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Assessment of hoki (*Macruronus novaezelandiae*) in 2015

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EXECUTIVE SUMMARY

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An updated assessment is presented for hoki that is based on the 2014 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 index new to this assessment was a research trawl survey from the Southern Plateau in December 2014. New proportions-at-age data came from the four commercial fisheries and the Southern Plateau research trawl survey.

The Deepwater Working Group agreed on a single base model run. In this base model 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. To improve fits to the Southern Plateau survey series two alternative models were investigated where two catchabilities were fitted to the Southern Plateau series instead of just one: (i) a different catchability from other years was used for 2004–07 inclusive, and (ii) a different catchability from other years was used for 2008–15 inclusive. However, it was decided that for a time series of the length of the Southern Plateau series it was not unexpected statistically for there to be a series of years where the biomass was consecutively low or high, and two catchabilities were not needed. Two models were run as sensitivity analyses to the base model: (i) the trawl surveys were upweighted, and (ii) a domed spawning selectivity was used (instead of an age dependent natural mortality).

The western hoki stock is estimated to have increased since about 2006, but is stable or declining in recent years if the trawl surveys are upweighted. The eastern biomass is estimated to have increased since about 2006, but is declining slightly in recent years if a domed spawning selectivity is used.

The western stock is estimated to be 36–69% B_0 and the eastern stock 43–78% B_0 (values are 95% CIs for the base case). 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 in 2010, 2012 and 2013 when it was likely to have been below average (although this is estimated with high uncertainty).

Five-year projections were carried out for the base model and the sensitivity run with upweighted trawl surveys. In the projections, future recruitments were selected at random from those estimated in 2004–2013, and future catches for each fishery were assumed to be equal to those assumed for 2015. Under these projections the eastern and western biomasses are likely to remain stable or decline slightly over the next five years.

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 was increased, with the last increase being to 160 000 t for 2014–15.

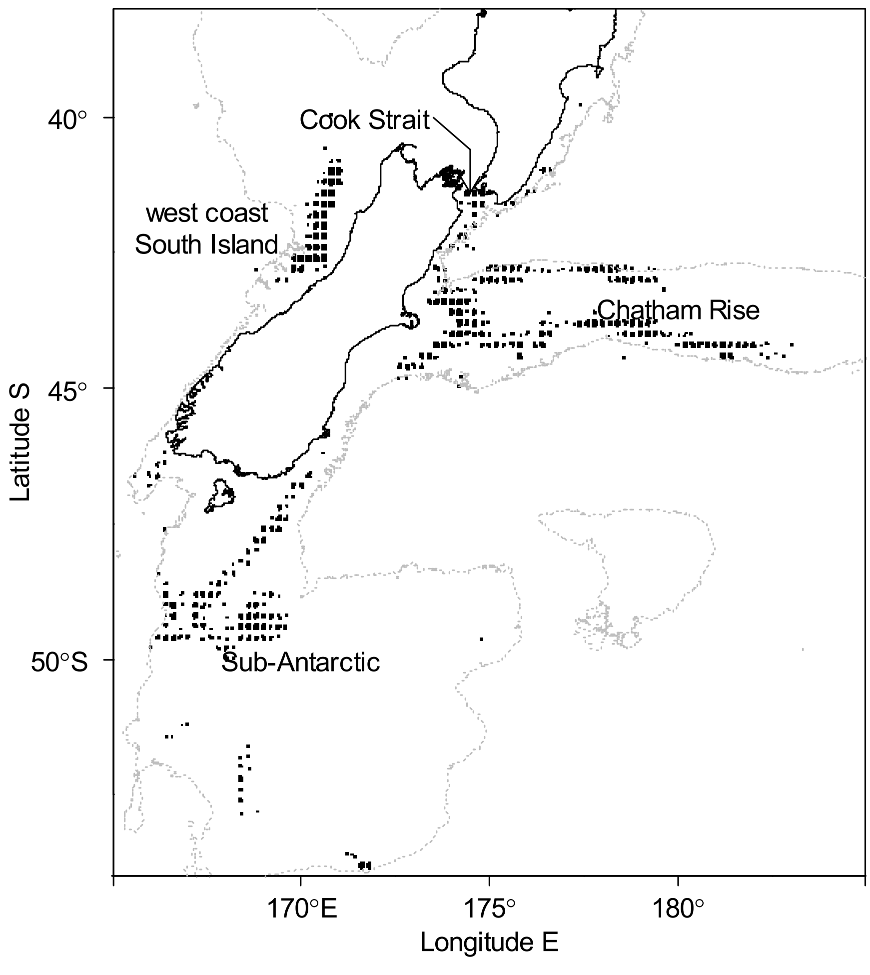


Figure 1: Southern New Zealand showing the main hoki fishing grounds, the 1000 m contour (broken grey line), and the position of all 2013–14 tows from TCEPRs (Trawl Catch and Effort Processing Returns) in which at least 10 t of hoki was caught (dots). Positions are rounded to the nearest 0.2 degrees and jittered.

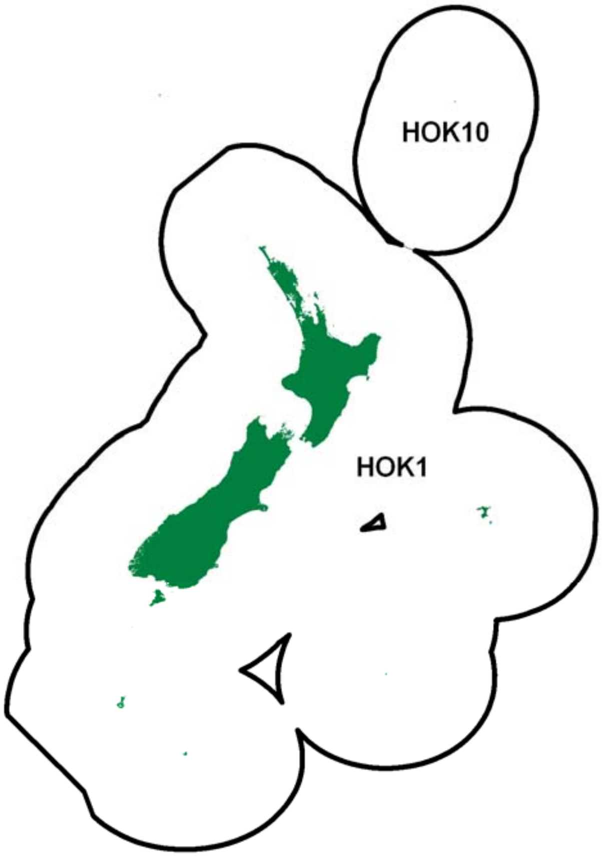


Figure 2: The Quota Management Areas for hoki.

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 2015 assessment of HOK 1, which is the fourteenth hoki assessment to use NIWA's general-purpose stock-assessment model CASAL (Bull et al. 2012). Since the last assessment in 2014 (McKenzie 2015b) there has been another trawl survey on the Southern Plateau in December 2014 (Bagley et al. in draft). Note that the Southern Plateau survey is also referred to as the Sub-Antarctic trawl survey.

The work reported here addresses objective 1 for the 2015 year of the Ministry for Primary Industries project DEE201002HOK: *To update the stock assessment of hoki including estimates of biomass, risk and yields.*

2. MODEL ASSUMPTIONS AND INPUTS FOR 2015

This section provides a summary of all model assumptions and inputs for the 2015 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. One change from the 2014 assessment is that catchability parameters are estimated as free parameters instead of being calculated analytically.

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 4). These runs were used to define the assumptions for the final model runs (Section 5), which were full Bayesian, and whose results provide the formal stock assessment.

The model is based on the fishing year starting on 1 October, which is labelled by its second part, so 1990 refers to the 1989–90 fishing year. This convention is applied throughout, so that, for instance, the most recent Southern Plateau survey, carried out in November–December 2014 is referred to as the 2015 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)
	EnspOLF, WnspOLF	proportions-at-age in catch from given fishery (from OLF[1])
Migrations	Ertn, Wrtn	return migrations of E and W fish from spawning
	Whome	migration of juvenile fish from CR to SA
	Espmg, Wspmg	spawning migrations of E and W fish
Selectivity	Espsl, Wspsl, Enspsl, Wnspsl	selectivity in commercial fisheries
	CRsl, SAsl	selectivity in trawl surveys

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

2.1 Model structure and catches

Two stocks are assessed. Fish from the eastern (E) stock spawn in Cook Strait (CS) and have their home grounds in Chatham Rise (CR); the western (W) stock spawn on the west coast South Island (WC) and have their home grounds in the 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 previous 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 since the 2003 assessment. *M* fraction is the proportion of natural mortality which occurs within the time step. An age fraction of, say, 0.25 for a time step means that a 2+ fish is treated as being of age 2.25 in that time step. The last column ("Prop. mort.") shows the proportion of that time step's mortality that is assumed to have taken place when each observation is made.

Step	Approx. Months	Processes	*M* fraction	Age fraction	Observations Label	Prop. mort.
1	Oct-Nov	Migrations Wrtn: WC–>SA, Ertn: CS–>CR	0.17	0.25	–	
2	Dec-Mar	Recruitment at age 1+ to CR (for both stocks)	0.33	0.60		
		part1, non-spawning fisheries (Ensp1, Wnsp1)			SAsum	0.5
					CRsum	0.6
3	Apr-Jun	Migration Whome: CR–>SA	0.25	0.90		
		part2, non-spawning fisheries (Ensp2, Wnsp2)			SAaut	0.1
					pspawn	
4	End Jun	Migrations Wspmg: SA–>WC, Espmg: CR–>CS	0.00	0.90	–	
5	Jul-Sep	Increment ages	0.25	0.0	CSacous	0.5
		spawning fisheries (Esp, Wsp)			WCacous	0.5

As in the previous 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. In 2014 the TACC was 150 000 t. For the current year (2015), the TACC is 160 000 t with a catch split arrangement for 100 000 t to be taken from the western stock and 60 000 t from the eastern stock.

It is expected that the additional 10 000 t quota for 2015 will be taken from the western stock with estimated catch split as follows (Graham Patchell, pers. comm.): Wnsp1 (10 000 t), Wnsp2 (12 000 t), Wsp (78 000 t). The split in 2015 for the eastern stock amongst the model fisheries (Ensp1, Ensp2, Esp) is expected to the same as in 2014, giving 2015 catches with a total of 60 000 t of: Ensp1 (29 000 t), Ensp2 (12 500 t), Esp (18 500 t).

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 the previous assessment (Table 5).

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

	Fishery						
Year	Ensp1	Ensp2	Wnsp1	Wnsp2	Esp	Wsp	Total
1972	1 500	2 500	0	0	0	5 000	9 000
1973	1 500	2 500	0	0	0	5 000	9 000
1974	2 200	3 800	0	0	0	5 000	11 000
1975	13 100	22 900	0	0	0	10 000	46 000
1976	13 500	23 500	0	0	0	30 000	67 000
1977	13 900	24 100	0	0	0	60 000	98 000
1978	1 100	1 900	0	0	0	5 000	8 000
1979	2 200	3 800	0	0	0	18 000	24 000
1980	2 900	5 100	0	0	0	20 000	28 000
1981	2 900	5 100	0	0	0	25 000	33 000
1982	2 600	4 400	0	0	0	25 000	32 000
1983	1 500	8 500	3 200	3 500	0	23 300	40 000
1984	3 200	6 800	6 700	5 400	0	27 900	50 000
1985	6 200	3 800	3 000	6 100	0	24 900	44 000
1986	3 700	13 300	7 200	3 300	0	71 500	99 000
1987	8 800	8 200	5 900	5 400	0	146 700	175 000
1988	9 000	6 000	5 400	7 600	600	227 000	255 600
1989	2 300	2 700	700	4 900	7 000	185 900	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	28 400	14 700	9 100	6 600	15 400	55 800	130 000
2013	29 900	11 800	6 500	7 600	18 600	57 200	131 600
2014	27 200	11 700	10 600	9 300	17 300	70 200	146 300
2015	29 000	12 500	10 000	12 000	18 500	78 000	160 000

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 prorated 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[1]	Ensp1	Ensp2	Ensp2

[1] no area stated

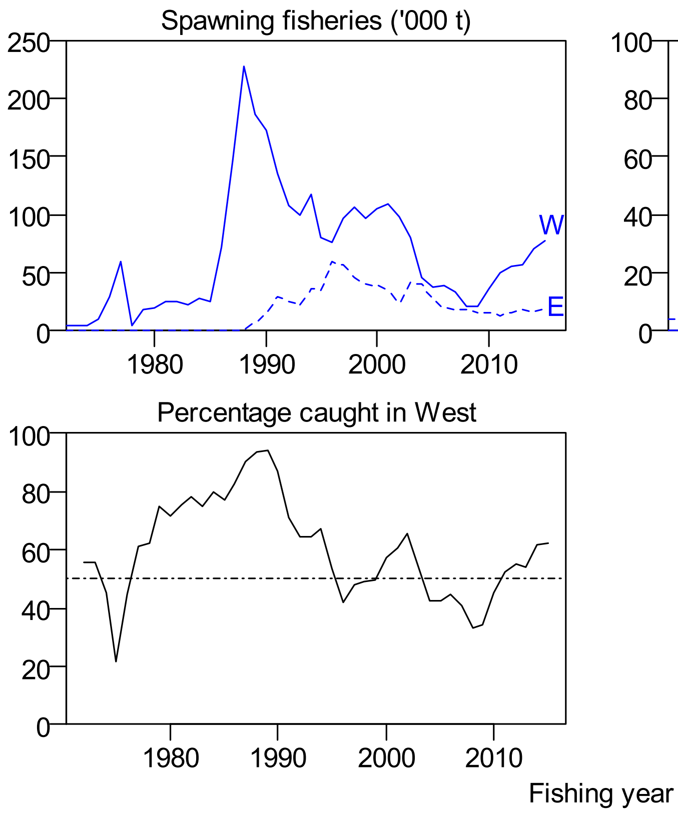


Figure 3: Annual catches by fishery for the spawning (top left panel) and non-spawning (top right panel) fisheries, and annual percentage of catch caught in western fisheries (Wsp, Wnsp1, Wnsp2) (bottom panel).

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

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

2.2 Ogives

The nine ogives used in the model are the same as in the previous assessment: four fishery selectivity ogives (one for each of the four fisheries: Espsl, Wspsl, Enspsl, Wnspsl), two trawl survey ogives (in areas CR and SA: CRsl, SAsl), and three migration ogives (for migrations Whome, Espmg, and Wspmg). 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 (Francis 2005, p. 11). In the first, the spawning selectivities (Espsl, Wspsl) are logistic, but natural mortality is allowed to vary with age (e.g., run 1.1). Alternatively, the spawning selectivities are domed, with natural mortality the same for all ages (i.e., run 1.6). 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 5 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	Ogive type	Description	Constraints
1.1	Spawning selectivity	Length-based, logistic	Same for M and F, same for E and W
	Non-spawning selectivity	Length-based, double-normal	Same for M and F, must be domed[1]
	Survey selectivity	Length-based, double-normal	Same for M and F, must be domed[1]
	Spawning migration	Free, ages 1–8	$O_{8,M,E} = O_{8,M,W}$, $O_{8,F,E} = O_{8,F,W} \geq 0.6$ $O_A=O_8$ for $A > 8$
	Home migration	Free, ages 1–7	Same for M and F, =1 for age > 7
1.6	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

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

As in previous years, the model attempted to estimate annual changes in Wspsl (the selectivity ogive for W spawning fishery). Following the recommendation of Francis (2006), these changes were restricted to years for which there were Wspage data (i.e., from 1988 onwards). The changes were driven by the median day of the fishery, 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 Wspsl. 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 2015).

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	2013	2014	Mean
298	300	301	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 Haist parameterisation of recruitment was used in final model runs (Bull et al. 2012, p. 32). Thus, recruitment at age 1 in year *y* in each stock was given by

$$R_y = R_0 \times \mathrm{YCS}_{y-2} \times \mathrm{SR}(\mathrm{SSB}_{y-2}),$$

where YCS_y is the year-class strength for fish spawned in year *y*, SR is a Beverton-Holt stock-recruit relationship with assumed steepness 0.75 (Francis 2009, p. 23), and SSB_y is the mid-season spawning stock biomass in year *y*.

Thirty-nine YCSs were estimated for each stock, for 1975 to 2013, inclusive. YCSs for the initial years (1970 to 1974) were fixed at 1. The E and W YCSs for 2013 were constrained (by a penalty function) to be equal for MPD runs, with the constraint removed for full Bayesian runs (Francis 2006, p. 9).

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 (Francis et al. 2003, p. 11). 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). The ageing error was estimated from replicate ageing data in a simple ageing model (Francis 2003, p. 10; Francis 2004, p. 12).

2.4 Observations

Three types of observations were used in the model: biomass indices (Table 8), proportions-at-age (by sex) (Table 9, Figure 4), and proportion spawning (Table 10). The biomass index new to this assessment is from a Southern Plateau trawl survey in December 2014 (Stevens et al. 2015).

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

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

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

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

	CRsumbio	SAsumbio	SAautbio	CSacous	WCacous
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 (–,0.28)
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)	–	225 (–,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)	–	359 (–,0.39)	–
2010	98 (0.15,0.25)	65 (0.16,0.26)	–	–	–
2011	94 (0.14,0.24)	–	–	298 (0.18,0.35)	–
2012	88 (0.10,0.22)	46 (0.15,0.25)	–	**–**	412 (–,0.34)
2013	124 (0.15,0.25)	56 (0.15,0.25)	–	353 (–,0.30)	357 (–,0.35)
2014	102 (0.10,0.22)	**–**	–	–	–
2015	–	**31 (0.13,0.24)**	–	–	–

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

Area	Label	Data type	Years	age data
WC	Wspage	Catch at age	1988–**14**	otoliths
SA	WnspOLF	Catch at age	1992–94, 96, 99–00	OLF
	Wnspage	Catch at age	2001–04, 06–**14**	otoliths
	SAsumage	Trawl survey	1992–94, 2001–10, 12, 13, **15**	otoliths
	SAautage	Trawl survey	1992, 96, 98	otoliths
CS	Espage	Catch at age	1988–**14***	otoliths
CR	EnspOLF	Catch at age	1992, 94, 96, 98	OLF
	Enspage	Catch at age	1999–**14**	otoliths
	CRsumage	Trawl survey	1992–14	otoliths

* 2011, 2012, 2013 values not included in model runs as they are not considered representative of the commercial fishery.

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).

	Age						
Year	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.

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

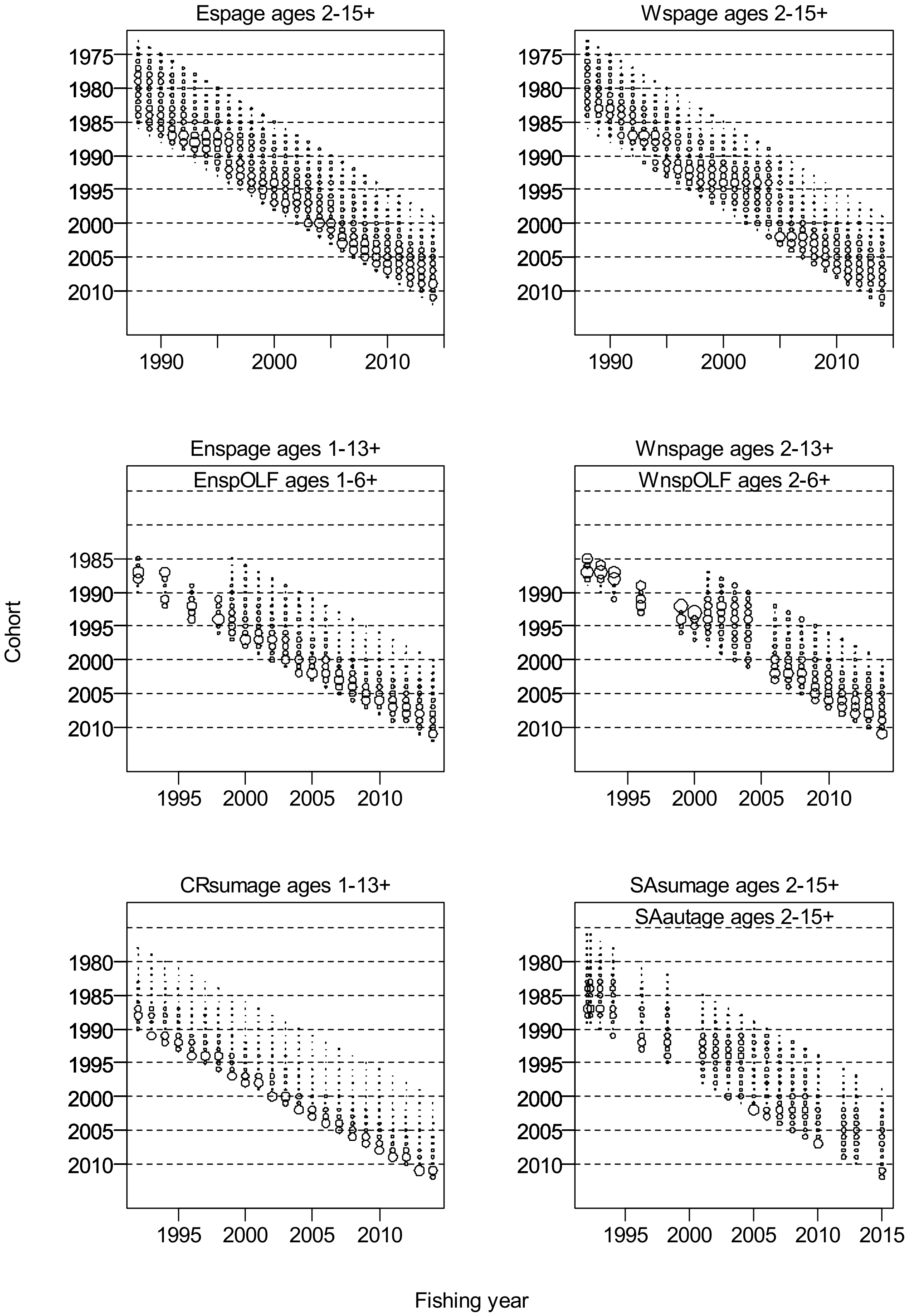


Figure 4: Proportions-at-age data, plotted by cohort and fishing year, with both sexes combined. The area of each circle is proportional to the associated proportion at age. Circle positions for the SAautage data in 1992 have been offset horizontally to allow them to be plotted on the same panel as the 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 (2011a) the weighting of data in stock assessments was explored and one of the conclusions drawn was that proportions-at-age data are often over-weighted in assessments. 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 current 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 total 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 initial model runs (see below) it was decided to upweight some trawl biomass indices by using their observation, rather than total, CVs. For the final model run there was no upweighting of the trawl biomass indices.

