



## Assessment of hoki (*Macruronus novaezelandiae*) in 2013

New Zealand Fisheries Assessment Report 2015/08

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ISSN 1179-5352 (online)

ISBN 978-0-477-10549-1 (online)

February 2015



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## EXECUTIVE SUMMARY

McKenzie, A. (2015). Assessment of hoki (*Macruronus novaezelandiae*) in 2013.

*New Zealand Fisheries Assessment Report 2015/08. 73 p.*

An updated assessment is presented for hoki that is based on the 2012 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 2013, a trawl survey on the Southern Plateau in December 2012, and an acoustic survey of spawning hoki on the west coast South Island in winter 2012. New proportions-at-age data came from the four fisheries and the two trawl surveys.

In the previous assessment 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 Southern Plateau survey series, but for the current assessment it was decided not to do this as it made only a small difference to the fits. However, no model runs were able to mimic the changes in the last four biomass estimates from the Southern Plateau 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 three final model runs. In all final model runs 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 final model runs it was assumed that the catchability for the Southern Plateau trawl surveys series is constant, whereas for the other two final runs, two catchabilities were fitted to this series instead of just one. For each model run with two catchabilities, two sensitivity runs were conducted: (1) using a domed spawning selectivity instead of allowing for an age varying natural mortality, and (2) not assuming natal fidelity (but assuming adult fidelity).

Both the eastern and western hoki stocks are estimated to be increasing after reaching their lowest levels in about 2006. The western stock is estimated to be 45–65% $B_0$  and the eastern stock 50–57% $B_0$ . The western stock experienced an extended period of poor recruitment from 1995 to 2001 inclusive. However, recruitment has been near or above average since 2001, except for 2010 where it was below average, and 2011 where it was well above average (though estimated with high uncertainty).

Five-year projections were carried out for each final run with two alternative recruitment scenarios: ‘ten-year’ (future recruitment selected from estimated levels in 2001–2011) and ‘drop 2011’ (recruitment selected from 2001–2010). Future catches for each fishery were assumed to be equal to those assumed for 2013. The projections indicate that with these assumed catches, the eastern and western biomasses are likely to rise in the next five years under ‘ten-year’ recruitment and to stay much the same when the large 2011 recruitment is omitted.

## 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 Southern Plateau) (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.

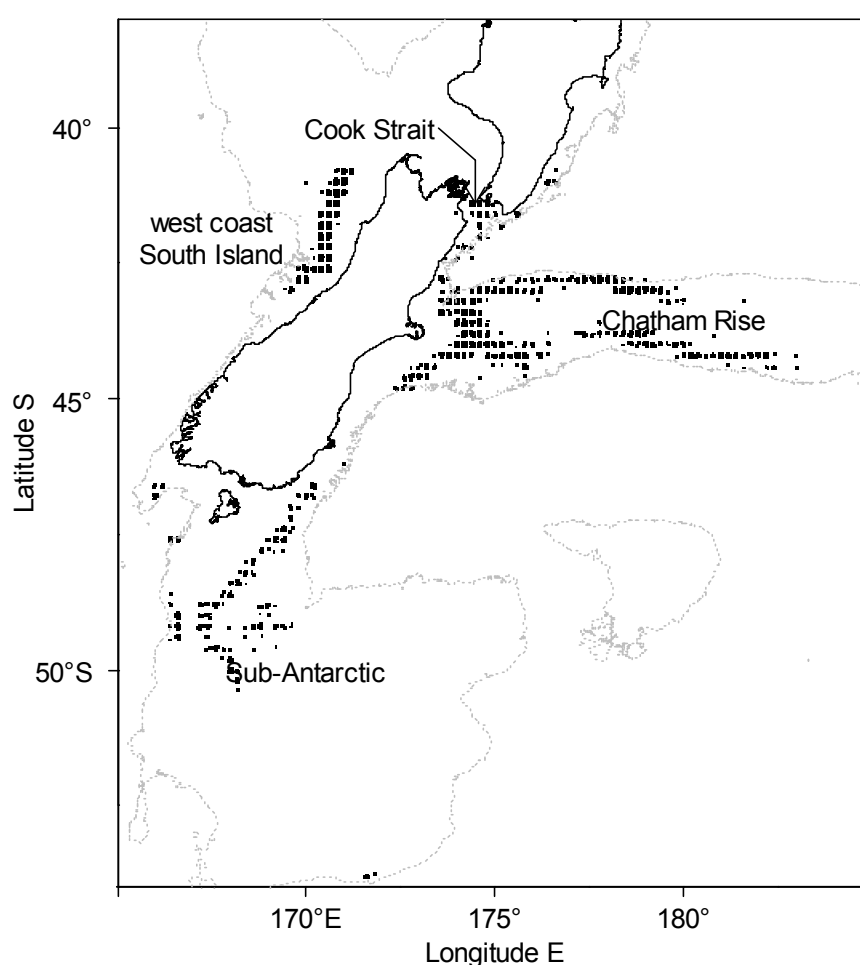
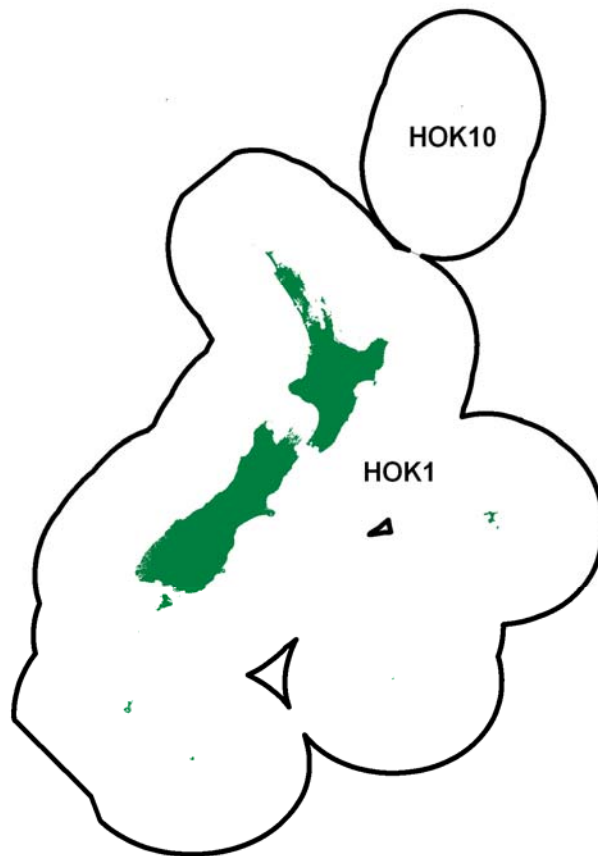


Figure 1: Southern New Zealand showing the main hoki fishing grounds, the 1000 m contour (broken grey line), and the position of all 2011–12 tows from TCEPRs (Trawl Catch and Effort Processing Returns) in which at least 10 t of hoki was caught (dots). Positions are rounded to the nearest 0.2 degrees 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 2013 assessment of HOK 1, which is the twelfth hoki assessment to use NIWA's general-purpose stock-assessment model CASAL (Bull et al. 2012). Since the last assessment (McKenzie 2013) there has been another trawl survey on the Chatham Rise in January 2013 (Stevens et al. 2014), a trawl survey on the Southern Plateau in December 2012 (Bagley et al. 2014), and an acoustic survey of spawning hoki on the west coast South Island in winter 2012 (O'Driscoll et al. 2014).

The work reported here addresses objective 1 for the 2013 year of the Ministry for Primary Industries project DEE201002HOK: *To update the stock assessment of hoki in 2013 including estimates of biomass, risk and yields.*

## 2. MODEL ASSUMPTIONS AND INPUTS FOR 2013

This section provides a summary of all model assumptions and inputs for the 2013 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 2012 assessment are that of the three final model runs, two have a time-varying catchability for the Southern Plateau trawl survey biomass series, whereas the single base model run for 2012 had a constant catchability.

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 that 1990 refers to the 1989–90 fishing year. This convention is applied throughout, so that, for instance, the most recent Southern Plateau 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	Southern Plateau
	WC	west coast South Island
Fishery	Esp	E spawning fishery
	Wsp	W spawning fishery
	Ensp1, Ensp2	first and second parts of E non-spawning fishery
	Wnsp1, Wnsp2	first and second parts of W non-spawning fishery
Observation	CSacous	CS acoustic biomass index
	WCacous	WC acoustic biomass index
	CRsumbio, CRsumage	biomass index and proportions-at-age from CR summer trawl survey
	SAsumbio, SAsumage	biomass index and proportions-at-age from SA summer trawl survey
	SAautbio, SAautage	biomass index and proportions-at-age from SA autumn trawl survey
	pspawn	proportion spawning (estimated from SA autumn trawl survey)
	Espage, Wnspage, etc	proportions-at-age in catch from given fishery (from otoliths)
Migrations	EnspOLF, WnspOLF	proportions-at-age in catch from given fishery (from OLF <sup>1</sup> )
	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 Southern Plateau (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 no direct evidence of natal fidelity for hoki, and 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 2012 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 2012 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 Wspmg: SA→WC, Espmg: 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 2012 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 (2013), the 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: 20 000 t (non-spawning), 50 000 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 Southern Plateau. The same proportions as in 2012 were used to split the western non-spawning catch into two parts.

For the eastern stock the catch was split: 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 2012.

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 2012 (Table 5).

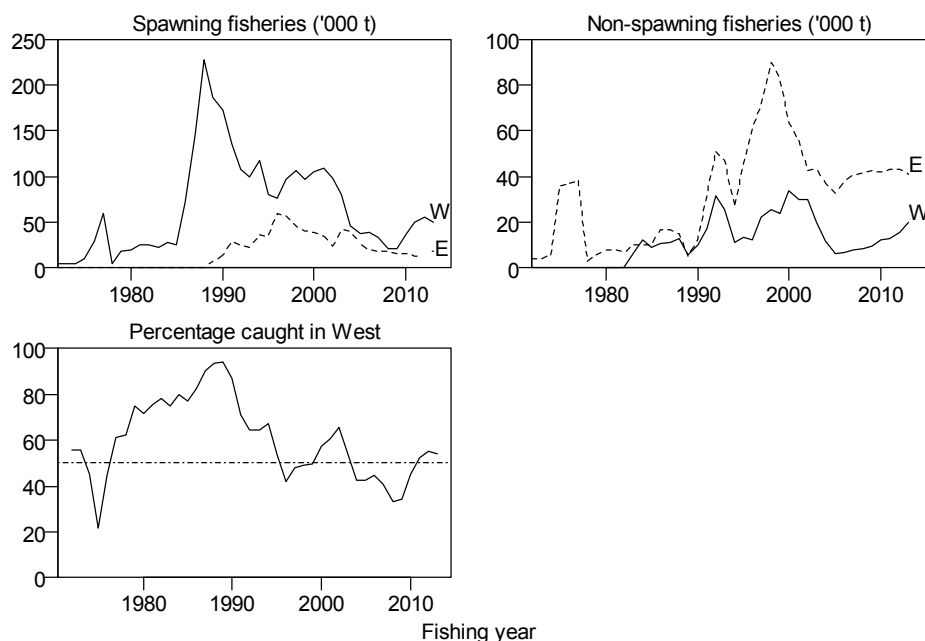
**Table 3: Catches (t) by fishery and fishing year (1972 means fishing year 1971–72), as used in the assessment.**

Year	Fishery						Total
	Ensp1	Ensp2	Wnsp1	Wnsp2	Esp	Wsp	
1972	1 500	2 500	0	0	0	5 000	9 000
1973	1 500	2 500	0	0	0	5 000	9 000
1974	2 200	3 800	0	0	0	5 000	11 000
1975	13 100	22 900	0	0	0	10 000	46 000
1976	13 500	23 500	0	0	0	30 000	67 000
1977	13 900	24 100	0	0	0	60 000	98 000
1978	1 100	1 900	0	0	0	5 000	8 000
1979	2 200	3 800	0	0	0	18 000	24 000
1980	2 900	5 100	0	0	0	20 000	28 000
1981	2 900	5 100	0	0	0	25 000	33 000
1982	2 600	4 400	0	0	0	25 000	32 000
1983	1 500	8 500	3 200	3 500	0	23 300	40 000
1984	3 200	6 800	6 700	5 400	0	27 900	50 000
1985	6 200	3 800	3 000	6 100	0	24 900	44 000
1986	3 700	13 300	7 200	3 300	0	71 500	99 000
1987	8 800	8 200	5 900	5 400	0	146 700	175 000
1988	9 000	6 000	5 400	7 600	600	227 000	255 600
1989	2 300	2 700	700	4 900	7000	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	19 000	13 800	4 200	2 100	27 000	38 100	104 200
2006	23 100	14 400	2 300	4 700	20 100	39 700	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	28 500	14 700	9 100	6 600	15 400	55 800	130 100
2013	27 000	14 000	11 600	8 400	19 000	50 000	130 000

**Table 4: Method of dividing annual catches by area and month 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
Southern Plateau	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	$a$	$4.79 \times 10^{-6}$							b
[W(kg)=aL(cm) <sup>b</sup> ]	$b$	2.89							
Proportion by sex at birth		0.5							c

## 2.2 Ogives

The nine ogives used in the model are the same as in 2012: four fishery selectivity ogives (one for each of the four fisheries: Espsl, Wpsl, Enpsl, Wnpsl), two trawl survey ogives (in areas CR and SA: CRsl, SAsl), and three migration ogives (for migrations Whome, Espmg, and Wpsmg). Two

alternative sets of ogive assumptions were used for the final runs and associated sensitivity 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 (Espsl, Wpspl) are logistic, but natural mortality is allowed to vary with age (i.e., runs 1.7, 1.16, 1.19). Alternatively, the spawning selectivities are domed, with natural mortality the same for all ages (i.e., runs 1.17, 1.20). When the domed selectivities were used it was also necessary to combine sexes in the model and make the selectivities age-based (Francis 2005).

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 the final runs and associated sensitivity runs (see Section 4 for further explanation of these runs). In the ogive constraints,  $O_{7,F,E}$  refers to the ogive value at age 7 for female fish from the E stock, etc. Runs 1.7, 1.16, and 1.19 have the same set of ogive assumptions, as do runs 1.17 and 1.20.**

Runs	Ogive type	Description	Constraints
1.7, 1.16 and 1.19	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
1.17 and 1.20	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 Wpspl (the selectivity ogive for W spawning fishery). Following the recommendation of Francis (2006), these changes were restricted to years for which there were Wspage data (i.e., from 1988 onwards). The changes were driven by the median day of the fishery, this being the day when half of the year's catch had been taken (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 day of the Wsp fishery, by year, as used in estimating annual changes in the selectivity Wpspl. The values represent the numbers of days since the previous 1 October. The overall mean value (305) was used for all years for which there was catch but no Wspage data (i.e., before 1988 and in 2013).**

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
2012	Mean										
298	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

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

where  $\text{YCS}_y$  is the year-class strength for fish spawned in year  $y$ ,  $\text{SR}$  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  $\text{SSB}_y$  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 2008, inclusive (so  $R_0$  is the mean recruitment over those years, ignoring the effect of the stock-recruit relationship).

Thirty-eight YCSs were estimated for each stock, for 1975 to 2012, inclusive. YCSs for the initial years (1970 to 1974) were fixed at 1. The E and W YCSs for 2012 were constrained (by a penalty function) to be equal for MPD runs, with the constraint removed for full Bayesian runs.

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

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

## 2.4 Observations

Three types of observations were used in the model: biomass indices (Tables 8), proportions-at-age (by sex) (Table 9, Figure 4), and proportion spawning (Table 10). Biomass indices new to this assessment are from a trawl survey on Chatham Rise in January 2013 (Stevens et al. 2014), a trawl survey in Southern Plateau in December 2012 (Bagley et al. 2014), and an acoustic survey of spawning hoki on the west coast South Island in winter 2012 (O'Driscoll et al. 2014).

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

Although both the CR and SA trawl surveys provide information about year-class strengths (YCSs) the CR survey is more reliable for recent year classes (McKenzie 2011, figure 5). Furthermore, the correlation between these estimates and model estimates of YCS is not strong until age 4 for the SA survey, but is quite strong at age 1 for the CR survey (Francis 2008, figure 32).

The proportions-spawning data (Table 10) use the recommended estimates of Francis (2009).

The age ranges for the proportions-at-age data in the model varies between data sets (Table 11). As in 2002 (and all subsequent years), all proportions less than 0.0001 were replaced by 0.0001 (for reasons, see Francis et al. (2003)). For the otolith-based data sets, the maximum ages were set as high as was possible without allowing the percentage of data points requiring 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 CVs (respectively) in parentheses. Bold values are new to this assessment.**

	<u>CRsumbio</u>	<u>SAsumbio</u>	<u>SAautbio</u>	<u>CSacous</u>	<u>WCacous</u>
1988	—	—	—	—	417 (0.22,0.60)
1989	—	—	—	—	249 (0.15,0.38)
1990	—	—	—	—	255 (0.06,0.40)
1991	—	—	—	191 (0.13,0.41)	341 (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)	—	613 (0.15,0.52)	549 (0.07,0.38)
1994	146 (0.10,0.22)	100 (0.09,0.22)	—	597 (0.06,0.91)	—
1995	120 (0.08,0.21)	—	—	411 (0.12,0.61)	—
1996	153 (0.10,0.22)	—	89 (0.09,0.22)	196 (0.09,0.57)	—
1997	158 (0.08,0.22)	—	—	302 (0.12,0.40)	655 (0.10,0.60)
1998	87 (0.11,0.23)	—	68 (0.11,0.23)	170 (0.10,0.44)	—
1999	109 (0.12,0.23)	—	—	245 (0.10,0.36)	—
2000	72 (0.12,0.23)	—	—	—	397 (0.14,0.60)
2001	60 (0.10,0.22)	56 (0.13,0.24)	—	217 (0.12,0.30)	—
2002	74 (0.11,0.23)	38 (0.16,0.26)	—	307 (0.13,0.35)	—
2003	53 (0.09,0.22)	40 (0.14,0.24)	—	222 (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)	—	124 (0.11,0.32)	—
2006	99 (0.11,0.23)	21 (0.13,0.24)	—	128 (0.17,0.34)	—
2007	70 (0.08,0.22)	14 (0.11,0.23)	—	218 (—,0.46)	—
2008	77 (0.11,0.23)	46 (0.16,0.26)	—	179 (—,0.30)	—
2009	144 (0.11,0.23)	47 (0.14,0.24)	—	334 (—,0.39)	—
2010	98 (0.15,0.25)	65 (0.16,0.26)	—	—	—
2011	94 (0.14,0.24)	—	—	269 (0.18,0.35)	—
2012	88 (0.10,0.22)	46 (0.15,0.25)	—	—	<b>412 (0.15,0.51)</b>
2013	<b>124 (0.15,0.25)</b>	<b>56 (0.15,0.25)</b>	—	—	—

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

Area	Label	Data type	Years	age data
WC	Wspage	Catch at age	1988–2012	otoliths
SA	WnspOLF	Catch at age	1992–94, 96, 99–2000	OLF
	Wnspage	Catch at age	2001–04, 06–12	otoliths
	SAsumage	Trawl survey	1992–94, 2001–10, 12, <b>13</b>	otoliths
	SAautage	Trawl survey	1992, 96, 98	otoliths
CS	Espage	Catch at age	1988–2012*	otoliths
CR	EnspOLF	Catch at age	1992, 94, 96, 98	OLF
	Enspage	Catch at age	1999–2012	otoliths
	CRsumage	Trawl survey	1992–2013	otoliths

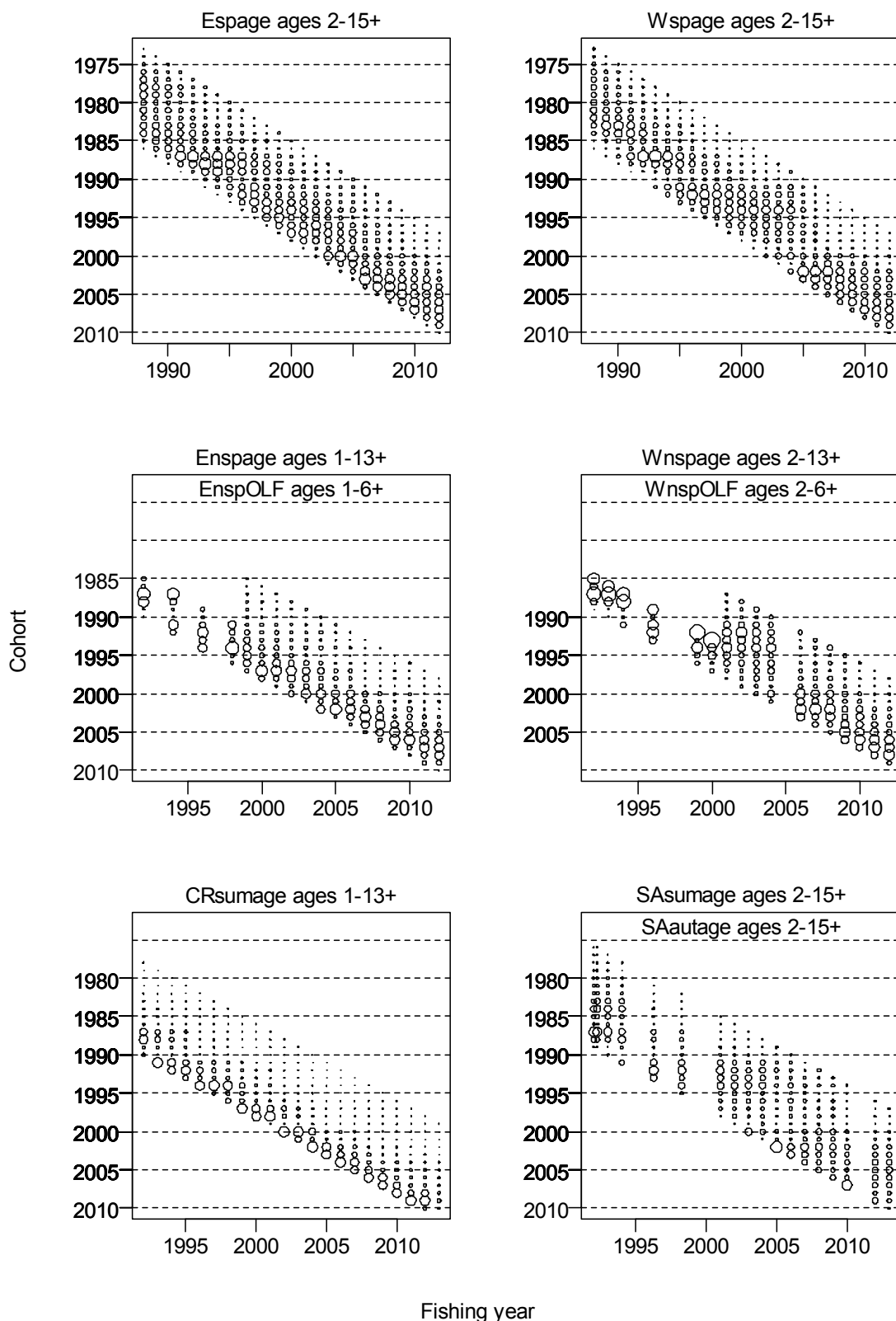
\* 2011 and 2012 values not included in initial model runs, except for a sensitivity run.

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

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

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

Data set	Age range	
	Lower	Upper
Espage, Wspage, SAsuage, 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 in 1992 have been offset horizontally to allow them to be plotted on the same panel as the SASumage data. Data new to the assessment are shown in Table 9.**



## 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 (2011) 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. Based on this, and explorations of reweighting for the 2011 assessment proportions-at-age data, it was decided by the Hoki Working Group to reweight the proportions-at-age data for the 2012 assessment using a multinomial error distribution (McKenzie 2013). 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. For the 2013 assessment this same reweighting procedure was followed.

The error distributions assumed were lognormal for all other data. This means that the weight assigned to each datum was controlled by an error CV. For the biomass indices, two alternative sets of CVs were available (see Table 8). The total CVs represent the best estimates of the uncertainty associated with these data, and were used in all initial model runs. The CVs for the acoustic indices were calculated using a simulation procedure intended to include all sources of uncertainty (O'Driscoll 2002), and the observation-error CVs 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 CVs were calculated as the sum of an observation-error CV (using the standard formulae for stratified random surveys, e.g., Livingston & Stevens (2002)) and a process-error CV, which was set at 0.2, (following Francis et al. 2001) (note that CVs add as squares:  $CV_{total}^2 = CV_{process}^2 + CV_{observation}^2$ ). In some model runs (see below) it was decided to upweight some trawl biomass indices by using their observation, rather than total, CVs.

For the proportion of fish that migrate to spawn (pspawn) the error distribution was lognormal, for which an arbitrary CV 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 151 (for runs where age-varying natural mortality is estimated) or 129 (where a domed spawning selectivity is used instead) (Table 12). Most of the associated prior distributions were intended to be uninformative; the main exceptions were those for the catchabilities (O'Driscoll et al. 2002), the proportion of the initial stock that is in the east stock (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 12: Parameters estimated in the final model runs, and their associated prior distributions. Where the number of parameters varied between model runs, the two values given are for runs where natural mortality is estimated or domed spawning selectivity is used instead (see Section 2.2 for an explanation of these model runs). Distribution parameters are: bounds for uniform and uniform-log; mean (in natural space) and CV 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	74
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	$M_{\text{male}}$ and $M_{\text{female}}$ ages 1–17	uniform	various		8,0
natural_mortality.all	$M$	lognormal	0.298	0.153	0,1
process error CVs		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	Epsl,Wspsl,Enpsl,Wnpsl	uniform	various		8,9
surv. selectivities	CRsl, SASl	uniform	various		6
					151,129

<sup>a</sup> A lower bound of 13 was used for run 1.17

<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 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.

For the 2003 assessment update a uniform prior was used for the proportion of the initial stock that is in the east stock (pE). However in the update this gave implausibly high values for pE and introduced other problems for the assessment (Francis 2004). For this reason an informed prior was introduced for the 2003 assessment and has been used since, and is used in this assessment. A sensitivity MCMC model run indicates that recent stock assessments are insensitive to the prior (Appendix 3).

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 specified in 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 some sensitivity model runs are done 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). However, 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 run which is sexed with an 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).

Three sets of initial exploratory runs were done: (1) incorporating the new data and comparing model fits to the 2012 assessment (2) investigating whether or not to upweight the trawl surveys to improve the fit to the biomass indices, and (3) a series of sensitivity runs with the observational data.

For the 2012 hoki stock assessment there were five final model runs taken through to the MCMC stage, of which one was the base case and the other four sensitivity runs (McKenzie 2013). The initial set of MPD runs for the 2013 hoki stock assessment include these, with some new sensitivity runs (Table 14). Note that Espage for 2011 and 2012 is excluded from initial model runs, except in a sensitivity model run.

The first 2013 MPD runs using all the new observations were labelled 1.1, 1.2, and 1.3. The short-hand descriptions for these model runs are “estimate age-varying M”, “domed spawning selectivity”, and “no natal fidelity”, respectively. The function of these model runs is to determine weights for the at-age data in the reweighting procedure. In the next set of the runs 1.4, 1.5, and 1.6 the at-age data is reweighted and a multinomial distribution used for the error function (as was the case for all final runs in the 2012 assessment). The reweighting results are summarised in Appendix 5. Calculated sample sizes are used in subsequent sensitivity analyses on these runs.

In the next three set of sensitivity runs the trawl surveys are not upweighted. Run 1.7 is the same as run 1.4 (i.e., with age-varying M), except the trawl surveys are not upweighted. The other two sensitivity runs differ from run 1.4 in that two catchabilities are fitted for the SAsumbio series instead of one, with no up-weighting of the trawl surveys. In run 1.8 the catchability from 2004 to 2007 inclusive is estimated separately from the other years in the series, whereas for run 1.9 the catchability from 2008 to 2013 inclusive is estimated separately.

A set of sensitivity tests are done on the model runs 1.4 (“estimate age-varying M”) and 1.8 (“04–07q different”) (Table 15). The first involves including the Cook Strait 2011 and 2012 spawning catch at age (Espage), the second removing the Southern Plateau non-spawning catch at age (Wnspage) from 2005 onwards, and the last halving the CVs. for the west coast South Island spawning acoustic index (WCacous).

### **3.1 Comparison to last year’s base model 1.3**

Retaining just the upweighted model run 1.4, the biomass trajectory is compared to the comparable model runs from last year’s assessment (Table 16, Figure 5). For the new assessment model runs, the eastern and western virgin biomasses and %B<sub>0</sub> in 2012 are estimated to be very similar to those from the 2012 assessment.

The year class strengths are very similar between assessments (Figure 6). Other graphs show selectivities, migration ogives, and fitted age-varying natural mortality, and are also very similar between assessments (Figures 7–9).

### **3.2 Other MPD results: trawl upweighting and data sensitivity analyses**

In run 1.4 the trawl surveys are upweighted, unlike the sensitivity run 1.7. Upweighting improves the fit for the last four years of CRsumbio, and about half the years up to 2007 for SAsumbio (Table 17, Figures 10–12). There is very little difference regarding the fits to the other biomass data sets SAautbio, CSacous, and WCacous.

There is some evidence of a change in catchability for SAsumbio (Figure 13). Run 1.4 uses a single catchability for SAsumbio, whereas runs 1.8 and 1.9 use two. Using two catchabilities improves the fit to SAsumbio, with the catchability for 2004–2007 estimated to be half the other years, or for 2008–2013 about 60% more (Figure 14, Tables 18–19). Biomass trajectories change, particularly for current biomass for run 1.8 (Figure 15).

The next three set of sensitivity analyses are conducted on both model runs 1.4 and 1.8 (Table 15). They make little difference to the biomass trajectories (Figures 16–18). Including Espage for 2011 and 2012 decreases the estimate of the east stock 2009 YCS (Figure 19); removing Wnspage from 2005 onward has very little impact on YCS estimates (Figure 20). Removing Wnspage from 2005 onwards changes slightly the associated selectivity Wnspsl (Figures 21–22). Halving the CVs for WCacous improves the fit to them minimally (Figures 23–24).

Current biomass for east and west stock are summarised for all model runs in Table 20.

