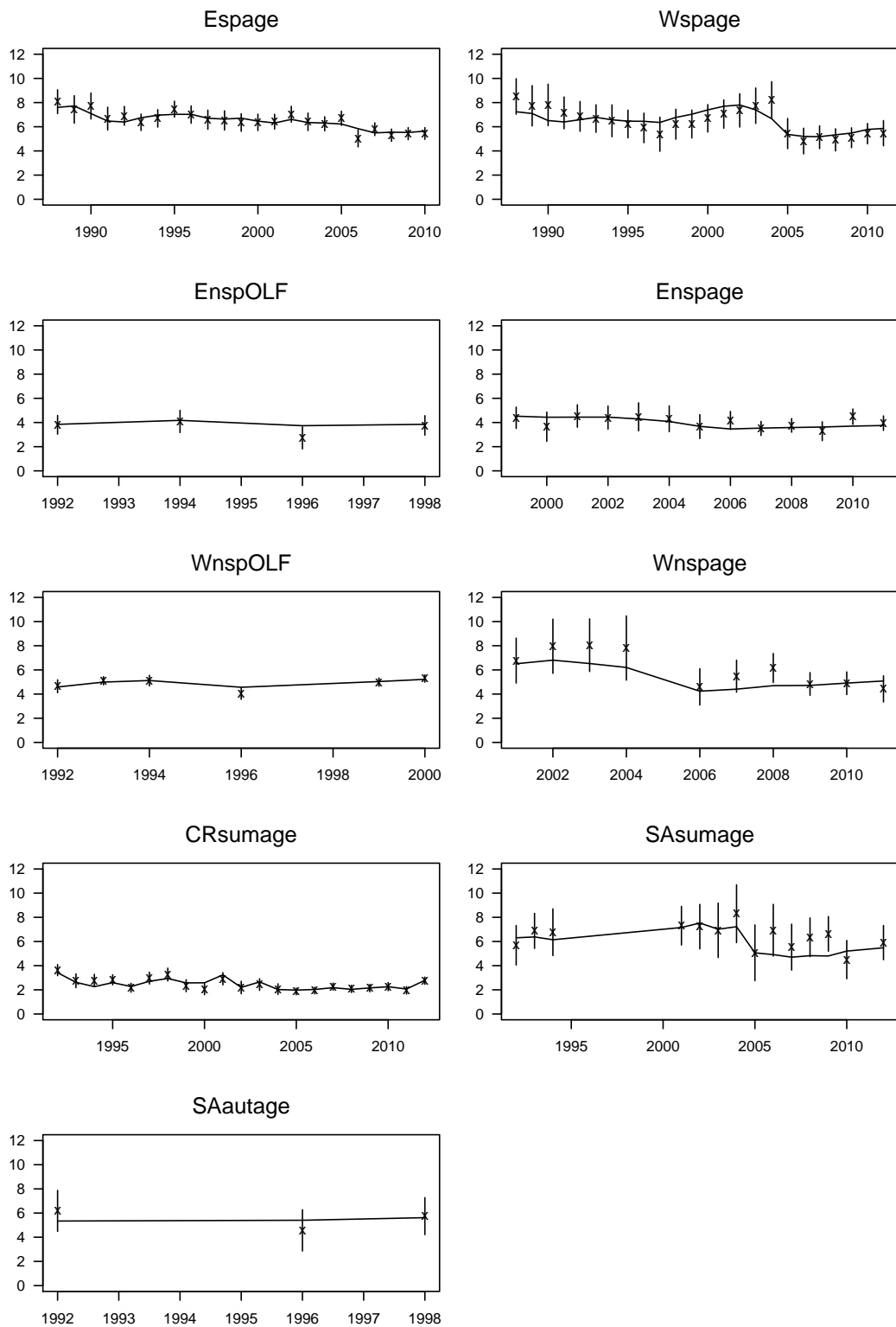
Stage	Espage	Wspage	EnspOLF	Enspage	WnspOLF	Wnspage	CRsumage	SAsumage	SAautage
Initial	650	901	89	323	80	171	1351	585	829
2	51	28	10	30	62	29	83	12	34
3	56	27	10	33	51	17	65	8	20
4	62	28	10	34	45	14	62	7	18
5	65	29	10	34	43	14	61	7	18
Final	67	30	10	34	44	14	59	7	18
Final/Initial	10	30	9	10	2	12	23	84	46