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 155 (for runs where age-varying natural mortality is estimated) or 133 (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 (Francis 2003 p. 34, Smith 2003, 2004, Appendix 3 of McKenzie 2015a), constant natural mortality (Smith 2004), and age-varying natural mortality (Cordue 2006, Francis 2008 p. 17). 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)). For year class strengths lognormal priors were used with a mean of one and CV of 0.95 (Francis 2004, p. 32).

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 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.

		Distribution			No. of
Parameter(s)	Description	Type	Parameters		parameters
log_B0_total	$\log(B_{0,E} + B_{0,W})$	uniform	12.6	16.2	1
B0_prop_stock1 (=pE)	$B_{0,E}/(B_{0,E} + B_{0,W})$	beta[0.1,0.6][a]	0.344	0.072	1
recruitment.YCS	year-class strengths	lognormal[b]	1	0.95	78
q[CSacous].q	catchability, CSacous	lognormal	0.77	0.77	1
q[WCacous].q	catchability, WCacous	lognormal	0.57	0.68	1
q[CRsum].q	catchability, CRsumbio	lognormal	0.15	0.65	1
q[SAsum].q	catchability, SAsumbio[c]	lognormal	0.17	0.61	1
q[SAaut].q	catchability, SAautbio	lognormal	0.17	0.61	1
natural_mortality	M_{male} & M_{female} ages 1–17	uniform	various		8,0
natural_mortality.all	M	lognormal	0.298	0.153	0,1
process error 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	Espsl,Wspsl,Enspsl,Wnspsl	uniform	various		8,9
surv. selectivities	CRsl, SAsl	uniform	various		6
					155,133

[a] This is a beta distribution scaled to have its range from 0.1 to 0.6, rather than the usual 0 to 1
[b] In one run a uniform prior was used
[c] 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.

For the 2003 assessment update a uniform prior was used for pE. However in the update to the 2003 assessment 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 of McKenzie 2015a).

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 runs, but it has little impact on the results) (Section 2.3). The third use of penalty functions was to link the spawning migration ogives for the two stocks (according to 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 it 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 2.7 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 make 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 separately.

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. PRE-ASSESSMENT MODEL RUNS

In this section we perform analyses using the previous assessment model from 2014 which uses just the data up to 2014. In particular we explore differences between MPD and MCMC estimates of virgin biomass, and the impact of fixing parameters in MCMC model runs.

3.1 Difference between MPD and MCMC estimates of virgin biomass

3.1.1 Background

At the end of 2014 the status of follow-up work to the hoki review was examined (Butterworth et al. 2014, McKenzie 2014). Of the recommended items to follow-up on, it was decided to look at the difference between MPD and MCMC estimates of initial virgin biomass (see the recommendation R–11 below).

R-11. *Examine the impact of selectivity (and other, e.g.* B_{mean}*) parameter specifications between MPD and MCMC runs.*

The Panel was concerned about the MPDs being near the edge (for critical parameters) of the credible intervals from the posterior distributions, and hence recommends that the reason for this be investigated and presented. For example, the two posterior samples provided indicated that a number of selectivity parameters were held fixed in the sampling of the posterior distribution, but were apparently estimated for the MPD runs. Documenting these characteristics of the assessment could be improved, and in instances when the MPD is near the credible limits some presentation on how this has occurred would be useful. This is considered important because MPD results are often presented and used for data weighting, and for the model selection process leading to the final MCMC base case set that is used to provide advice.

Note that in the hoki assessment reports it is explicitly mentioned that migration and selectivity parameters that hit bounds are held fixed in MCMCs in order to improve convergence, and tables are given showing which parameters are fixed and at what values. In the following we explore why MPD estimates for critical parameters (i.e. virgin biomass) lay near the bounds for credible intervals of the corresponding MCMC. First we look back at past assessments to see if this gives some insight as to why this occurs. Then we look at base run 1.11 from the 2014 assessment in more detail.

In the results that follow it is clear why the MPD and MCMC estimates of initial virgin east and west biomass differ. This is because the MCMC estimate of *total* virgin biomass (east and west stock combined) is higher than the MPD estimate. Just why this happens in the MCMC is unclear, but may be related to the year class strength estimates.

3.1.2 Differences in estimates from previous assessments

In this section we track back through previous assessments to discern when a separation between MPD and MCMC results began. We follow back the base model run 1.11 from the 2014 assessment, a model in which there was age-varying natural mortality (in contrast to the main other type of model where a domed spawning selectivity is used instead) and a single catchability for the Southern Plateau trawl survey.

Initial and current biomass estimate graphs for the assessments from 2006 to 2014 are shown in Figures 5–13. Each graph shows a number of model runs, only one of which is a predecessor to run 1.11 from the 2014 assessment. The number in brackets that follows the year of the assessment refers to the model run that is the predecessor. For example for the 2013 assessment, model run 1.7 is the predecessor to the 2014 assessment run (see Figure 6). In all the model runs shown the migration and selectivity parameters that hit bounds are fixed at these (see the associated tables in the assessment reports).

Although there have been a number of changes in the assessment model since 2006 (Appendix 2), there are some consistent themes across the graphs. Concentrating on the critical quantity B_0, the main points to note are:

a. For both east and west stocks, the MPD estimates of virgin biomass have always been less than the MCMC median estimates.

b. This separation between MPD and MCMC median virgin biomass estimates became more pronounced when the at-age data was reweighted in 2012 (Appendix 1). More pronounced in the sense that instead of MPD estimates lying inside the 95% confidence interval (Figure 8), they end up on the 95% confidence interval boundary line (Figure 7).

c. When a domed spawning selectivity is used (instead of an age varying natural mortality) there is a different trend between east and west B_0 estimates. In all of the model runs the east stock MPD estimate of B_0 is lower, but there is no consistent pattern for the west stock.

In the next section we look at the base model from the 2014 assessment (run 1.11) in more detail to try to understand why this occurs.

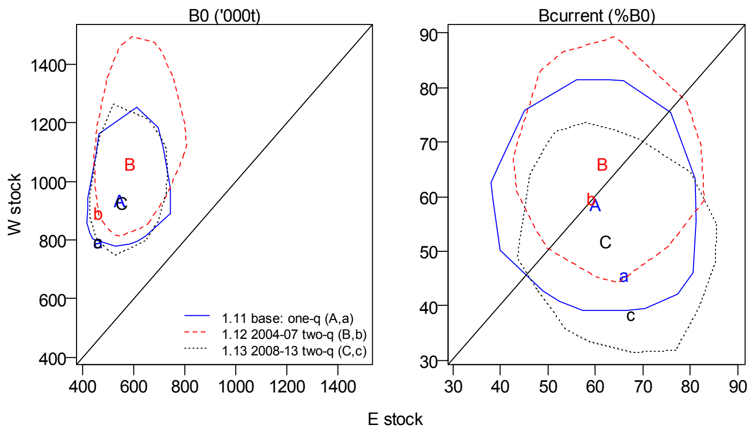


Figure 5: 2014 assessment (1.11). The other two runs (1.12, 1.13) use two catchabilities for the Southern Plateau summer trawl. Estimates and approximate 95% confidence intervals for virgin (B_0) and current ($B_{current}$ as %B_0) biomass by stock for the three runs 1.11, 1.12, and 1.13. In each panel the points 'A', 'B', 'C' indicate best estimates (median of the posterior distribution) for these three runs, 'a', 'b', 'c' are the MPD estimates, and the polygons (with solid, broken and dotted lines, respectively) enclose approximate 95% confidence intervals. Diagonal lines indicate equality (y = x).

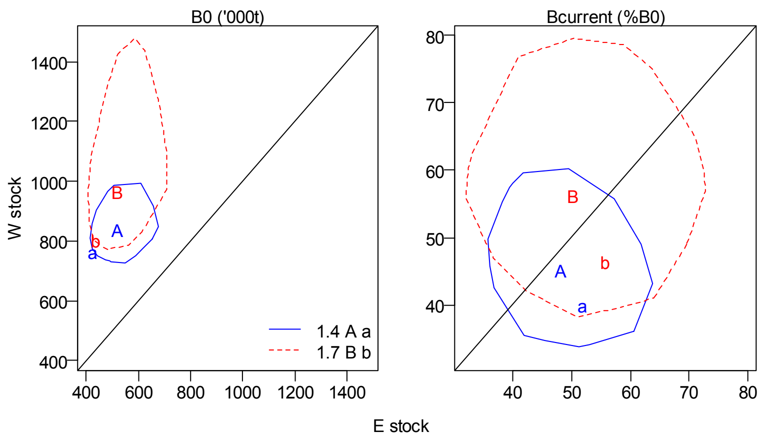


Figure 6: 2013 assessment (1.7). The other run (1.4) is a continuity run which differs in that the trawl surveys are upweighted.

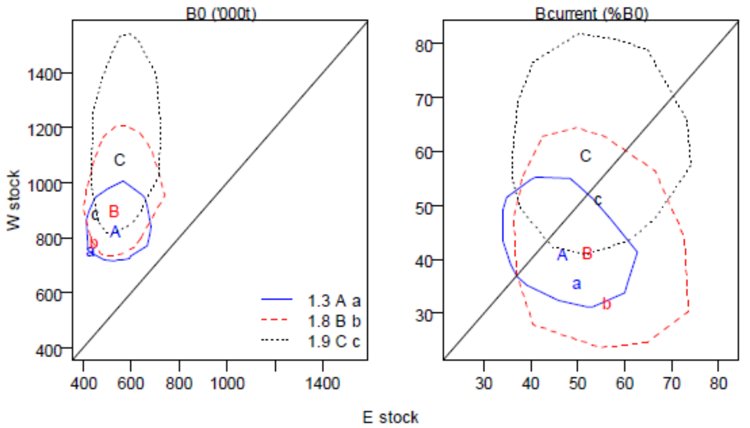


Figure 7: 2012 assessment (run 1.3). The other two runs (1.8, 1.9) use two catchabilities for the Southern Plateau summer trawl.

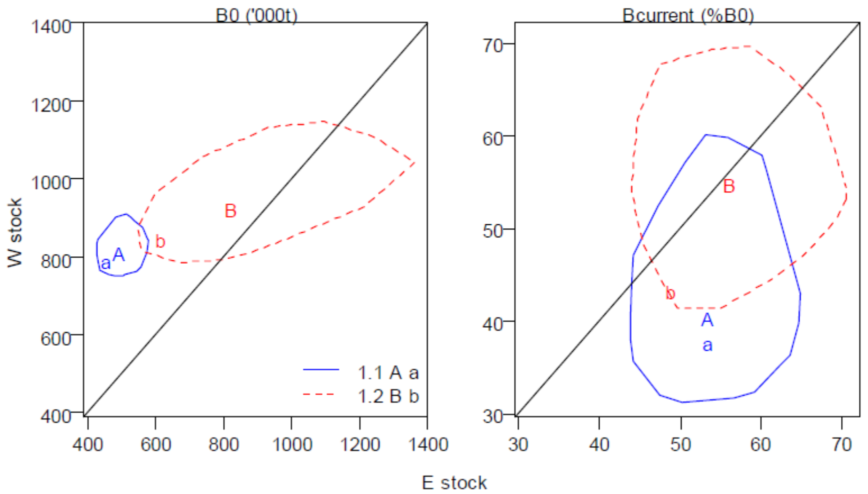


Figure 8: 2011 assessment (1.1). The other run (1.2) uses a domed spawning selectivity (instead of age varying natural mortality).

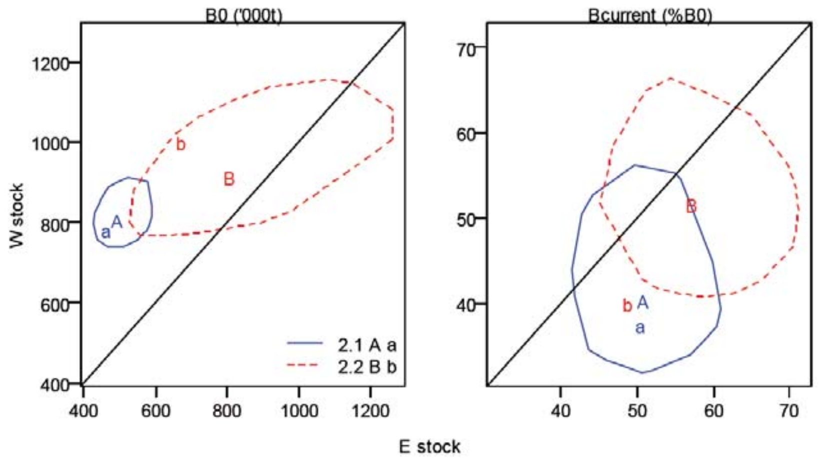


Figure 9: 2010 assessment (run 2.1). The other run (2.2) uses a domed spawning selectivity (instead of age varying natural mortality).

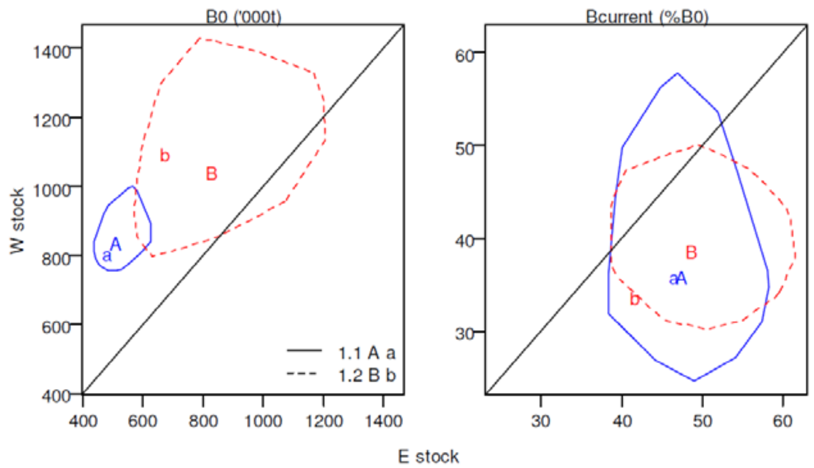


Figure 10: 2009 assessment (1.1). The other run (1.2) uses a domed spawning selectivity (instead of age varying natural mortality).

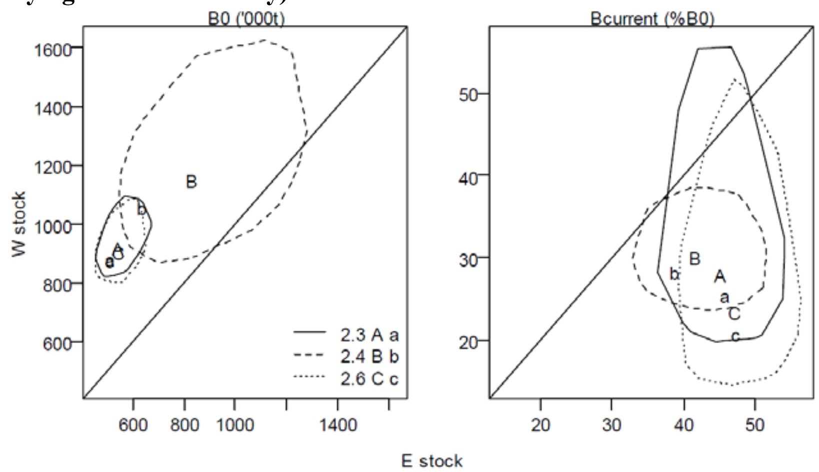


Figure 11: 2008 assessment (2.3). The other run 2.4 uses a domed spawning selectivity (instead of age varying natural mortality), and in 2.6 the last Southern Plateau summer trawl survey is dropped.

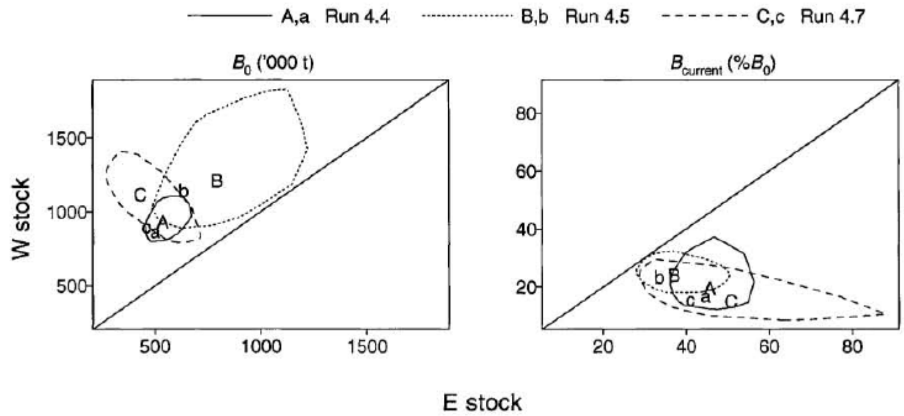


Figure 12: 2007 assessment (4.4). The run 4.5 uses a domed spawning selectivity (instead of age varying natural mortality), and in 4.7 natal fidelity is not assumed and both trawl and acoustic biomass indices are upweighted.

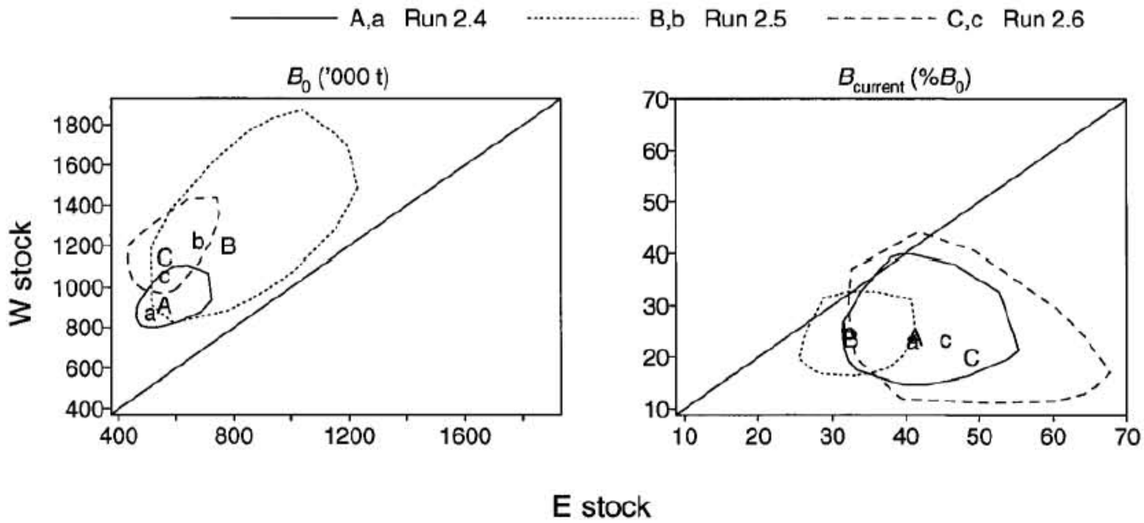


Figure 13: 2006 assessment (2.4). The model run 2.5 uses a domed spawning selectivity, and run 2.6 is the similar to 2.4 except that natal fidelity is not assumed.

3.1.3 Detailed exploration of model run 1.11 from the 2014 assessment

We now look at the base run 1.11 from the 2014 assessment to explore reasons why the MPD and MCMC results for virgin biomass differ. Before this, some explanation is needed as to how the virgin biomass is parameterised in this model. While the plots in the previous section show virgin biomass for the east and west stocks, what is actually estimated in the model is the log of the total virgin biomass (east and west stock combined) and a parameter for estimating what proportion of this total is in the eastern stock. To summarise, the relevant estimated parameters are:

1. log_B0_total. The log of the total virgin biomass (east and west combined). This has a uniform prior from 12.6 to 16.2.

2. pE. The proportion of the total virgin biomass that is in the east stock. This has an informed beta prior.

We first compare the posterior profiles on log_B0_total for the MPD and MCMC model setups. The model setup for the MCMC differs from that for the MPD in two ways: (i) migration or ogive parameters that hit bounds are set at the bounds for the MCMC, and (ii) the east and west equality penalty for the 2012 YCS estimate is dropped for the MCMC. These changes should make little difference to the posterior profile on log_B0_total. Comparing the two posterior profiles shows that they are very similar with both having a minimum at the MPD estimate, this being less than the MCMC median (Figures 14 and 15).

The MPD estimate for log_B0_total is located in the left-tail of the MCMC posterior, while for pE the MPD and MCMC median match (Figures 16–18). This explains why the both east and west stock estimates of virgin biomass are less for the MPD estimates compared to the MCMC median: log_B0_total is estimated to be less in the MPD.

Why this happens is unclear. Objective function values from the chain are higher than for the MPD, so the MPD does not appear to be at a local minimum (Figure 19). The trace for the prime parameter of interest, log_B0_total, displays some correlation, but is otherwise unexceptional (Figure 20). For other parameters the traces mostly look satisfactory except for four (Appendix 3): (a) proportion of male and females of age 1 that undertake a western spawning migration (two parameters in total), (b) the tail of the eastern non-spawning commercial fishery selectivity, and (c) the peak for the eastern spawning commercial fishery.