**Table 13: Final model runs for the 2012 hoki stock assessment. The base model run was 1.3, the other model runs are sensitivity runs. For all model runs the at-age data was reweighted.**

Run	Response to lack of old fish in the observations	Two catchabilities for SAsumbio?	Trawl surveys up-weighted?	Natal fidelity?
1.3	M dependent on age	N	Y	Y
1.8	M dependent on age	08–12 q different	N	Y
1.9	M dependent on age	04–07q different	N	Y
1.4	Domed spawning selectivity	N	Y	Y
1.11	M dependent on age	N	Y	N

**Table 14: Comparison of initial MPD runs for the 2013 hoki stock assessment. Aspects of a model run that distinguish it from earlier runs are shown in bold italics.**

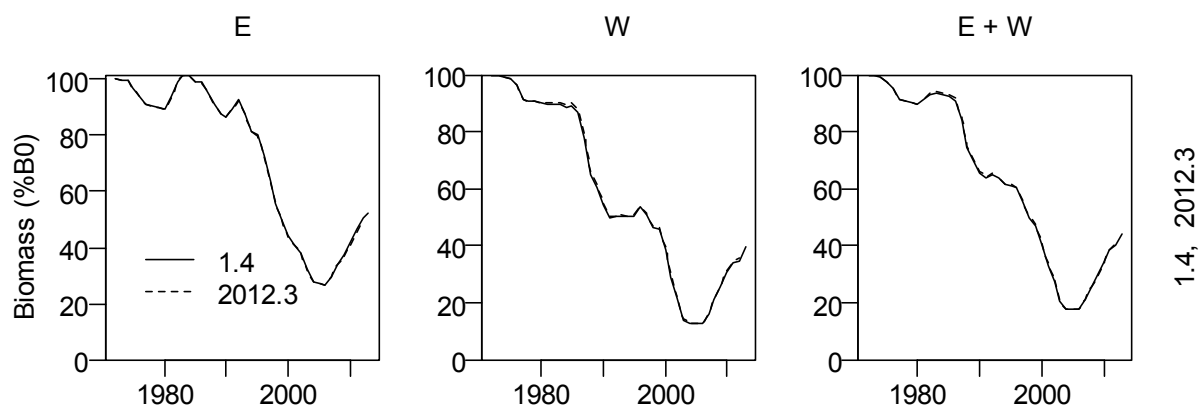
Run	Response to lack of old fish in the observations	Two catchabilities for SAsumbio?	Trawl surveys up-weighted?	Natal fidelity?	At-age reweighted?
1.1	M dependent on age	N	Y	Y	N
1.2	Domed spawning selectivity	N	Y	Y	N
1.3	M dependent on age	N	Y	N	N
1.4	M dependent on age	N	Y	Y	<b>Y</b>
1.5	Domed spawning selectivity	N	Y	Y	<b>Y</b>
1.6	M dependent on age	N	Y	N	<b>Y</b>
1.7	M dependent on age	N	N	Y	Y
1.8	M dependent on age	<b>04–07q different</b>	N	Y	Y
1.9	M dependent on age	<b>08–13q different</b>	N	Y	Y

**Table 15: Model run labelling for a set of three sensitivity runs to the runs 1.4 and 1.8.**

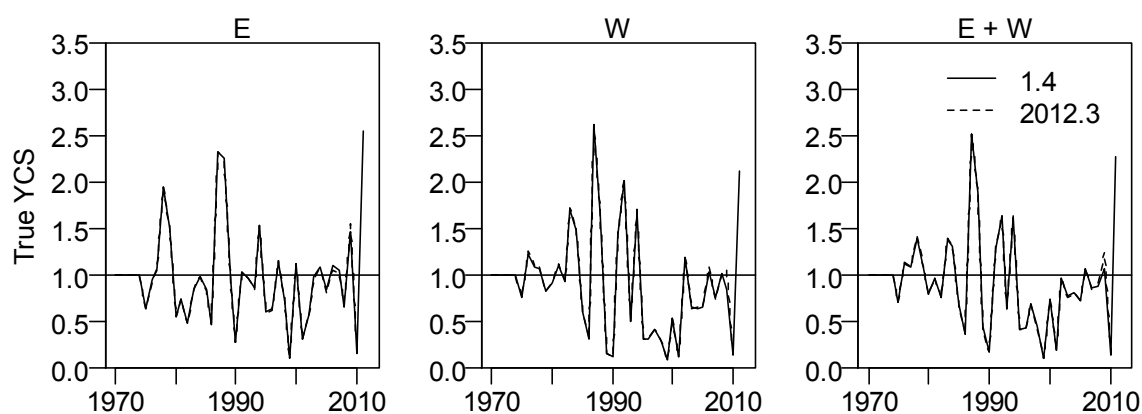
	Initial run	
Sensitivity	1.4	1.8
Include Espage 2011 and 2012	1.10	1.13
Remove Wnspage 2005 onwards	1.11	1.14
Halve WCacous CVs.	1.12	1.15

**Table 16: Comparison of old and new biomass estimates for the individual stocks, E and W, and the combined E + W stock. Model run 1.3 was the base case for the 2012 assessment.**

Assessment year	Run	B <sub>0</sub> (‘000 t)			B <sub>2012</sub> (%B <sub>0</sub> )			B <sub>2013</sub> (%B <sub>0</sub> )		
		E	W	E+W	E	W	E+W	E	W	E+W
2012	1.3	428	759	1187	50	36	41	–	–	–
2013	1.4	421	763	1184	51	35	40	52	40	44



**Figure 5: Comparison of biomass trajectories from different runs: E stock (left column), W stock (middle column), and E + W stocks combined (right column). The graphs compare each new run (solid lines) with the corresponding run from 2012 (broken lines). The label 2012.3 refers to run 1.3 from 2012.**



**Figure 6: True YCS estimates for new run 1.4 (solid lines) compared to the comparable run from last year's assessment. The label 2012.3 denotes run 1.3 from the 2012 assessment.**

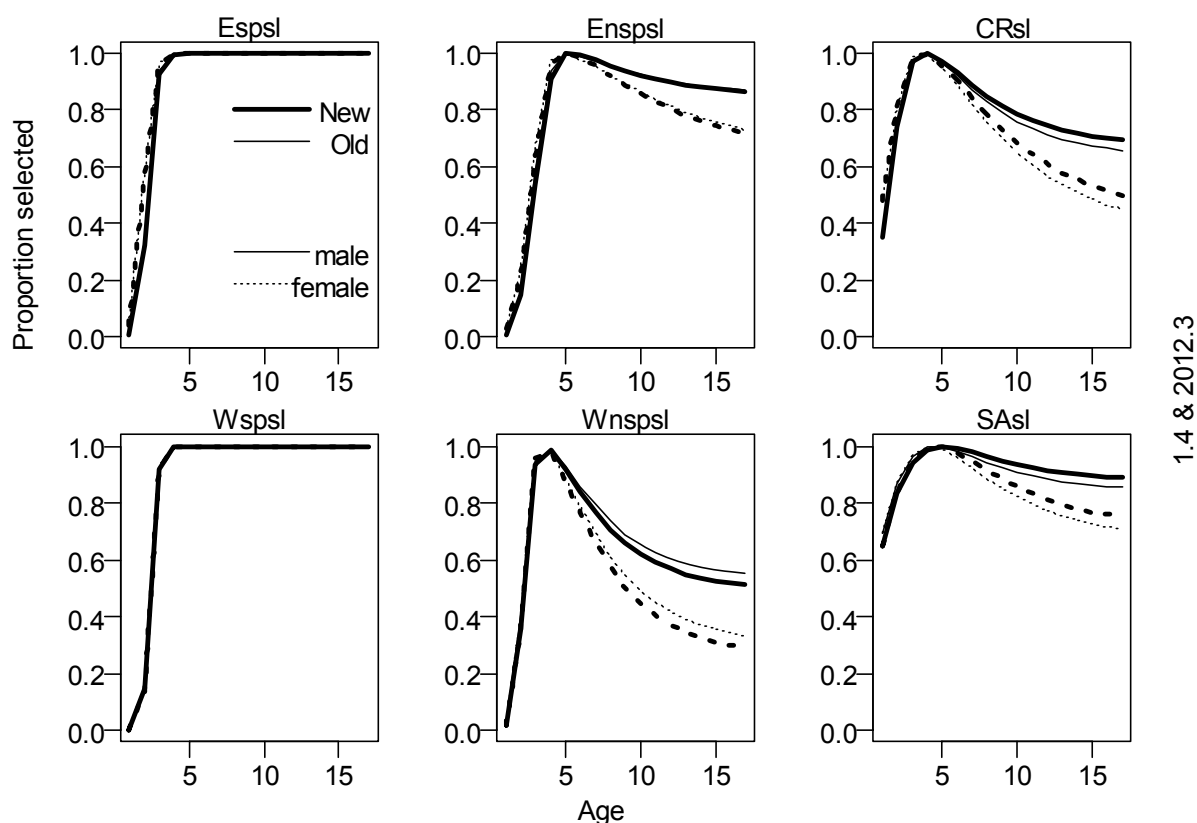


Figure 7: Estimated selectivity curves for new model run (heavy lines) and analogous 2012 run (light lines). Males are shown by a solid line, females by a dotted line. The label 2012.3 denotes run 1.3 for the 2012 assessment.

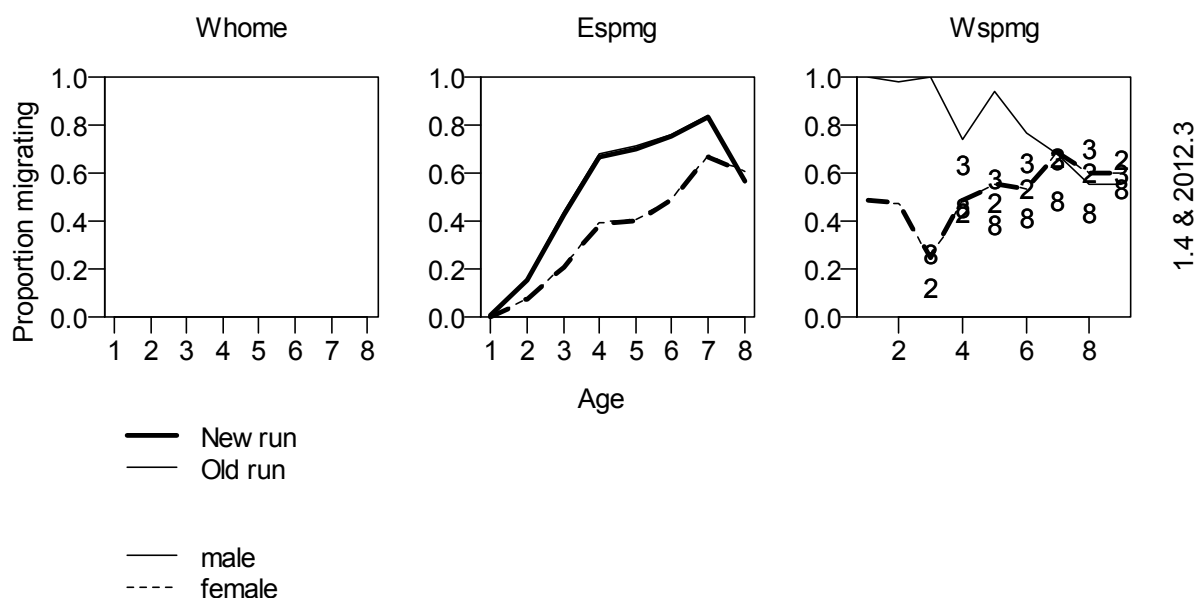
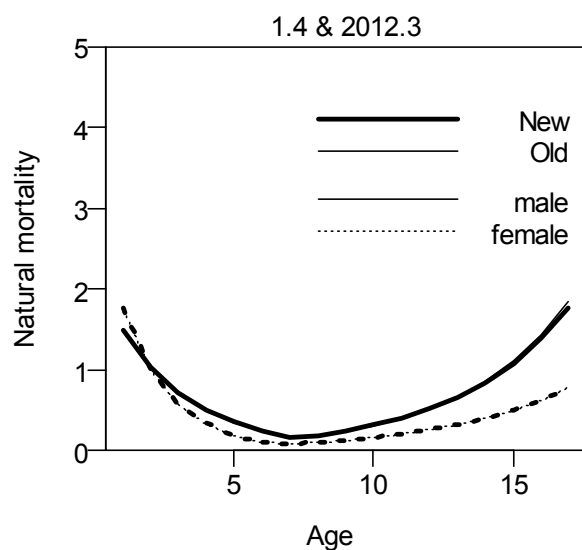


Figure 8: Estimated migration ogives for new and old runs. Each row of plots compares ogives from a new run (heavy lines) with those from the analogous 2012 runs (light lines). Where ogives differ by sex, female ogives are plotted as broken lines. The observations pspawn are also plotted in the rightmost panel, with the plotting symbol identifying the year of sampling ('2' = 1992, '3' = 1993, '8' = 1998). The label 2012.3 denotes run 1.3 for the 2012 assessment.

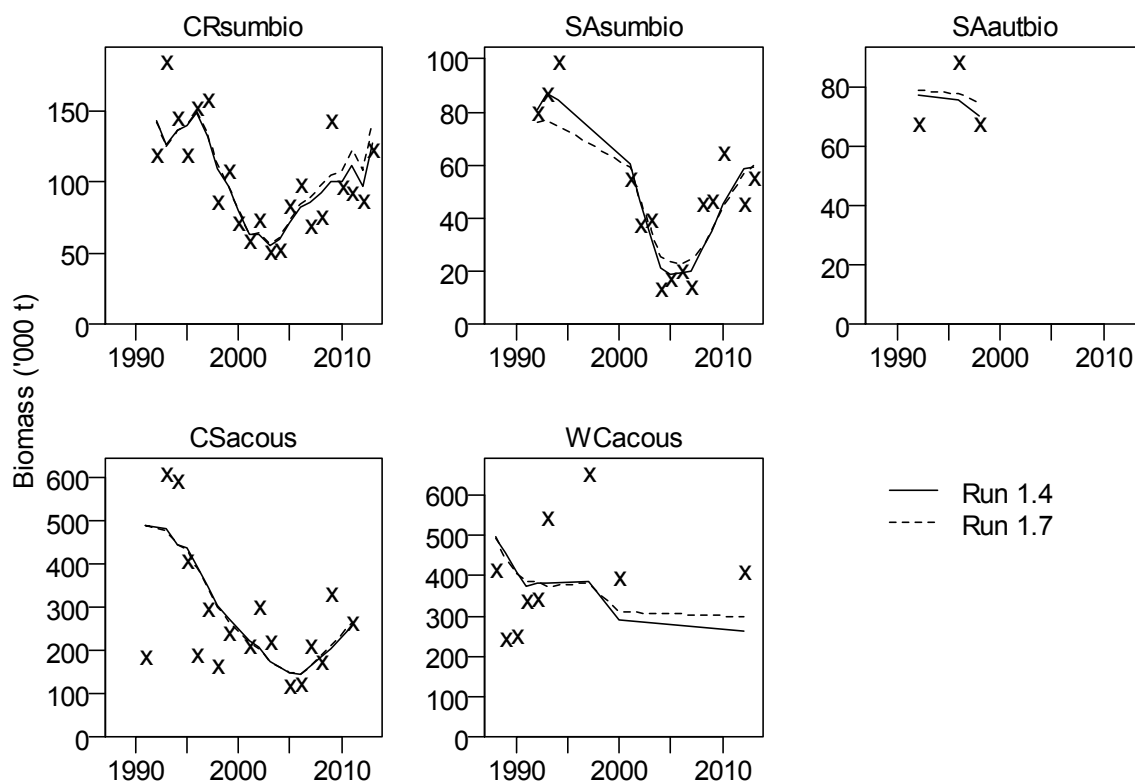


**Figure 9: Comparison between age-dependent natural mortality estimated in the new run (heavy lines) and the corresponding run from 2012 (light lines). The label 2012.3 denotes run 1.3 for the 2012 assessment.**

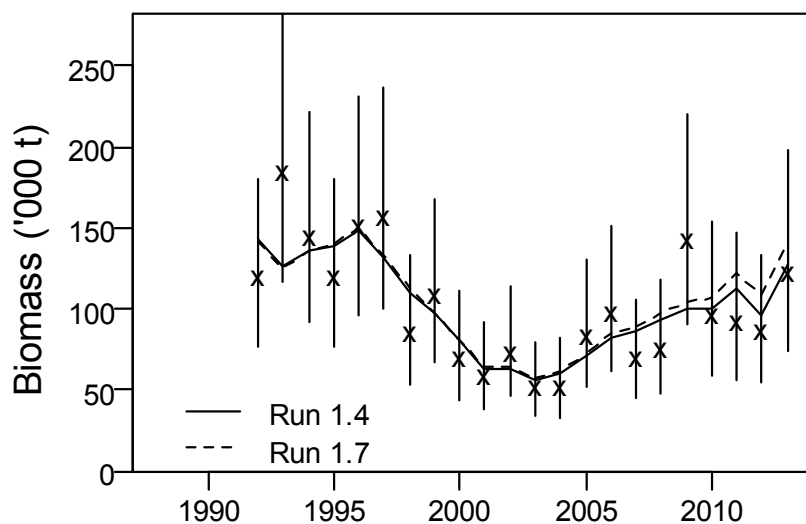
**Table 17: Goodness of fit to biomass indices as measured by SDNR (standard deviation of the normalised residuals) for some new model runs. For this table the normalised residuals were calculated using the original CVs (i.e., ignoring changes in CVs. for upweighting trawl biomass data sets).**

Run	CRsumbio	SAsumbio	SAautbio	CSacous	WCacous
1.4	0.81	1.05	0.69	0.94	0.98
1.7	0.86	1.31	0.7	0.94	0.94





**Figure 10: Fit to biomass indices for runs 1.4 and 1.7 showing observed ('x') and expected values (lines). In model run 1.4 the trawl survey indices are upweighted, for 1.7 they are not.**



**Figure 11: Fits to CRsumbio for runs 1.4 and 1.7, 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 2013). The trawl survey indices are upweighted (solid lines) or not upweighted (dashed lines).**

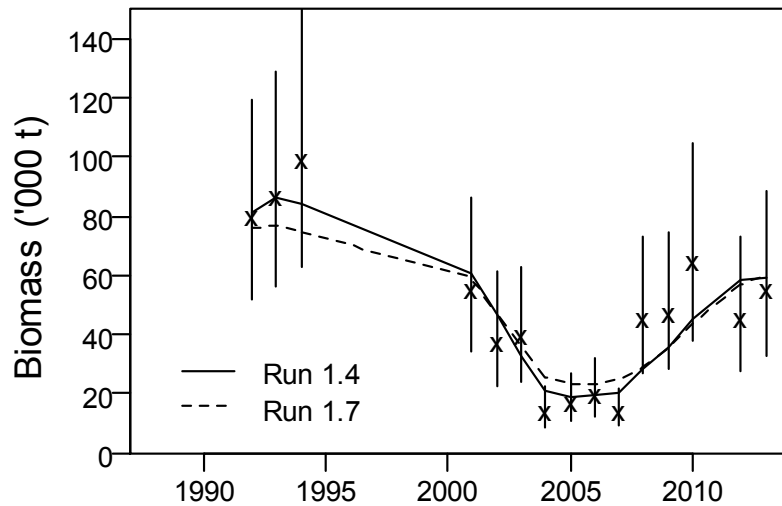


Figure 12: Fits to SAsumbio for runs 1.4 and 1.7, showing observed ('x', with vertical lines showing 95% confidence intervals) and expected values (lines). Plotted years are as in the model (so the last survey is plotted at 2013). The trawl survey indices are upweighted (solid lines), and non upweighted (dashed lines).

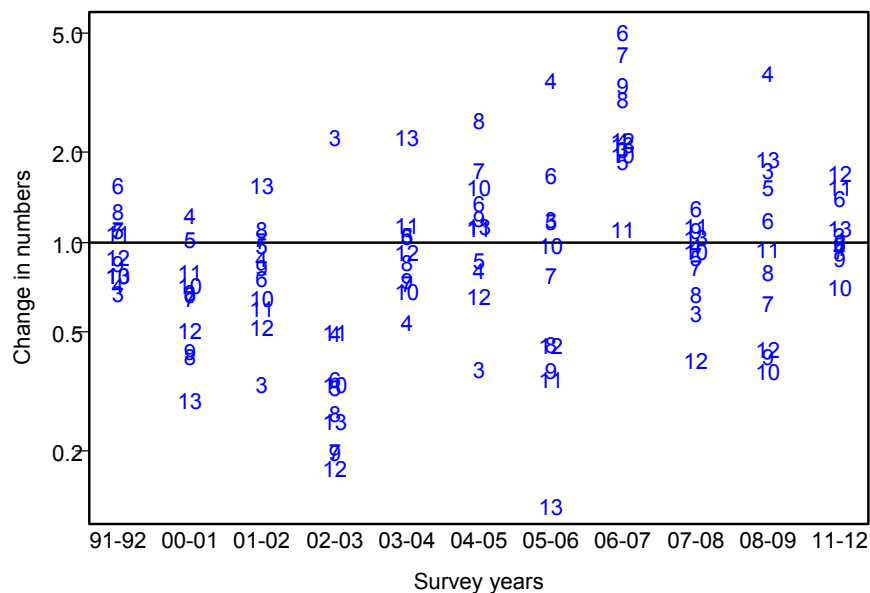
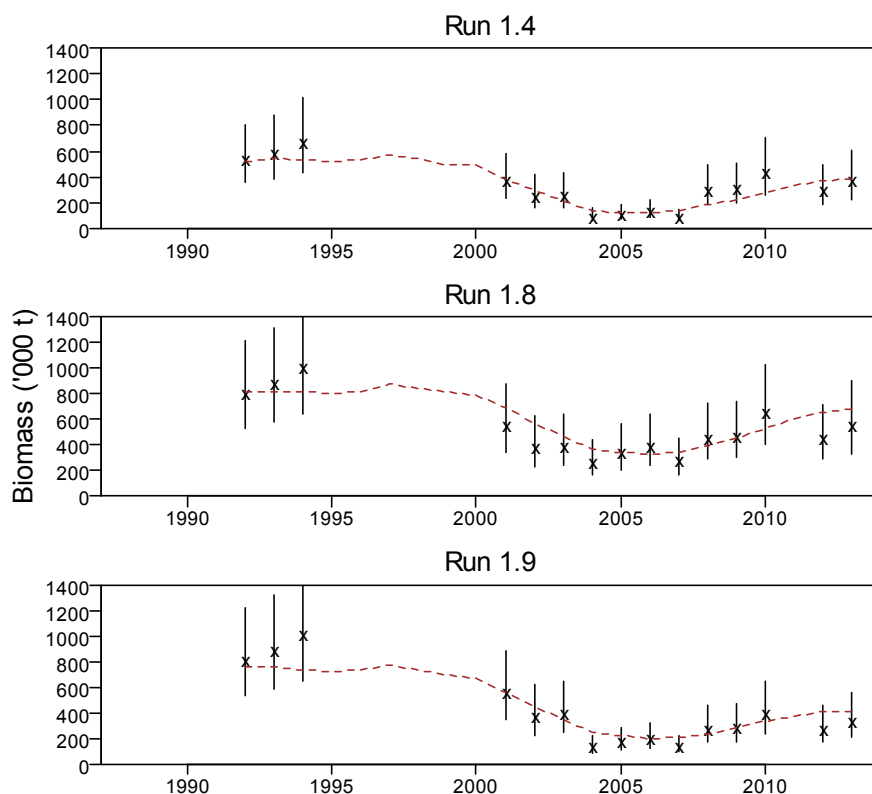


Figure 13: Changes, between surveys one year apart in the Southern Plateau summer series, in estimated numbers of selected cohorts. Each plotted point indicates how the estimated number in a cohort changed between the two surveys; the plotting symbol is the age of the cohort in the earlier survey. For example, for the 06–07 survey years, the estimated number in the cohort that was aged 6 in the 2006 survey increased by a factor of about five in the 2007 survey. Note that the 2006 Southern Plateau summer survey year is in the 2007 fishing year.



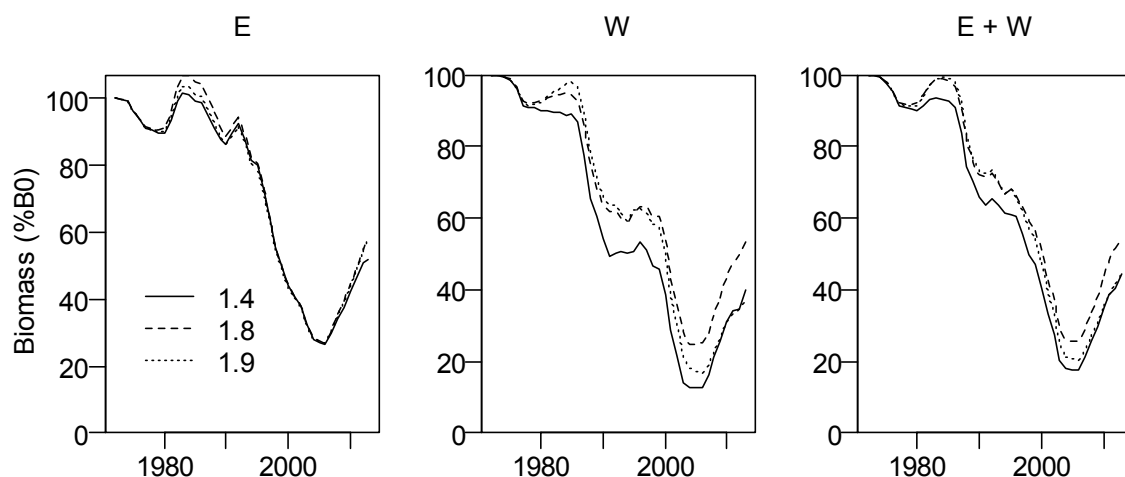
**Figure 14: Fits to SAsumbio for runs 1.4, 1.8, and 1.9 showing observed biomass scaled to absolute biomass by dividing the former by catchability ('x', with vertical lines showing 95% confidence intervals) and expected values (dashed lines). Plotted years are as in the model (so the last survey is plotted at 2013). The trawl survey indices are upweighted for model run 1.4, but not for model runs 1.8 and 1.9. In run 1.8 the years 2004–2007 inclusive have a separate catchability from other years; for run 1.9 the years 2008–2013 inclusive have a separate catchability from other years.**

**Table 18: Estimated catchability for selected model runs.**

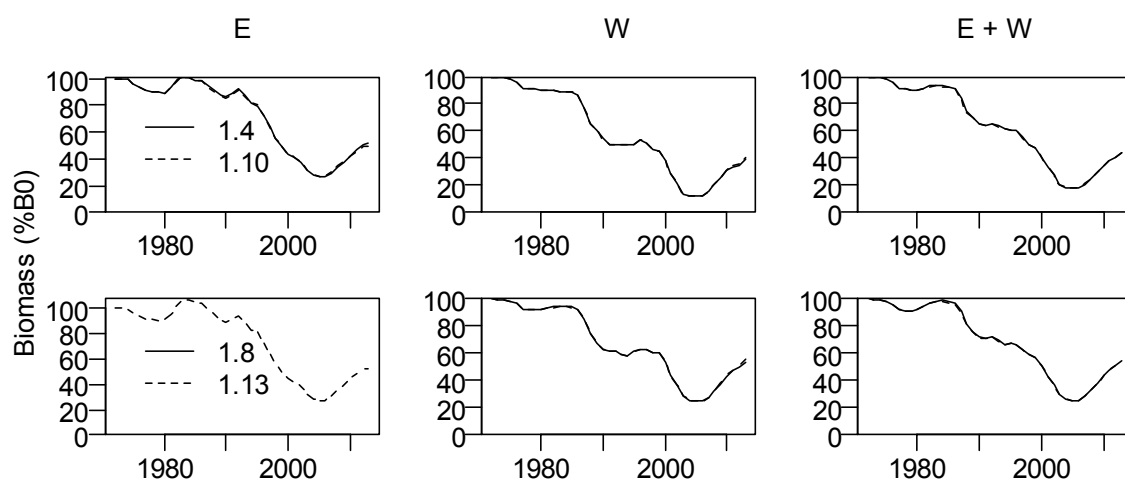
Run	Catchability		
	1992–2003	2004–07	2008–13
1.4	0.16	0.16	0.16
1.8	0.10	0.05	0.10
1.9	0.10	0.10	0.16

**Table 19: Objective function values for selected model runs.**

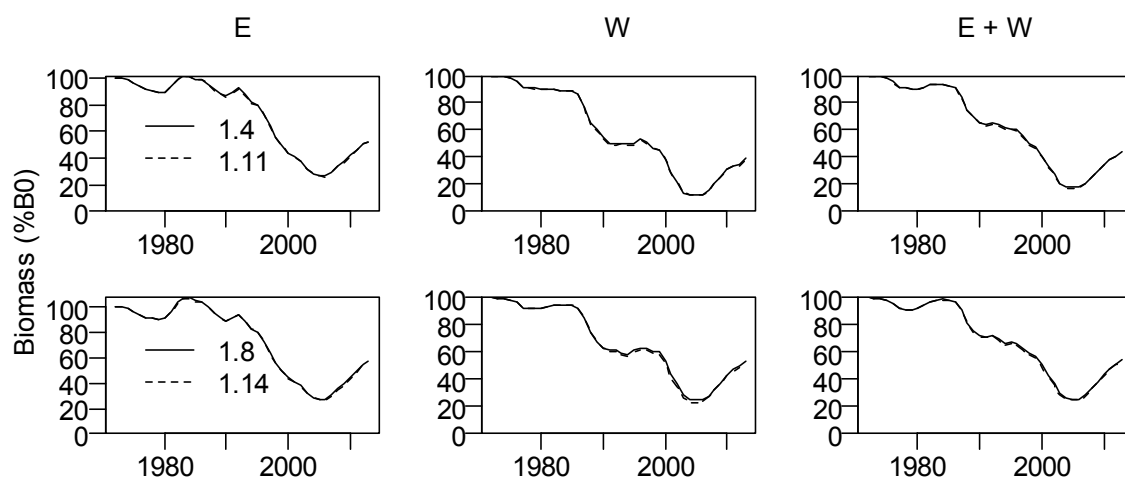
Run	age-varying M	Trawl surveys upweighted?	Objective function	
			SAsumbio	Total
1.4	age-varying M	Y	-7.2	2459.7
1.7	age-varying M	N	-9.7	2436.1
1.8	04-07q different	N	-16.6	2425.1
1.9	08-13q different	N	-14.2	2430.2