**Figure A10: Model 1.1. Equivalent multinomial N values for the observational error. The number above each panel is the mean value over the fishing years. The values are same for model 1.10.**

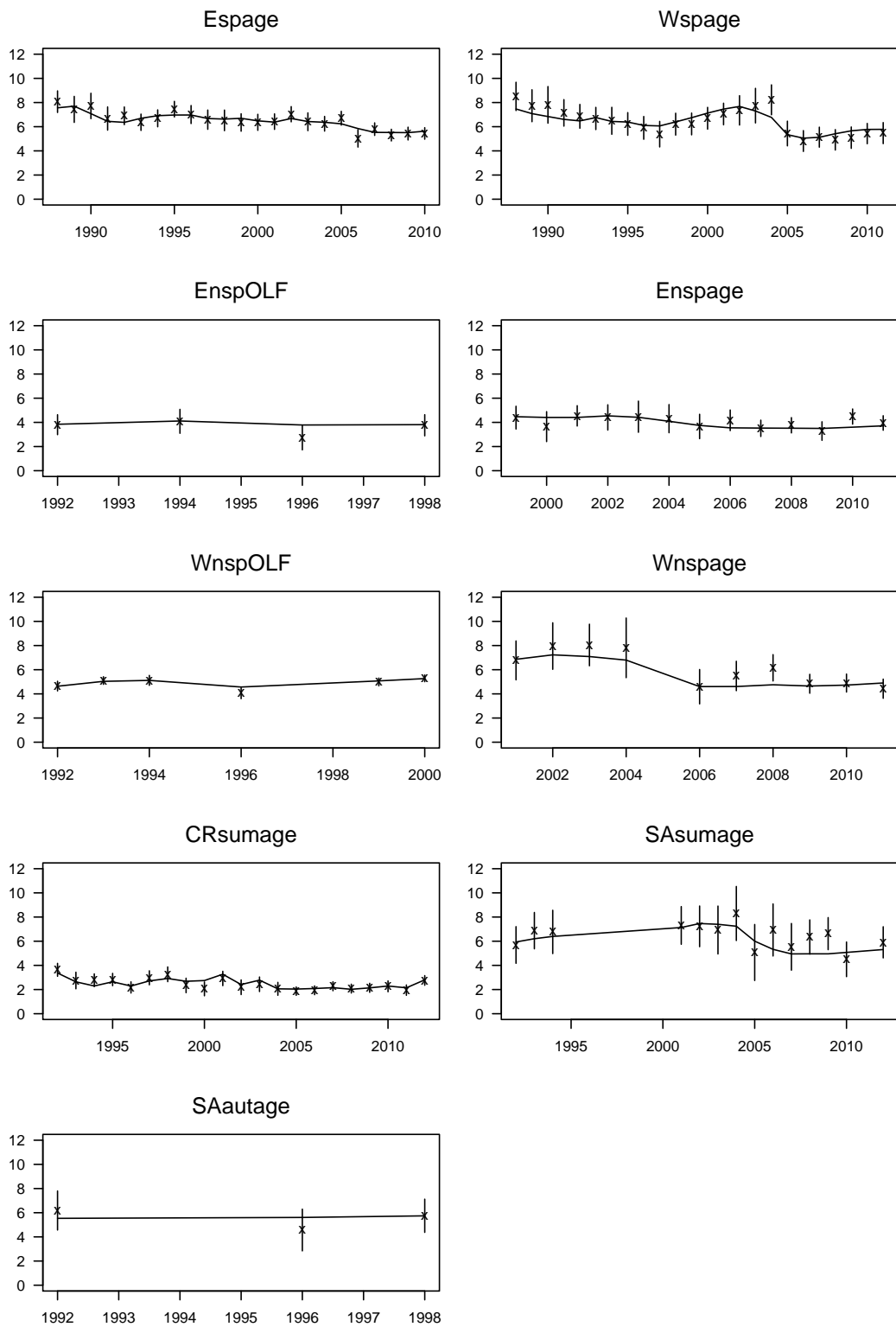


**Figure A11: Model 1.2. Equivalent multinomial N values for the observational error. The number above each panel is the mean value over the fishing years.**