The MCMC median values are compared to the MPD values for all parameters as a ratio in Figure 21. MCMC estimates of east and west YCS are nearly double the values in the MPD. Note that these YCS estimates are before they are re-scaled via the Haist parameterisation (which involves dividing by their mean value over some defined years). Other parameters with a ratio greater than 1.25 are: (a) migration proportions for 1, 2, 3, and 5 year old juvenile male fish from the Chatham Rise to the Southern Plateau, (b) three parameters for the western/eastern spawning migration of 1 or 2 year old fish, and (c) a limb parameter for the Chatham Rise trawl survey selectivity. A similar pattern is seen if the MCMC mode values are compared to the MPD values (Figures 22), and likewise if the posterior MCMC density for the some of the east YCSs are compared to the MPD estimates (Figures 23–24).

Further investigations may illuminate why the MPD and MCMC estimates of log_B0_total differ, but the Deepwater Working Group felt that this was not worth pursing further.

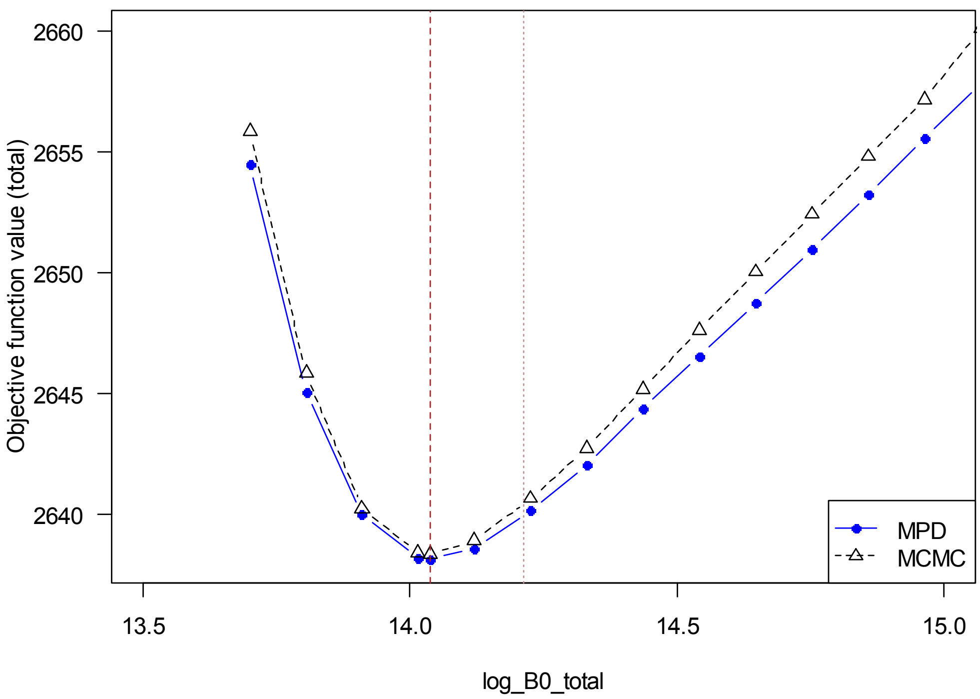


Figure 14: Posterior profile on the estimated parameter log_B0_total. For the MPD model run 1.11, and the corresponding MCMC model set up (with fixed values for migration and ogive parameters that hit bounds, and removal of the equality penalty for the last estimated YCS removed). The vertical dashed line shows the MPD estimate for log_B0_total, the vertical dotted line median value from the posterior for the MCMC.

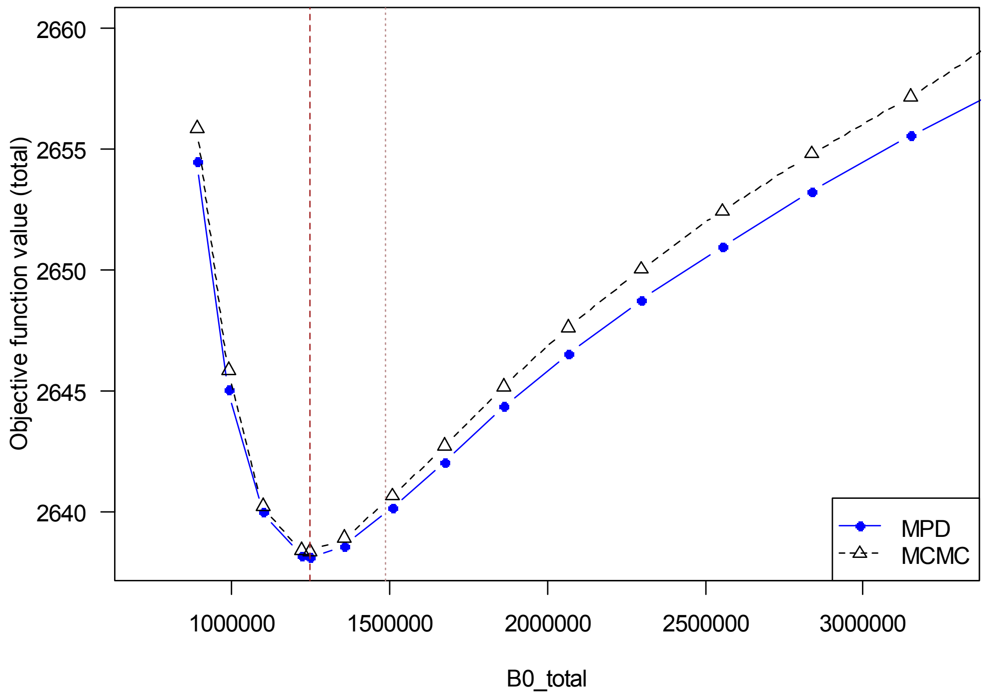


Figure 15: As in Figure 14, but with the x-axis rescaled to be in terms of B0_total instead of log_B0_total.

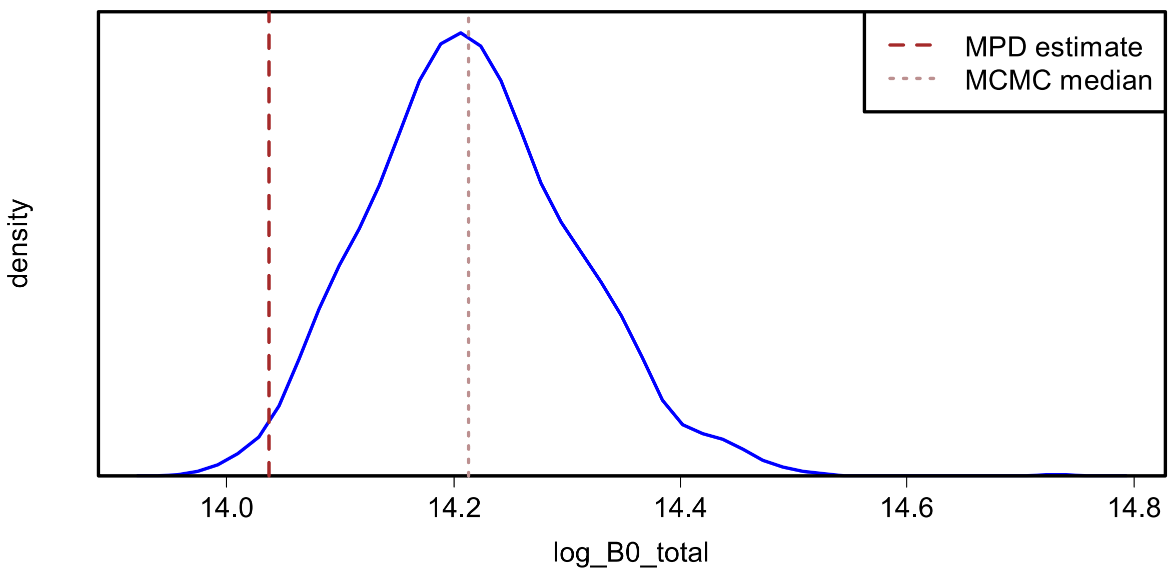


Figure 16: Posterior for log_B0_total. The vertical dashed line shows the position of the MPD estimate, and the dotted line that of the MCMC median.

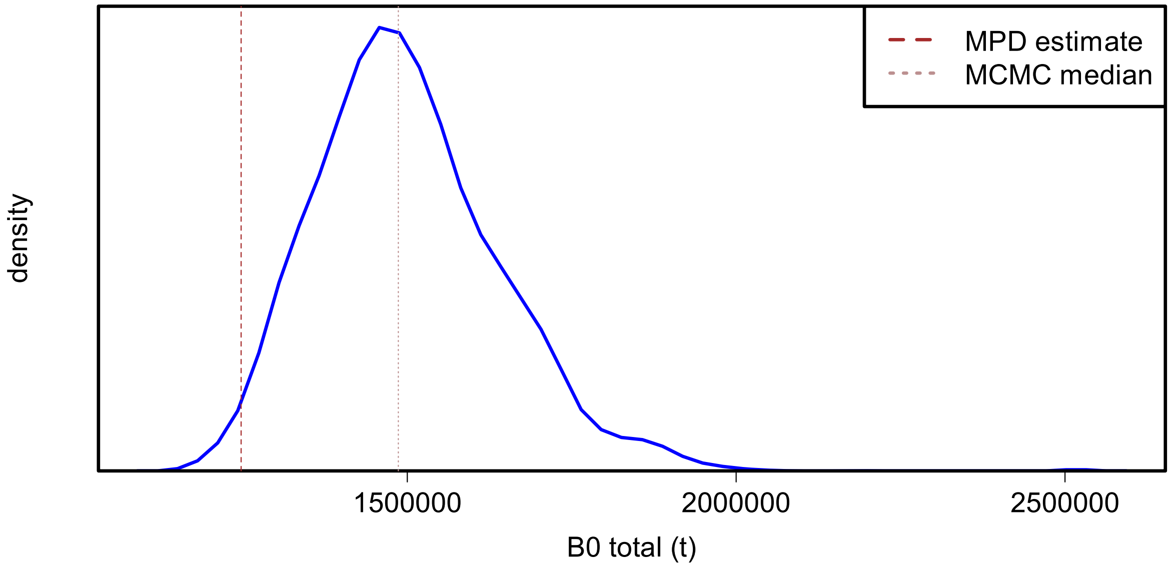


Figure 17: As in Figure 16, but with the x-axis rescaled to be in terms of B0 total instead of log_B0_total.

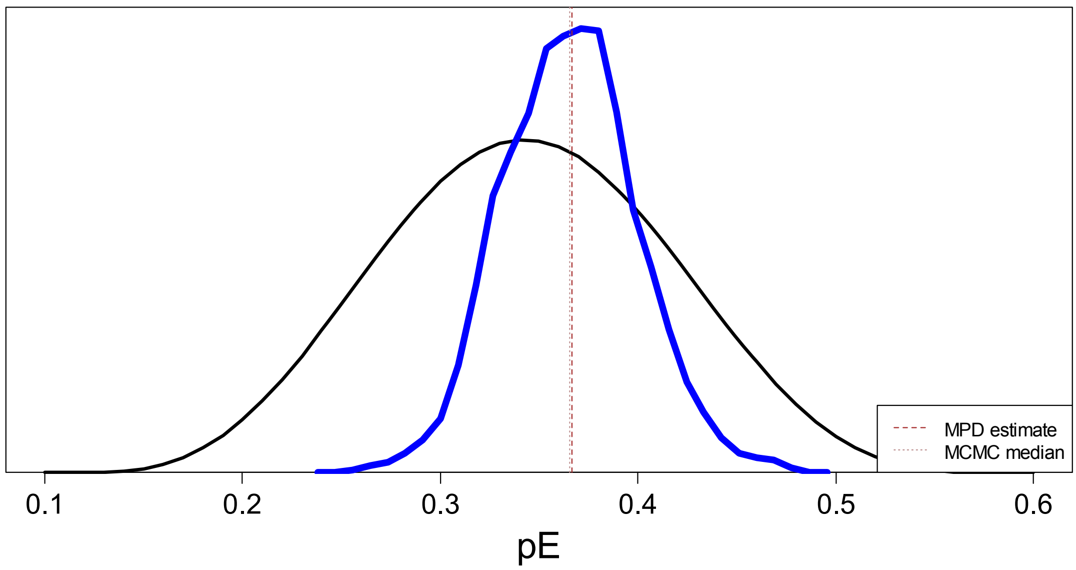


Figure 18: Posterior for pE. The black line shows the prior, the thicker blue line the posterior. The vertical dashed and dotted lines show the position of the MPD estimate, and the median from the corresponding MCMC (they overlap).

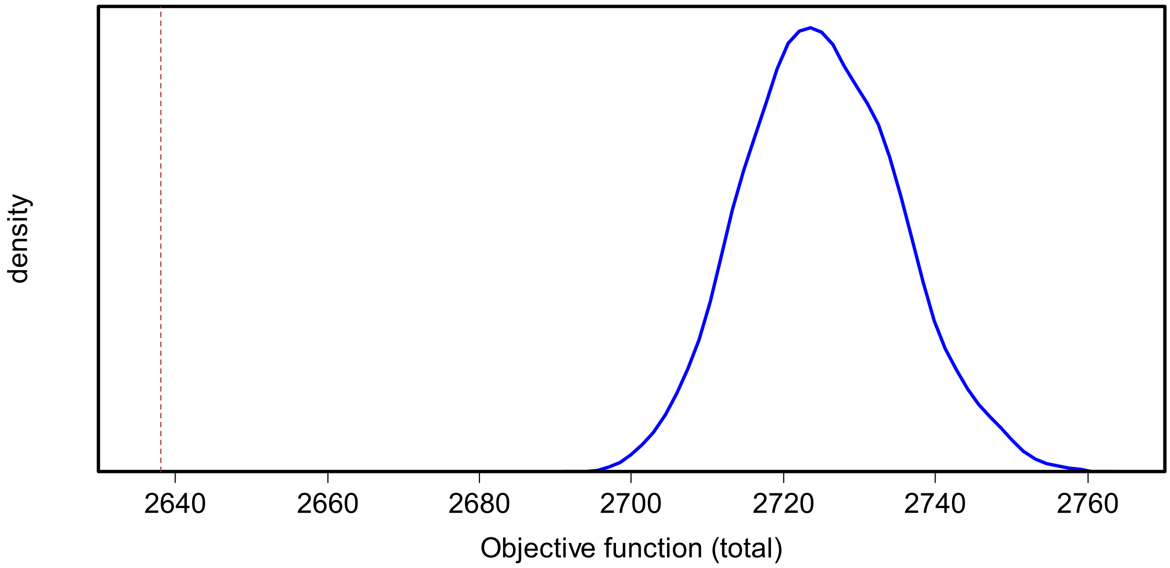


Figure 19: Density function for the total objective function values in the MCMC. The vertical dashed line shows the objective function value for the MPD.

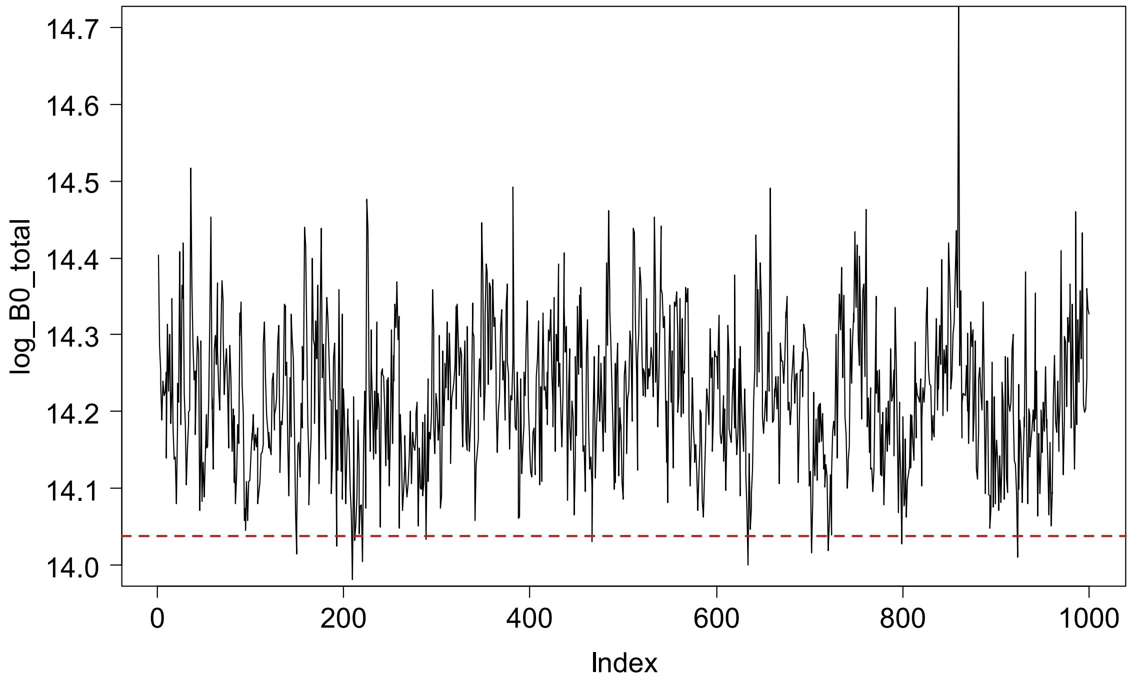


Figure 20: The trace for the free parameter log_B0_total for run 1.11 (after combining three chains with discarding and thinning). The horizontal dashed lines shows the MPD estimate for log_B0_total.

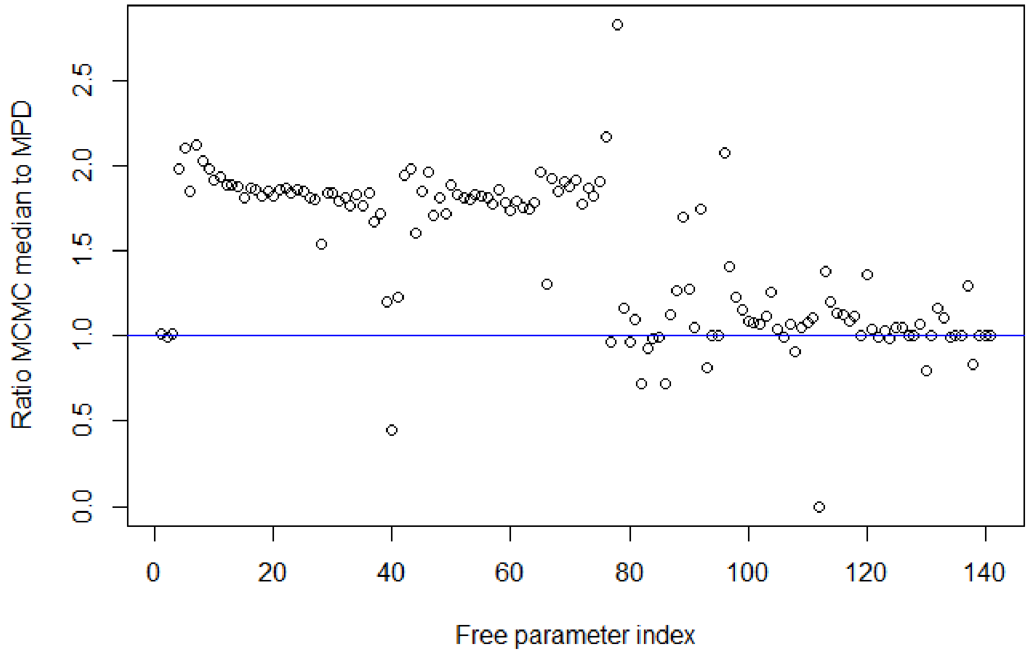


Figure 21: Ratio of the MCMC median estimate of a free parameter to the MPD estimate. The parameters indexed 4 to 41 are the western YCS estimates, and 42 to 79 the eastern YCS estimates. These YCS estimates are before the Haist parametrisation is applied (which involves dividing them by their mean value over some defined years).

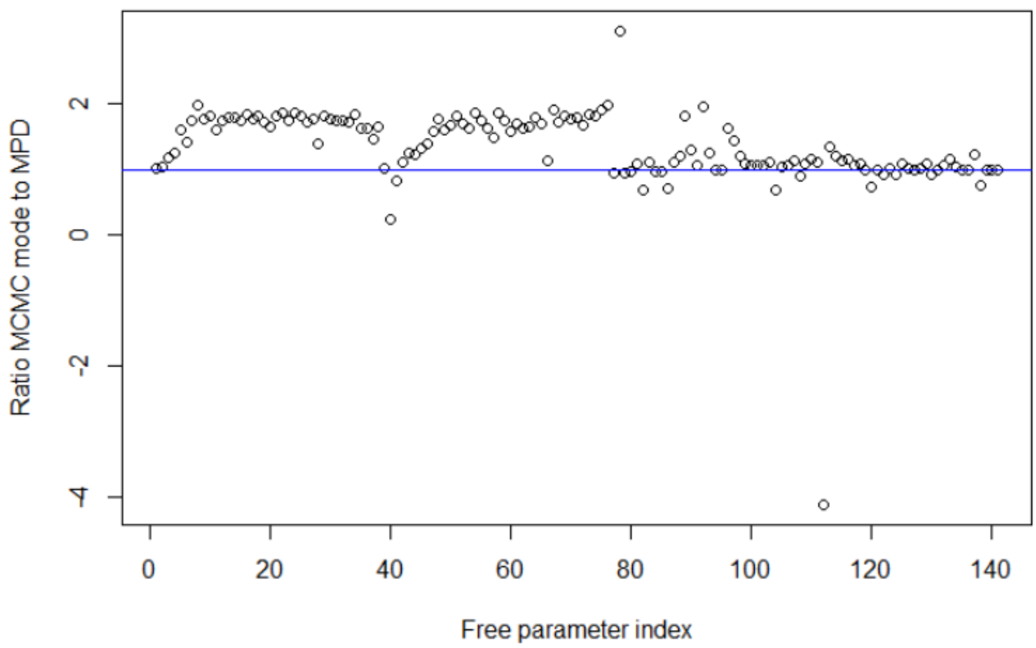


Figure 22: As in Figure 21, but instead plotting the ratio of the MCMC mode estimate of a free parameter to the MPD estimate.