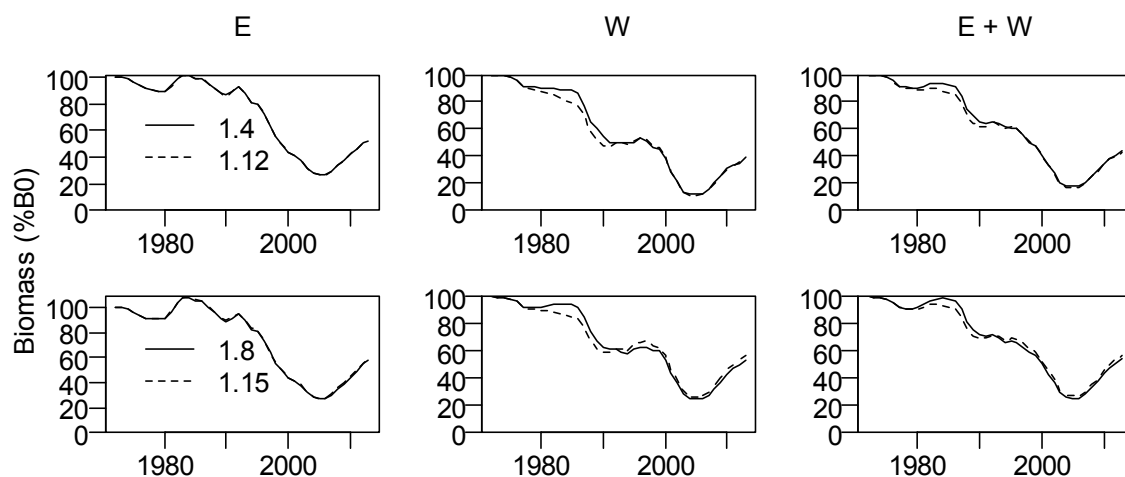
**Figure 15: Comparison of biomass trajectories from runs 1.4, 1.8, and 1.9: E stock (left column), W stock (middle column), and E + W stocks combined (right column).**



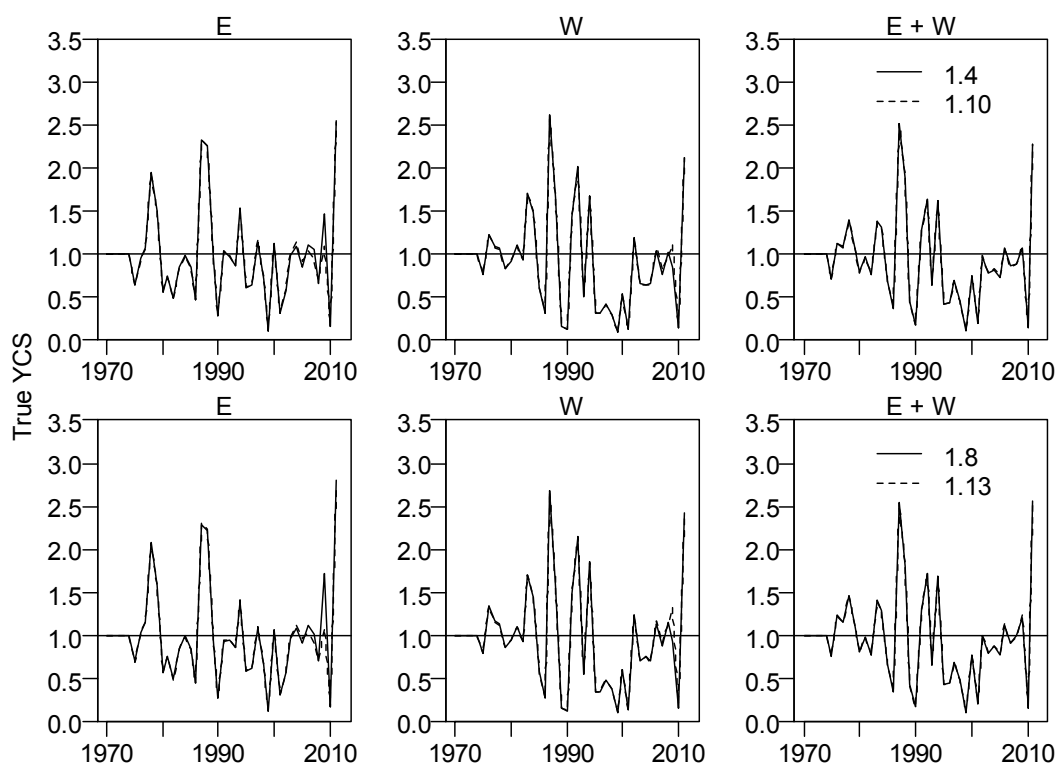
**Figure 16: Comparison of biomass trajectories from runs (1.4, 1.10) and (1.8, 1.13): E stock (left column), W stock (middle column), and E + W stocks combined (right column).**



**Figure 17: Comparison of biomass trajectories from runs (1.4, 1.11) and (1.8, 1.14): E stock (left column), W stock (middle column), and E + W stocks combined (right column).**



**Figure 18: Comparison of biomass trajectories from runs (1.4, 1.12) and (1.8, 1.15): E stock (left column), W stock (middle column), and E + W stocks combined (right column).**



**Figure 19: True YCS estimates excluding Espage for 2011 and 2012 (solid line) or including it (dashed line).**

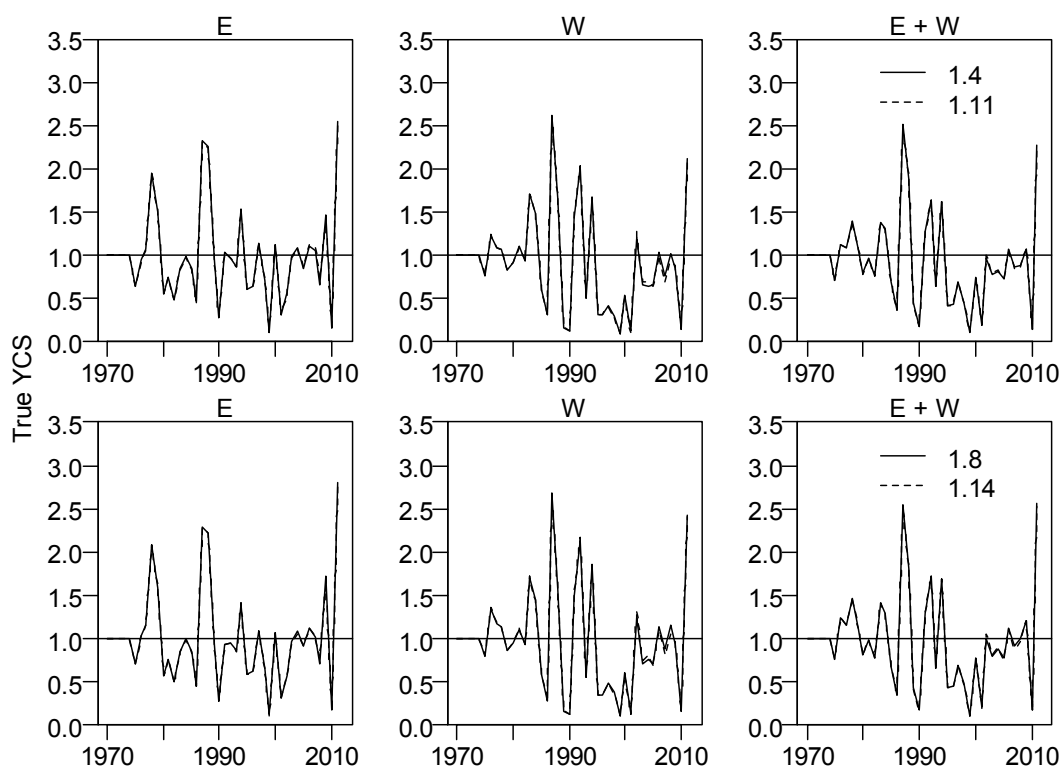


Figure 20: True YCS estimates including Wnspage from 2005 onward (solid line) or excluding them (dashed line).

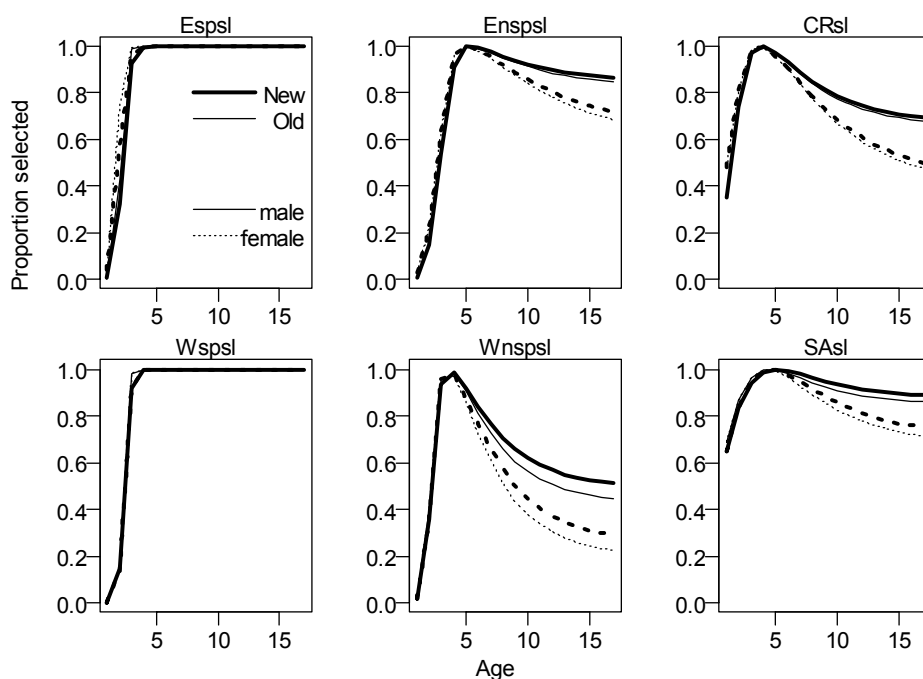
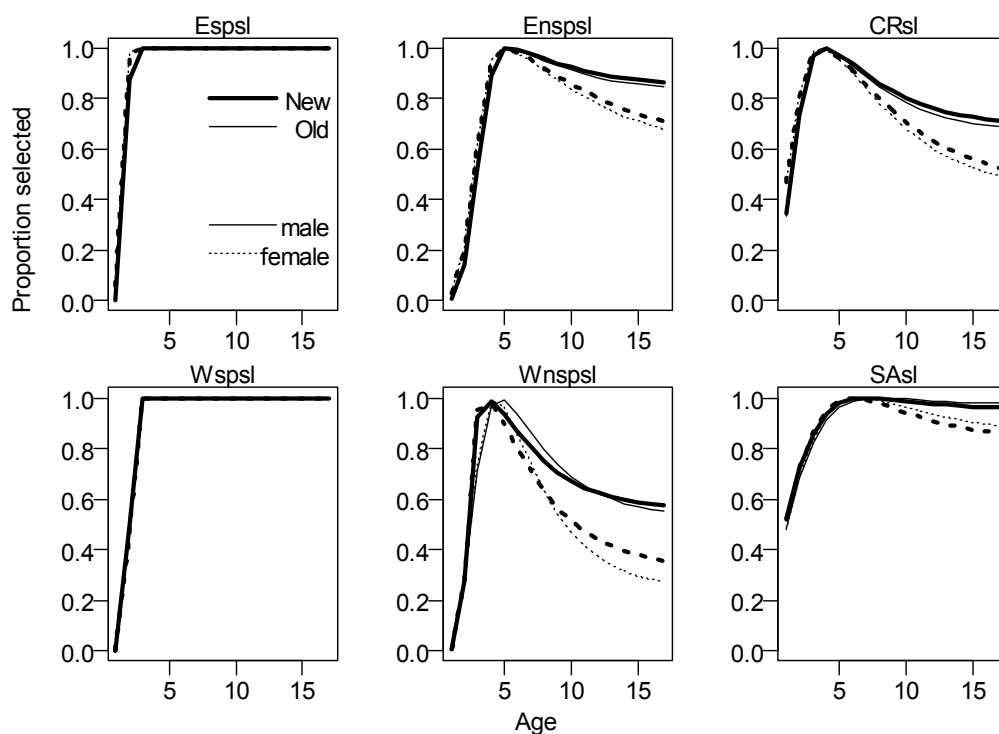
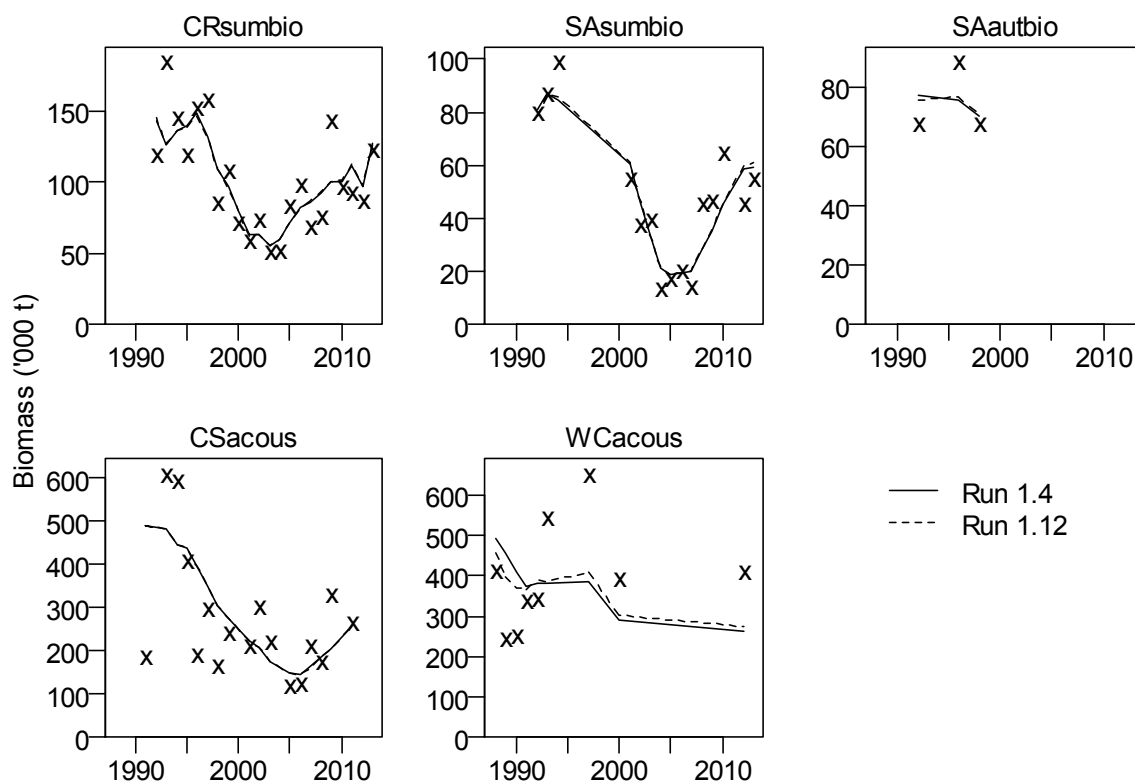


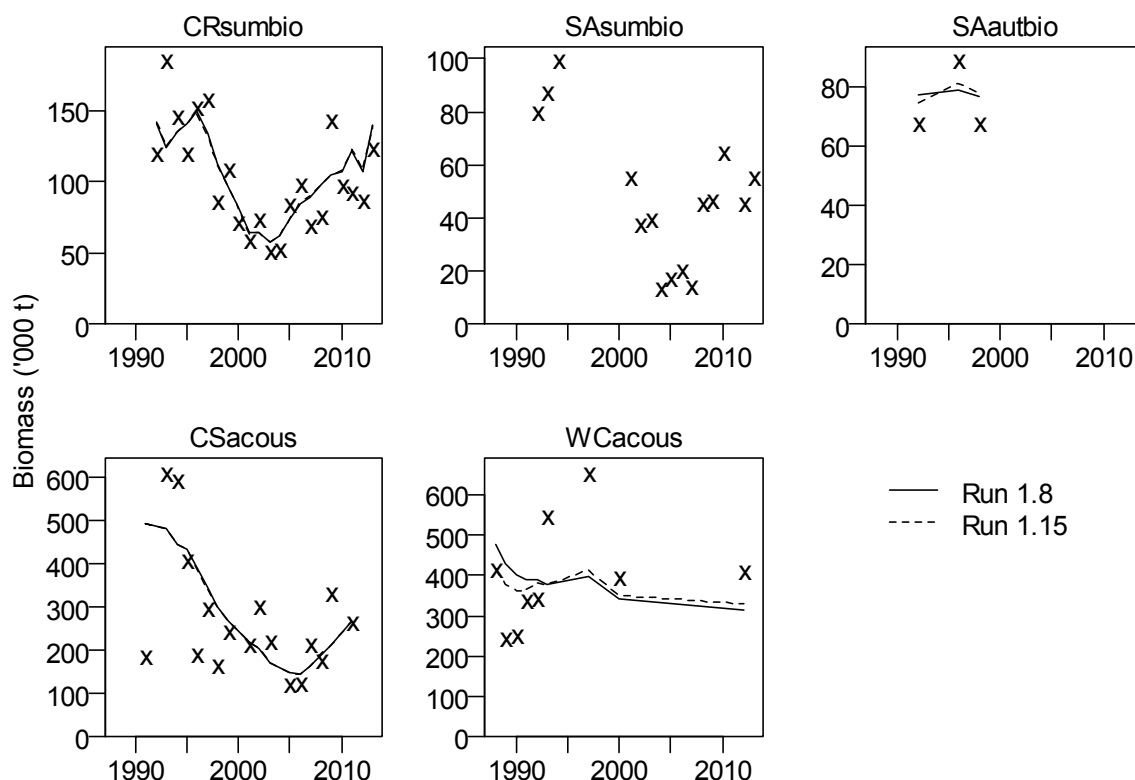
Figure 21: Estimated selectivities: 1.4 (heavy lines), 1.11 (light lines). Males are shown by a solid line, females by a dotted line.



**Figure 22: Estimated selectivities. 1.8 (heavy line), 1.14 (light line). Males are shown by a solid line, females by a dotted line.**



**Figure 23: Fits to biomass indices for model runs 1.4 and 1.12.**



**Figure 24: Fits to biomass indices for model runs 1.8 and 1.15.**

**Table 20: Comparison of current biomass for all initial model runs.**

Run	$B_{\text{current}} (\%B_0)$	
	E	W
1.4	52	40
1.5	44	52
1.6	43	57
1.7	56	47
1.8	57	53
1.9	58	37
1.10	49	41
1.11	52	38
1.12	52	38
1.13	52	56
1.14	57	51
1.15	58	57

#### 4. FINAL MODEL ASSESSMENT RESULTS

It was decided by the Hoki Plenary to take seven runs through to the MCMC stage, with three of these final model runs and the other four sensitivity runs (Table 21). An additional run (1.4) was taken to the MCMC stage as a continuity run with the base model run from the last assessment. In all of these model runs the at-age data is reweighted. Only in the continuity run are the trawl surveys upweighted.



In the 2008 assessment the model was unable to fit the threefold increase in estimated biomass between the 2007 and 2008 surveys in the summer Southern Plateau series (see SAsumbio in Table 8). This biomass increase was sustained in the four subsequent surveys (2009, 2010, 2012 and 2013). Furthermore, the SAsumbio data shows large annual changes in numbers-at-age which cannot be explained by changes in abundance, and are suggestive of a change in catchability for the survey. Because of this, and to improve the fit to the SAsumbio series, two model runs were done where it was assumed that the catchability has changed over time. In run 1.16, the catchability for 2004–2007 inclusive is estimated separately from the other years in the series, whereas for run 1.19 the catchability from 2008–2013 inclusive is estimated separately.

In some sensitivity model runs, natal fidelity was not assumed (i.e., 1.18, 1.21), in contrast to the other model runs.

**Table 21: Distinguishing characteristics for all model runs taken to MCMC, with the three final runs marked with an asterisk. Aspects of a model run that distinguish it from other runs are shown in *bold italics*. Run 1.4 is a continuity run with the same structure as the base case from the last assessment; 1.7 differs from 1.4 in that the trawl survey indices are not upweighted. Run 1.16 is a final run with sensitivity runs 1.17 and 1.18. Run 1.19 is a final run with sensitivity runs 1.20 and 1.21.**

Label	Two catchabilities for SAsumbio?	Response to lack of old fish in the observations	Trawl surveys up-weighted?	Sex in model and selectivities length-	Natal fidelity?
1.4	No	M dependent on age	Yes	Yes	Yes
1.7*	No	M dependent on age	No	Yes	Yes
1.16*	04–07q different	M dependent on age	No	Yes	Yes
1.17	04–07q different	<i><b>Domed spawning selectivity</b></i>	No	<i><b>No</b></i>	Yes
1.18	04–07q different	M dependent on age	No	Yes	<i><b>No</b></i>
1.19*	08–13q different	M dependent on age	No	Yes	Yes
1.20	08–13q different	<i><b>Domed spawning selectivity</b></i>	No	<i><b>No</b></i>	Yes
1.21	08–13q different	M dependent on age	No	Yes	<i><b>No</b></i>

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 2012 assessment, 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 (Table 22). Diagnostic plots comparing the three chains for each run suggest reasonably good convergence for all runs (Figure 25). 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 (Table 23). For current spawning biomass the final model runs (1.7, 1.16, 1.19) estimate the eastern stock to be at 50–57%  $B_0$ , and for the western stock 45–65%  $B_0$  (Table 23, Figures 26–27).

For the last assessment there was a single base model run and for it the trawl surveys were upweighted. For this assessment the comparable run is the continuity run 1.4, and comparing the biomass in 2012 between the two runs shows little difference (Figure 28).

Final model run 1.7 is the same as continuity run 1.4 except that the trawl surveys are not upweighted. This change impacts mostly on the western stock resulting in a higher but more uncertain virgin biomass, and a current biomass (% $B_0$ ) that is higher and also more uncertain (Figure 29). For the western stock the year class strength estimates are slightly different between runs 1.4 and 1.7 from 2004–2008, although estimated with high uncertainty in both cases (Figures 30–31).

For the two time-varying catchability final model runs (1.16, 1.19), using a domed spawning selectivity as a sensitivity gives a current biomass (% $B_0$ ) that is slightly higher for the eastern stock, and more so for the western stock (Figures 32–33). If natal fidelity is not assumed, the current

biomass ( $\%B_0$ ) for the eastern stock is estimated to be lower, but higher for the western stock (Figures 32–33).

All final model runs and their sensitivity runs suggest that the western stock is rebuilding, both in absolute terms and relative to  $B_0$  (Figures 34–40). The eastern stock has also been rebuilding, but with a very slight decline in the last year or two in some runs (Figures 34–40).

All model runs estimate a low YCS in 2010 followed by a high YCS in 2011 (Figures 41–44).

The estimated selectivities for 1.4 and the three final model runs 1.7, 1.16, and 1.19 are very similar (Figures 45–46). As in previous years, the selectivity and migration ogives for the runs assuming age-dependent natural mortality are very different from the runs without this assumption (Figures 47–51). For the no natal fidelity runs the selectivity and migration ogives are similar to the final model runs to which they are sensitivity analyses (Figures 47–51).

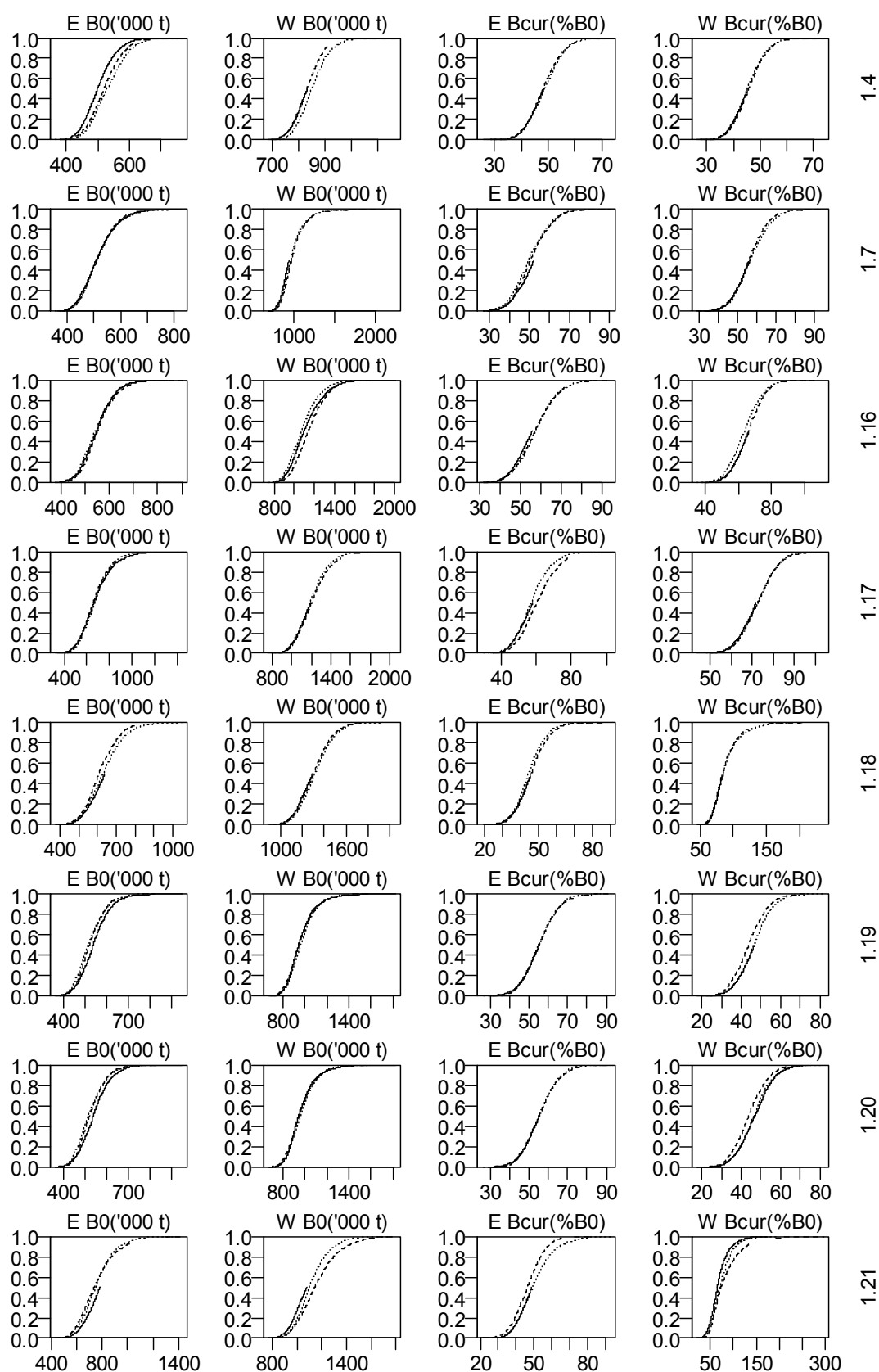
Estimated natural mortality is very similar across the continuity run 1.4 and the three final model runs (1.7, 1.16, 1.19) (Figure 52). With no natal fidelity the estimated natural mortality for young fish is estimated to be higher (Figure 53).

A comparison of priors and posteriors for various parameters showed few changes relative to the previous year's assessment (Figures 54–55). With no natal fidelity the catchability for *SAsumbio* from 2004–2007 is estimated to be much lower than for other model runs (Figure 56), but not when this catchability is estimated separately for 2008–2013 (Figure 57).

Priors and posteriors not associated with the Southern Plateau trawl survey (*SAsumbio*) are similar for runs 1.16 and 1.19 (Figure 58). For *SAsumbio* catchabilities the posteriors are similar across runs 1.16 and 1.19 for 1992 onwards (first row of Figure 59), but differ for the periods 2004–07 and 2008–13 where the catchabilities are estimated separately (second row of Figure 59).