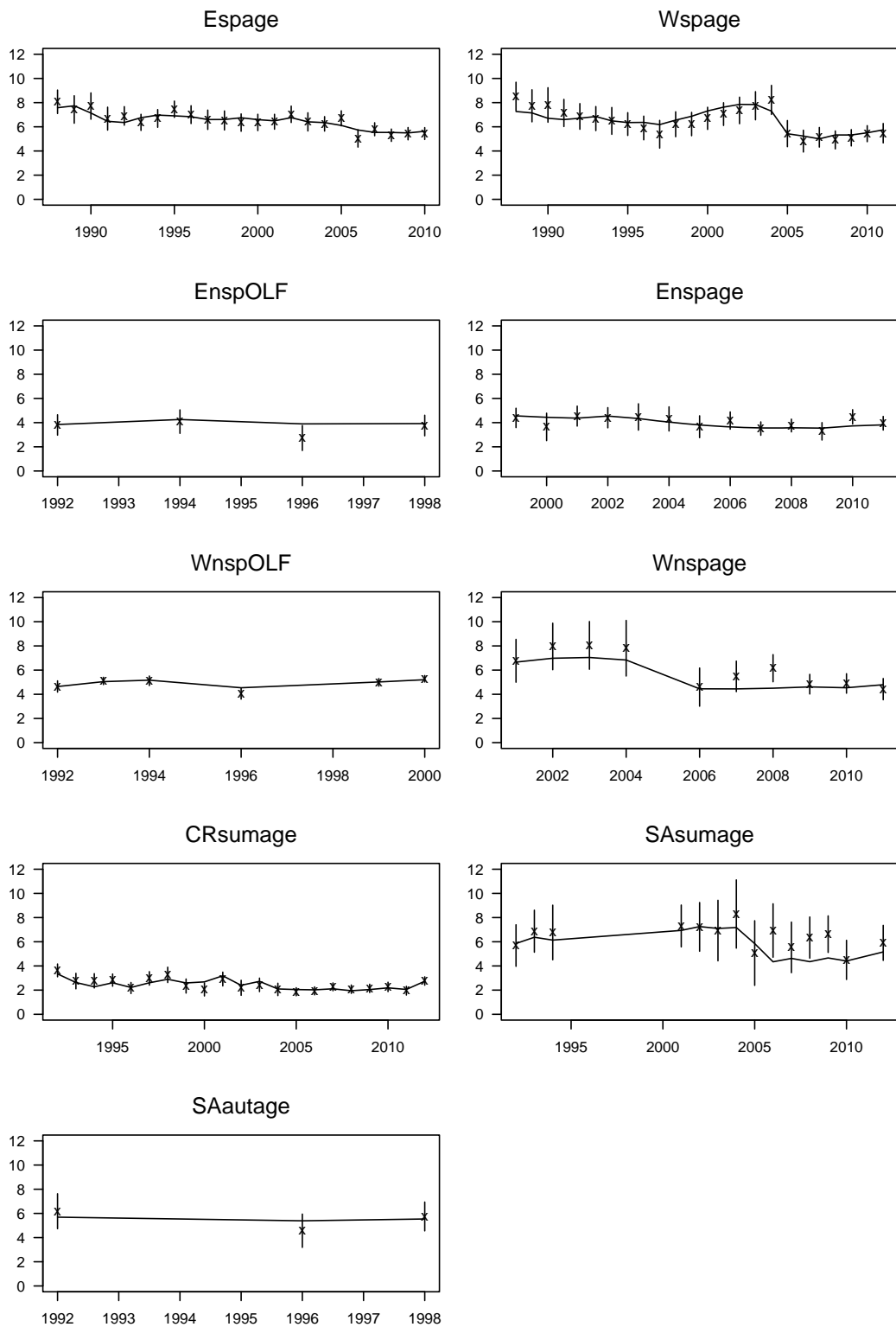


**Figure A12: Model 1.1. Observed ('x', with 95% c.i.s. as vertical lines) and expected (lines) for the at-age data sets in run 1.1 after reweighting.**