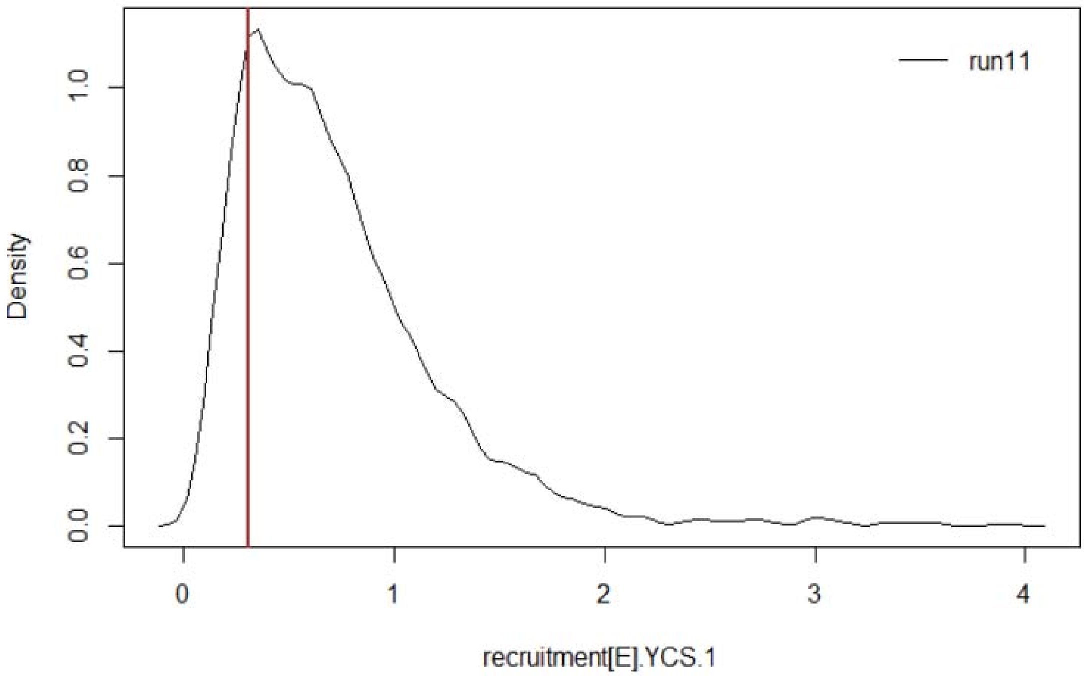


Figure 23: Density for the first estimated east YCS (black line) and MPD estimate (vertical brown line).

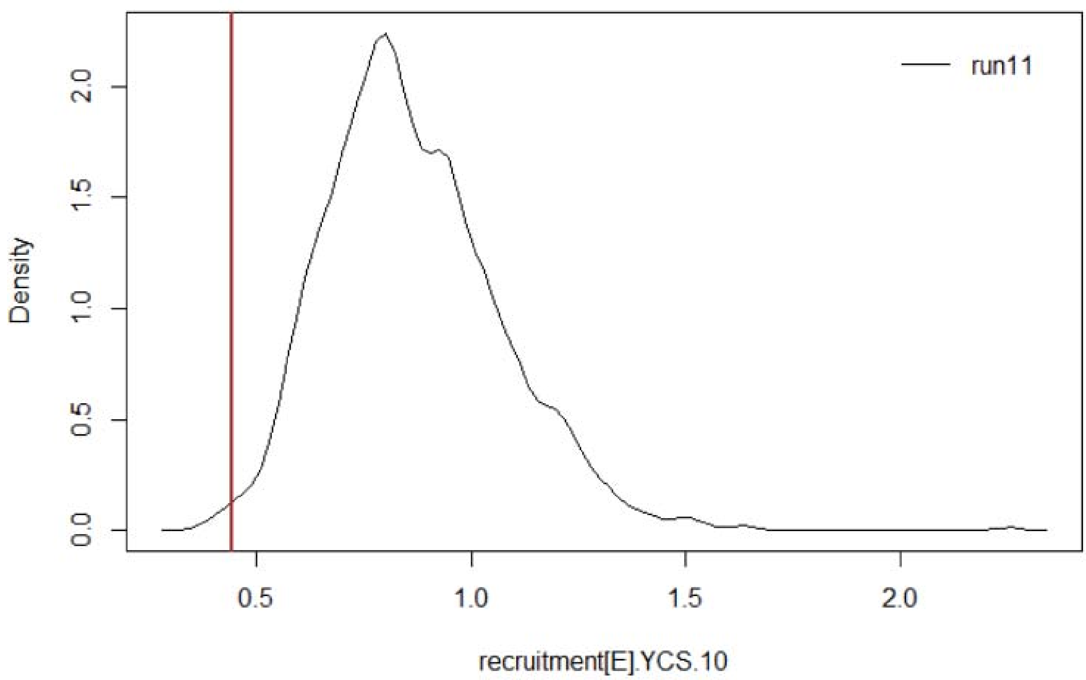


Figure 24: Density for the 10th estimated east YCS (black line) and MPD estimate (vertical brown line).

3.2 The impact of fixing parameters in MCMCs

3.2.1 Background

For the 2014 hoki stock assessment final MCMC model runs there was a base case with a number of sensitivity runs (McKenzie 2015b, Table 13). In order to aid convergence of the MCMC chains, migration and selectivity parameters in MPD runs that ran into their bounds have been fixed at the bounds in the MCMCs since the 2004 assessment (Francis 2005 – p. 63, Table 14).

Ideally all estimated parameters are free in the MCMCs (i.e. not set at a bound). Two questions are:

1. Does this procedure of setting parameters at bounds still aid in convergence?
2. What impact does it have on biomass estimates?

Three MCMC runs investigated this, these being variations on the base case 1.11 from the 2014 assessment (Table 15). Note that in the 2014 assessment catchability parameters were estimated as nuisance parameters (except in one sensitivity run), whereas in the 2015 assessment they are estimated as free.

3.2.2 Chain convergence and biomass estimates

For the case where catchabilities are estimated as nuisance parameters, setting the parameters at the bounds has little impact on convergence, although the estimate of western current biomass differs (Figures 25–26). For the case where catchabilities are estimated as free parameters, setting the parameters at the bounds aids convergence, though there is little difference in biomass estimates (Figures 25–26).

For the 2015 assessment, it was decided by the Deepwater Working group not to set any parameters at the bounds for the MCMCs.

Table 13: 2014 hoki stock assessment. Description of final model runs, including sensitivity runs to run 1.13 (2008–13 two-*q*).

Run	Main assumptions
1.11 - base case	natal fidelity *M* is age-dependent year class strengths (YCSs) are parameterised as Haist with lognormal priors there is no penalty on the YCSs catchabilities are estimated as nuisance parameters
1.12 - 2004–07 two-*q*	as 1.11 but with a different *q* for 2004–07
1.13 - 2008–13 two-*q*	as 1.11 but with a different *q* for 2008–13
1.14	as 1.13 but natal fidelity is not assumed
1.15	as 1.13 but domed spawning selectivity (instead of *M* age-dependent)
1.16	as 1.13 but uniform prior on YCSs (instead of lognormal)
1.17	as 1.13 but Francis parameterisation (instead of Haist)
1.18	as 1.13 but E=W 2011, 2012 YCS penalty (instead of no penalty)
1.19	as 1.13 but estimated catchabilities as "free" instead of "nuisance" parameters

Table 14: 2014 hoki stock assessment. Migration and selectivity parameters held fixed in the MCMC base run 1.11 (one-q) and the MCMC run 1.13 (2008–13 two-q) for which the sensitivity runs were conducted (with fixed values in parentheses). Similar parameters were fixed for the sensitivity runs. 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).

Whome7(1), EspmgF1(0), EspmgF8(0), WspmgF8(0.6), Wnspsl.a1(64), Espsl.sL(4), CRsl.a1(64), SAsl.a1(84), SAsl.sL(44), SAsl.sR(44).

Table 15: MCMC runs investigating the impact of fixing parameters at bounds.

Run descriptions	Main assumptions
1.11	Base case from 2014 assessment
1.11, not set bounds	as 1.11 but parameters not set at bounds
free q, set bounds	as 1.11 but with catchabilities estimated as free parameters
free q, not set bounds	as 1.11, catchabilities free and parameters not set at bounds

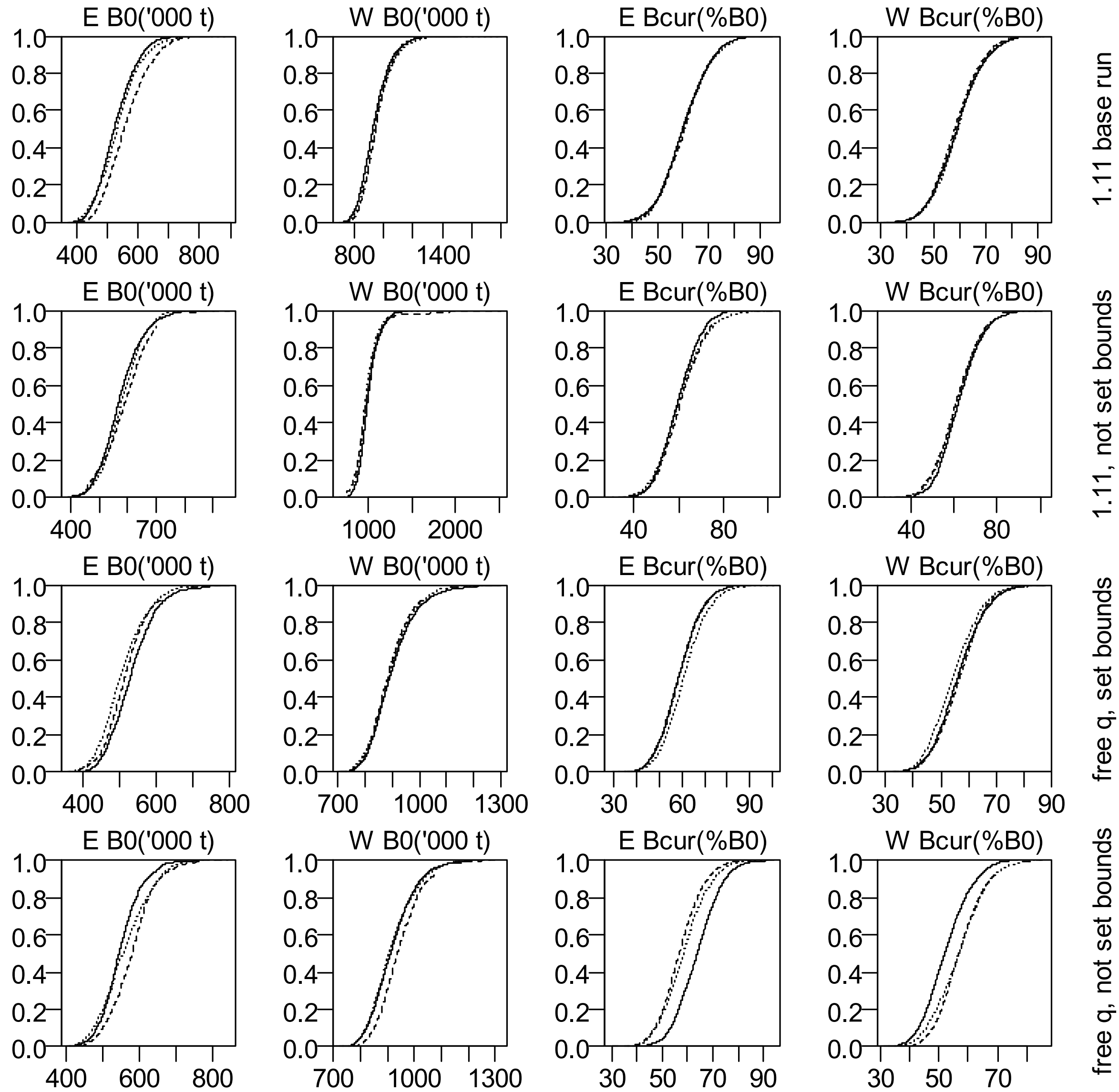


Figure 25: Diagnostics for MCMC chains for the four runs. Each panel contains cumulative probability distributions, for B_0 or $B_{current}$, for three chains from the same model run.

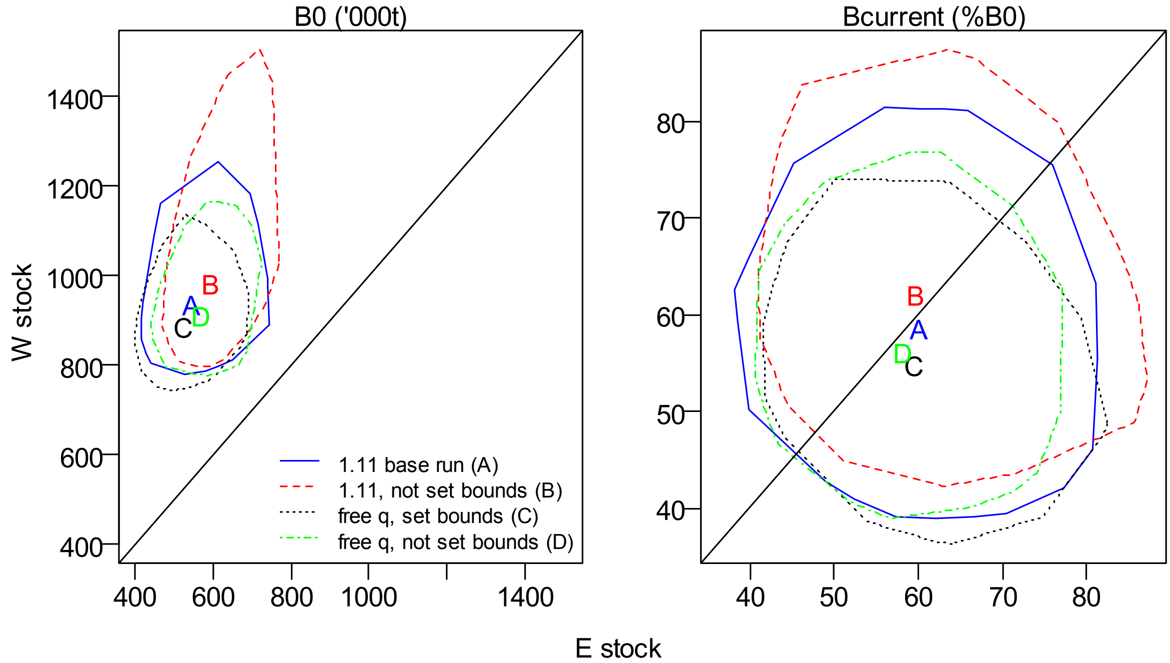


Figure 26: Estimates and approximate 95% confidence intervals for virgin (B_0) and current ($B_{current}$ as $\%B_0$) biomass by stock for the four runs 1.11, 1.21, 1.22, and 1.23. In each panel the points 'A', 'B', 'C' indicate best estimates (median of the posterior distribution) for these three runs and the polygons (with solid, broken and dotted lines, respectively) enclose approximate 95% confidence intervals. Diagonal lines indicate equality (y = x).

4. INITIAL EXPLORATORY MODEL RUNS

For the 2014 hoki stock assessment final model MCMC runs there was a single base run, and eight sensitivity runs (see Table 13). The base run had age-varying natural mortality, a single catchability for the Southern Plateau trawl survey, assumed natal fidelity, and the trawl surveys were not upweighted.

The initial set of MPD runs for the 2015 hoki stock assessment includes an update of the base model run from the 2014 assessment, a version where the trawl surveys are upweighted, and model runs where two catchabilities are used for the Southern Plateau trawl survey (Tables 16).

A change for the 2015 model runs is that surveys' catchabilities are estimated as free parameters instead of analytically. This will have very little impact on parameter estimates in MPD runs, but more in MCMC estimation (see p. 47 of McKenzie 2015b).

Following the change made for the 2014 assessment, the YCSs are parameterised using the Haist parameterisation with lognormal priors (McKenzie 2015b, Section 3). As in previous assessment MPD runs there is an equality penalty for the 2013 east and west YCSs (i.e. the last year of YCSs estimated in the model), which is dropped in MCMC runs.

A starting model was set up in which a robustified lognormal error distribution was used for the at-age data. The function of this model run is to determine weights for the at-age data in the reweighting procedure used for the at-age data, and after reweighting the model becomes run 1.1 in which a multinomial distribution is used for the at-age data. The reweighting results are summarised in Appendix 4. The effective sample sizes from this reweighting are used in all MPD runs.

Biomass estimates for all initial model runs are summarised in Table 17. Details are given in the following sections.

Table 16: 2015 hoki stock assessment. Comparison of initial MPD runs. Aspects of a model run that distinguish it from earlier runs are shown in bold italics. Run 1.1 has an age-varying natural mortality and assumes natal fidelity, as do the other runs in this table.

Run	Two catchabilities for SAsumbio?	Trawl surveys upweighted?
1.1	N	N
1.2	N	***Y***
1.3	***04–07 two-q***	N
1.4	***08–15 two-q***	N

Table 17: Comparison of MPD biomass estimates for all initial model runs.

Run	Description	B_0(‘000 t)		B_{2015}(%B_0)	
		E	W	E	W
1.1	trawl not upweighted	444	774	61	44
1.2	trawl upweighted	431	703	63	27
1.3	04–07 two-q	451	835	62	48
1.4	08–15 two-q	443	759	63	34

4.1 Comparison to base model from the last assessment in 2014

The biomass trajectories from the 2015 model run 1.1 with a single catchability for the Southern Plateau trawl survey is compared to similar model runs from last year's assessment (Table 18, Figure 27). For the updated assessment model the eastern and western virgin biomasses are very similar to those from the 2014 assessment. Estimated eastern biomass in 2014 (%B_0) is a bit less for the updated assessment.

The year class strengths differ in 2011, with the new model run 1.1 estimating the east YCS to be lower and the west YCS higher, though very similar for the combined east and west YCS combined (Figure 28). Other graphs show selectivities, migration ogives, and fitted age-varying natural mortality; they are all very similar between the current and previous assessments (Figures 29–31).

Table 18: Comparison of old and new biomass estimates for the individual stocks, E and W, and the combined E + W stock. The label 2014.11 refers to run 1.11 from the 2014 assessment (see Table 13), while run 1.1 is for the 2015 assessment (see Table 16).

	B_0('000 t)			B_{2014}(%B_0)			B_{2015}(%B_0)		
Run	E	W	E+W	E	W	E+W	E	W	E+W
2014.11	458	791	1249	66	45	53	NA	NA	NA
1.1	444	774	1218	62	46	52	61	44	50

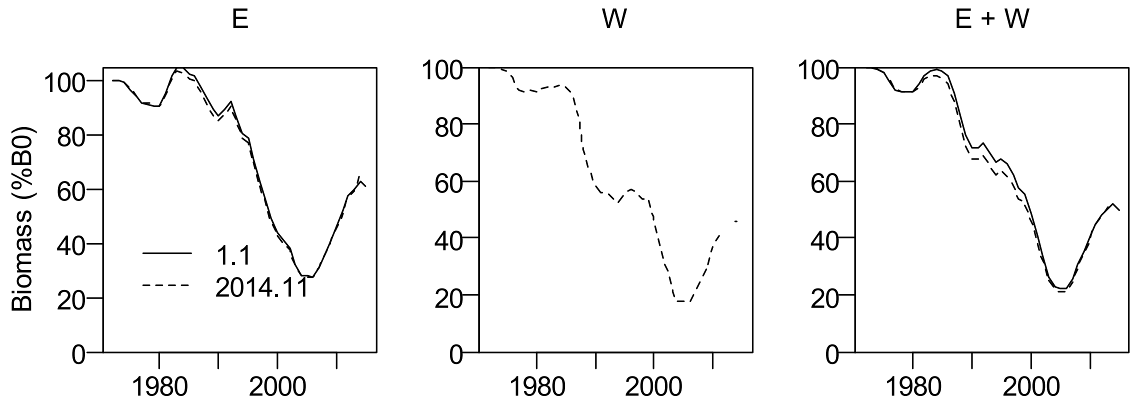


Figure 27: Comparison of biomass trajectories from different runs: E stock (left column), W stock (middle column), and E + W stocks combined (right column). The graphs compare run 1.1 from 2015 (solid lines) with the corresponding run from 2014 (broken lines). The label 2014.11 denotes run 1.11 from the 2014 assessment.

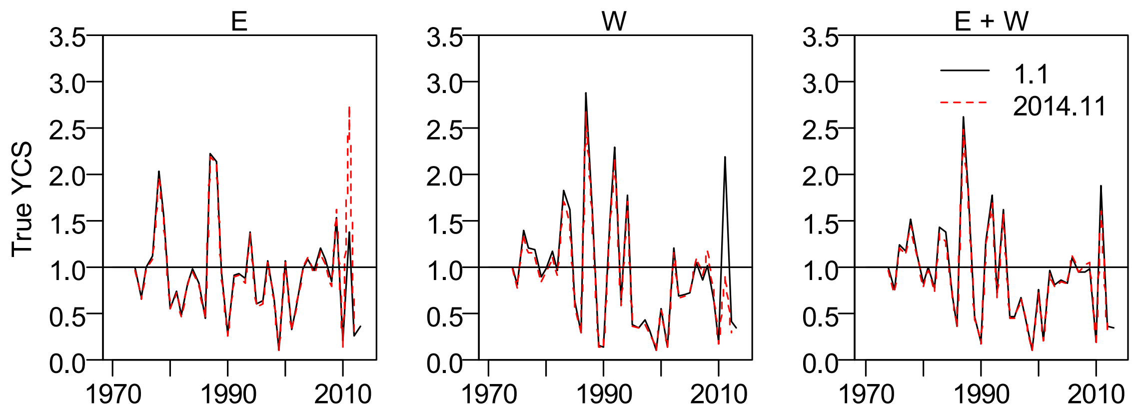


Figure 28: True YCS estimates for new run 1.1 from 2015 (solid lines) compared to the comparable run from last year's assessment. The label 2014.11 denotes run 1.11 from the 2014 assessment.