**Table 22: 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 meanings of the other abbreviations, refer to Table 1.**

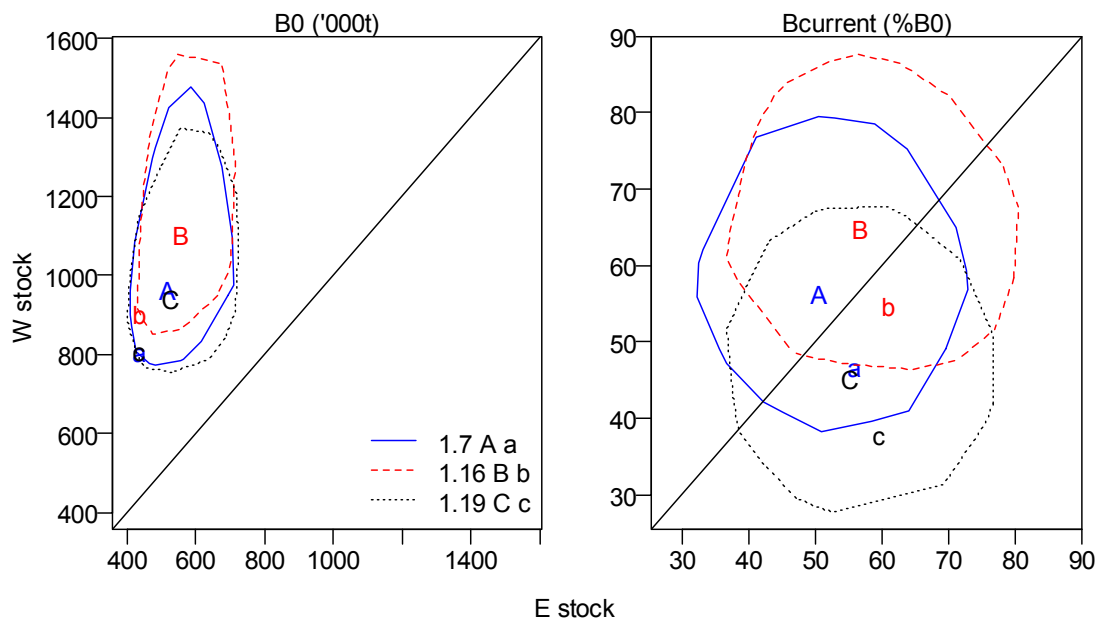
Run	Parameters (fixed values)
1.4	WspmgM1(1), WspmgM3(1), EspmgF1(0), WspmgF8(0.6), Wnpspl.a1(64), CRsl.a1(64), SAsl.sL(44), SAsl.sR(44)
1.7	EspmgF1 (0), EspmgF8 (0.6), WspmgF8 (0.6), Wnpspl.a1(64), Espsl.sL(4), CRsl.a1(64), SAsl.a1(84), SAsl.sL(44), SAsl.sR(44).
1.16	EspmgF1(0), WspmgF8(0.6), Enpspl.sR(44), Wnpspl.a1(64), Espsl.aL(4), CRsl.a1(64), SAsl.a1(84), SAsl.sL(44), SAsl.sR(44)
1.17	Whome6(1), Wnpspl.sR(50), CRsl.a1(1), CRsl.sL(1), SAsl.sR(1)
1.18	Whome2(0.5), Whome7(0), Whome8(0), EspmgF1(0), EspmgF8(0.6), WspmgF8(0.6), Espsl.sL(4), CRsl.a1(64), SAsl.a1(84), SAsl.sR(44)
1.19	WhomeM7(1), EspmgF1(0), EspmgF8(0.6), WspmgF8(0.6), Wnpspl.a1(64), Espsl.sL(4), CRsl.a1(64), SAsl.a1(84), SAsl.sL(44), SAsl.sR(44)
1.20	Whome6(1), Wnpspl.aR(50), CRsl.a1(1), CRsl.sL(1)
1.21	Whome3(0.01), Whome7(0), Whome8(0), EspmgF1(0), EspmgF8(0.6), WspmgF8(0.6), CRsl.a1(64), SAsl.a1(84), SAsl.sR(44)



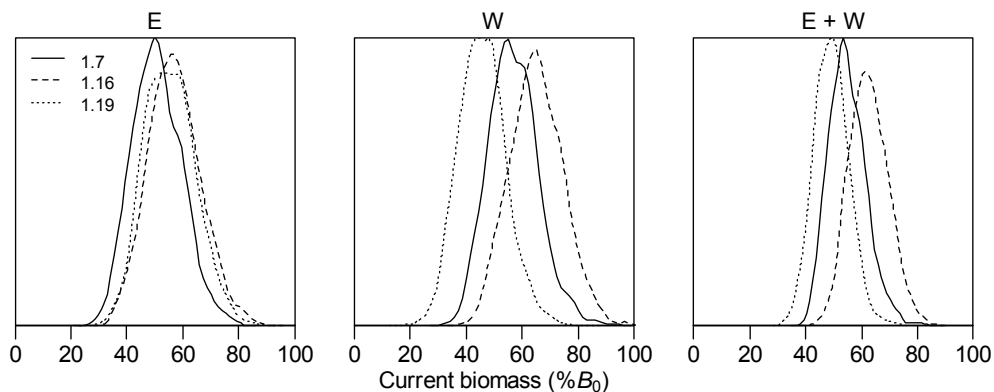
**Figure 25: Diagnostics for MCMC chains for the seven runs: 1.4, 1.7, and 1.16–1.21. Each panel contains cumulative probability distributions, for  $B_0$  or  $B_{\text{current}}$ , for three chains from the same model run.**

**Table 23: Estimates of spawning biomass (medians of marginal posterior, with 95% confidence intervals in parentheses) for the seven runs.  $B_{\text{current}}$  is the biomass in mid-season 2013.**

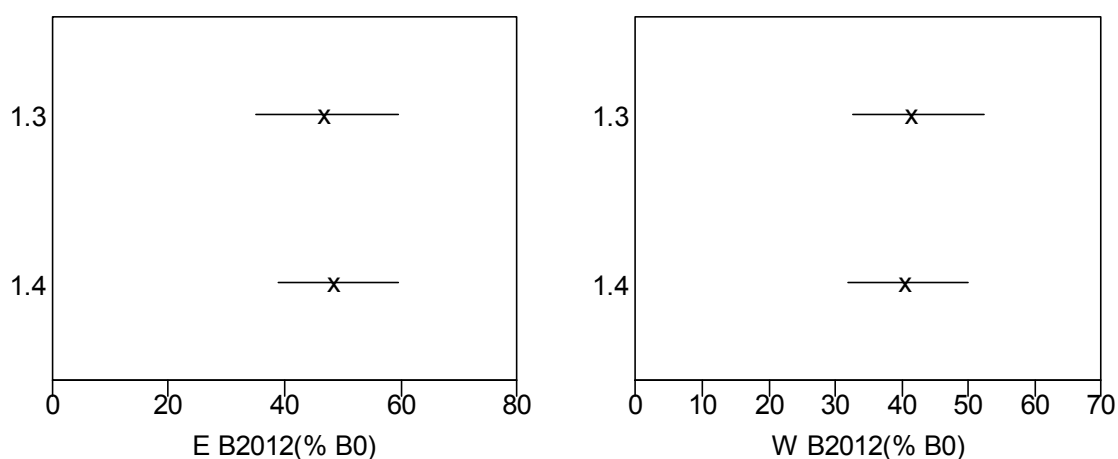
Run	$B_0$ ('000 t)		$B_{\text{current}}$ ('000 t)		$B_{\text{current}}$ (% $B_0$ )		
	E	W	E	W	E	W	E+W
1.4	519(430,635)	838(743,966)	250(179,356)	382(272,529)	48(37,61)	45(35,58)	47(40,55)
1.7*	518(421,672)	967(791,1346)	263(164,389)	550(339,967)	50(36,69)	56(41,77)	54(44,70)
1.16*	553(445,696)	1105(871,1485)	313(198,473)	721(446,1163)	57(40,76)	65(48,84)	62(50,76)
1.19*	525(417,693)	945(778,1286)	288(180,436)	434(257,757)	55(39,74)	45(31,63)	49(37,62)
1.17	675(465,1007)	1203(933,1601)	395(232,668)	871(578,1302)	58(41,81)	73(57,91)	68(55,81)
1.18	627(465,838)	1314(1056,1621)	277(161,468)	1128(707,2126)	44(30,64)	85(62,150)	72(56,118)
1.20	651(453,996)	1079(840,1440)	398(236,671)	603(352,956)	60(42,83)	55(39,75)	58(45,71)
1.21	768(558,1122)	1106(894,1487)	368(207,636)	780(396,1833)	48(33,69)	70(41,146)	62(43,108)



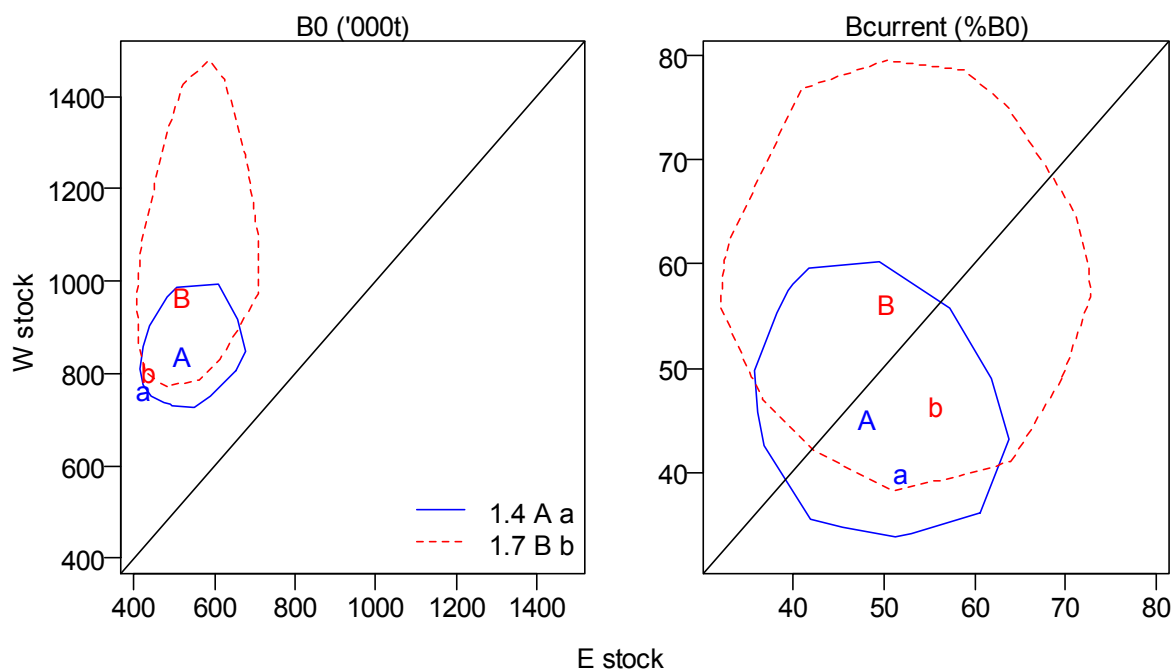
**Figure 26: Estimates and approximate 95% confidence intervals for virgin ( $B_0$ ) and current ( $B_{\text{current}}$  as % $B_0$ ) biomass by stock for the three final runs 1.7, 1.16, and 1.19. In each panel the points 'A' and 'B' indicate best estimates (median of the posterior distribution) for these three runs, 'a' and 'b' are the MPD estimates, and the polygons (with solid, broken and dotted lines, respectively) enclose approximate 95% confidence intervals. Diagonal lines indicate equality ( $y = x$ ).**



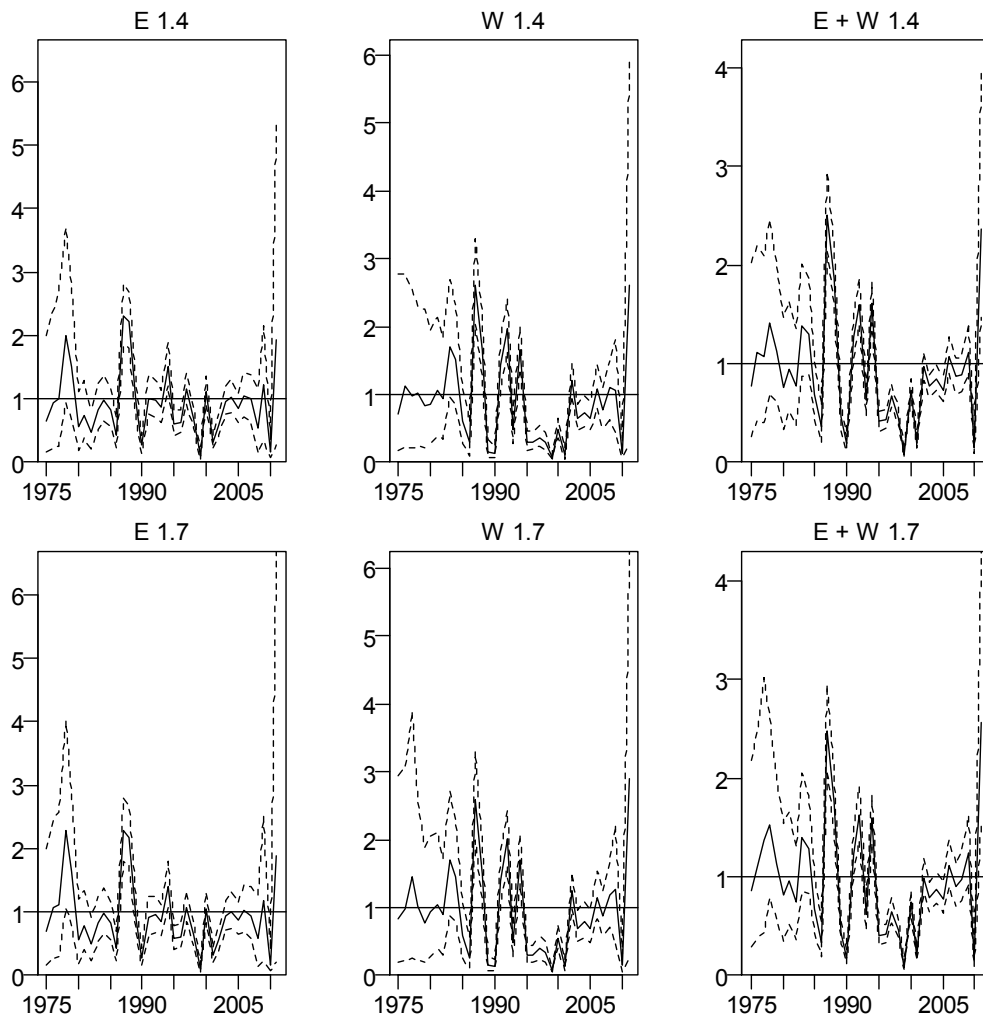
**Figure 27: Estimated posterior distributions of current (spawning) biomass ( $B_{2012-13}$ ), expressed as % $B_0$ , for the E (left panel), W (middle panel) and E + W stocks (right panel) from the three final model runs (1.7, 1.16, 1.19).**



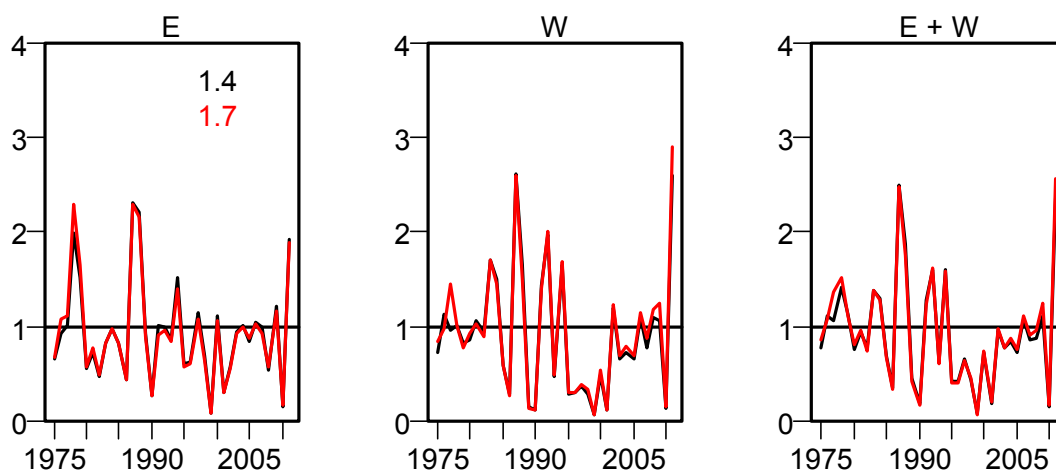
**Figure 28: Comparison of 2013 continuity run (1.4) with the comparable run from 2012 (1.3): estimates of stock status in 2012 ( $B_{2012}$  as  $\%B_0$ ), with 95% confidence intervals shown as horizontal lines.**



**Figure 29: As for Figure 26 but for the continuity run 1.4 and final model run 1.7.**



**Figure 30: Estimated year-class strengths (YCSs) from the runs 1.4 and 1.7 showing medians (solid lines) and 95% confidence intervals (broken lines) by run for E (left panels), W (middle panels) and E + W (right panels).**



**Figure 31: Estimated median year-class strengths (YCSs) from the runs 1.4 (black lines) and 1.7 (red lines).**

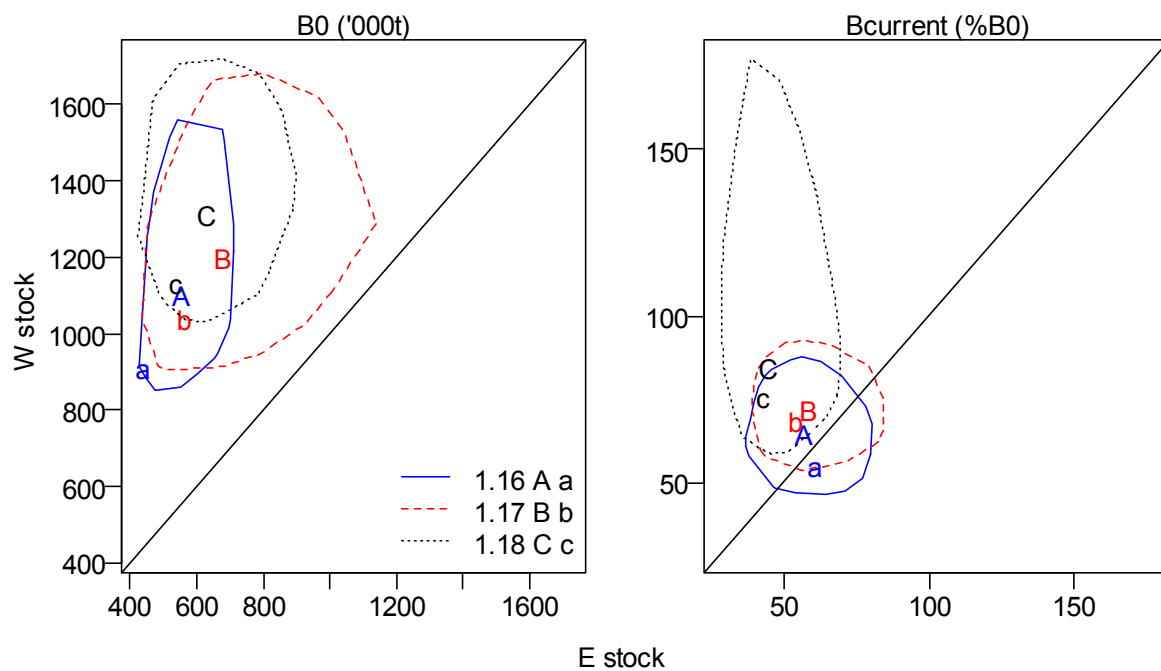


Figure 32: As for Figure 26 but for the final model run 1.16 and the two sensitivity runs 1.17, and 1.18.

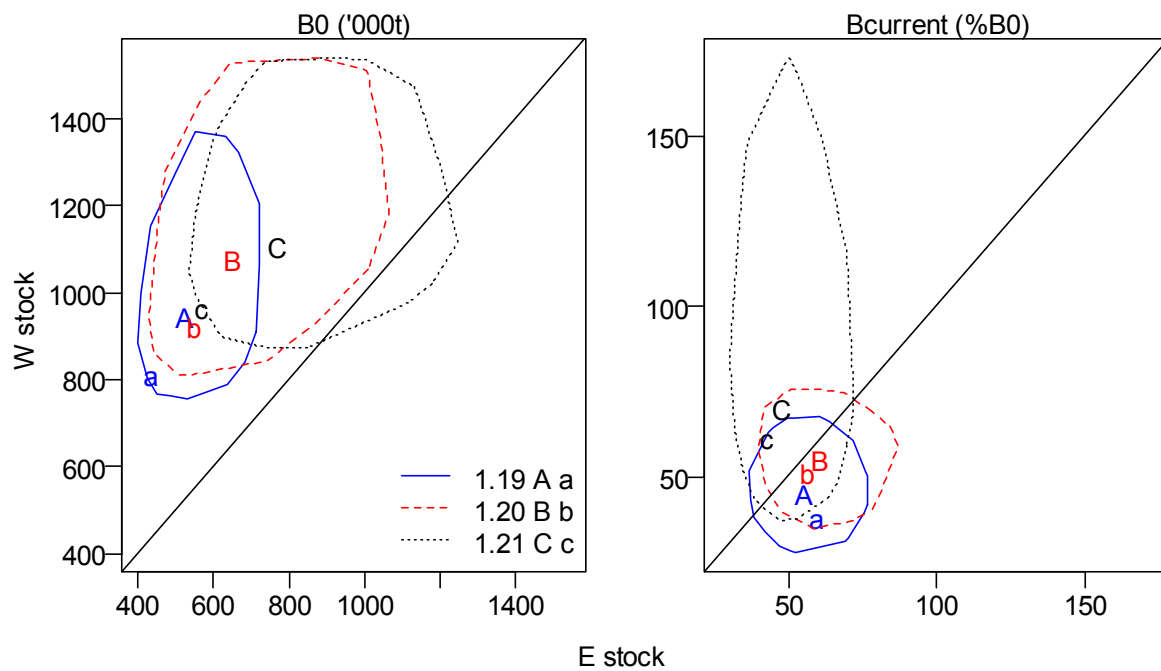
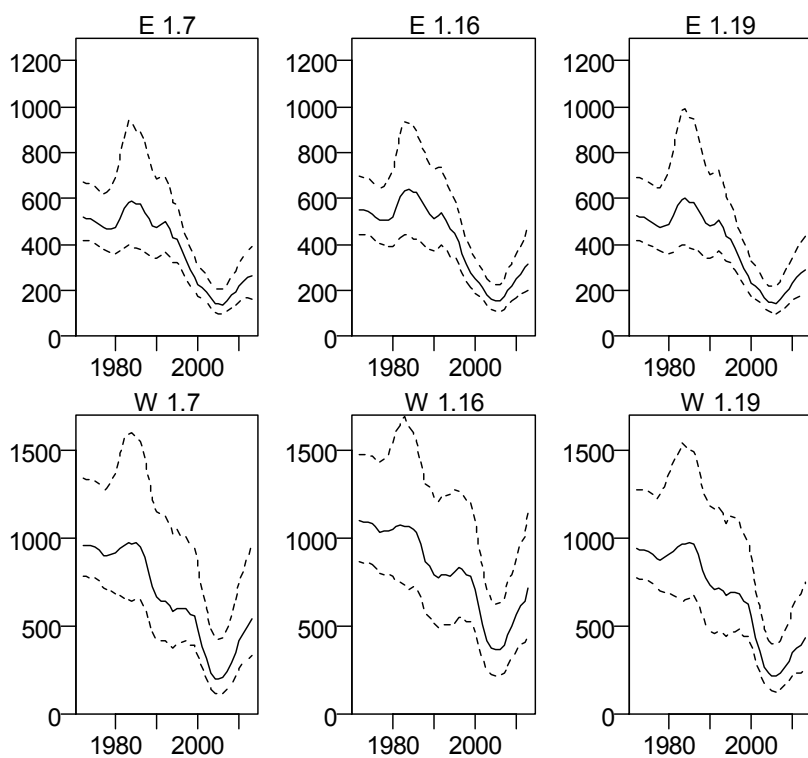
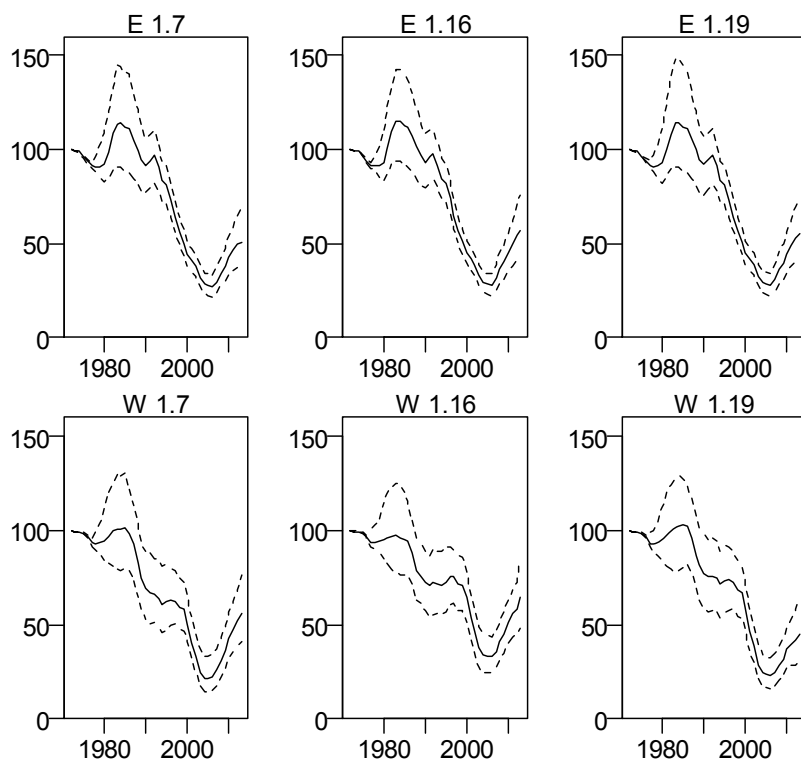


Figure 33: As for Figure 26 but for the final model run 1.19 and the two sensitivity runs 1.20, and 1.21.

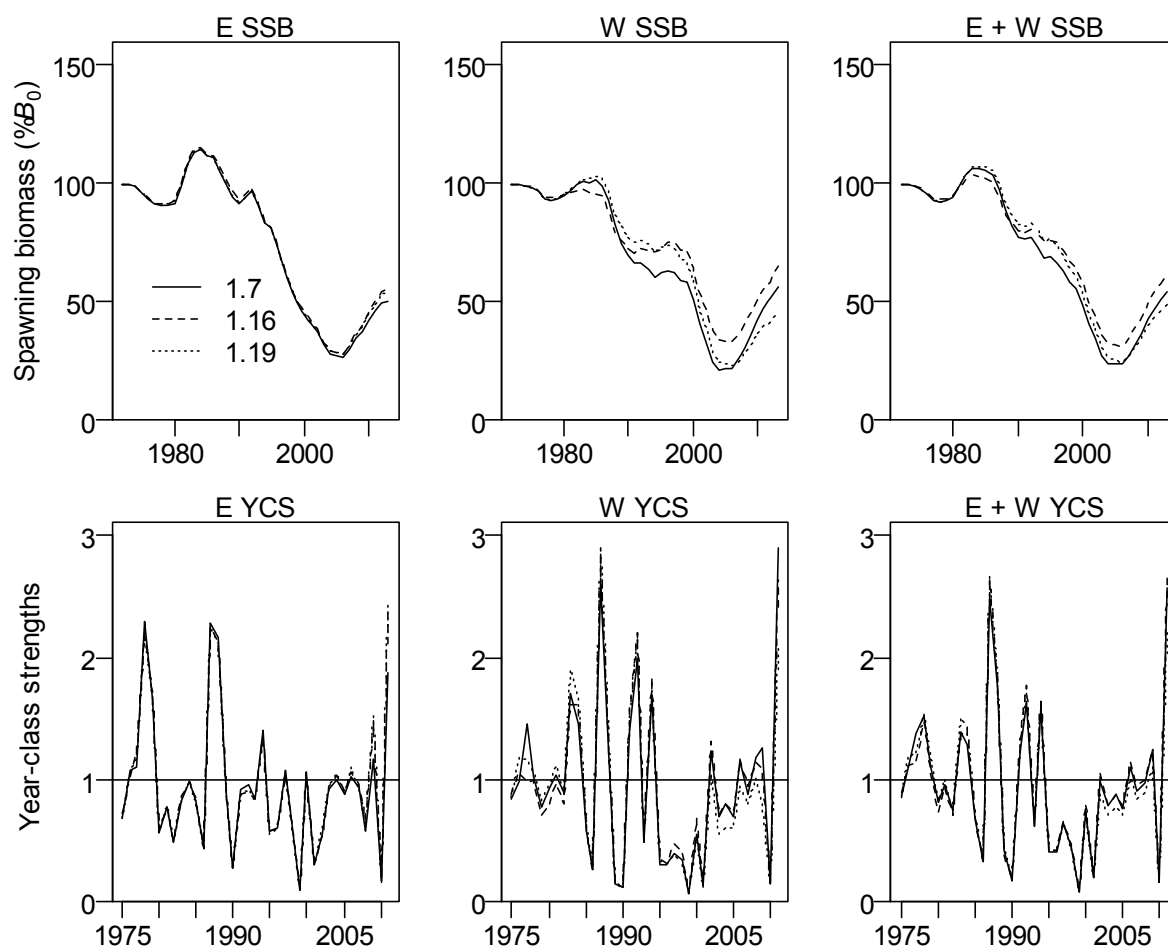


**Figure 34: Estimated spawning biomass trajectories from final model MCMC runs (1.7, 1.16, 1.19), showing medians (solid lines) and 95% confidence intervals (broken lines) by run for E (upper panels) and W (lower panels).**