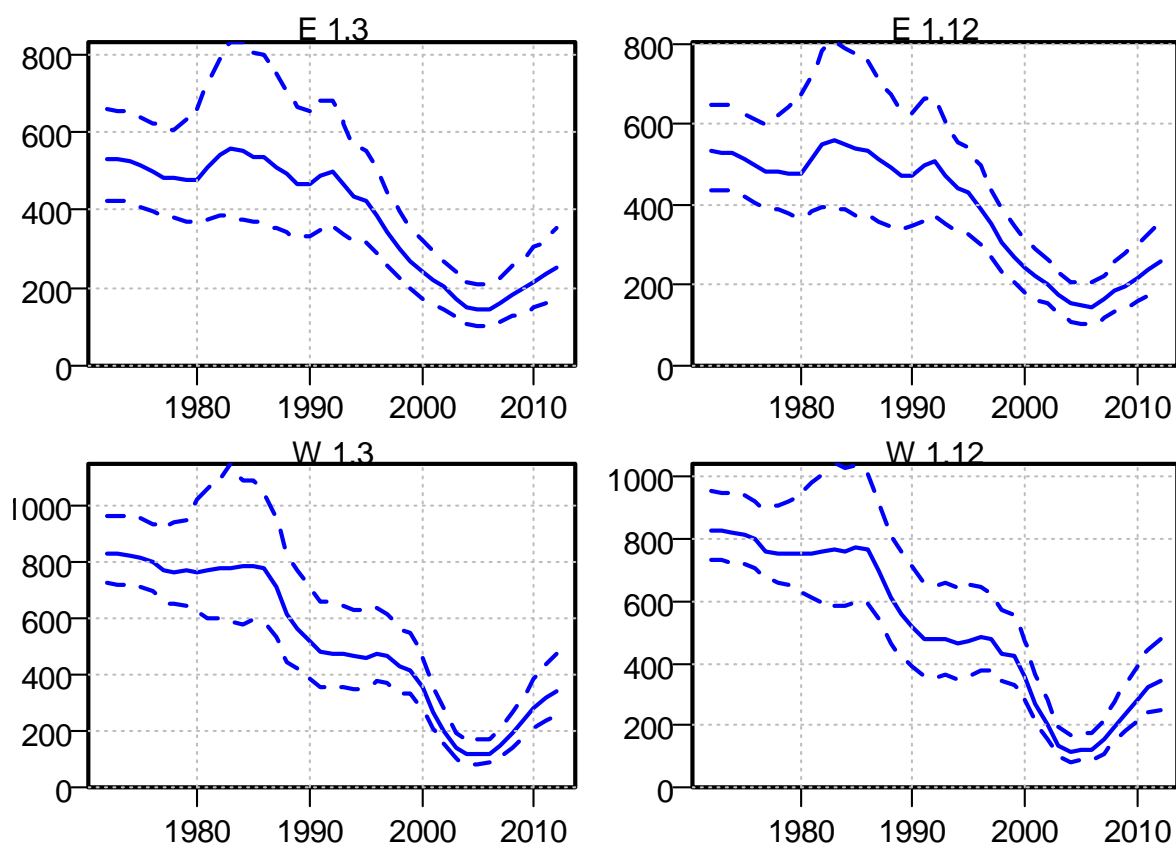
**Figure A13: Model 1.2. Observed ('x', with 95% c.i.s. as vertical lines) and expected (lines) for the at-age data sets in run 1.1 after reweighting.**



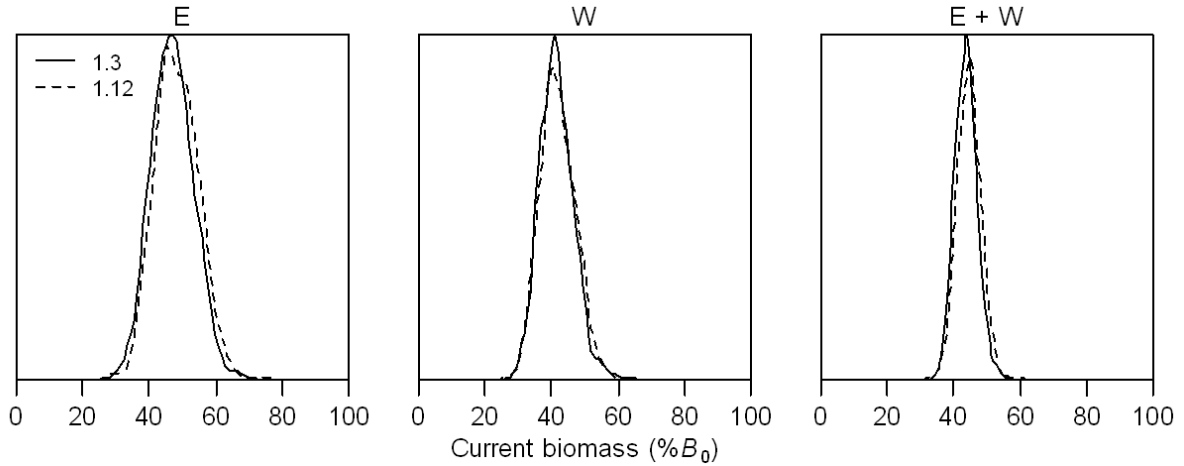
**Figure A14: Model 1.10. Observed ('x', with 95% c.i.s. as vertical lines) and expected (lines) for the at-age data sets in run 1.1 after reweighting.**