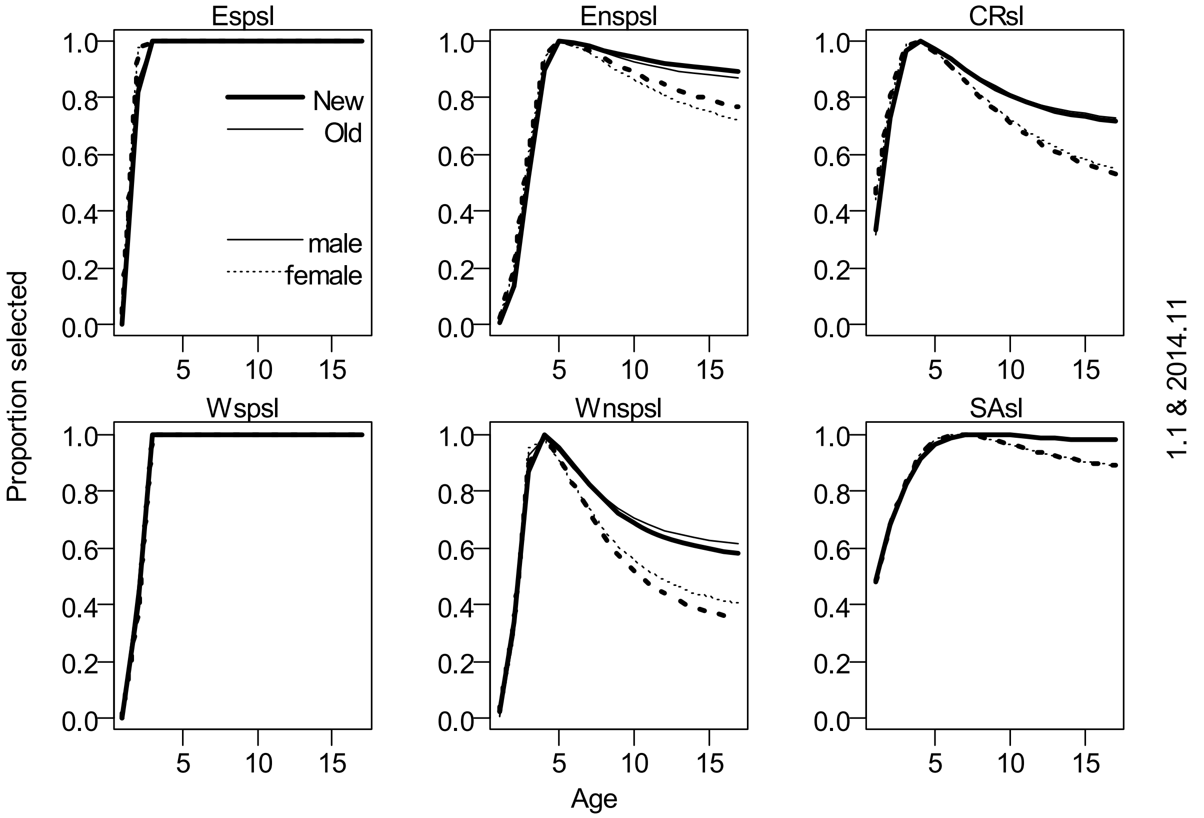


Figure 29: Estimated selectivity curves for the new model run 1.1 from new 2015 (heavy lines) and analogous old 2014 run (light lines). Males are shown by a solid line, females by a dotted line. The label 2014.11 denotes run 1.11 for the 2014 assessment.

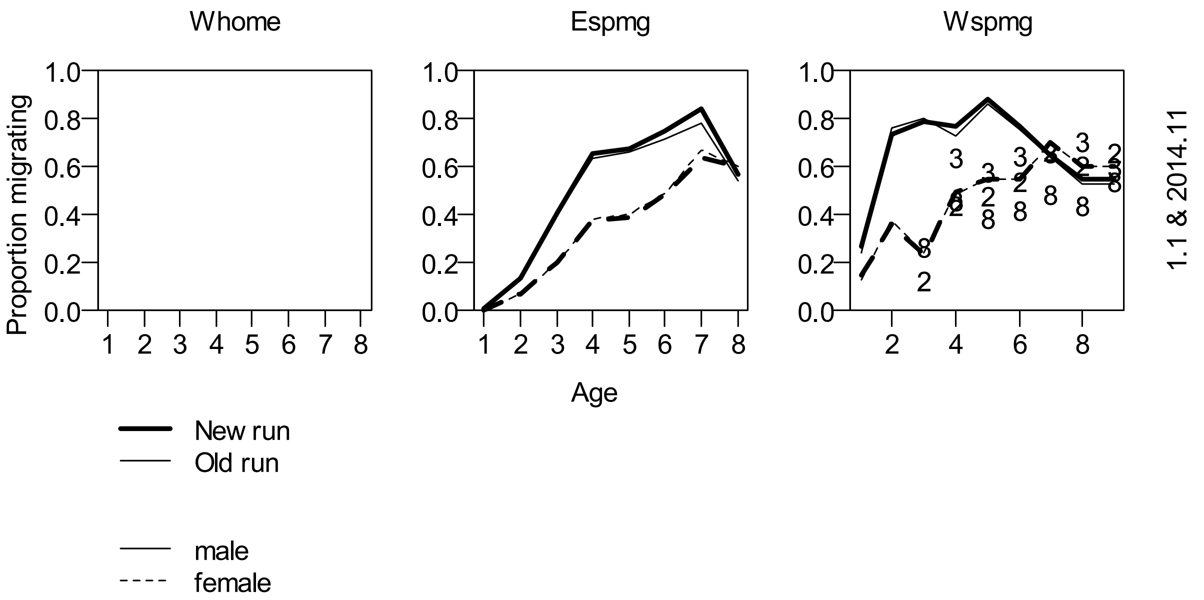


Figure 30: Estimated migration ogives for new run 1.1 from 2015 (heavy lines) and the old run 1.11 from 2014 (light lines). Each row of plots compares ogives from the new run (heavy lines) with that from the analogous 2014 runs (light lines). Where ogives differ by sex, female ogives are plotted as broken 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 2014.11 denotes run 1.11 for the 2014 assessment.

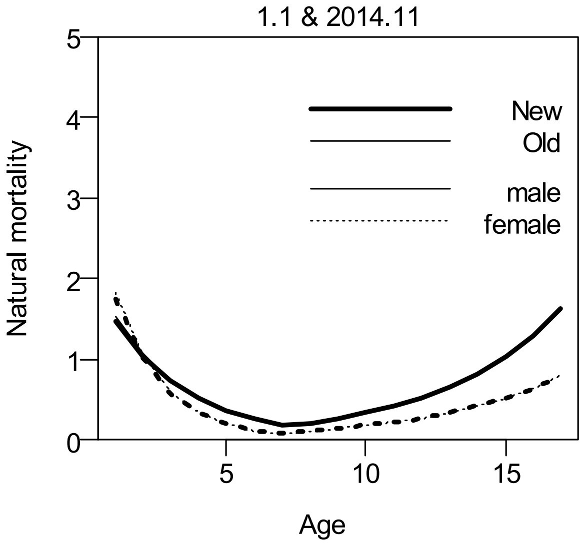


Figure 31: Comparison between age-dependent natural mortality estimated in the new run 1.1 from 2015 (heavy lines) and the corresponding run 1.11 from 2014 (light lines). The label 2014.11 denotes run 1.11 for the 2014 assessment.

4.2 2015 MPD results: trawl upweighting

In run 1.2 the trawl surveys are upweighted, unlike run 1.1. Upweighting slightly improves the fit for the last four years of CRsumbio, and about half the years for SAsumbio (Table 19, Figures 32–34). There is little difference in the fits to the other biomass data sets SAautbio, CSacous, and WCacous.

With trawl survey upweighting, current western biomass is estimated to be less (relative to run 1.1) and there is a more pronounced decline in recent years (Figure 35). The trawl surveys have some impact on the estimated YCSs, with upweighting increasing the 2011 east stock YCS and decreasing the 2012 west stock YCS (Figure 36).

Table 19: Goodness of fit to biomass indices as measured by SDNR (standard deviation of the normalised residuals) for trawl surveys not upweighted (run 1.1) and upweighted (run 1.2). 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	Trawl surveys upweighted?	CRsumbio	SAsumbio	SAautbio	CSacous	WCacous
1.1	No	0.83	1.47	0.64	0.95	0.94
1.2	Yes	0.80	1.15	0.66	0.95	1.07

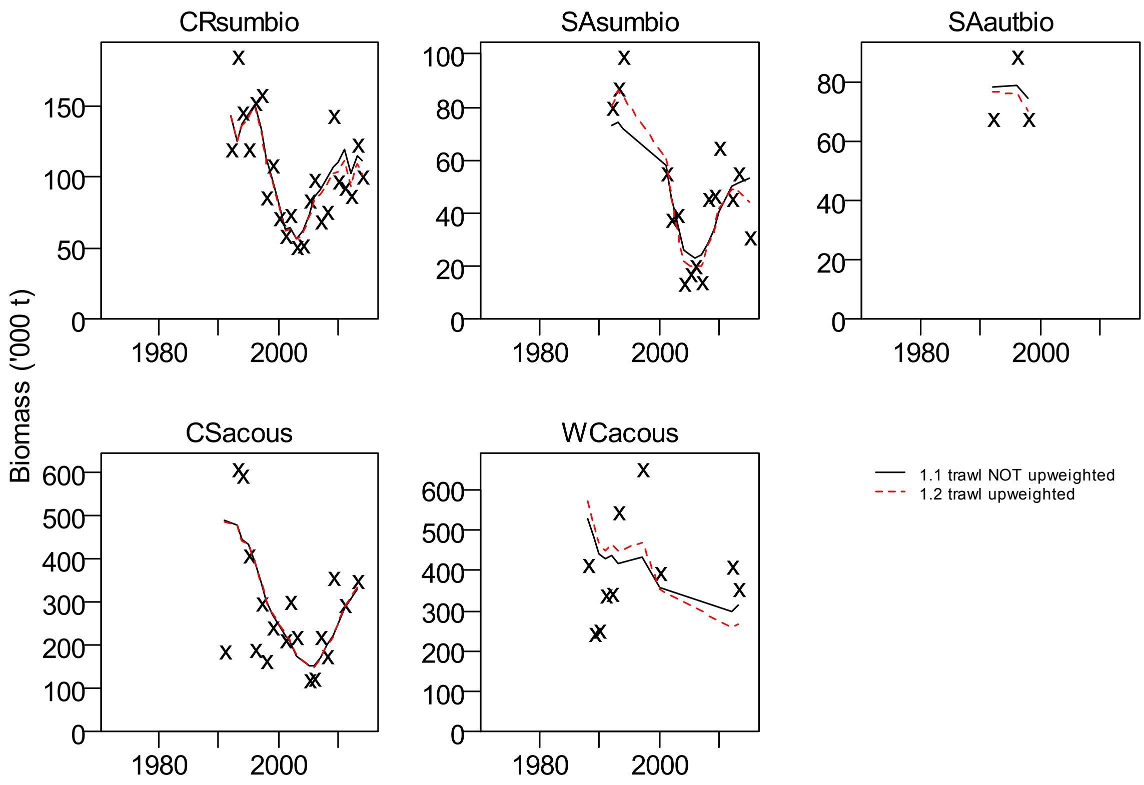


Figure 32: Fit to biomass indices for 2015 assessment run 1.1 (trawl surveys not upweighted) and 1.2 (trawl surveys upweighted). Shown are observed ('×') and expected values (lines).

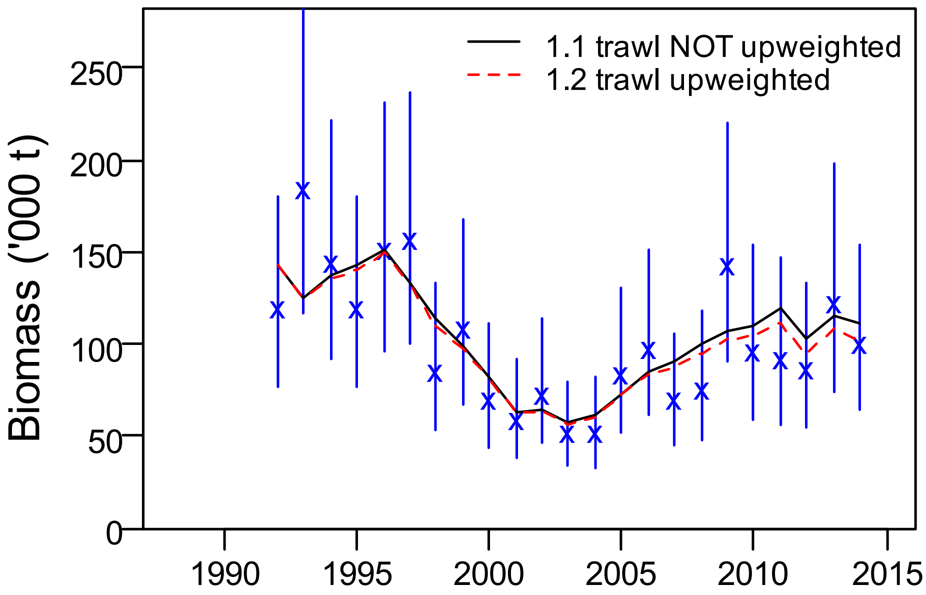


Figure 33: Fits to CRsumbio for 2015 runs 1.1 and 1.2, showing observed ('×', with vertical lines showing 95% confidence intervals including 0.20 process error) and expected values (lines). Plotted years are as in the model (so the last survey is plotted at 2014). The trawl survey indices are not upweighted (solid lines) or upweighted (dashed lines).

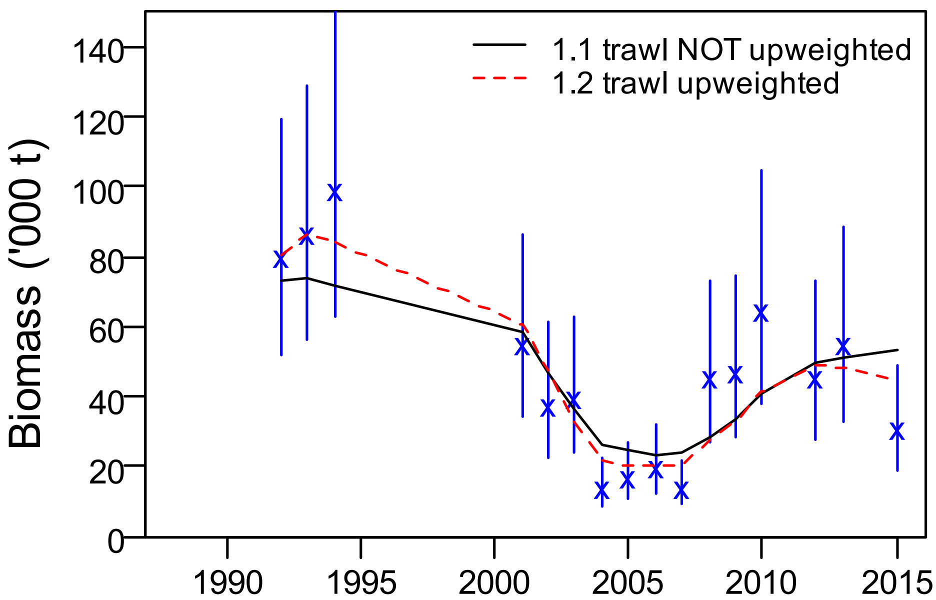


Figure 34: Fits to SAsumbio for 2015 runs 1.1 and 1.2, showing observed ('×', with vertical lines showing 95% confidence intervals including 0.20 process error) and expected values (lines). Plotted years are as in the model (so the last survey is plotted at 2015). The trawl survey indices are not upweighted (solid lines), and upweighted (dashed lines).

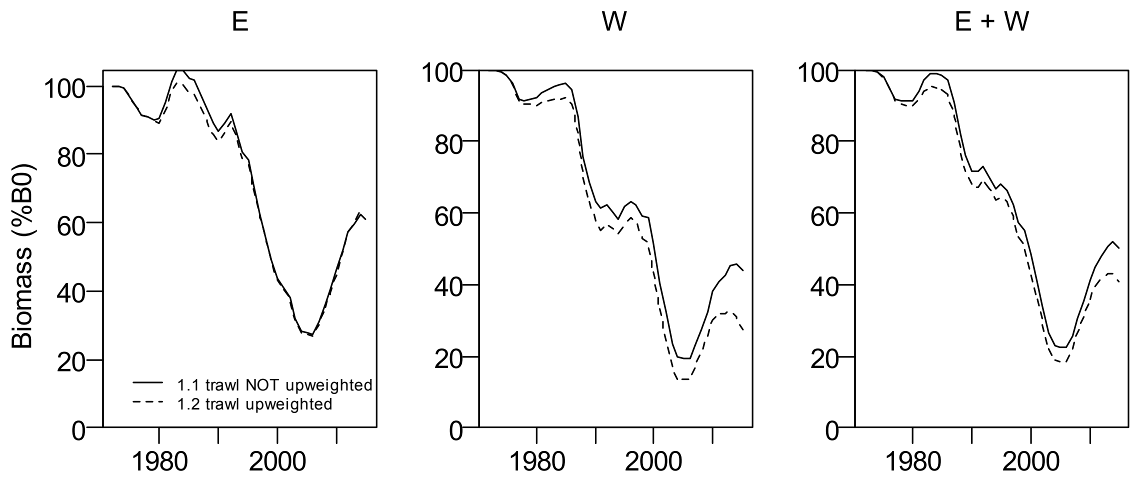


Figure 35: Comparison of biomass trajectories for runs 1.1 and 1.2: E stock (left column), W stock (middle column), and E + W stocks combined (right column).

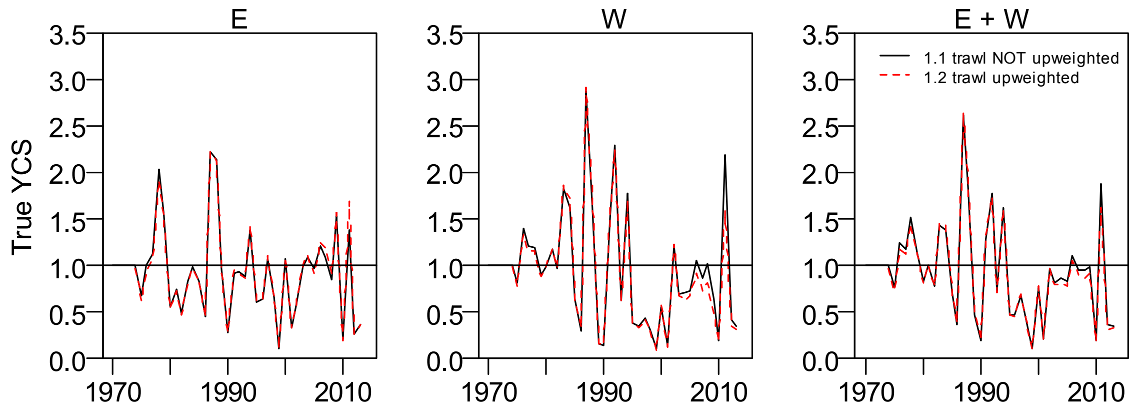


Figure 36: True YCS estimates for 2015 runs 1.1 and 1.2.

4.3 2015 MPD results: using two catchabilities for Southern Plateau trawl survey

From the numbers-at-age data for the Sub-Antarctic summer trawl there appears to have been a change in catchability in the 2004 and 2008 fishing years, as evidenced by the abrupt change in numbers-at-age across all age groups in the 2003 and 2007 survey years (Figures 37–38). The change in 2004 (and slight downward trend in previous years) may partly be explained by the rapid decline in abundance of the western stock over this time (see Figure 27). However, the large increase in numbers for all age groups in 2008 cannot be explained in this way.

Run 1.1 uses a single catchability for SAsumbio, whereas runs 1.3 and 1.4 use two. Using two catchabilities improves the fit to SAsumbio (Figure 39, Table 20), with the catchability for 2004–2007 estimated to be half the other years or 50% more for 2008–2015 (Table 21). The improvement in fit and estimated catchabilities are similar to the analogous model runs of the 2014 assessment.

Biomass trajectories for the western stock differ between the single and two catchability models (Figure 40).

Table 20: Objective function values for selected model runs.

		Trawl surveys	Objective function	
Run		upweighted?	SAsumbio	Total
1.1	single q	N	-7.0	2748.9
1.3	04-07q different	N	-14.4	2738.1
1.4	08-15q different	N	-11.4	2744.2

Table 21: Estimated catchability for the model runs.