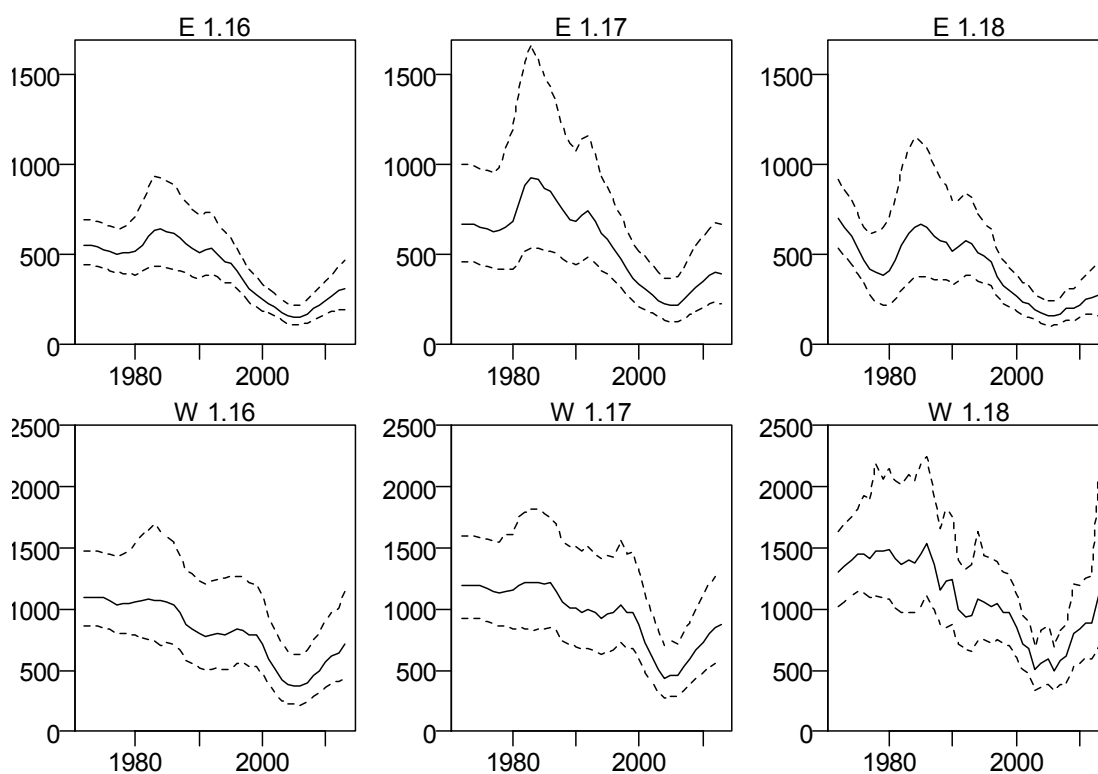


**Figure 35: As for Figure 34, but plotted as % $B_0$ .**

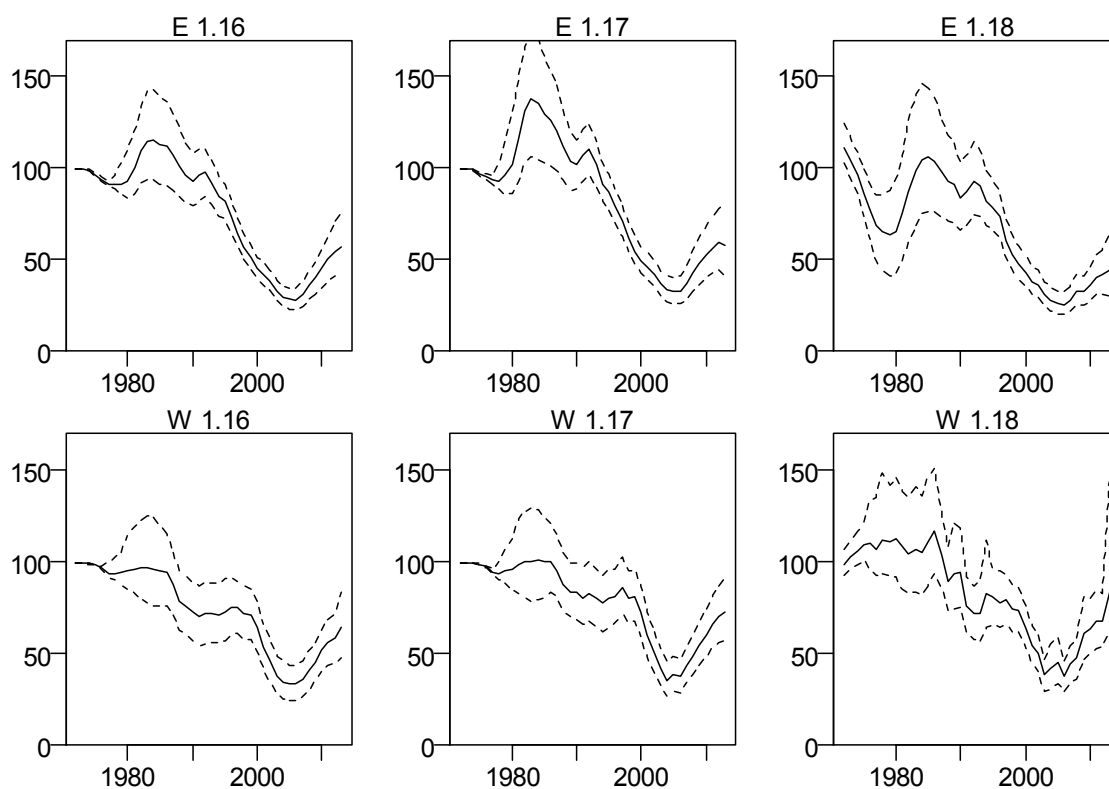




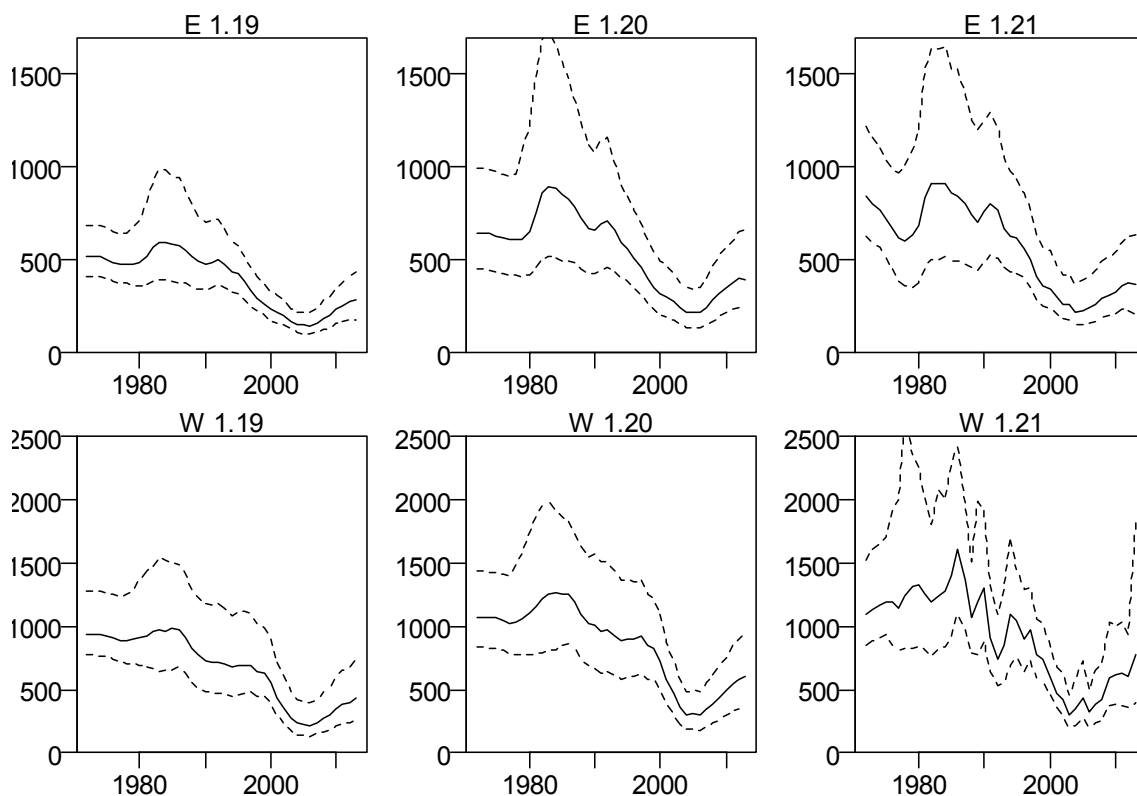
**Figure 36: Estimated spawning biomass trajectories (SSB, upper panels) and year-class strengths (YCS, lower panels) for the E (left panels), W (middle panels) and E + W stocks (right panels) from the three final model runs with either one SAsumbio catchability (Run 1.7) or two catchabilities (Runs 1.16, 1.19). Plotted values are medians of marginal posterior distributions. Years are fishing years ('1990' is the 1989–90 fishing year).**



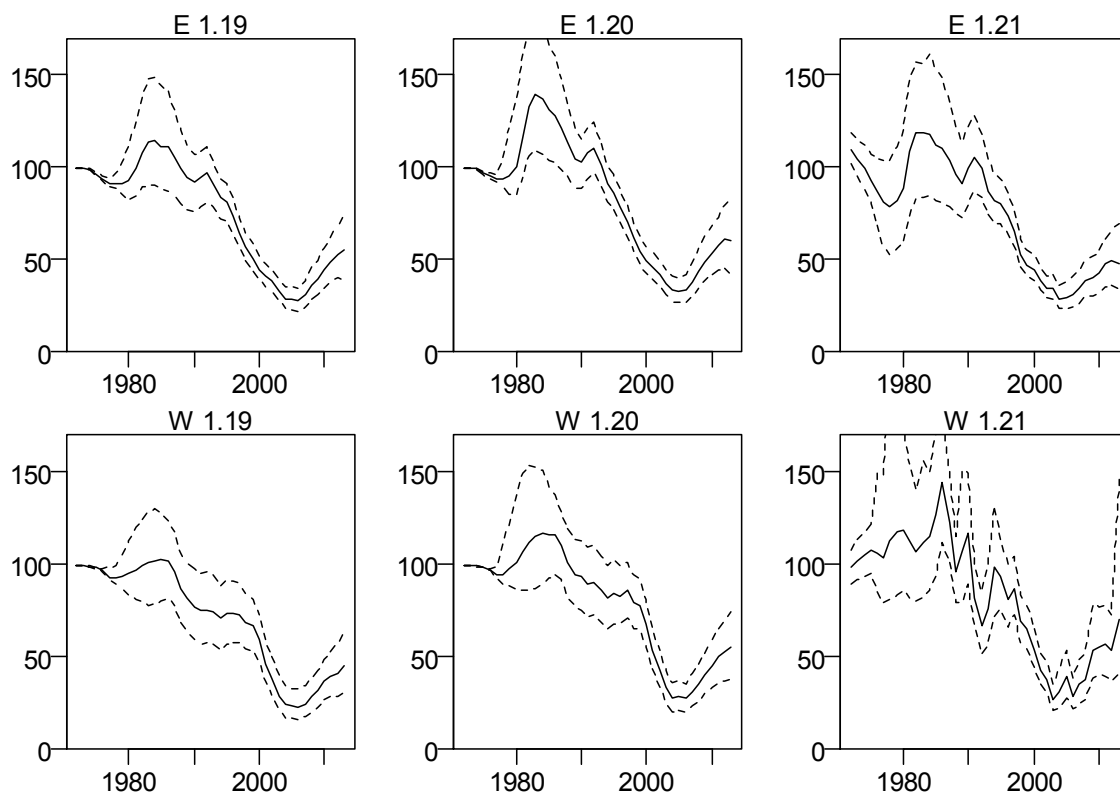
**Figure 37: Estimated spawning biomass trajectories from the final MCMC run 1.16 and its two sensitivity runs, showing medians (solid lines) and 95% confidence intervals (broken lines) by run for E (upper panels) and W (lower panels).**



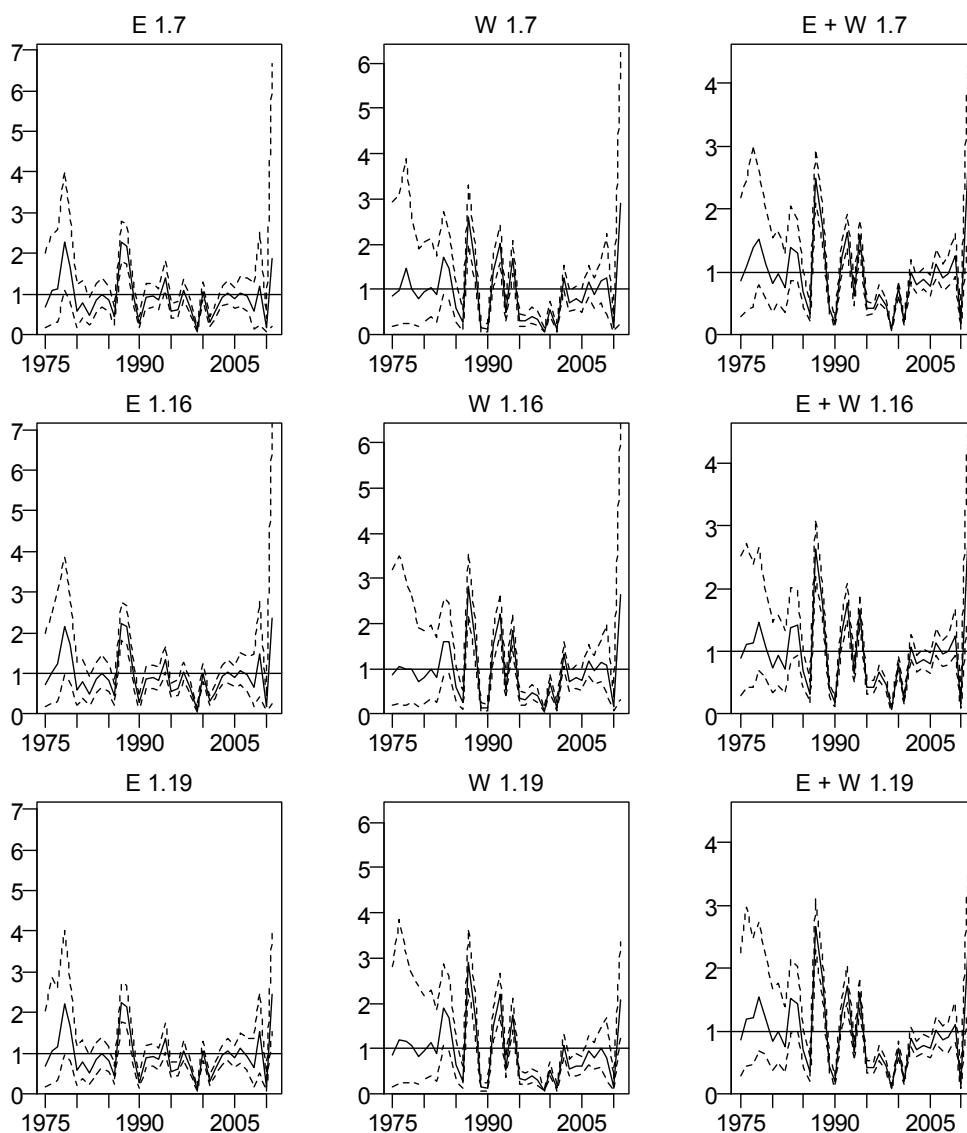
**Figure 38: As for Figure 37, but plotted as %B<sub>0</sub>.**



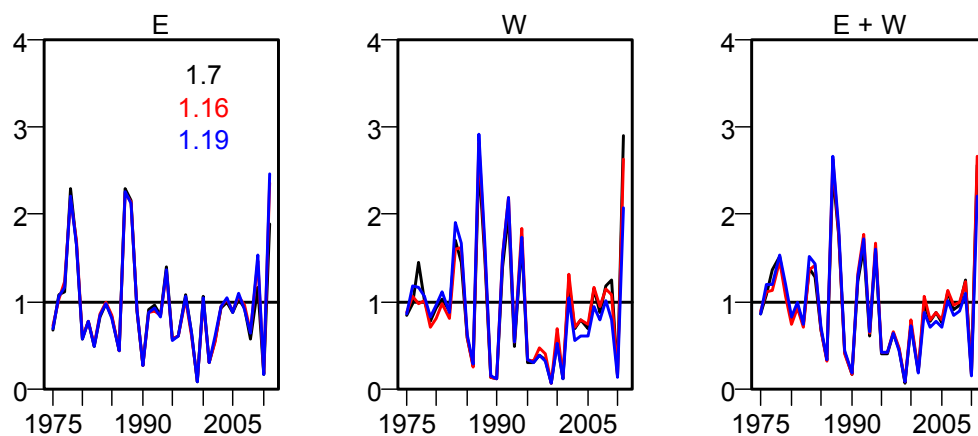
**Figure 39: Estimated spawning biomass trajectories from the final MCMC run 1.19 and its two sensitivity runs, showing medians (solid lines) and 95% confidence intervals (broken lines) by run for E (upper panels) and W (lower panels).**



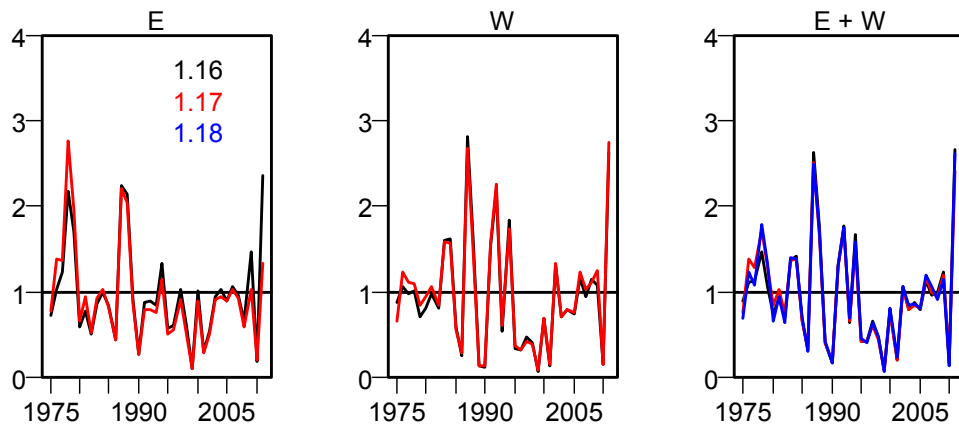
**Figure 40: As for Figure 39, but plotted as %B<sub>0</sub>.**



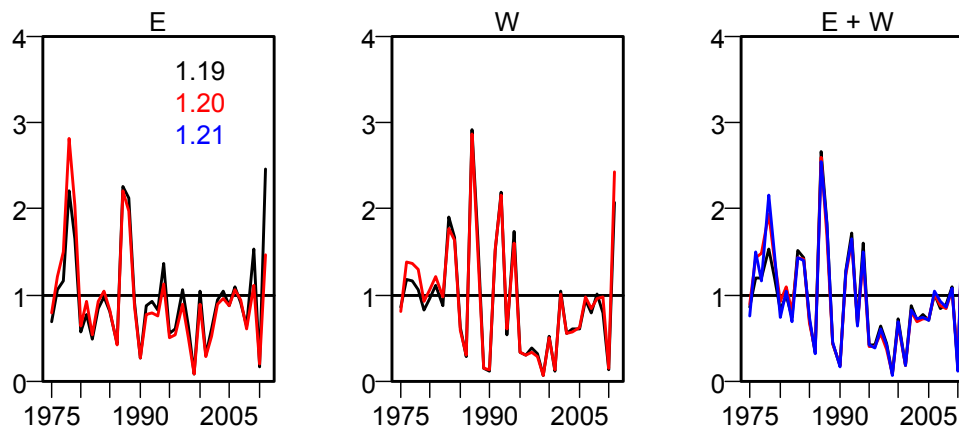
**Figure 41: Estimated year-class strengths (YCSs) from the three final model runs 1.7, 1.16, and 1.19 showing medians (solid lines) and 95% confidence intervals (broken lines) by run for E (left panels), W (middle panels) and E + W (right panels).**



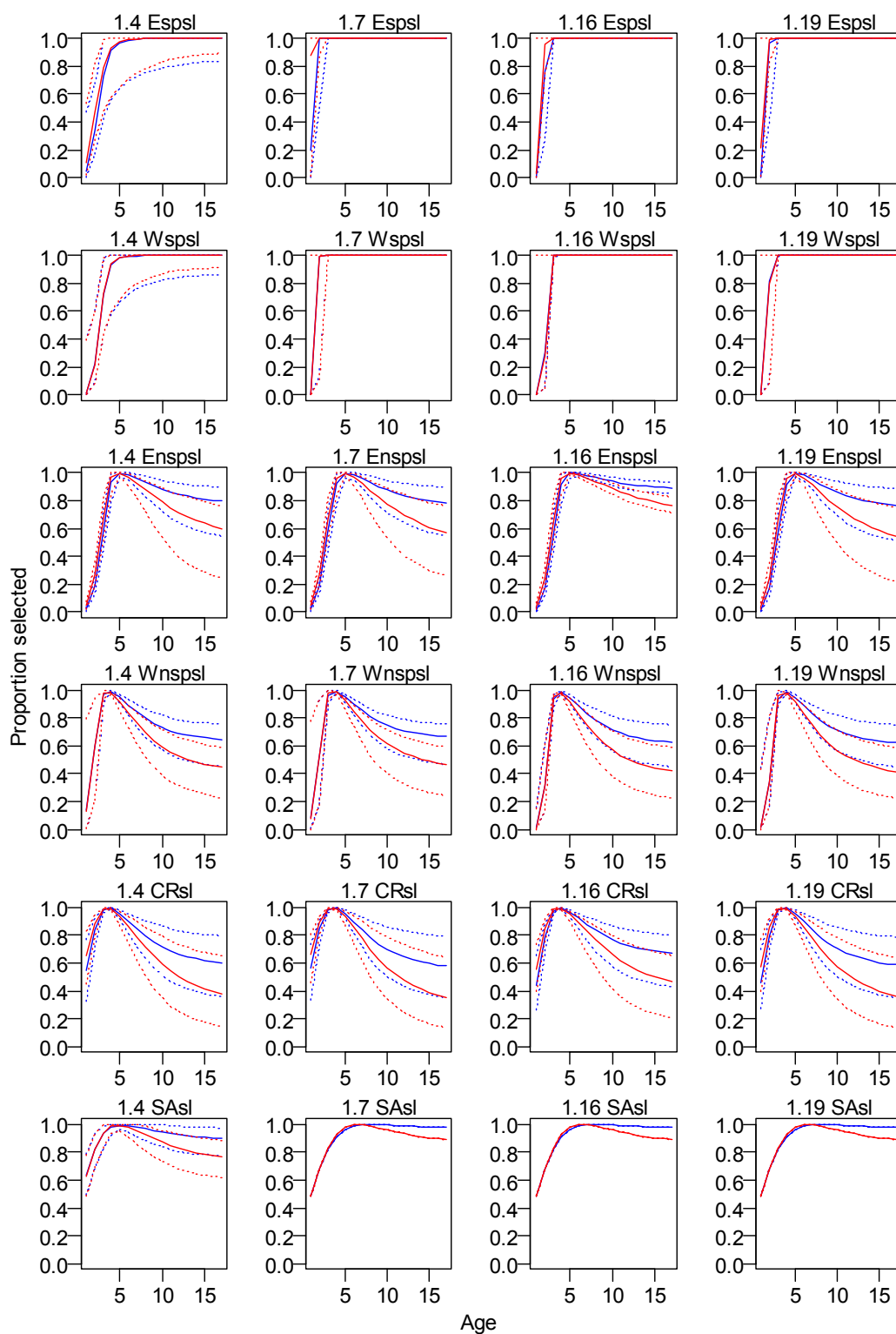
**Figure 42: Estimated median year-class strengths (YCSs) from the final model runs 1.7 (black lines), 1.16 (red lines), and 1.19 (blue lines).**



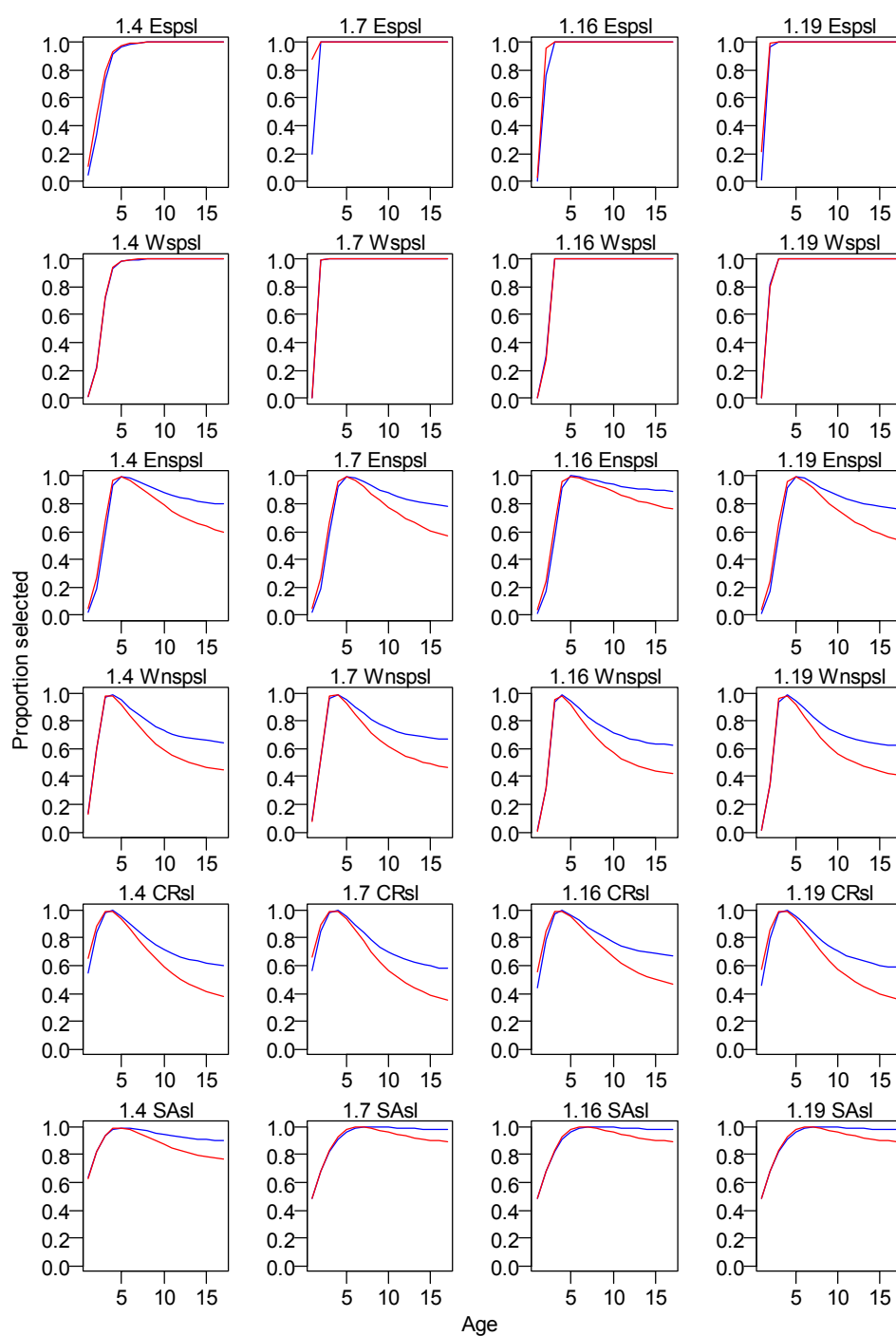
**Figure 43: Estimated median year-class strengths (YCSs) from the final model run 1.16 (black lines), and the two sensitivity runs 1.17 (red lines) and 1.18 (blue lines).**



**Figure 44: Estimated median year-class strengths (YCSs) from the final model run 1.19 (black lines), and the two sensitivity runs 1.20 (red lines) and 1.21 (blue lines).**



**Figure 45: Posterior estimates of selectivity ogives for the continuity MCMC runs 1.4 and the three final MCMC runs 1.7, 1.16, and 1.19. Solid lines are medians; broken lines show 95% confidence intervals. Where ogives differ by sex they are plotted as blue for males and red for females. Where they differ by stock or time step the plotted curves are for one selected combination (E step 2 for Enspsl and CRsl, W step 2 for Wnspsl and SAsl). Note that some selectivity parameters are held fixed in MCMC runs (see Table 22).**



**Figure 46:** As in Figure 45 but showing just the medians from the MCMC runs.

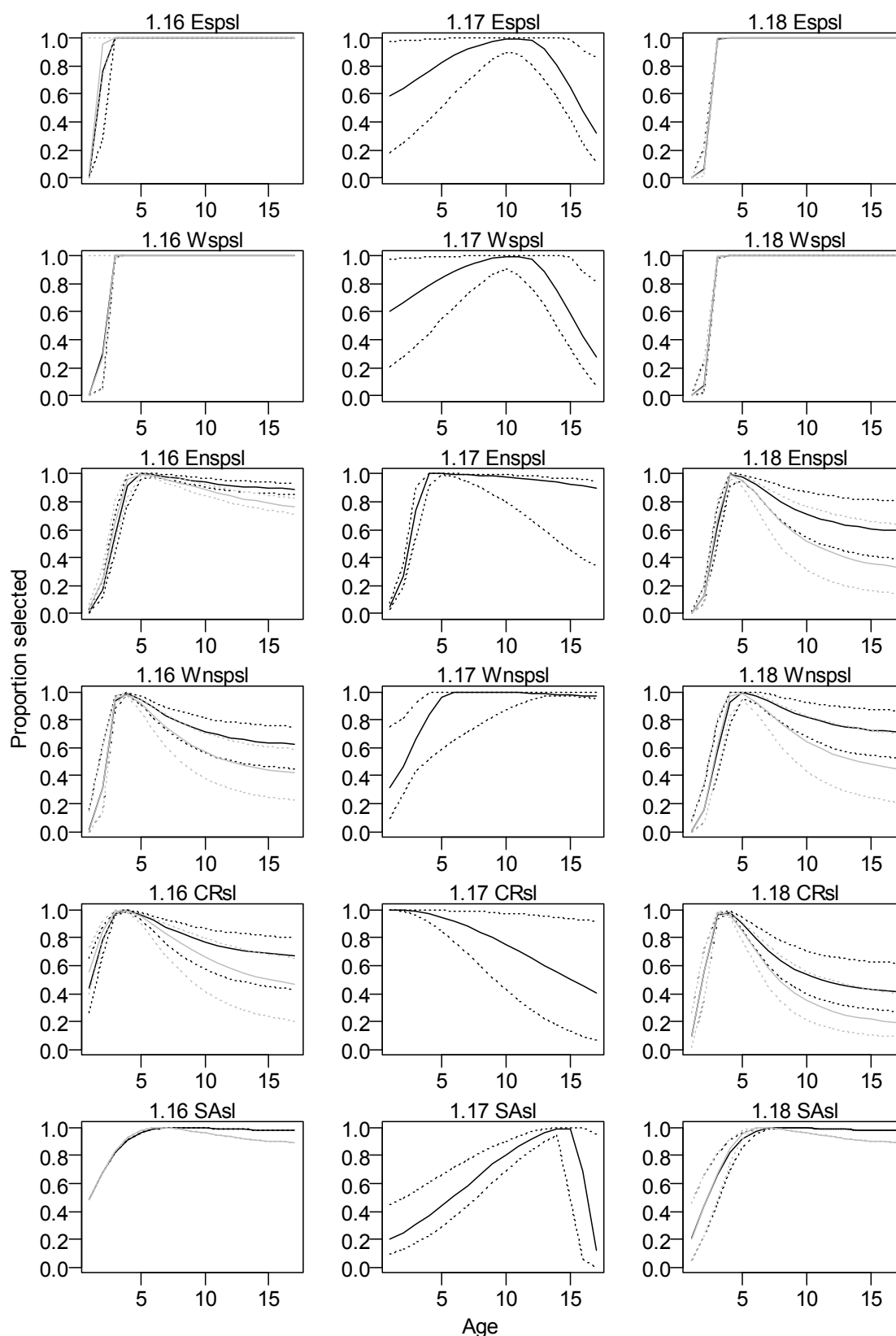
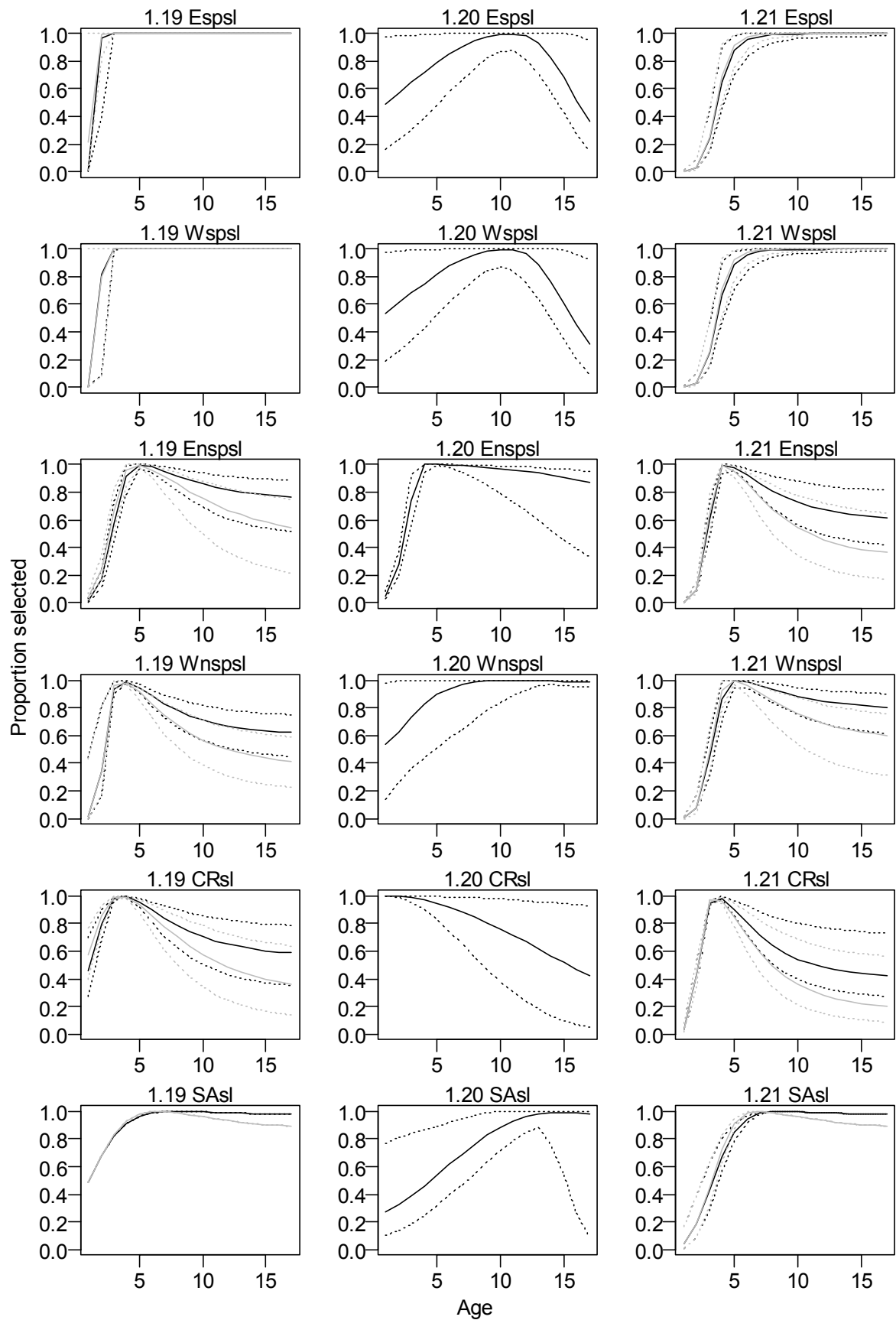
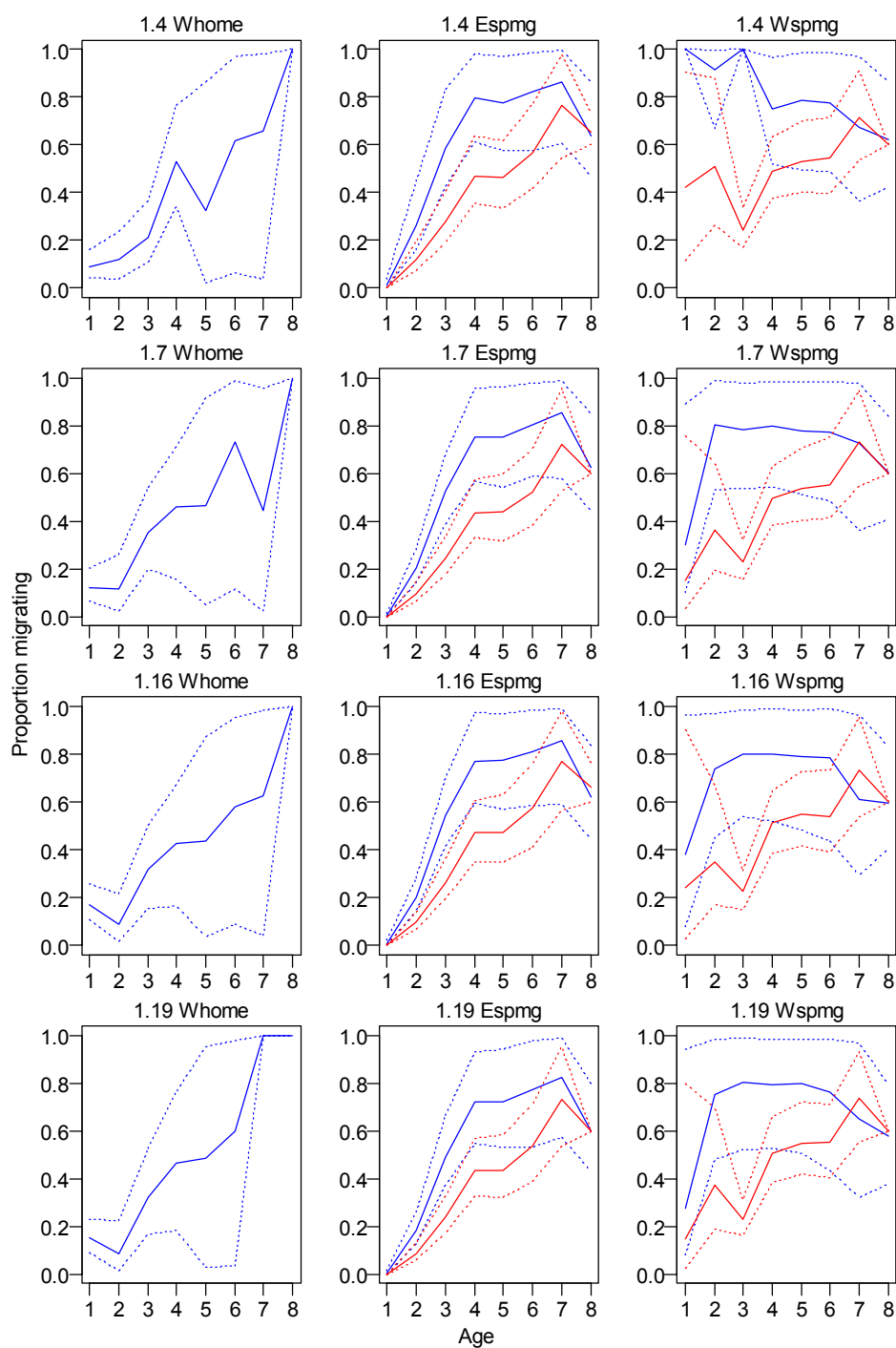