## Appendix 5: Impact of 2010 YCS penalty on MCMC results

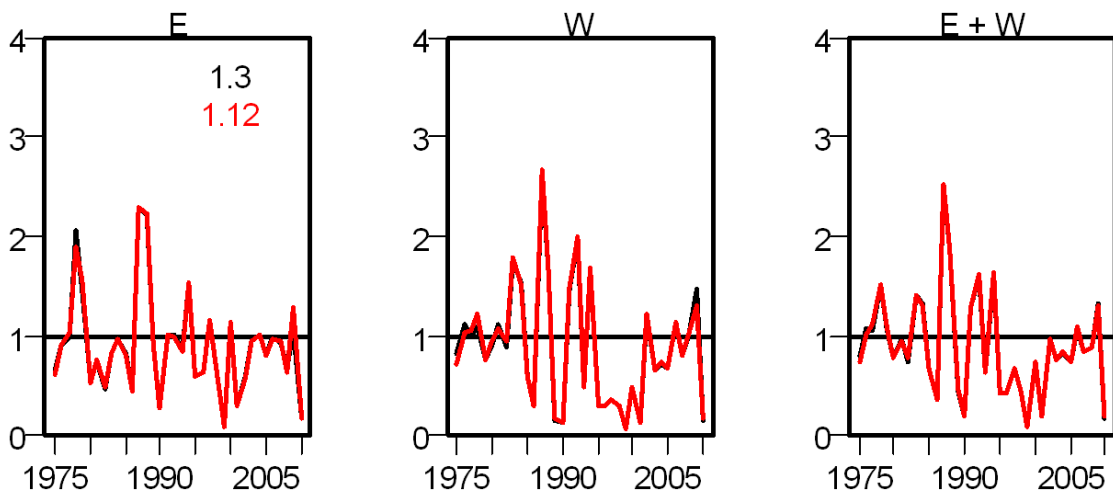
The E and W YCSs for 2010 were constrained (by a penalty function) to be equal for MPD runs. In previous assessments this constraint was removed for the full Bayesian runs, but was inadvertently left in for the Bayesian runs for this assessment. However, an additional Bayesian run 1.12 where the penalty was dropped for the base model run 1.3 shows that this makes very little difference to the results (Figures A15–A19).



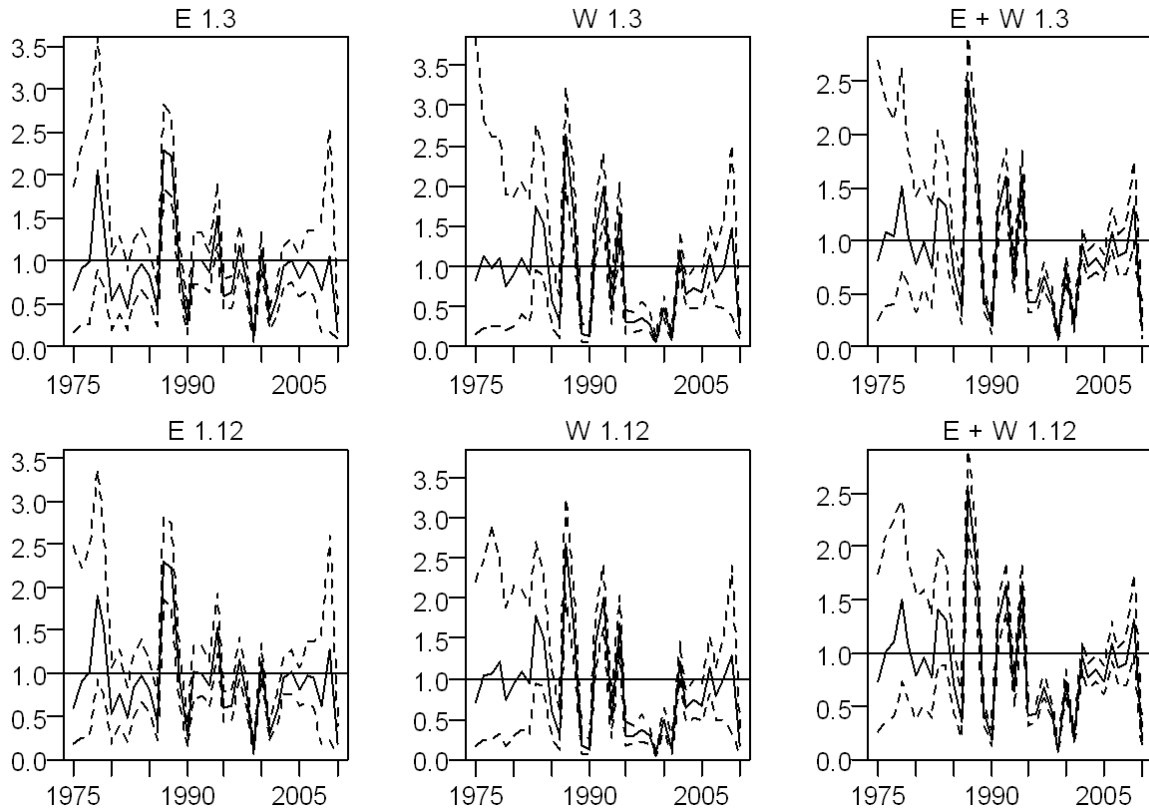
**Figure A15:** Estimated spawning-biomass trajectories from the MCMC runs, showing medians (solid lines) and 95% confidence intervals (broken lines) by run for E (upper panels) and W (lower panels).