	Catchability		
run	1992–2003	2004–2007	2008–2015
1.1	0.10	0.10	0.10
1.3	0.09	0.05	0.09
1.4	0.09	0.09	0.14

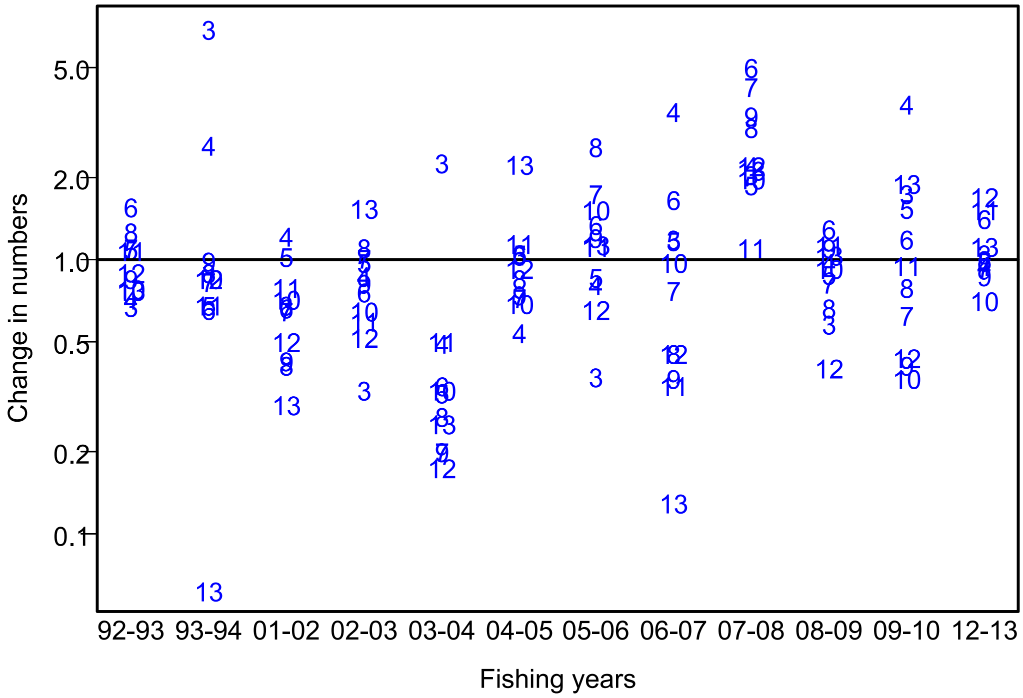


Figure 37: Changes, between surveys one year apart in the Southern Plateau summer series, in estimated numbers of selected cohorts. Each plotted point indicates how the estimated number in a cohort changed between the two surveys; the plotting symbol is the age of the cohort in the earlier survey. For example, for the 06-07 fishing years, the estimated number in the cohort that was aged 6 in the 2006 fishing year survey increased by a factor of about five in the 2007 fishing year survey. Note that the 2006 fishing year survey takes places in summer of the 2005 calendar year.

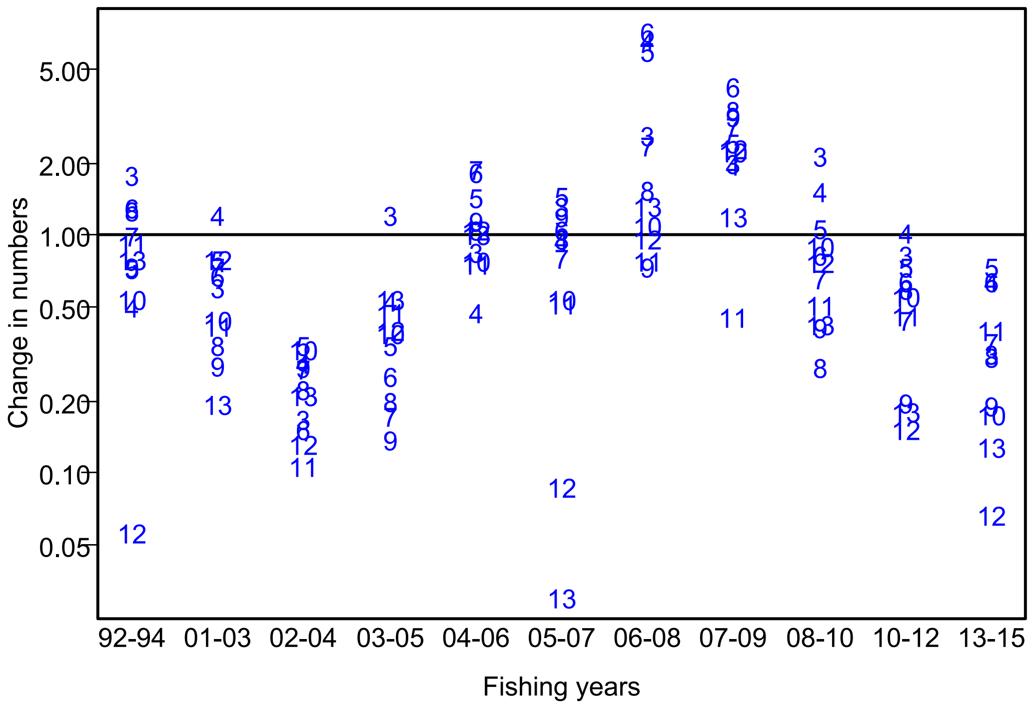


Figure 38: As Figure 37, but changes between surveys two years apart.

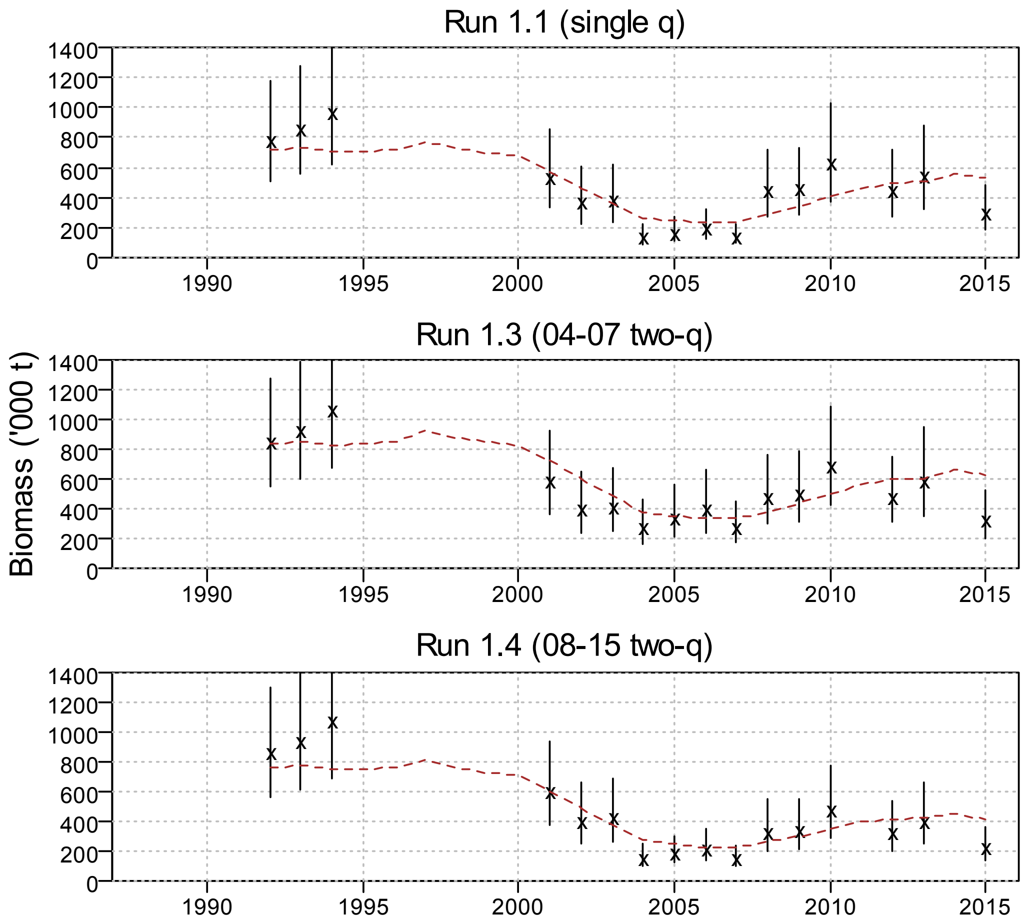


Figure 39: Fits to SAsumbio for runs 1.1, 1.3, and 1.4 showing observed values scaled to model biomass by dividing by catchability ('×', with vertical lines showing 95% confidence intervals) and expected values (dashed lines). Plotted years are as in the model (so the last survey is plotted at 2015). The trawl survey indices are not upweighted for all runs.

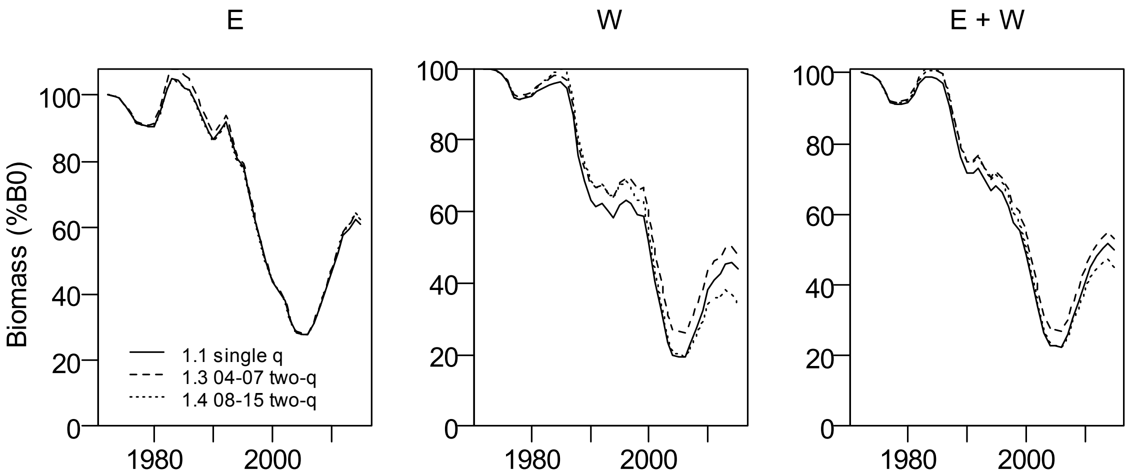


Figure 40: Comparison of biomass trajectories from different runs: E stock (left column), W stock (middle column), and E + W stocks combined (right column).

5. FINAL MODEL ASSESSMENT RESULTS

5.1 Final model run results

It was decided by the Deepwater Working Group to take six runs through to the MCMC stage (Table 22). The base run 1.1 uses a single catchability for the Southern Plateau trawl survey (SAsumbio). All other model runs are sensitivity analyses to this base run. In model run 1.2 the trawl surveys are upweighted, and for model runs 1.3 and 1.4 two catchabilities are used for the Southern Plateau trawl survey. In the last two model runs natal fidelity is not assumed (run 1.5) or a domed spawning selectivity is used instead of an age-dependent natural mortality (run 1.6). The base run was decided upon after investigating the first four model runs (1.1–1.4) with runs 1.5 and 1.6 decided upon after this as additional sensitivity runs.

A sequence of MCMC runs using the base case model from the 2014 assessment demonstrates that biomass estimates are influenced by how catchability parameters are estimated (p. 47 of McKenzie 2015b), and whether or not parameters are set at bounds (Section 3.2). It was decided by the Deepwater Working Group to construct the MCMCs for the 2015 assessment differently from the 2014 assessment in that:

a) Catchability parameters are estimated as free parameters instead of calculated analytically.

b) For the 2014 assessment and those prior to it, migration and selectivity parameters in MPD runs that ran into their bounds were fixed at the bounds in their MCMCs. For the MCMC runs here no parameters are set at their bounds.

c) The chains are of length 4 million samples instead of 2 million, as a longer chain is beneficial for estimation, and the time required to generate them still feasible.

For the MCMC model runs the at-age data is reweighted, with this being done separately for each model run (and as previously as MPD model runs).

Table 22: Distinguishing characteristics for all MCMC final model runs, including all sensitivities to the base run 1.1.

Run	Main assumptions
1.1 - base case	natal fidelity *M* is age-dependent single q for Southern Plateau trawl series trawl surveys are not upweighted
1.2	as 1.1 but the trawl surveys are upweighted
1.3 - 2004–07 two-*q*	as 1.1 but with a different q for 2004–07
1.4 - 2008–15 two-*q*	as 1.1 but with a different q for 2008–15
1.5	as 1.1 but natal fidelity is not assumed
1.6	as 1.1 but domed spawning selectivity (instead of *M* age-dependent)

For each model run three MCMC chains of length 4 million samples were created, each chain having a different starting point, which was generated by stepping randomly away from the MPD.

Diagnostic plots comparing the three chains for each run suggest reasonable convergence for the runs (Figures 41–44). To form the final single chain for each run, the first 1/8 of each chain was discarded (i.e. the first 500 000 samples from the chain of length 4 million were discarded), the three chains concatenated, and the resulting chain thinned by systematic sub-sampling to produce a posterior sample of length 2000.

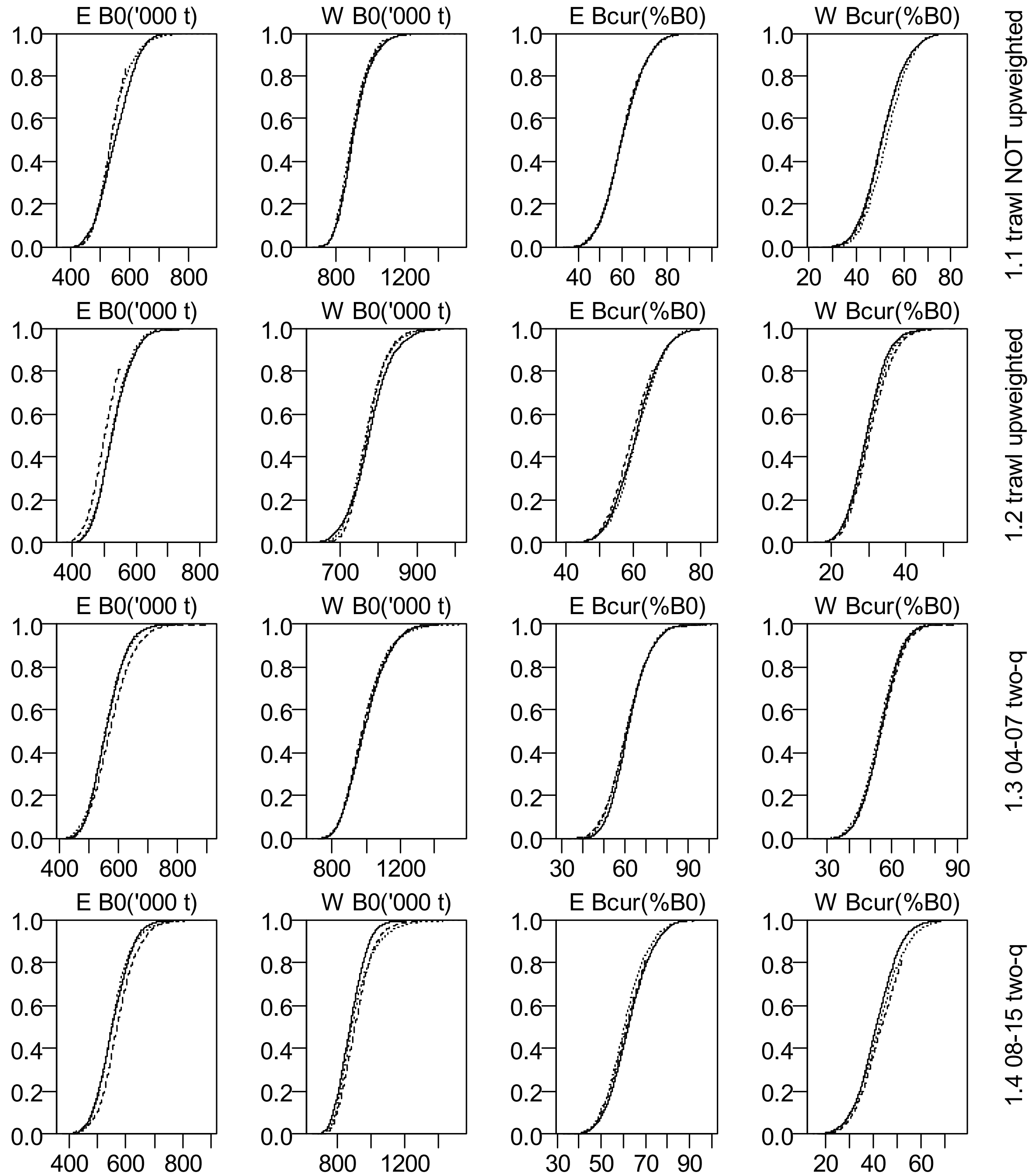


Figure 41: Diagnostics for MCMC chains for the four runs: 1.1 to 1.4. Each panel contains cumulative probability distributions, for B_0 or $B_{current}$, for three chains from the same model run. Samples from the burn in period are discarded for these results.

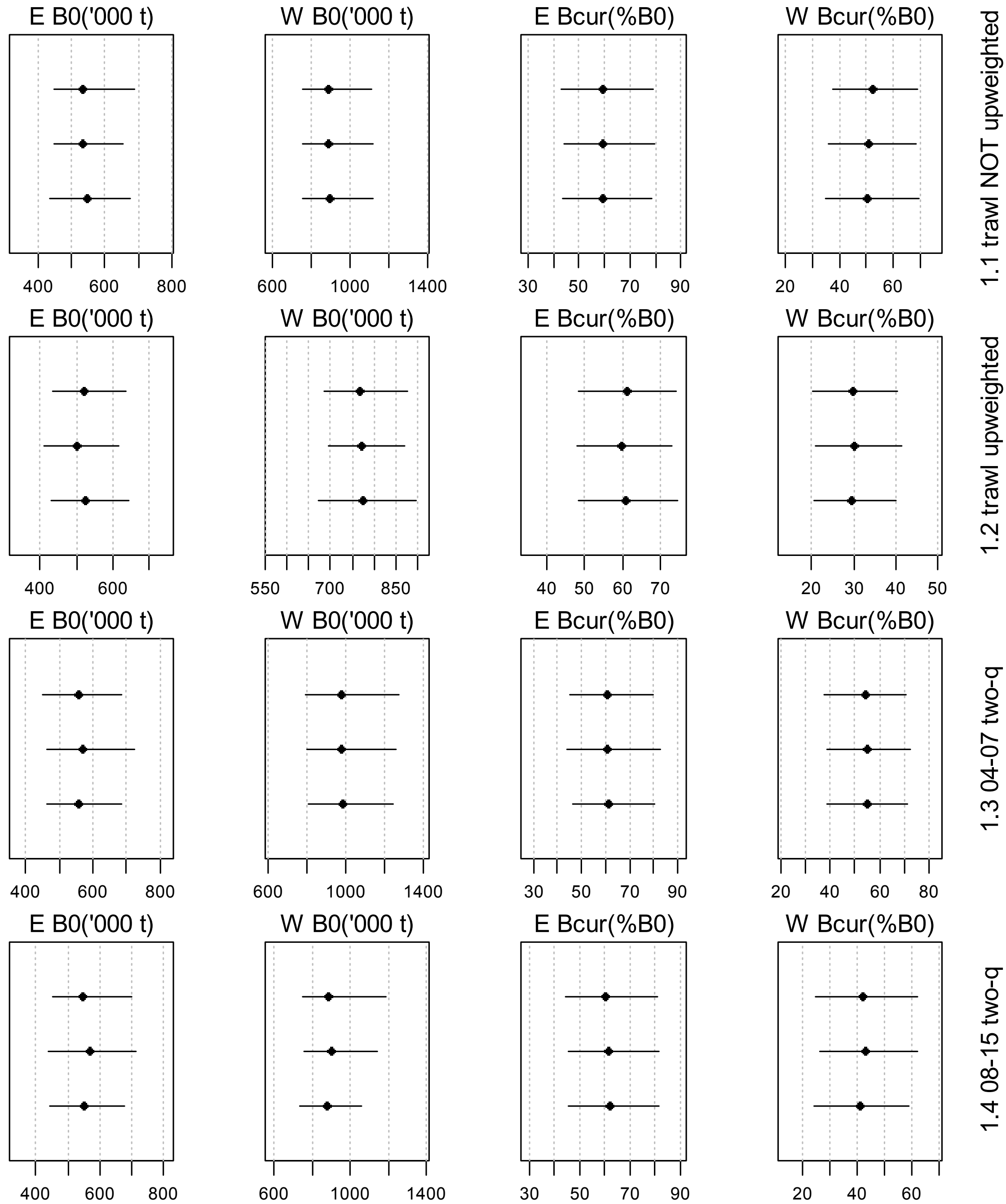


Figure 42: Further diagnostics for MCMC chains for the four runs: 1.1 to 1.4. Each panel contains the median (solid dot) and 95% confidence interval, for B_0 or $B_{current}$, for three chains from the same model run.

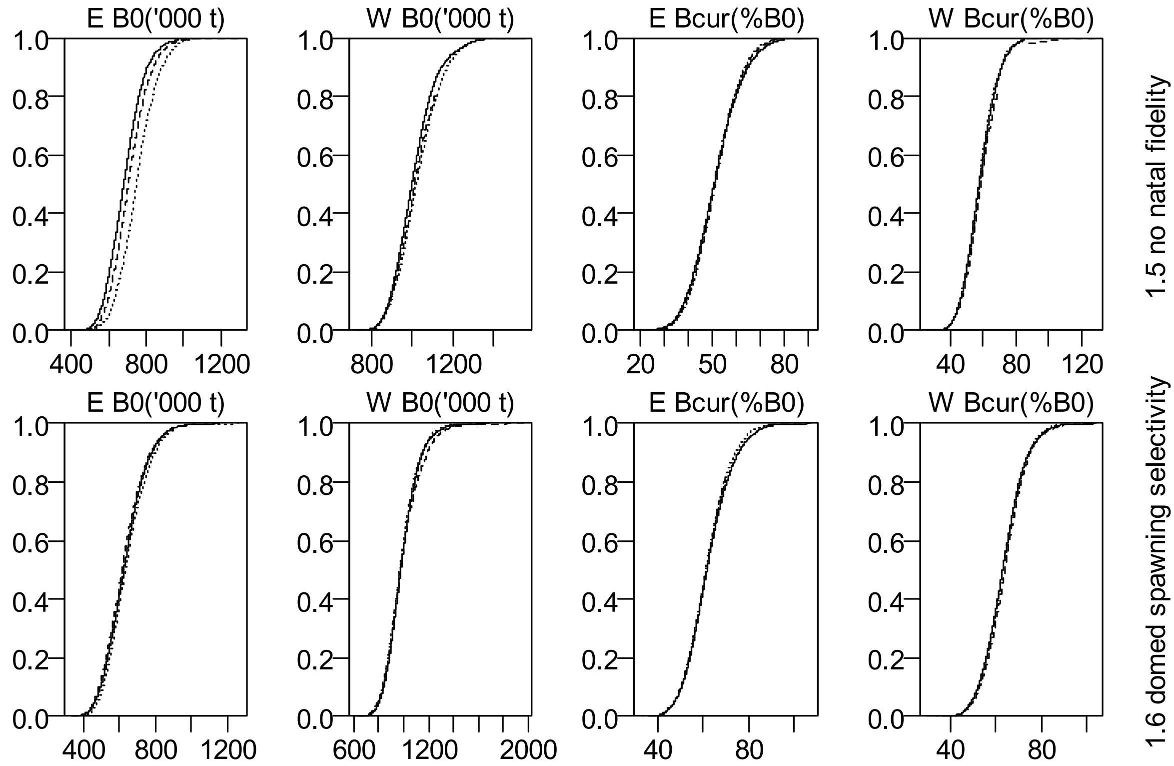


Figure 43: Diagnostics for MCMC chains for the two runs: 1.5 and 1.6. Each panel contains cumulative probability distributions, for B_0 or $B_{current}$, for three chains from the same model run. Samples from the burn in period are discarded for these results.