Figure 47: As in Figure 45 but for the MCMC run 1.16, and the two sensitivity runs 1.17 and 1.18.

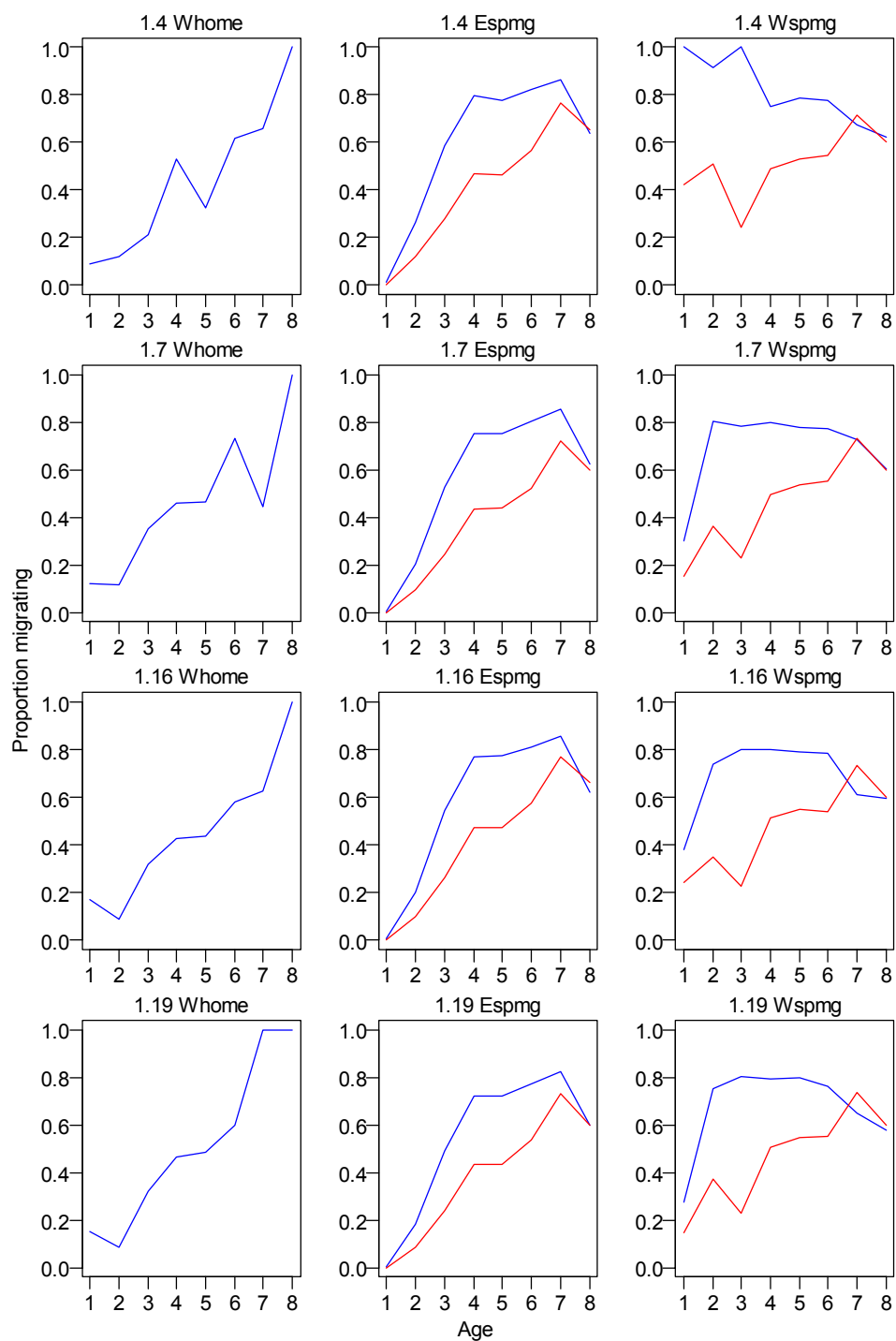




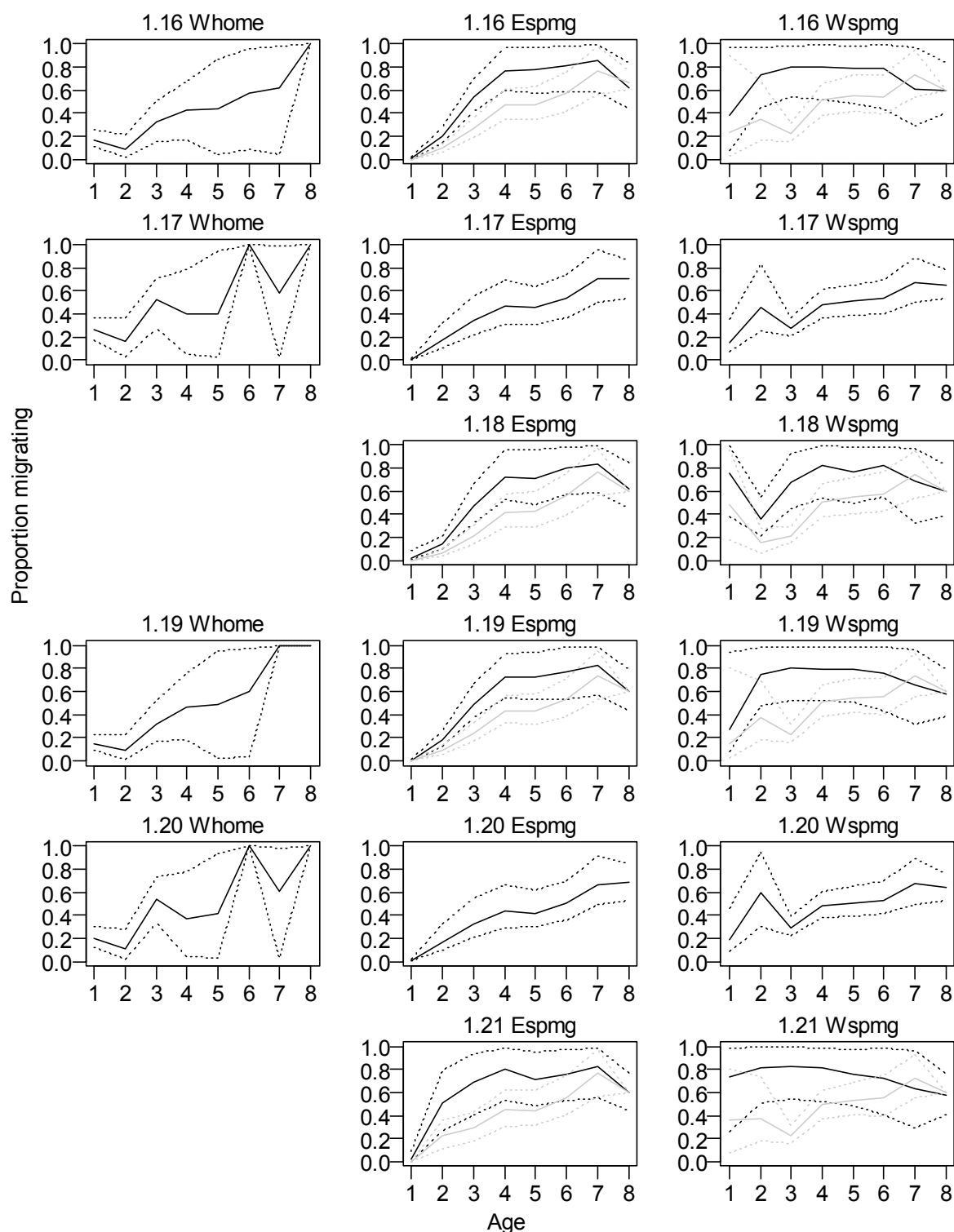
**Figure 48:** As in Figure 45 but for the MCMC run 1.19, and the two sensitivity runs 1.20 and 1.21.



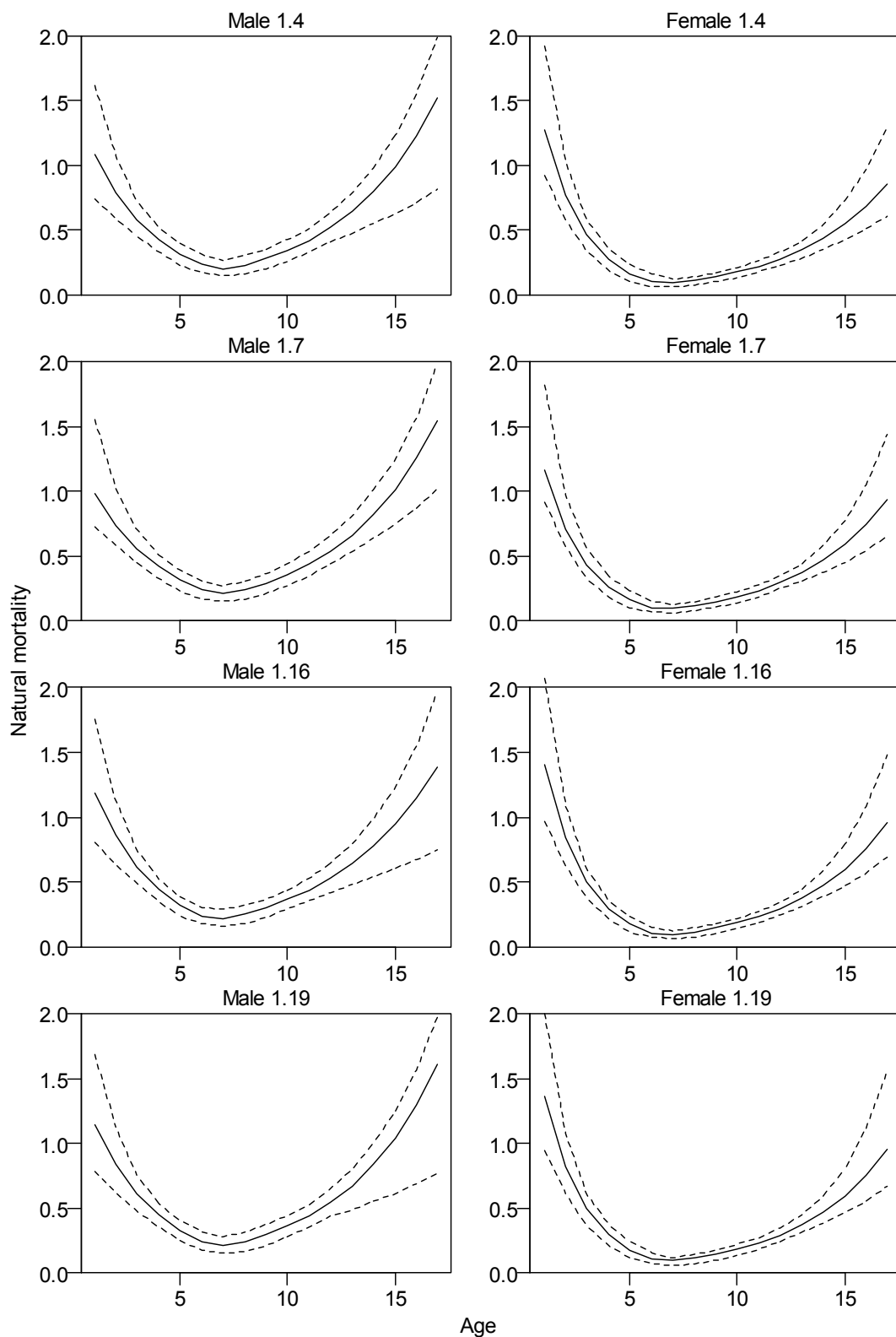
**Figure 49: Migration ogives for the continuity MCMC runs 1.4 and the three final MCMC runs 1.7, 1.16, and 1.19. Solid lines are medians; broken lines show 95% confidence intervals. Where ogives differ by sex they are plotted as blue for males and red for females.**



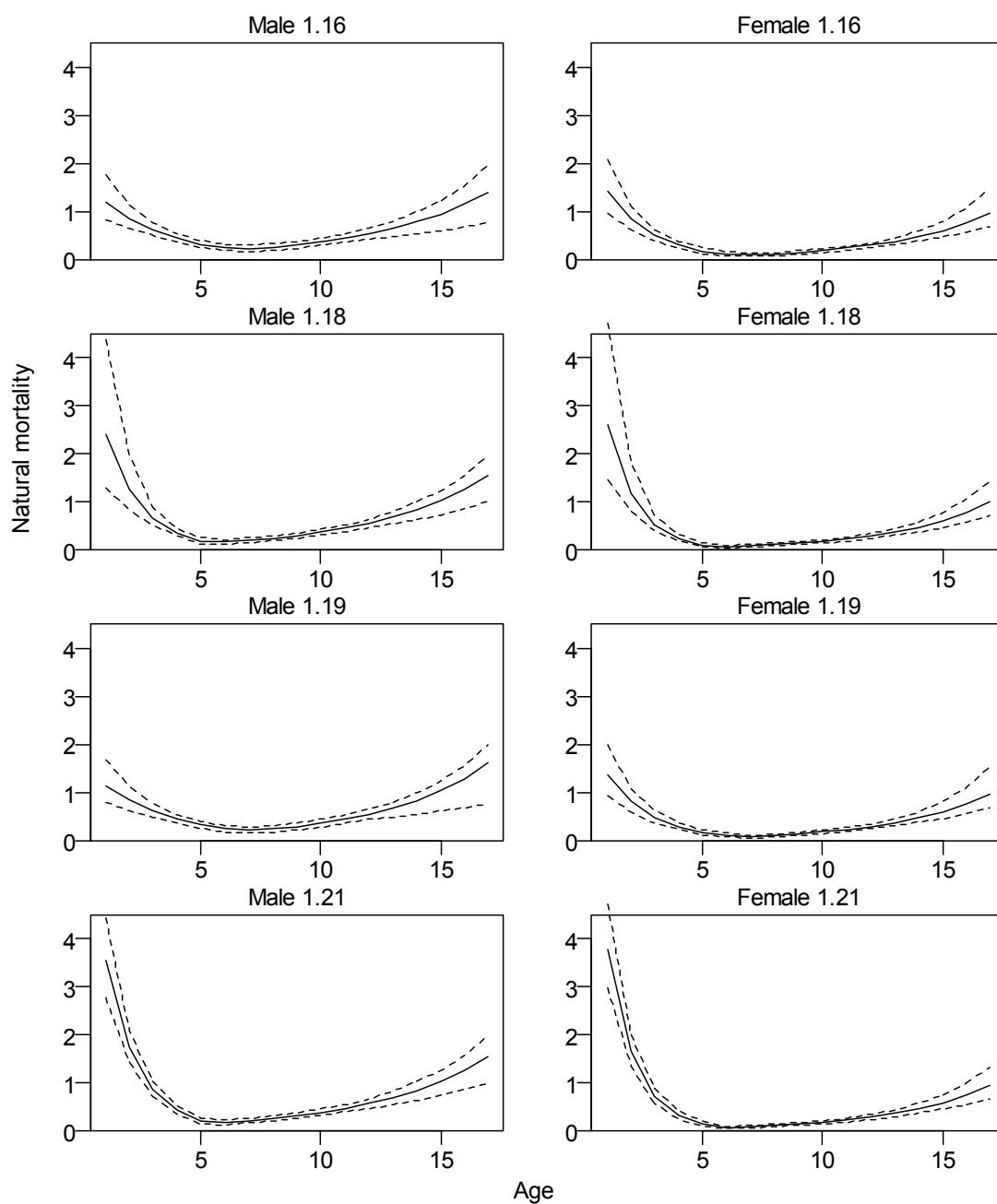
**Figure 50:** As in Figure 49 but showing just the medians from the MCMC runs.



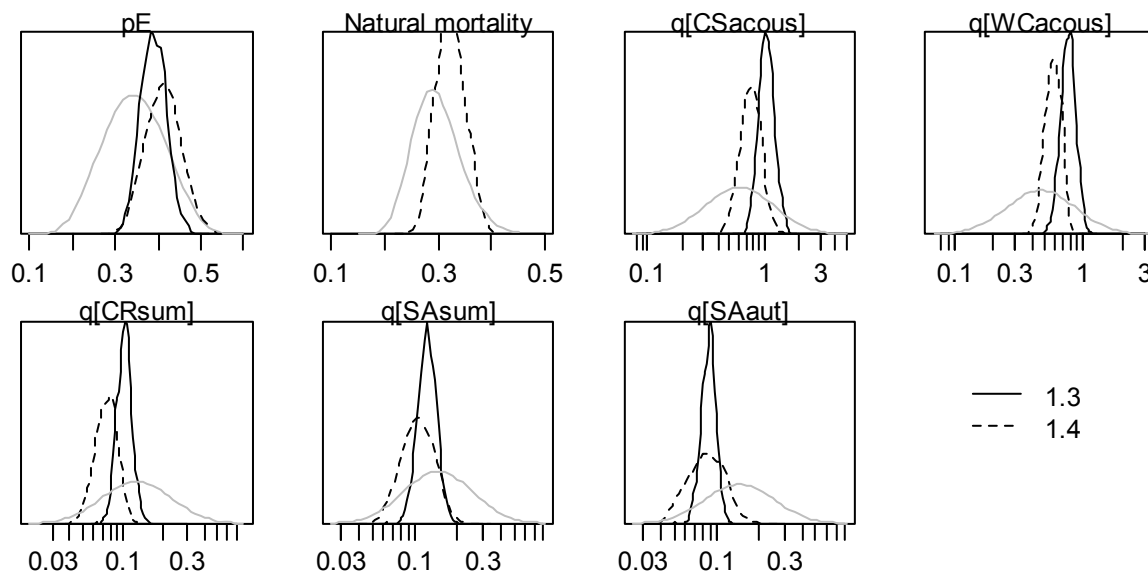
**Figure 51: Migration ogives estimated in two of the final model runs (1.16, 1.19) and their sensitivity runs (1.17, 1.18; 1.20, 1.21). Solid lines are medians, broken lines show 95% confidence intervals. Where ogives differ by sex they are plotted as black for males and grey for females.**



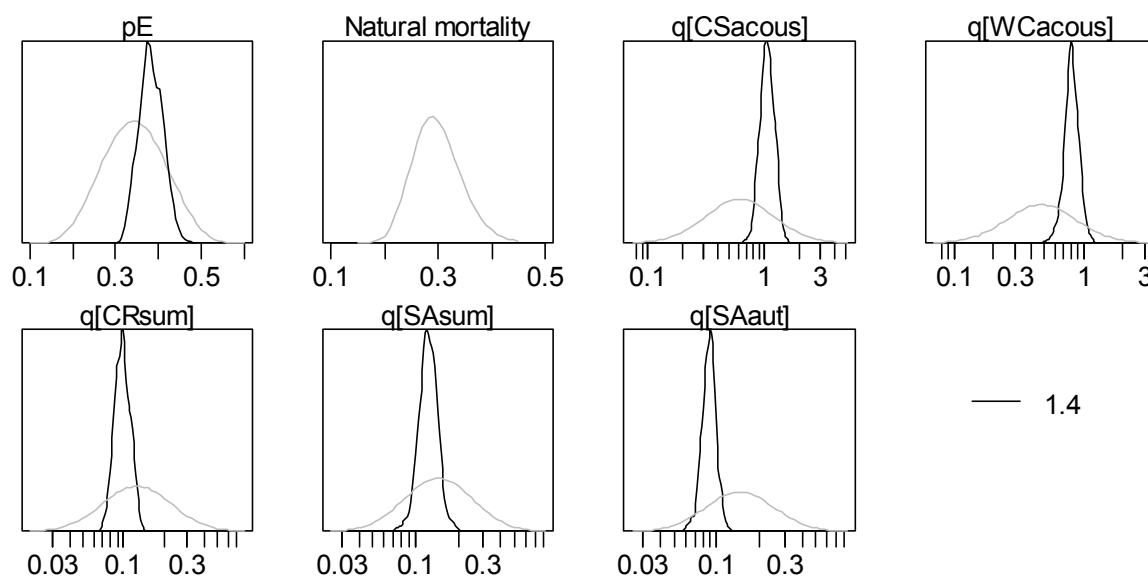
**Figure 52: Estimates of age-dependent natural mortality ogives for the continuity MCMC run 1.4 and the three final runs 1.7, 1.16, and 1.19. Solid lines are medians; broken lines show 95% confidence intervals.**



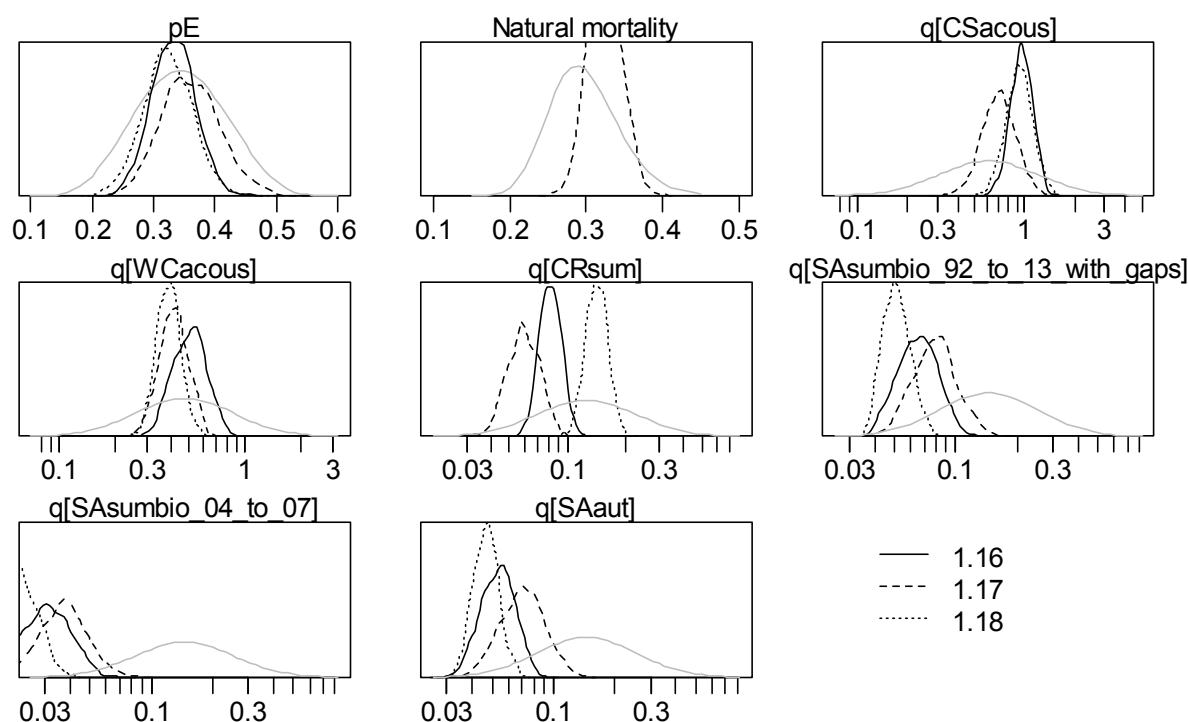
**Figure 53: Estimates of age-dependent natural mortality ogives for runs 1.16, 1.18, 1.19, and 1.21 showing median estimates (solid lines) and 95% confidence intervals (broken lines) for each sex.**



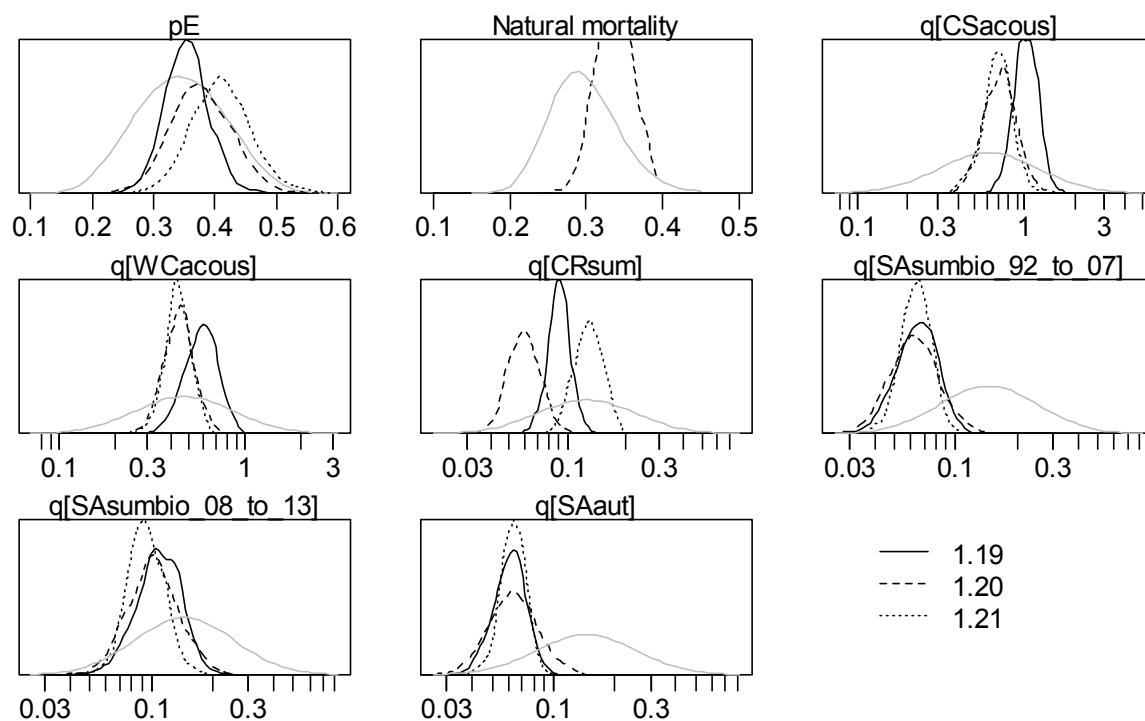
**Figure 54: 2012 assessment prior (grey lines) and estimated posterior (black lines) distributions from the two MCMC runs for 1.3 and 1.4 for the following parameters: pE (proportion of  $B_0$  in E stock), natural mortality (independent of age, run 1.4 only), and survey catchabilities (acoustic and trawl).**