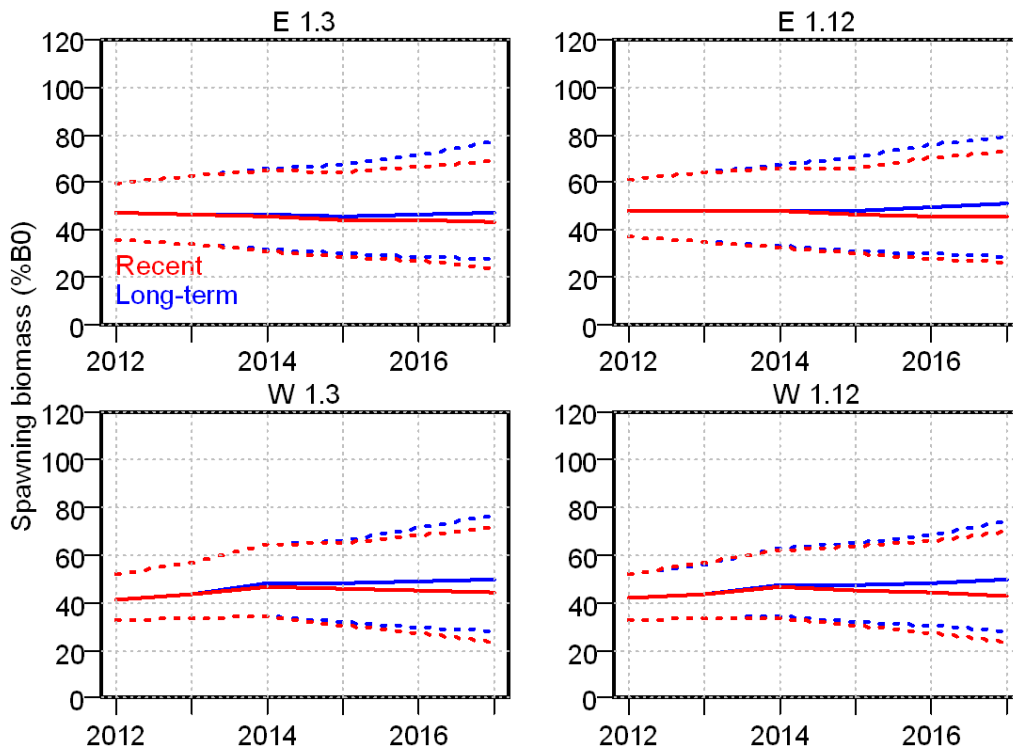
**Figure A16: Estimated posterior distributions of current (spawning) biomass ( $B_{2010-11}$ ), expressed as % $B_0$ , for the E (left panel), W (middle panel) and E + W stocks (right panel) from the base case model (run 1.3) and run 1.12.**



**Figure A17: Estimated year-class strengths (YCSs) showing medians for the runs 1.3 (black lines) and 1.12 (red lines) for E, W, and E + W.**



**Figure A18:** Estimated year-class strengths (YCSs) from the runs 1.3 and 1.12 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 A19:** 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' (blue lines) or 'recent' recruitment (red lines). Each panel shows results for one stock (E or W) from one of the MCMC runs 1.3 and 1.12.