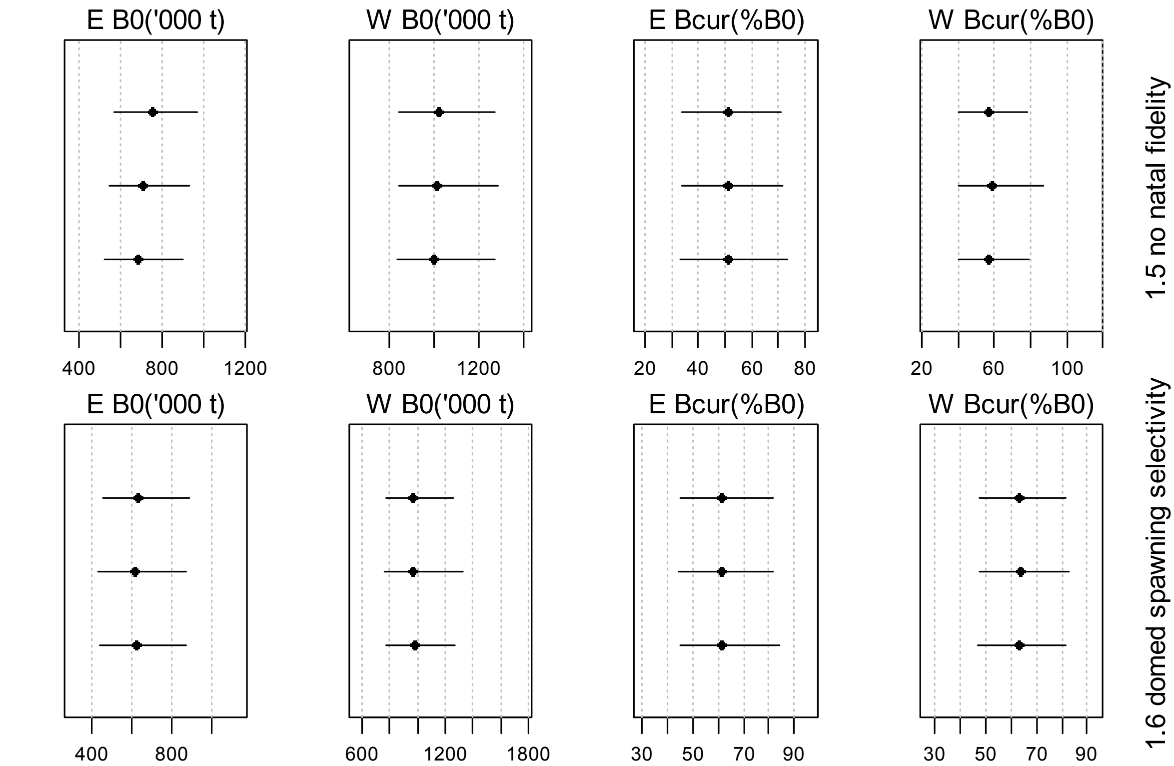


Figure 44: Further diagnostics for MCMC chains for the two runs: 1.5 and 1.6. Each panel contains the median (solid dot) and 95% confidence interval, for B_0 or $B_{current}$, for three chains from the same model run.

The MCMC results for all runs show that the western spawning stock was originally larger than the eastern spawning stock (Table 23, Figures 45–47). The models estimate the current spawning biomass for the eastern stock to be at 51–61% B_0, and for the western stock 30–63% B_0 (values are ranges for the medians).

For the western stock, estimates of current biomass differ greatly depending on whether the trawl survey data are upweighted or not. For the base case current western biomass is estimated to be 51% B_0, but if the trawl surveys are upweighted 30% B_0. Compared to the base case, current biomass for the 2004–07 two-q model is slightly higher (55% B_0), and lower for the 2008–15 two-q model (42% B_0).

Fits to the Southern Plateau trawl survey indicated that both models 1.1 (single catchability) and 1.2 (trawl surveys upweighted) need more process error, although probably only a bit more for model 1.1 while a lot more for model 1.2 (Figure 48–51). Based on the acceptability of the fits to model 1.1, and that a sequence of four low biomass estimates from a series of this length is not uncommon statistically, it was decided by the Deepwater Working Group to choose model 1.1 as the base case.

For a continuity model run, model 1.1 with a single q is compared to model 1.11 from 2014 with a single q. Note that these models differ in their MCMC implementation in that for 2015: (i) catchability parameters are estimated as free instead of analytical, and (ii) migration and selectivity parameters are not set at their MPD bounds. For estimated biomass in 2014, the new assessment result is similar to the previous one for the eastern stock, and less so for the western stock (Figure 52).

The model runs indicate that the western biomass has been increasing since about 2006, but flattening and declining in recent years if the trawl surveys are upweighted (Figures 53–56). The eastern biomass has been increasing since about 2006, but declining slightly in recent years if a domed spawning selectivity is used (Figures 53–56).

All model runs estimate a low YCS in 2012 followed by another below average YCS in 2013 (Figures 57–61).

The estimated selectivities are similar for the first four models, as are the migration ogives and natural mortality estimates (Figures 62–64), and are similar to those for the 2014 assessment.

The biggest difference between priors and posteriors occurs for the estimate of the Southern Plateau catchability for 2004–07 (Figures 65–67).

Table 23: Estimates of spawning biomass (medians of marginal posterior, with 95% confidence intervals in parentheses) for the six runs. $B_{current}$ is the biomass in mid-season 2015.

	B_0('000 t)		$B_{current}$('000 t)		$B_{current}$(%B_0)		
Run	E	W	E	W	E	W	E+W
1.1	540(446,674)	897(758,1126)	322(213,476)	459(286,735)	59(43,78)	51(36,69)	55(43,67)
1.2	517(425,636)	773(686,887)	313(221,426)	230(150,337)	60(48,74)	30(20,40)	42(35,50)
1.3	563(461,707)	978(804,1258)	343(225,519)	537(319,838)	60(45,80)	55(38,71)	57(45,70)
1.4	556(450,693)	890(746,1133)	336(226,515)	372(197,646)	61(45,81)	42(25,61)	49(38,63)
1.5	711(539,943)	1011(844,1268)	364(207,599)	584(360,956)	51(33,71)	58(40,82)	55(44,71)
1.6	629(443,882)	976(767,1293)	383(239,607)	618(393,963)	61(45,82)	63(47,81)	63(51,76)

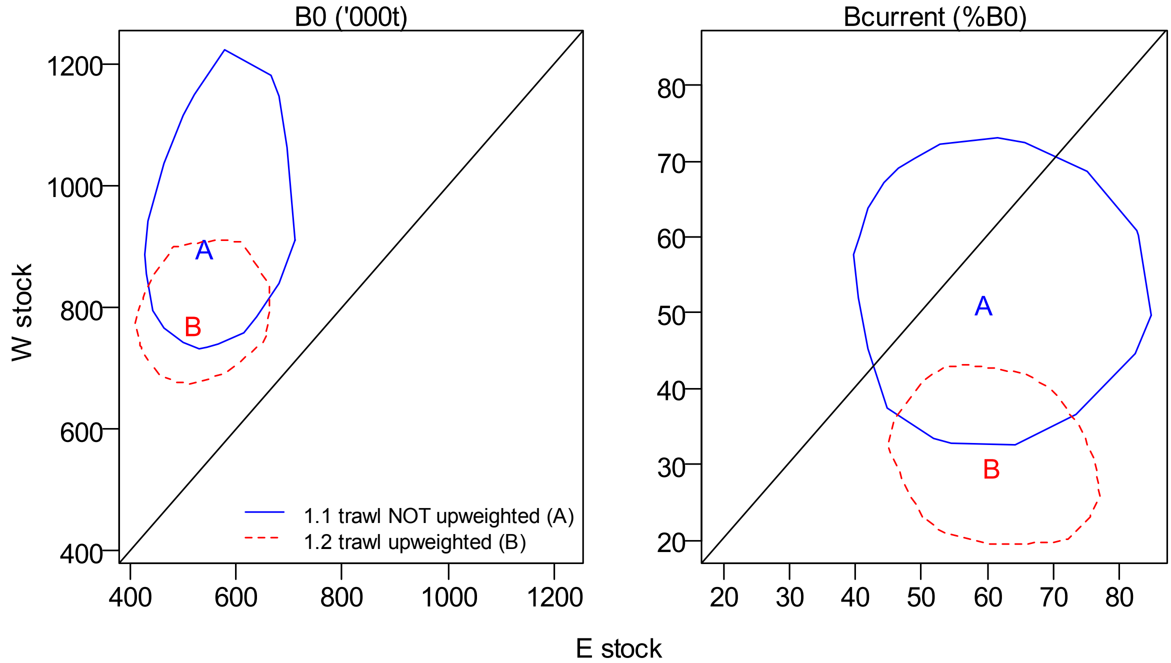


Figure 45: Estimates and approximate 95% confidence intervals for virgin (B_0) and current ($B_{current}$ as $\%B_0$) biomass by stock for the three runs 1.1 and 1.2. In each panel the points 'A', 'B' indicate best estimates (median of the posterior distribution) for these three runs, and the polygons (with solid, broken and dotted lines, respectively) enclose approximate 95% confidence intervals. Diagonal lines indicate equality (y = x).

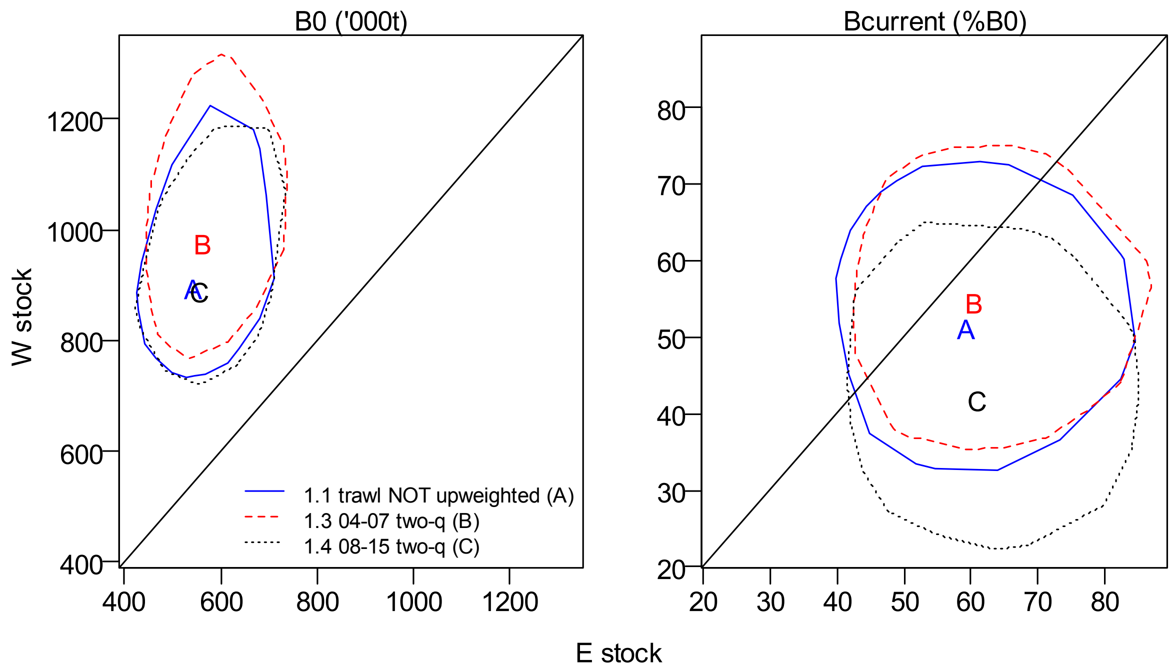


Figure 46: As for Figure 45 but for the runs 1.1, 1.3, and 1.4.

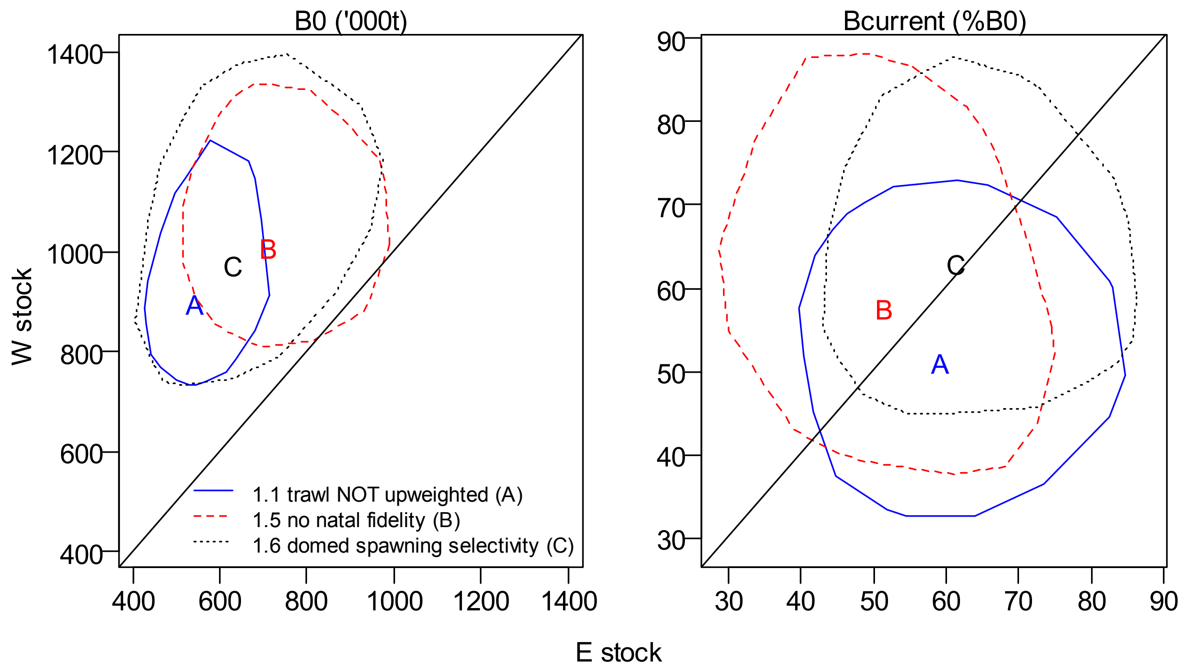


Figure 47: Estimates and approximate 95% confidence intervals for virgin (B_0) and current ($B_{current}$ as $\%B_0$) biomass by stock for the three runs 1.1, 1.5, and 1.6. In each panel the points 'A', 'B' indicate best estimates (median of the posterior distribution) for these three runs, and the polygons (with solid, broken and dotted lines, respectively) enclose approximate 95% confidence intervals. Diagonal lines indicate equality (y = x).

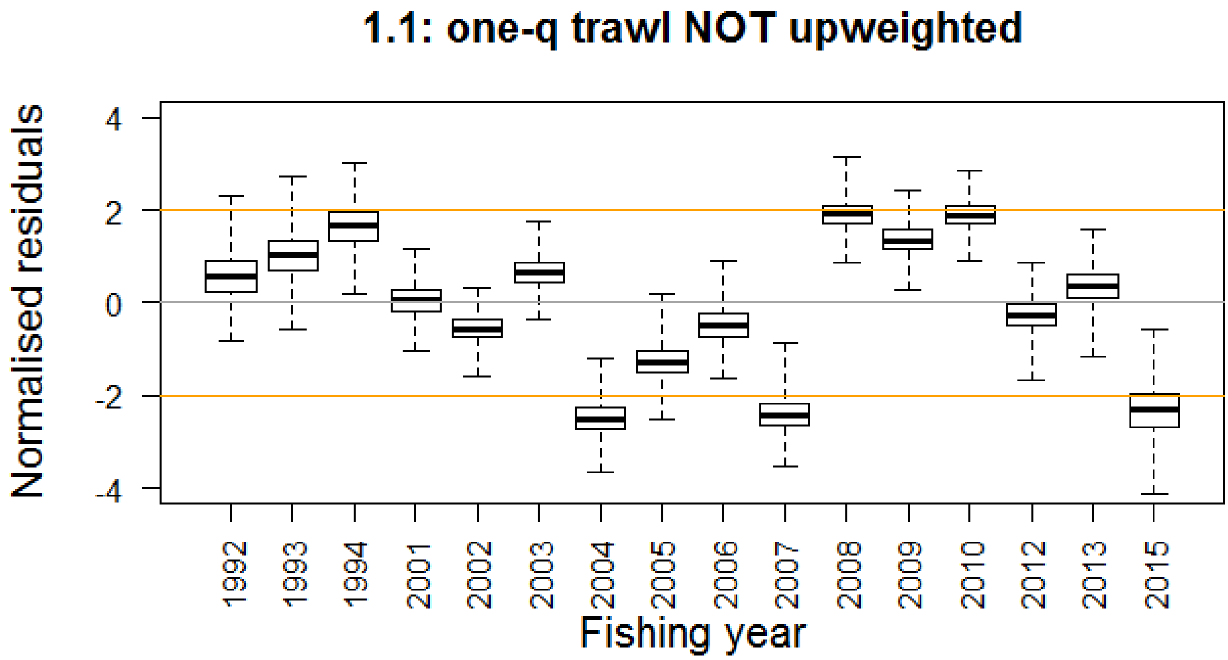


Figure 48: MCMC normalised residuals for model 1.1 and the fit to the Southern Plateau trawl survey.

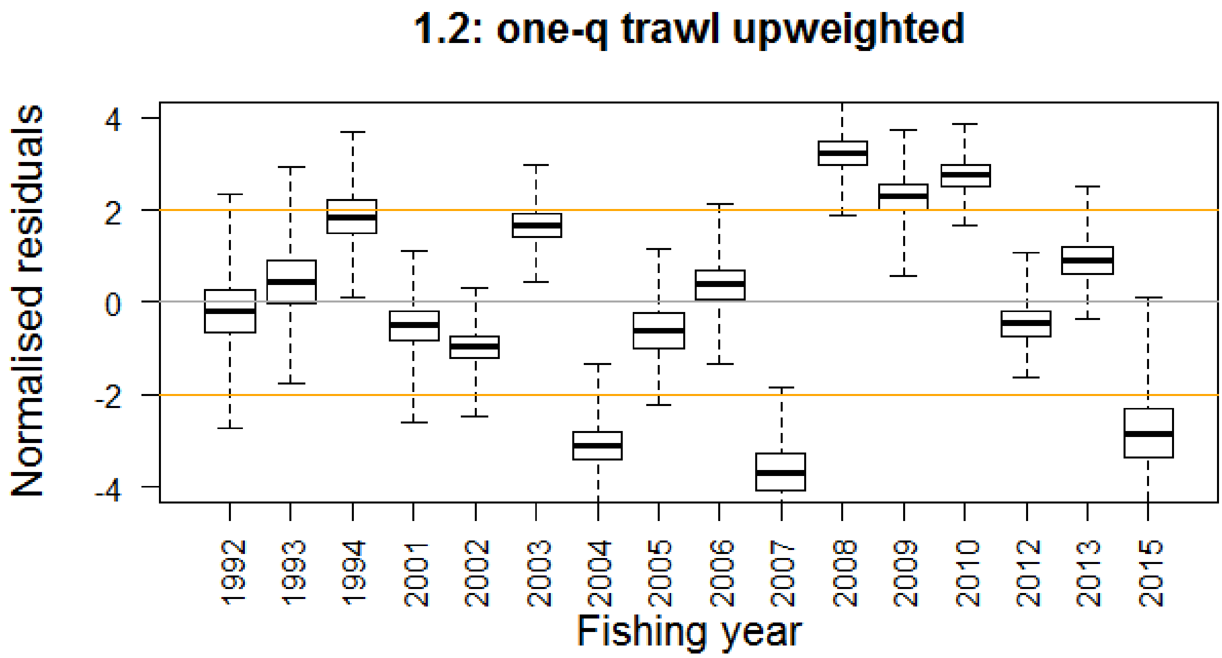


Figure 49: MCMC normalised residuals for model 1.2 and the fit to the Southern Plateau trawl survey.