**Figure 55: 2013 assessment prior (grey lines) and estimated posterior (black lines) distributions from the MCMC run 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).**

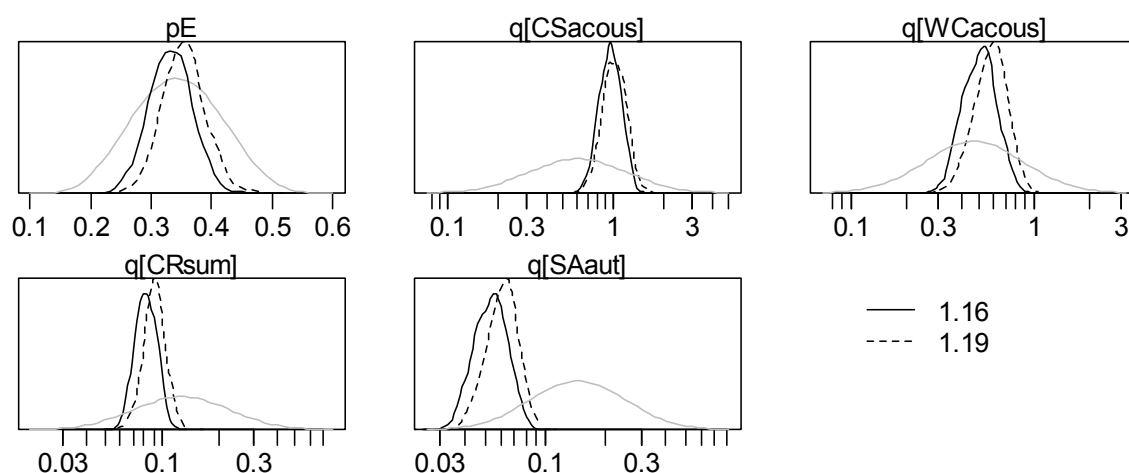


**Figure 56: 2013 assessment prior (grey lines) and estimated posterior (black lines) distributions from the MCMC run 1.16 and the two sensitivity runs 1.17 and 1.18 for the following parameters: pE (proportion of  $B_0$  in E stock), natural mortality (independent of age, run 1.17 only), and survey catchabilities (acoustic and trawl).**

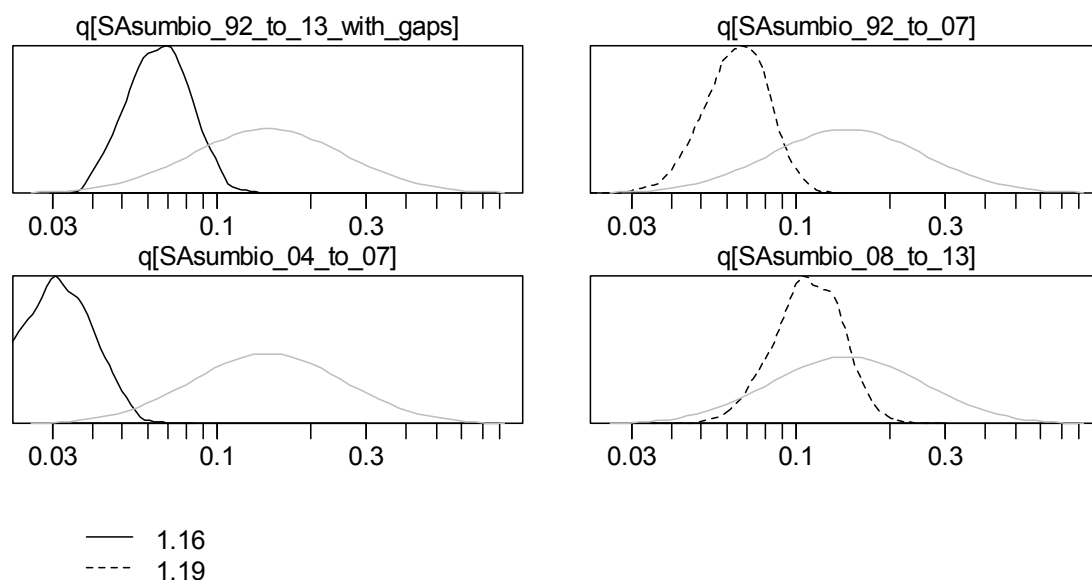


**Figure 57: 2013 assessment prior (grey lines) and estimated posterior (black lines) distributions from the MCMC run 1.19 and the two sensitivity runs 1.20 and 1.21 for the following parameters: pE (proportion of  $B_0$  in E stock), natural mortality (independent of age, run 1.20 only), and survey catchabilities (acoustic and trawl).**





**Figure 58:** Assessment prior (grey lines) and estimated posterior (black lines) distributions from the base MCMC runs 1.16 and 1.19 for the following parameters:  $pE$  (proportion of  $B_0$  in E stock), and some of the survey catchabilities (acoustic and trawl).

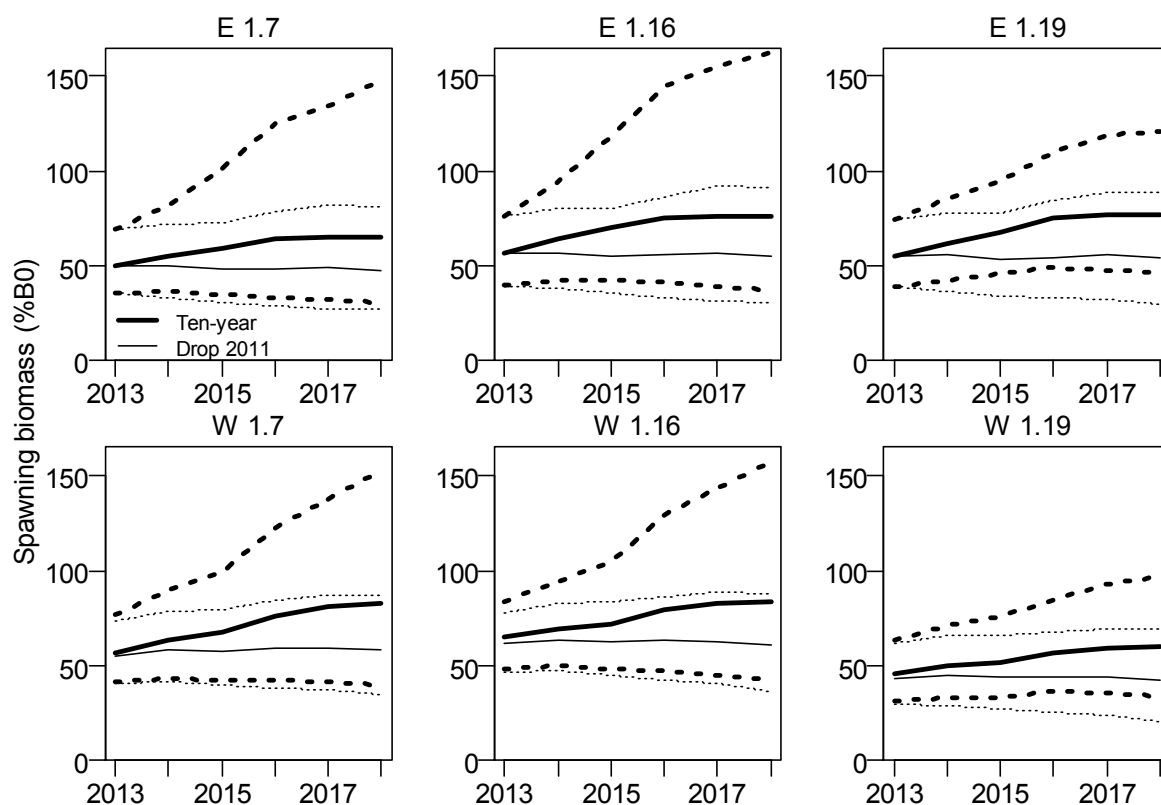


**Figure 59:** As in Figure 58, but for the  $SAsumbio$  trawl survey catchabilities. Run 1.16 is the first column, and run 1.19 is the second column.

## 5. PROJECTIONS

Five-year projections were carried out, for each of the three final runs (1.7, 1.16, 1.19), under each of two alternative assumptions about future recruitment: ‘ten-year’ (in which future recruitments were selected at random from those estimated for 2001–2011) and ‘drop 2011’ (future recruitments selected from 2001–2010). The drop 2011 recruitment option was considered because of the poorly estimated 2011 years class strength which may not persist in the future. In all projections, future catches in each fishery were assumed to be the same as for 2013 (i.e., as in the last line of Table 3). The projections indicate that with these assumed catches, the E and W biomasses are likely to rise in the next five years under ‘ten-year’ recruitment and to stay much the same when the large 2011 recruitment is omitted (Figures 60).

The probabilities of the current (2013) and projected spawning stock biomass being below the hard limit of 10%  $B_0$ , the soft limit of 20%  $B_0$ , and the lower and upper ends of the interim management target range of 35–50%  $B_0$  are presented in Tables 24–25 for the case where future catches remain at 2013 levels. The probability of either stock being less than either the soft or the hard limit over the five year projection period is negligible. Both stocks are projected to be within or above the 35–50%  $B_0$  target range by the end of the projection period.



**Figure 60:** Projected spawning biomass (as % $B_0$ ) assuming randomised recruitment from 2012 onwards (thick lines) or 2011 onwards (thin lines) recruitment: median (solid lines) and 95% confidence intervals (broken lines) for the three final runs (Runs 1.7, 1.16 and 1.19).

**Table 24:** Probabilities (rounded to two decimal places) associated with projections for SSB (% $B_0$ ) for the three final runs (1.7, 1.16 and 1.19) for the ten-year recruitment option (recruitments selected from 2001–2011).

	2013			2018		
	1.7	1.16	1.19	1.7	1.16	1.19
<b>EAST</b>						
P(SSB<10% $B_0$ )	0	0	0	0	0	0
P(SSB<20% $B_0$ )	0	0	0	0	0	0
P(SSB<35% $B_0$ )	0.02	0	0.01	0.06	0.01	0
P(SSB<50% $B_0$ )	0.48	0.23	0.30	0.26	0.13	0.05
<b>WEST</b>						
P(SSB<10% $B_0$ )	0	0	0	0	0	0
P(SSB<20% $B_0$ )	0	0	0	0	0	0
P(SSB<35% $B_0$ )	0	0	0.09	0.01	0	0.03
P(SSB<50% $B_0$ )	0.21	0.05	0.7	0.1	0.06	0.22

**Table 25: Probabilities (rounded to two decimal places) associated with projections for SSB (% $B_0$ ) for the three final runs (1.7, 1.16 and 1.19) with the drop 2011 recruitment option (recruitments selected from 2001–2010).**

	2013			2018: drop 2011		
	1.7	1.16	1.19	1.7	1.16	1.19
EAST						
P(SSB<10%B <sub>0</sub> )	0	0	0	0	0	0
P(SSB<20%B <sub>0</sub> )	0	0	0	0	0	0
P(SSB<35%B <sub>0</sub> )	0.02	0	0.01	0.14	0.05	0.08
P(SSB<50%B <sub>0</sub> )	0.48	0.23	0.30	0.56	0.35	0.40
WEST						
P(SSB<10%B <sub>0</sub> )	0	0	0	0	0	0
P(SSB<20%B <sub>0</sub> )	0	0	0	0	0	0.02
P(SSB<35%B <sub>0</sub> )	0	0	0.09	0.02	0.01	0.25
P(SSB<50%B <sub>0</sub> )	0.21	0.05	0.70	0.26	0.19	0.73

## 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 61).

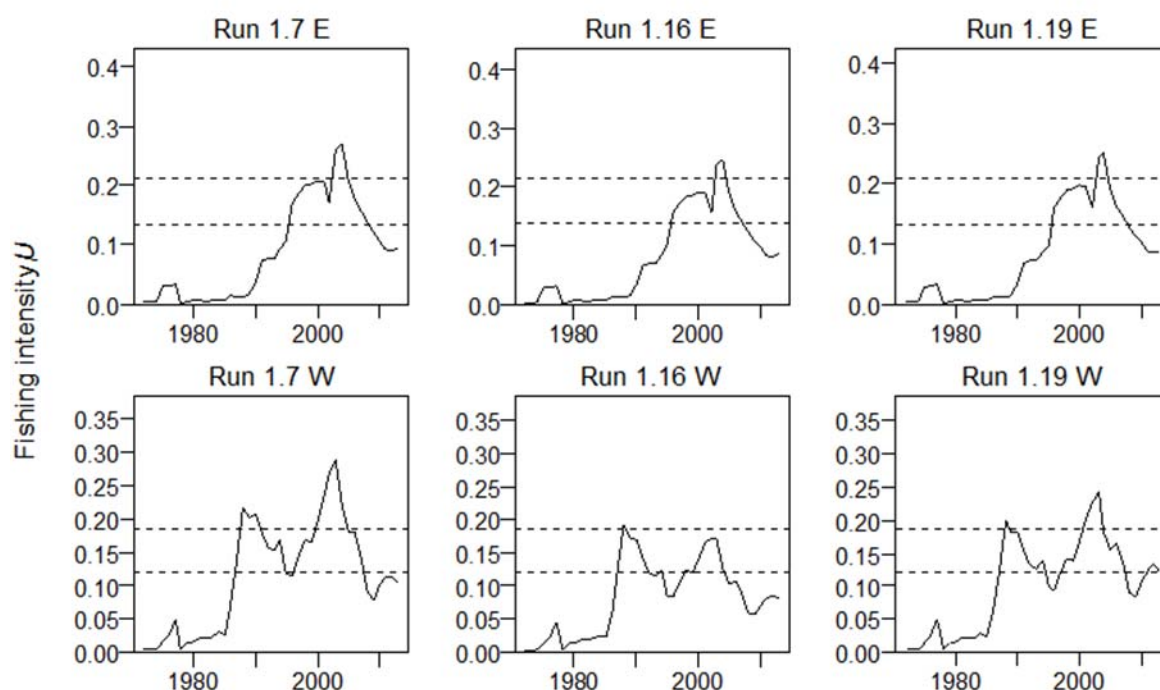


Figure 61: Fishing intensity,  $U$  (from MPDs), plotted by run and stock. Also shown (as broken lines) are the reference levels  $U_{35\%B_0}$  (upper line) and  $U_{50\%B_0}$  (lower line), which are the fishing intensities that would cause the spawning biomass to tend to 35%  $B_0$  and 50%  $B_0$ , 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, assuming a harvest strategy in which the exploitation rate for fishery  $f$  was  $mU_{f,2013}$ , where  $U_{f,2013}$  is the estimated 2013 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  $m$ .

For all of the three final runs (runs 1.7, 1.16 and 1.19) estimates of  $B_{MSY}$  were 25% for the E stock. For the W stock they were 27% (run 1.7) and 26% (runs 1.16 and 1.19).

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 2004–06) their lowest levels since the fishery began. Both stocks are currently well above the lower end of the target range of 35% with the western stock estimated to be 45–65% $B_0$  and the eastern stock 50–57% $B_0$ . The western stock experienced an extended period of poor recruitment from 1995 to 2001, but recruitment appears to have been mostly near or above average since then, although it was probably well below average in 2010 and well above average in 2011. All projections suggest that continued fishing at current levels is likely to allow the biomass of both stocks to rise in the next five years under ‘ten-year’ recruitment and to stay much the same when the large 2011 recruitment is omitted.

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 CVs 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 DEE201002HOK. Thank you to Peter Horn and Kevin Sullivan for reviewing the manuscript, and for the sharp editorial eye of Marianne Vignaux.

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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 26: Changes in stock-assessment model assumptions and input data for each year since the first CASAL assessment of hoki in 2002.**

Year	Changes
2003	<p>Changed timing of spawning migrations from the middle to the end of the non-spawning fisheries (and after the autumn SA surveys)</p> <p>Earliest estimated YCS changed to 1977 from 1980</p> <p>Assumed Beverton-Holt stock-recruit relationship</p> <p>Disallowed annual variation in selectivities for Wnsp fishery</p> <p>Allowed for ageing error (expected to reduce bias in estimates of YCSs)</p> <p>Process errors for at-age data sets estimated within the model</p> <p>Non-uniform prior on pE</p> <p>Max. age of otolith-based at-age data increased from 10 (plus group) to 12 (no plus group)</p> <p>First use of otolith-based at-age data for non-spawning fisheries (Enspage &amp; Wnspage)</p> <p>Forced equality of recent W and E YCSs extended from 2 y to 3 y</p> <p>Improvements in methods of converting ogives from size-based to age-based and implementing annual variation in selectivities</p>
2004	<p>First use of age-dependent natural mortality and domed spawning selectivities to cope with lack of old fish</p> <p>Maximum age in partition increased from 13 y to 17 y</p> <p>New parameterisation for YCSs</p> <p>Earliest estimated YCS changed to 1975 from 1977</p> <p>Change in priors for CSacous catchability and pE</p> <p>Max. age of otolith-based at-age data increased from 12 (no plus group) to 13/15 (plus group)</p>
2005	<p>For runs with domed spawning selectivities, spawning selectivities (rather than migrations) constrained to be equal</p> <p>Some at-age data revised</p>
2006	<p>Annual variation in Wsp selectivity restricted to years with significant data and constrained by non-uniform prior on controlling parameter</p> <p>Forced equality of recent W and E YCSs reduced from 3 y to 1 y</p> <p>Added smoothing penalty for age-dependent natural mortality</p> <p>First model run without the assumption of natal fidelity</p>
2007	<p>New parameterisation (double-exponential) and prior for age-dependent natural mortality</p>
2008	<p>Models runs without natal fidelity dropped</p> <p>Stock recruitment steepness reduced from 0.90 to 0.75</p> <p>1998 proportions spawning data re-analysed</p>
2009	<p>Median catch day re-calculated using a new first year</p> <p>1992 and 1993 proportions spawning data re-analysed</p>
2010	<p>Allow two catchabilities for the Southern Plateau trawl survey in sensitivity model runs</p>
2011	<p>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)</p>
2012	<p>Re-weight the proportions-at-age data (the procedure giving them a substantial down-weighting)</p> <p>Re-introduce a sensitivity model run without natal fidelity</p>
2013	<p>Of the three final model runs, two have a time-varying catchability for the Southern Plateau trawl survey biomass series.</p>

### Appendix 3: Sensitivity to the prior on the proportion of the virgin biomass in the east stock (pE)

#### Summary

For the 2003 assessment an informative prior on the proportion of virgin biomass in the east stock (pE) was introduced in order to fix some particular problems that occurred. The sensitivity of the stock assessment results in the 2012 assessment to this prior are evaluated by replacing it with a uniform prior on [0.1, 0.7]. The stock assessment results were found to be insensitive to the prior used.

#### Background

For the 2002 stock assessment pE had a uniform prior on [0.1, 0.7] (Francis 2003). Partway through the 2003 stock assessment this prior was narrowed “to better reflect the Working Group’s belief and to prevent what were believed to be implausibly high estimates of pE” (Francis 2004, Figure 62). In particular for the 2002 assessment pE was estimated to be 20–30% whereas the update to 2003 using the uniform prior gave proportions of about 40–50% (Table 27). Two additional problems were that the fit to the biomass trawl survey indices CRsumbio were poor, and natural mortality was estimated to be much higher.

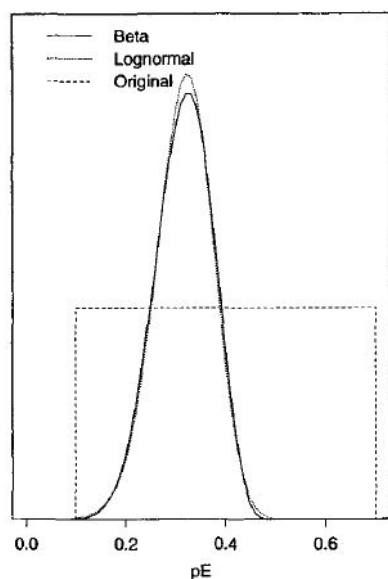
Posterior profile analyses for the 2003 assessment identified that: (i) pE and natural mortality were positively correlated, and (ii) CRsumbio fits better at low values of pE whereas the survey proportions-at-age data (CRsumage, SAautage, SASumage) fitted better at high values of pE.

To address these problem the Hoki Working Group decided to (i) use an informed scaled beta distribution prior on, and (ii) upweight the trawl surveys.

**Table 27: Comparison of MPD estimates from four final runs in the 2002 with analogous runs (the same but for updated data and assumptions – denoted 3.x) for the 2003 assessment (from Francis 2004, table 22).**

Run	Comment	No. of pars	Obj. fn.	<u>B<sub>0</sub> ('000 t)</u>		<u>B<sub>current</sub> (%B<sub>0</sub>)</u>		pE	Mavg
				E	W	E	W		
6.1	from 2002	99	-355.6	302	679	50	34	0.31	0.30
6.2	from 2002	102	-358.2	329	763	49	39	0.30	0.30
6.3	from 2002	102	-389.3	308	1016	41	62	0.23	0.33
propns.at2	from 2002	91	-348.1	337	1581	49	72	0.18	0.33
3.1	like 6.1	114	-327.1	706	843	76	31	0.46	0.39
3.2	like 6.2	117	-322.2	916	937	76	36	0.49	0.40
3.3	like 6.3	117	-332.8	814	783	72	28	0.51	0.36
3.4	like propns-at2	106	-309.2	691	965	67	35	0.42	0.36





**Figure 62: Three priors on pE: the original prior (used in 2002), the transformed lognormal prior from Smith (2003), and the scaled beta prior used in the assessment (from Francis 2004, figure 22).**

### Using a uniform prior

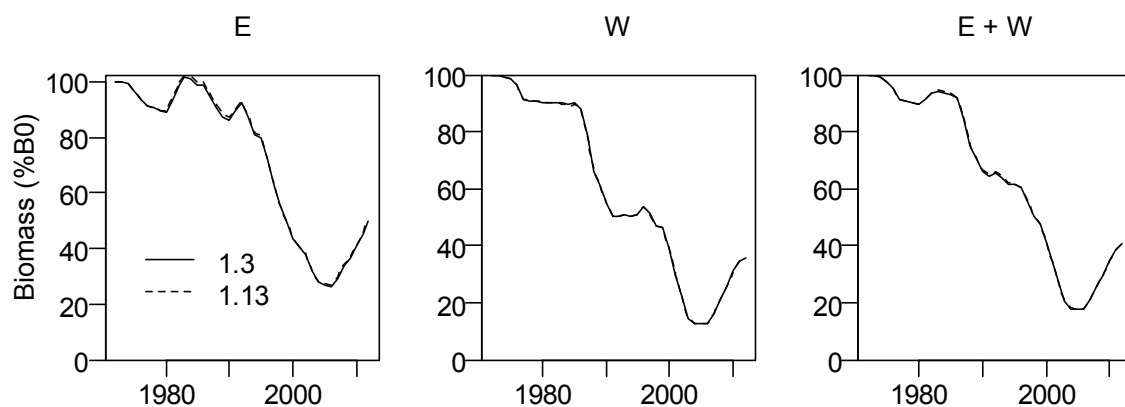
The base run 1.3 from the 2012 hoki assessment uses the scaled beta prior on pE (Table 28). In this model run natural mortality is age dependent, the trawl surveys were upweighted, and adult natal fidelity is assumed. There have been many changes to the hoki stock assessment model since 2003 (Appendix 2), but of particular pertinence is the down-weighting of the proportions-at-age data for the 2012 assessment.

A run 1.13 was done where the scaled beta prior was replaced by a uniform prior on [0.1, 0.7] the run being taken to both the MPD and MCMC stages. The MPD biomass trajectories and natural mortality estimates are very similar between the two runs (Figures 63–64).

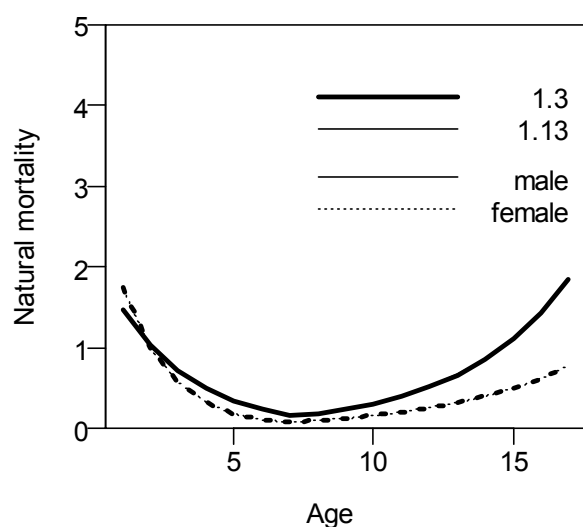
Diagnostics for the run 1.13 MCMC chain are good (Figure 65). The virgin and current biomasses are very similar between the two runs, the most overt change being an increase in the current eastern biomass (Figure 66–67), and an associated slight shift to the right of the pE posterior (Figure 68).

**Table 28: Comparison of key aspects of five final MCMC runs for the 2012 hoki assessment. The base model run is 1.3, the other model runs are sensitivity runs. For all model runs the at-age data is reweighted.**

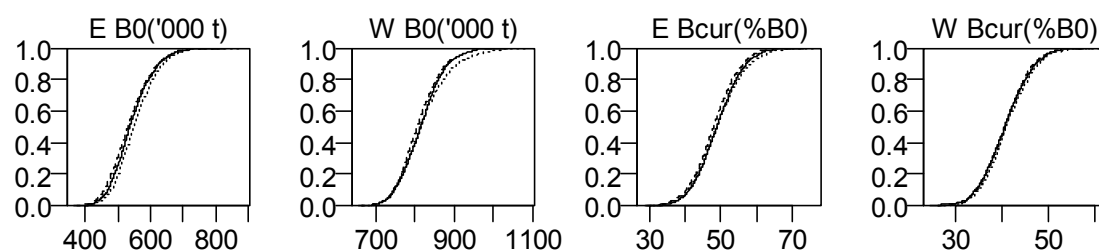
Run	Response to lack of old fish in the observations	Two catchabilities for SAsumbio?	Trawl surveys up-weighted?	Natal fidelity?
1.3	M dependent on age	N	Y	Y
1.8	M dependent on age	08–12 q different	N	Y
1.9	M dependent on age	04–07q different	N	Y
1.4	Domed spawning selectivity	N	Y	Y
1.11	M dependent on age	N	Y	N



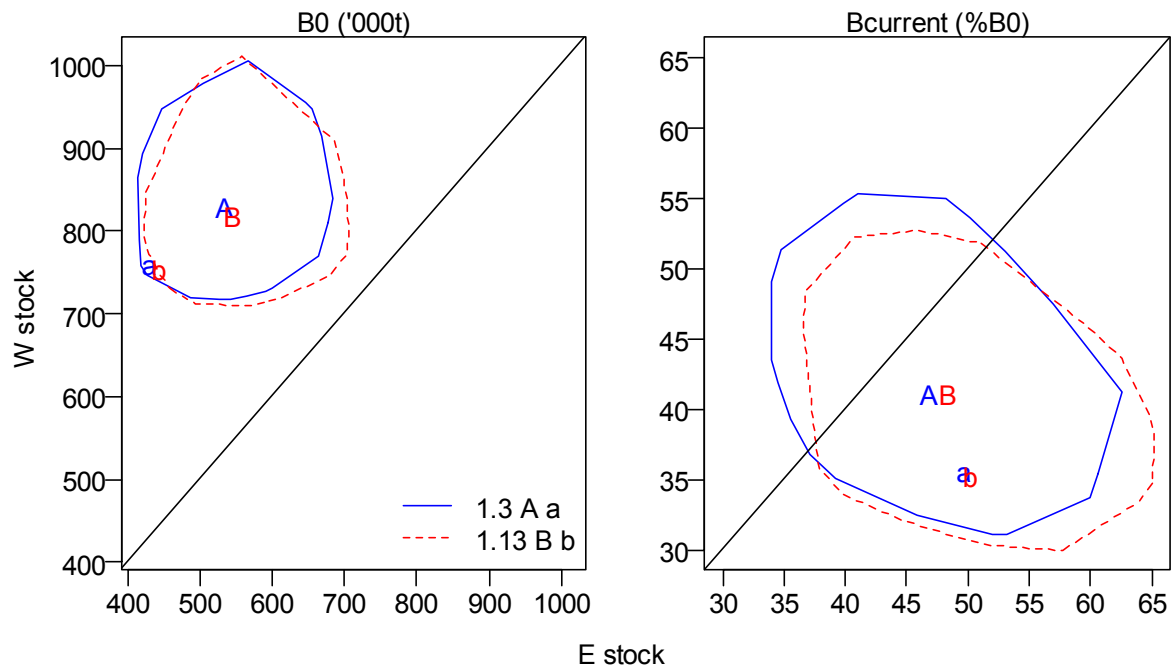
**Figure 63: Comparison of MPD biomass trajectories from different runs: E stock (left column), W stock (middle column), and E + W stocks combined (right column).**



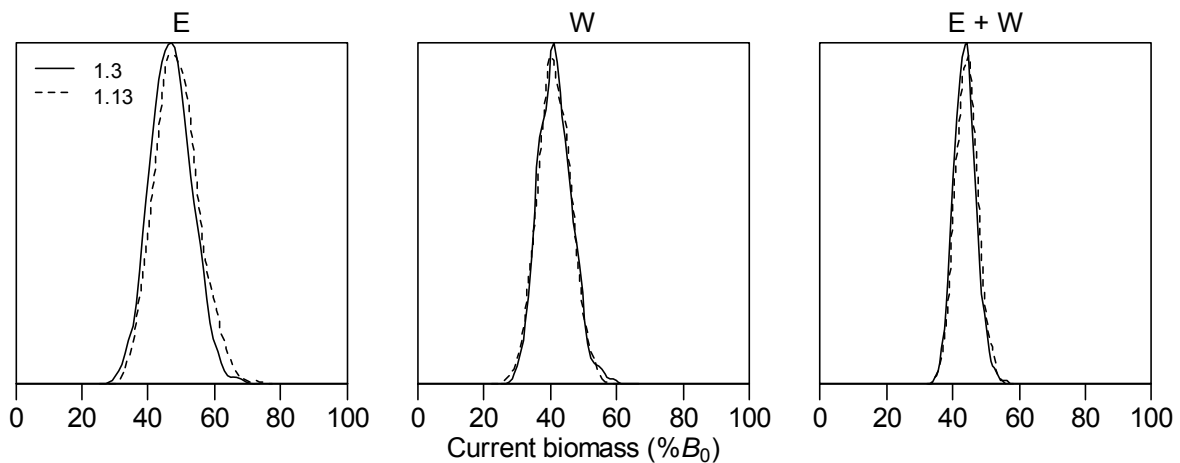
**Figure 64: MPD estimates of age-dependent natural mortality ogives for runs 1.3 and 1.13 for each sex. The lines for 1.3 and 1.13 overlap.**



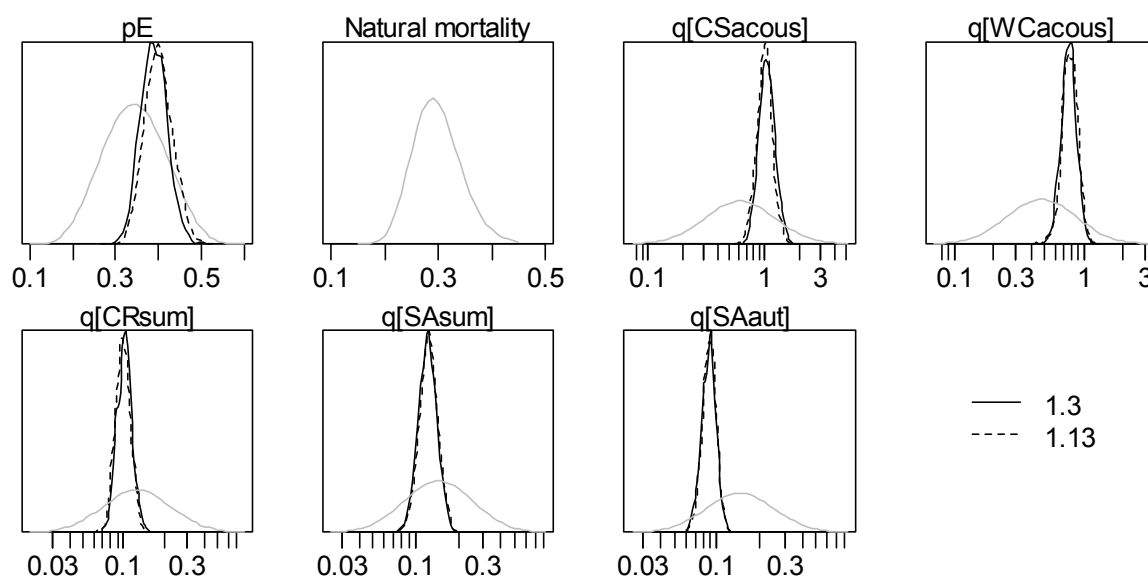
**Figure 65: Diagnostics for MCMC chains for the run 1.13. Each panel contains cumulative probability distributions, for  $B_0$  or  $B_{current}$ , for three chains from the same model run.**



**Figure 66: 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 and 1.13. In each panel the points 'A' and 'B' indicate best estimates (median of the posterior distribution) for these three runs, 'a' and '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 67: 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 run 1.13.**



**Figure 68:** 2012 assessment prior (grey lines) and estimated posterior (black lines) distributions from the two MCMC runs 1.3 and 1.13 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). For run 1.13 the prior for pE is uniform on [0.1, 0.7] (not shown on graphs).

#### **Appendix 4: Prior for pE document**

The report by Smith (2003) documenting the construction of the prior on pE proved particularly difficult to find, so for future reference it is reproduced in this appendix. Thank you to Paul Starr for finding it.

## Fitting a Prior for the Proportion of $B_0$ in the Eastern Stock

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Mary Livingstone and Rosie Hurst were asked to assess their prior views on the proportion of the virgin biomass  $B_0$ , which was contained in the original eastern stock. The views of Mary were obtained first on her own. Later Rosie was asked her views (with Mary present) and then the two came to an agreement about 5 percentiles for  $p$ , the proportion in the eastern stock. Both felt there was effectively 0 probability that the proportion was more than 0.5 and 0 probability that it was less than 0.1. Both experts believed that the prior distribution of  $p$  was left skewed (thicker tail for the smaller values of  $p$ ).

**Table 1: Table of values for  $p$  and their cdf's.**

$x$	0.1	0.2	0.25	0.333	0.37	0.40	0.50
$P(p \leq x)$	0.0	0.01	0.20	0.50	0.80	0.99	1.00

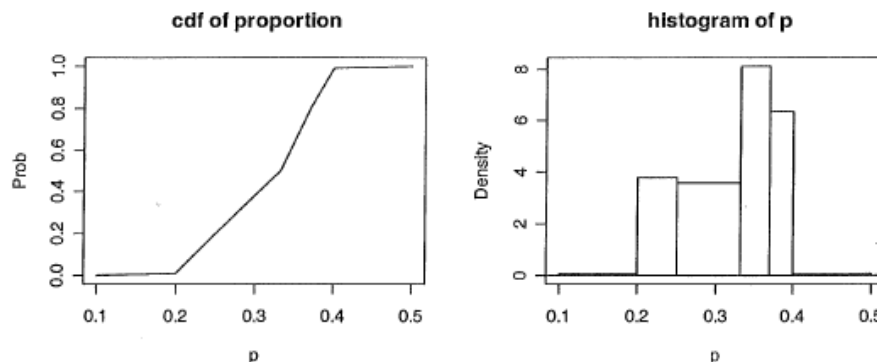
The elicited cdf values imply the histogram for  $p$  given in Table 2.

**Table 2: Histogram of elicited probabilities for  $p$**

Range	0.1 – 0.2	0.2 – 0.25	0.25 – 0.333	0.333 – 0.37	0.37 – 0.4	0.4 – 0.5
Prob	0.01	0.19	0.3	0.3	0.19	0.01

The elicited cdf and histogram are plotted in Figure 1.

**Figure 1: Elicited Prior Distribution**



There are many ways to model an elicited prior distribution. The elicitation process itself involves the uncertainties that the experts have about their own beliefs. Any fitting process should allow for the common situation, which is the case in this exercise, that experts are less certain about the tails of the prior than the central part. In this case they had more confidence in the median value than in the 20-percentiles, which in turn they were more confident about than the 1-percentiles. It is also common for experts to make their tail probabilities too small. This feature is in evidence in the histogram plot in Figure 1. In technical jargon the experts prior is often too platykurtotic (table like). See O'Hagan (1998).

A beta family prior is not very appropriate to model the elicited prior as any member of the beta family centred on a value smaller than 0.5 will be right skewed.

A possible model might be to fit a log-normal probability model to  $1 - p$  as this model would be left skewed (for  $p$ ). As was done for the Hoki mortality prior  $M$  (Hoki Working Group paper 2002/xx) the prior is fitted using a Binomial GLM with a probit link function.

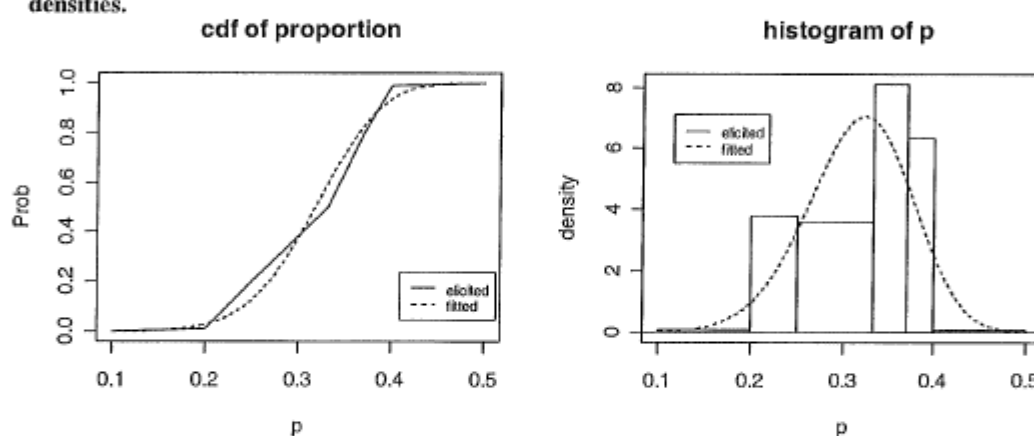
The model for the prior distribution on the proportion NOT in the eastern stock ( $1 - p$ ) is lognormal with parameters

$$\hat{\mu} = -0.3835 \text{ and } \hat{\sigma} = 0.0834.$$

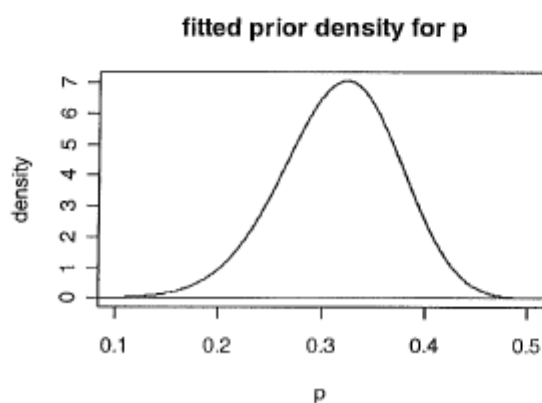
**Table 3: Table of elicited and fitted quantiles for  $p$ .**

quantile	0.01	0.20	0.50	0.80	0.99
elicited	0.20	0.25	0.33	0.37	0.40
fitted	0.173	0.269	0.319	0.365	0.439

**Figure 3: Probability plot with cdf of the fitted model and a histogram with the fitted lognormal densities.**



**Figure 4: Plot of the density of the fitted prior distribution on  $p$**



## Reference

O'Hagan, A. (1998). Eliciting expert beliefs in substantial practical applications. *The Statistician* 47: 21-35.

## Appendix 5: Reweighting the 2013 assessment at-age data

The same procedure as in McKenzie (2013) was used to reweight the at-age data for the model runs 1.1–1.3 giving models 1.4–1.6 respectively. Summary results from the reweighting are shown in the tables and figures below: initial and final effective sample sizes (Tables 29–31), initial effective sample sizes based on the observational error (Figures 69 & 70), and observed and expected ages after reweighting (Figures 71–73).

**Table 29: 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. Initial/Final values are rounded to the nearest integer.**

Stage	Espage	Wspage	EnspOLF	Enspage	WnspOLF	Wnspage	CRsumage	SAsumage	SAautage
Initial	650	902	89	327	80	174	1360	580	829
2	57	33	13	30	96	18	87	12	24
3	63	24	12	32	47	12	83	9	13
4	67	22	12	31	39	10	82	9	12
5	70	21	12	30	37	10	82	9	11
Final	71	21	12	30	36	10	82	9	11
Initial/Final	9	43	7	11	2	17	17	64	75

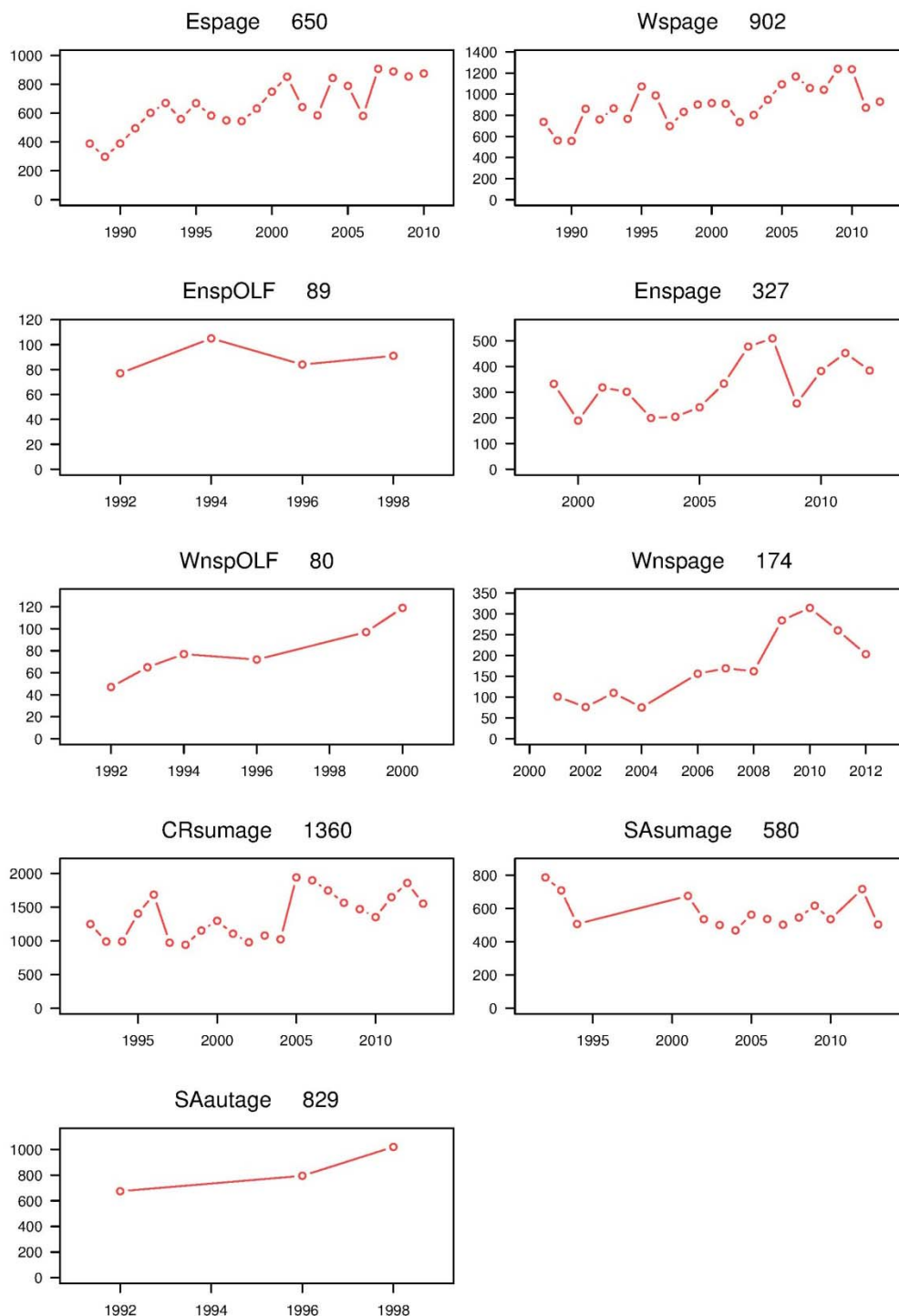
**Table 30: Model run 1.2. Iterative reweighting for multinomial sample sizes using method TA1.8. Shown are the mean values of N for the at age data sets in the model. Initial/Final values are rounded to the nearest integer.**

Stage	Espage	Wspage	EnspOLF	Enspage	WnspOLF	Wnspage	CRsumage	SAsumage	SAautage
Initial	542	744	75	274	66	158	1131	504	772
2	58	35	12	26	99	22	86	11	25
3	61	28	10	27	50	19	59	9	13
4	66	27	10	27	44	19	54	9	12
5	69	27	10	27	43	19	53	9	12
Final	70	27	10	27	44	19	52	9	12
Initial/Final	8	28	8	10	2	8	22	56	64

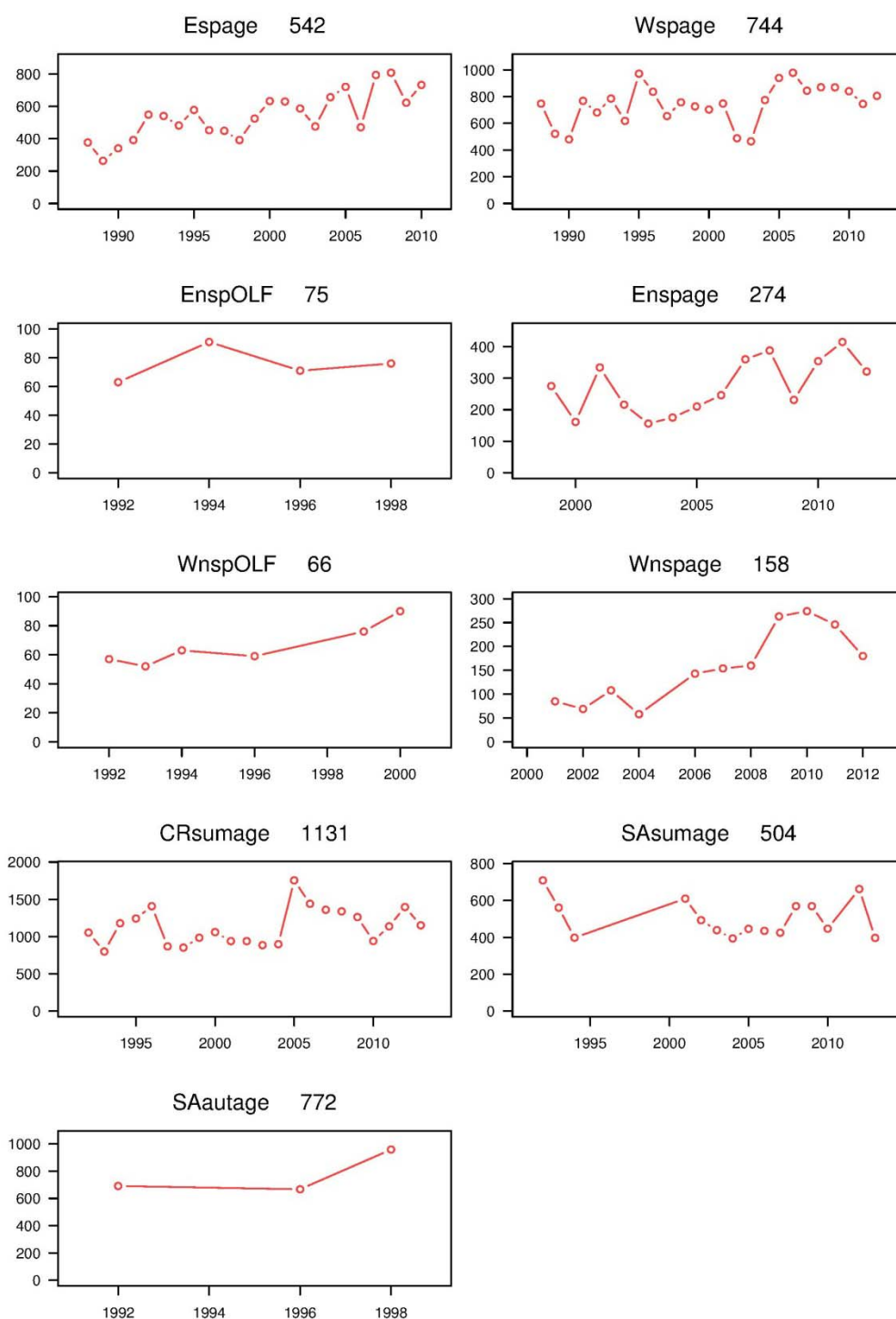
**Table 31: Model run 1.3. Iterative reweighting for multinomial sample sizes using method TA1.8. Shown are the mean values of N for the at age data sets in the model. Initial/Final values are rounded to the nearest integer.**

Stage	Espage	Wspage	EnspOLF	Enspage	WnspOLF	Wnspage	CRsumage	SAsumage	SAautage
Initial	650	902	89	327	80	174	1360	580	829
2	52	27	10	30	56	26	85	12	35
3	56	26	10	32	53	15	69	9	21
4	62	27	10	33	46	13	65	9	18
5	66	28	10	33	45	13	62	8	18
Final	68	28	10	33	45	13	61	8	18
Initial/Final	10	32	9	10	2	13	22	72	46

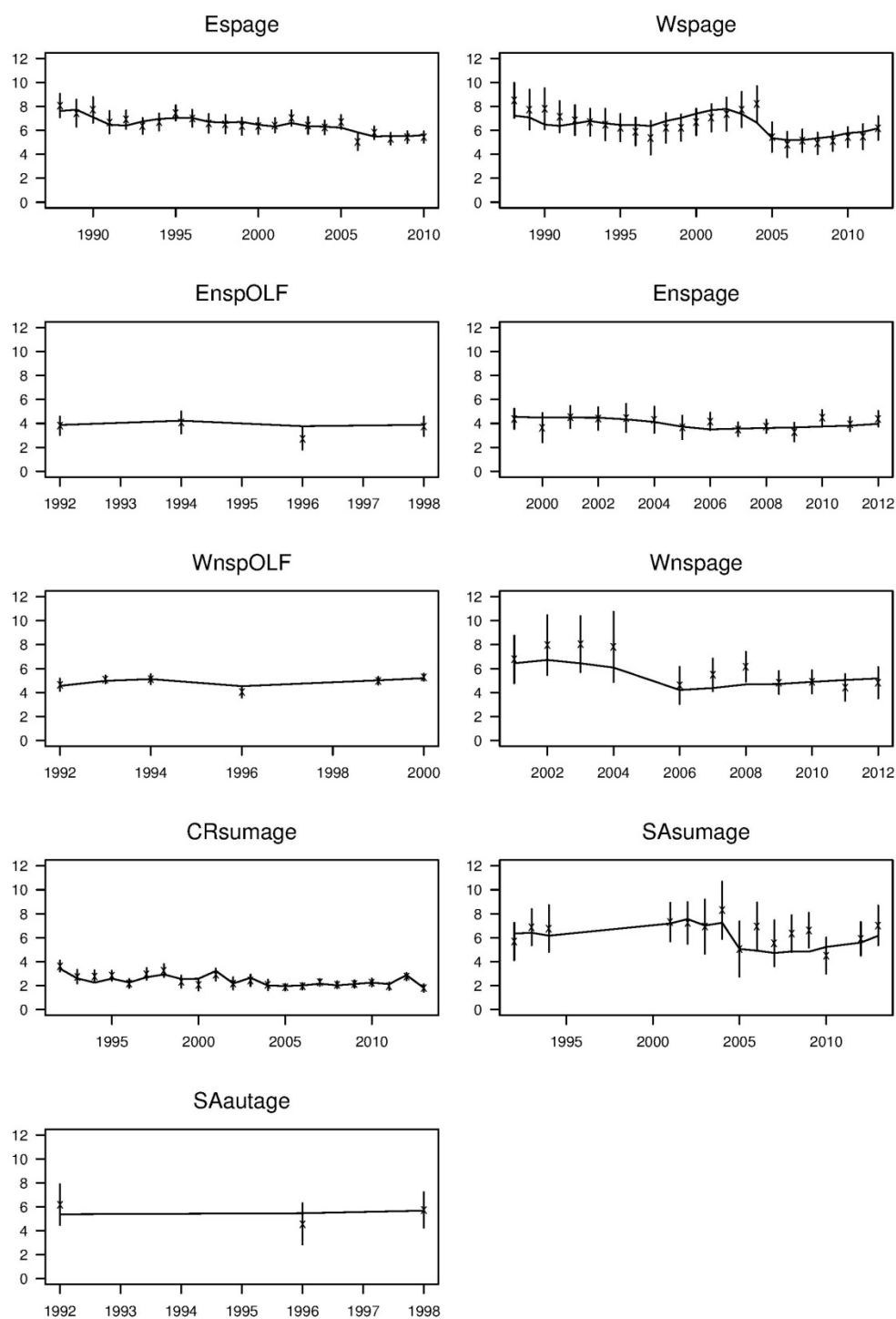




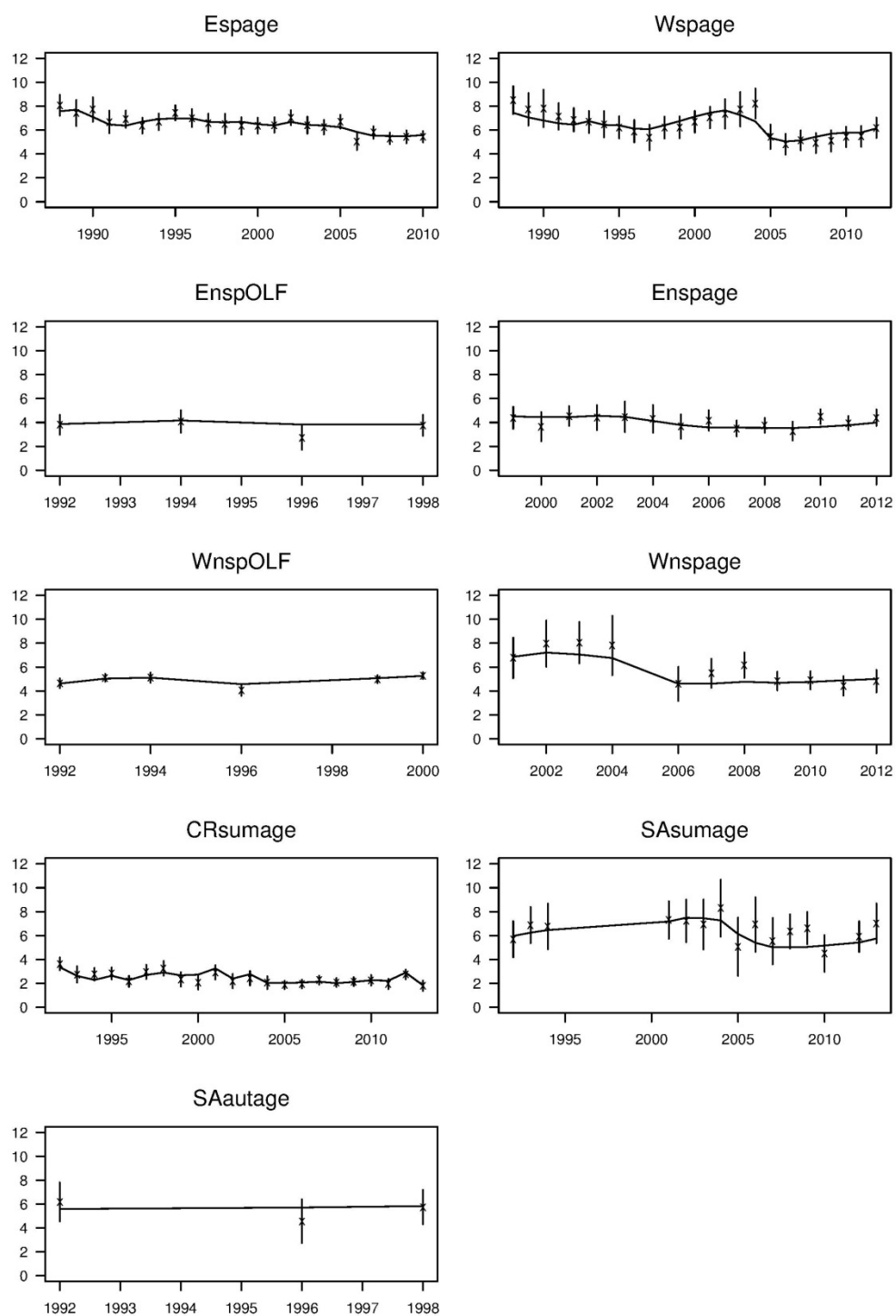
**Figure 69: Model 1.1 and 1.3. Equivalent multinomial N values for the observational error. The number above each panel is the mean value over the fishing years.**



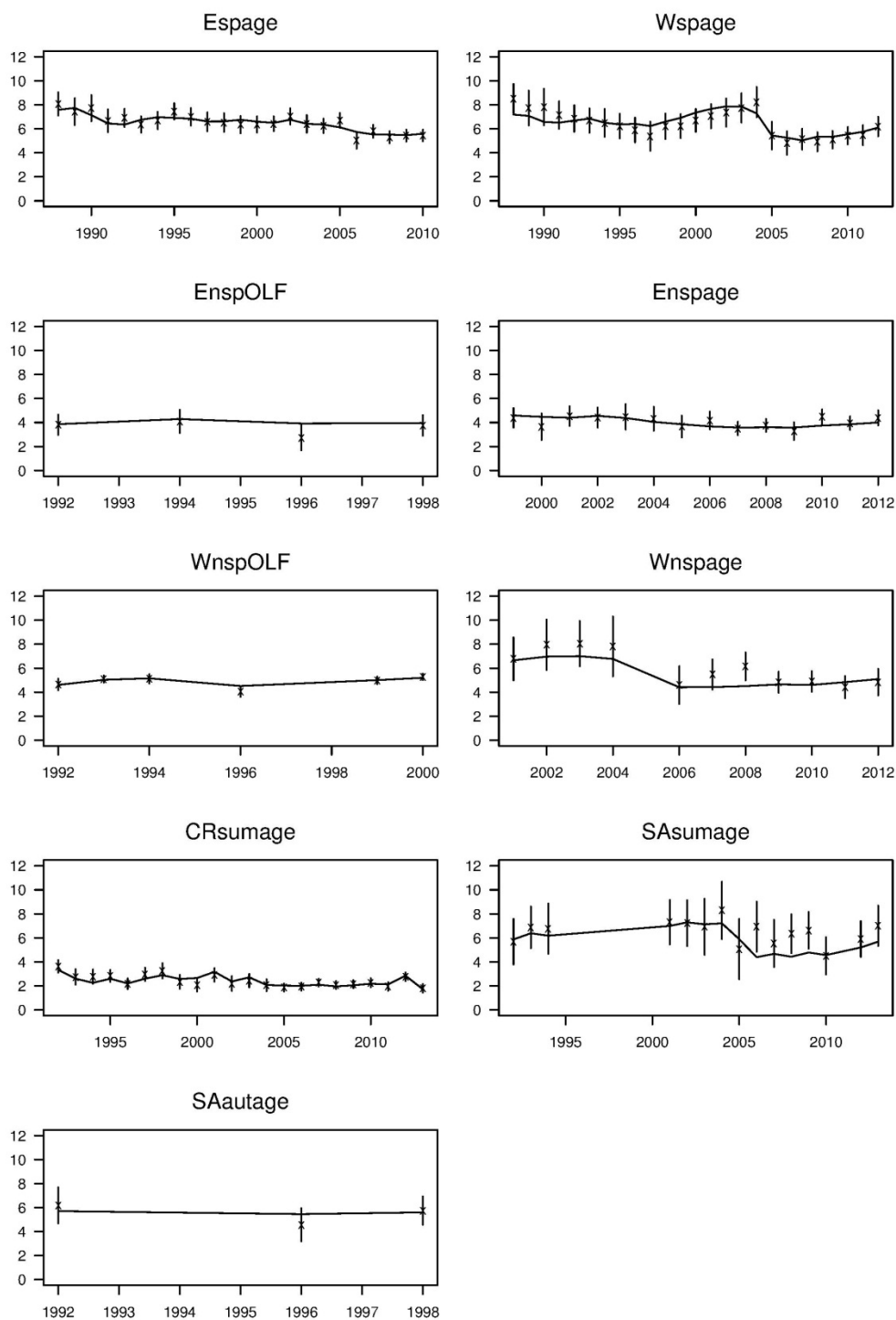
**Figure 70: Model 1.2. Equivalent multinomial N values for the observational error. The number above each panel is the mean value over the fishing years.**



**Figure 71: 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 72: Model 1.2. Observed ('×', with 95% c.i.s. as vertical lines) and expected (lines) for the at-age data sets in run 1.1 after reweighting.**



**Figure 73: Model 1.3. Observed ('×', with 95% c.i.s. as vertical lines) and expected (lines) for the at-age data sets in run 1.1 after reweighting.**