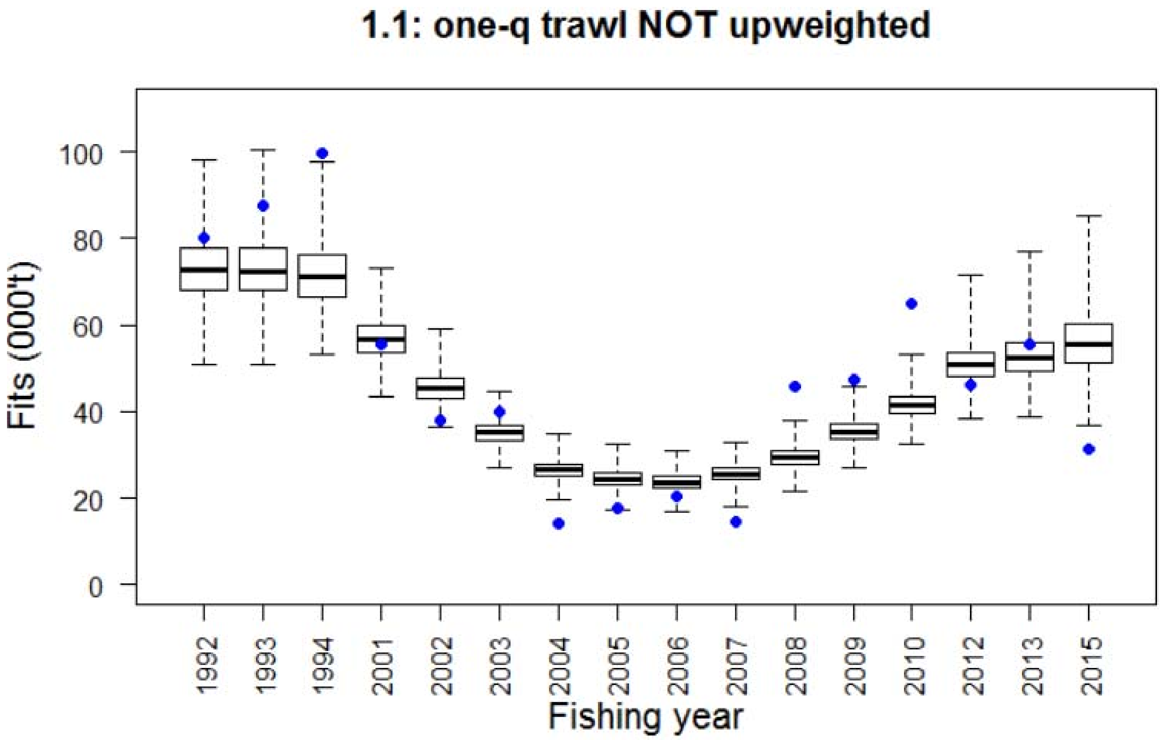


Figure 50: MCMC fits for model 1.1 to the Southern Plateau trawl survey. The fits for each year are shown as box-and-whisker plots, where the central rectangle of the plots has horizontal lines (from bottom to top) at the quartiles: 25% (lower quartile), 50% (median), and 75% (upper quartile). The interquartile range (IQR) is equal to the upper quartile minus the lower quartile. The upper whisker extends to the smallest value less than the upper quartile + 1.5×IQR; the lower whisker to the smallest values greater than the lower quartile – 1.5×IQR.

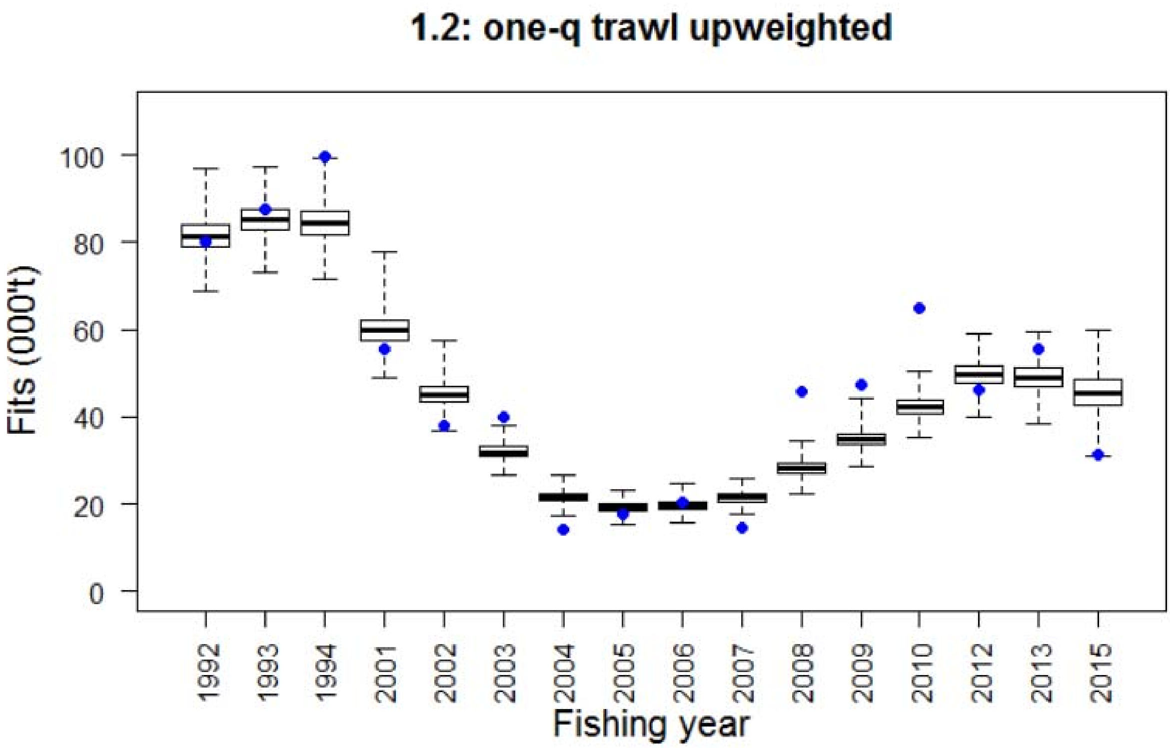


Figure 51: MCMC fits for model 1.2 to the Southern Plateau trawl survey. For plot explanation see the caption for Figure 50.

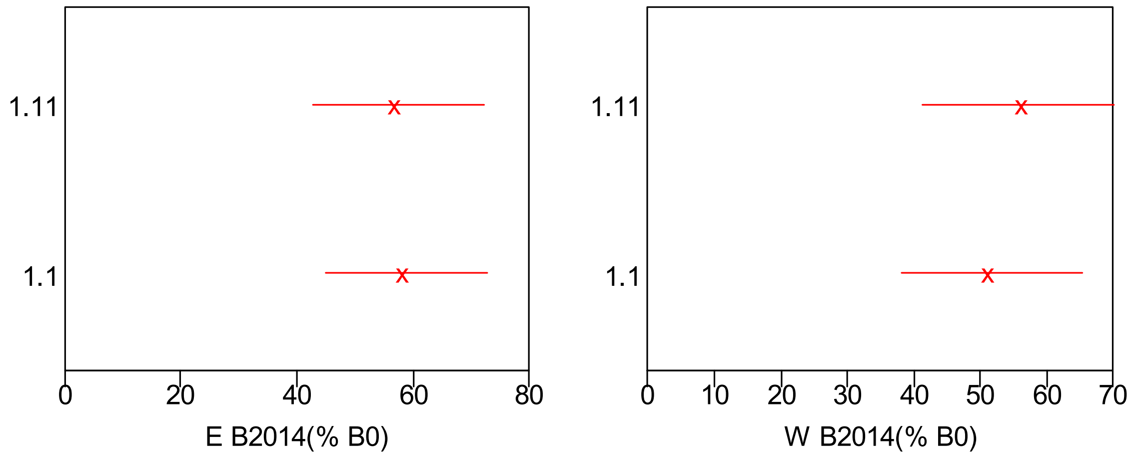


Figure 52: Comparison of 2015 continuity run 1.1 (single q) with the comparable run from 2014 (1.11): estimates of stock status in 2014 (B_{2014} as $\%B_0$), with 95% confidence intervals shown as horizontal lines.

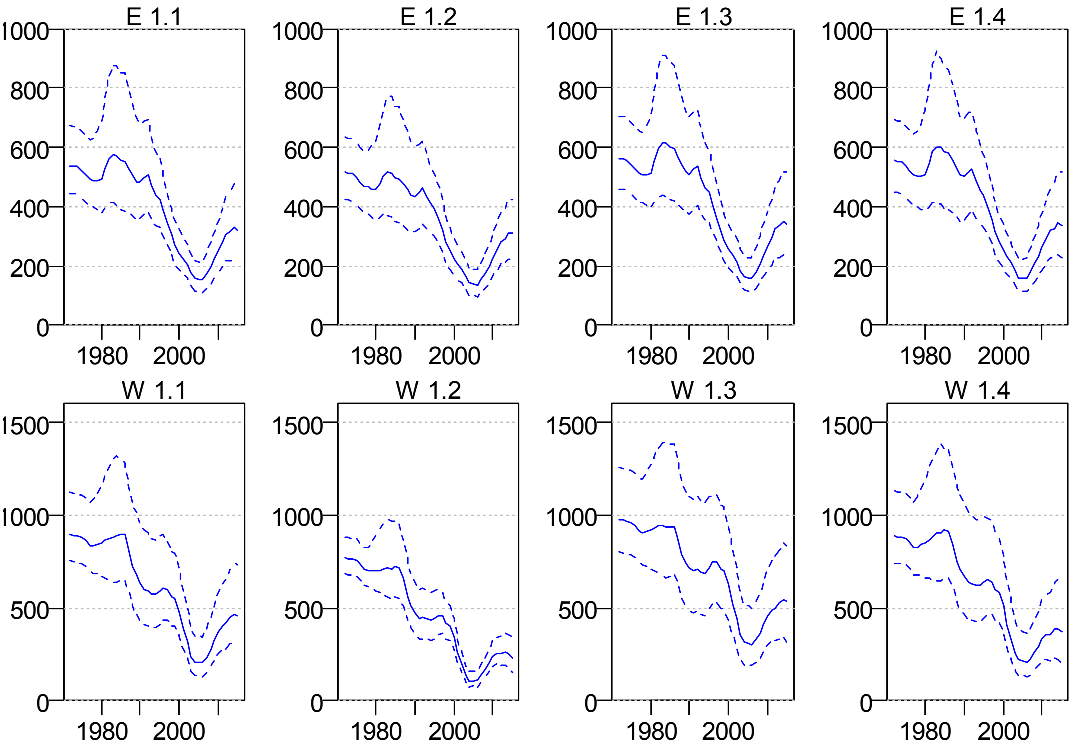


Figure 53: Estimated spawning-biomass trajectories from the MCMC runs, showing medians (solid lines) and 95% confidence intervals (broken lines) by run for E (upper panels) and W (lower panels).

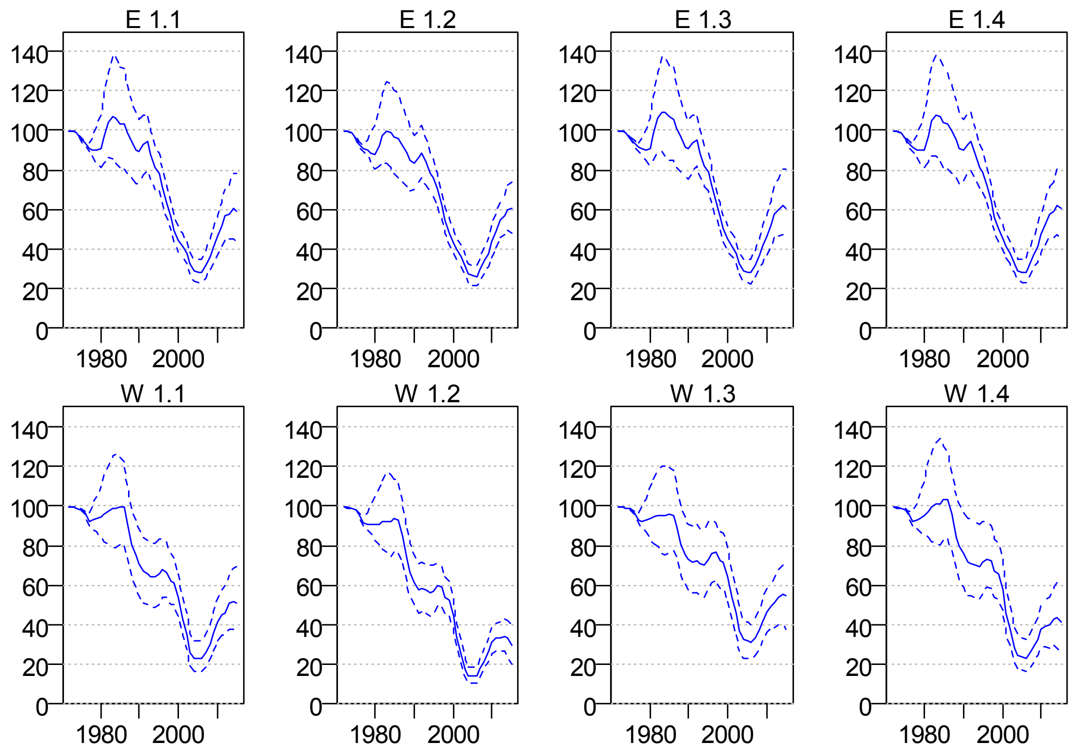


Figure 54: As for Figure 53, but plotted as $\%B_0$.

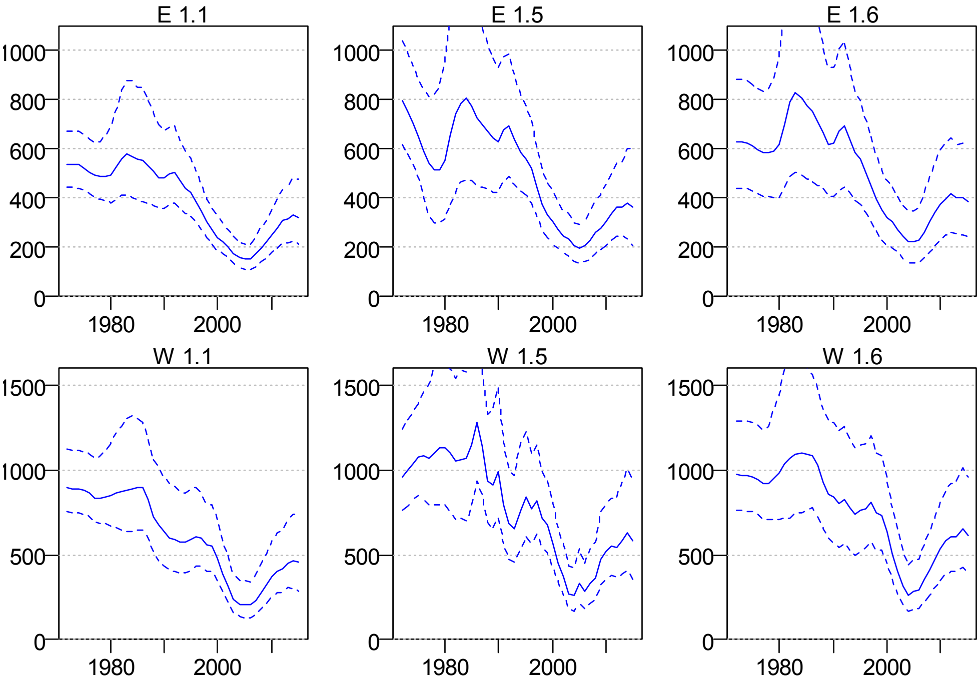


Figure 55: Estimated spawning-biomass trajectories from the MCMC runs, showing medians (solid lines) and 95% confidence intervals (broken lines) by run for E (upper panels) and W (lower panels).

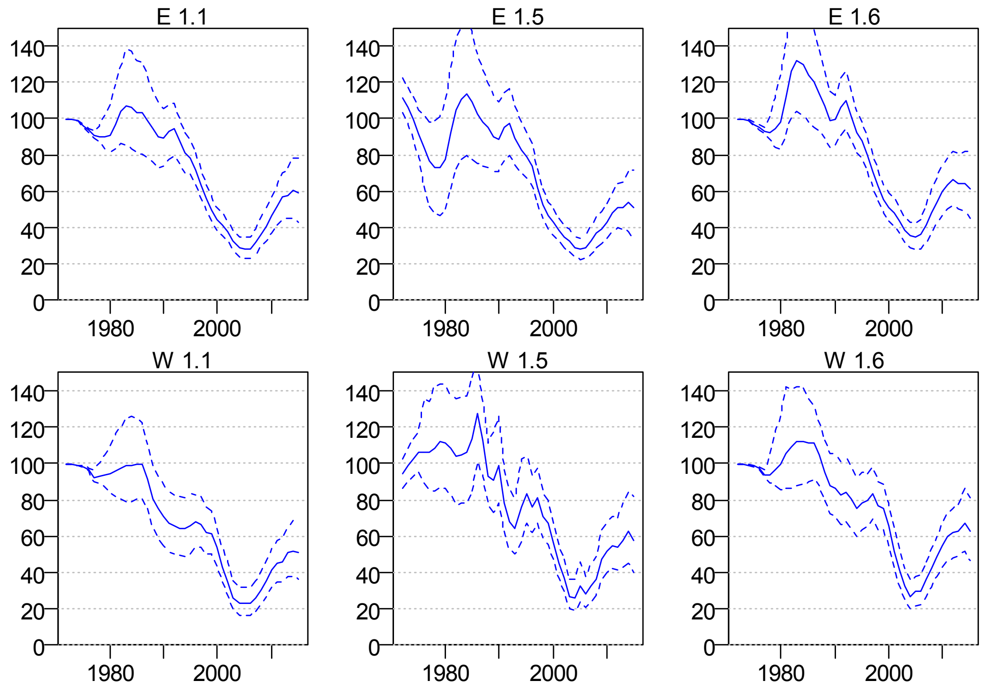


Figure 56: As for Figure 53, but plotted as %B_0.

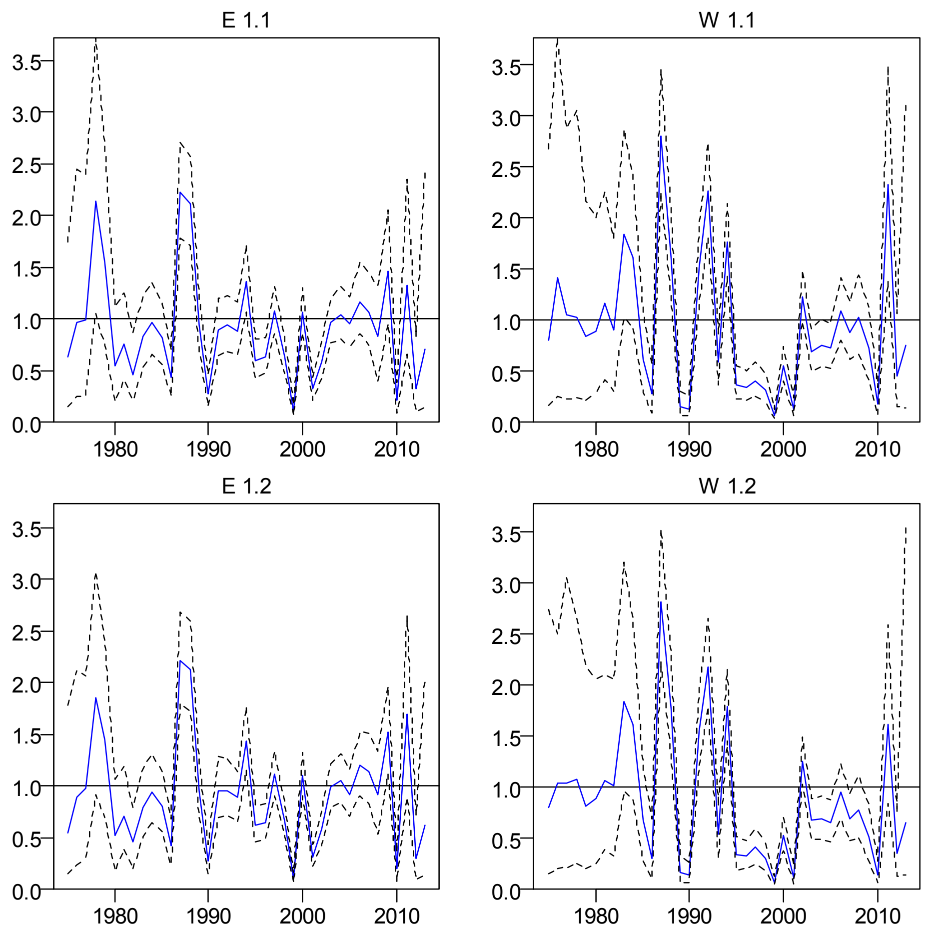


Figure 57: Estimated year-class strengths (YCSs) from the base runs 1.1 and 1.2 showing medians (solid lines) and 95% confidence intervals (broken lines) by run for E (left panels), W (right panels)

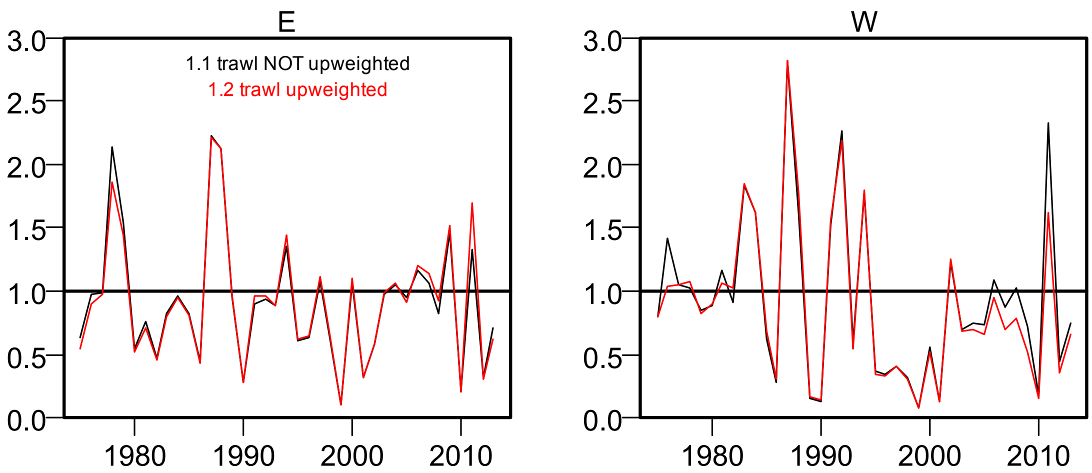


Figure 58: As in Figure 57 but showing just the medians.

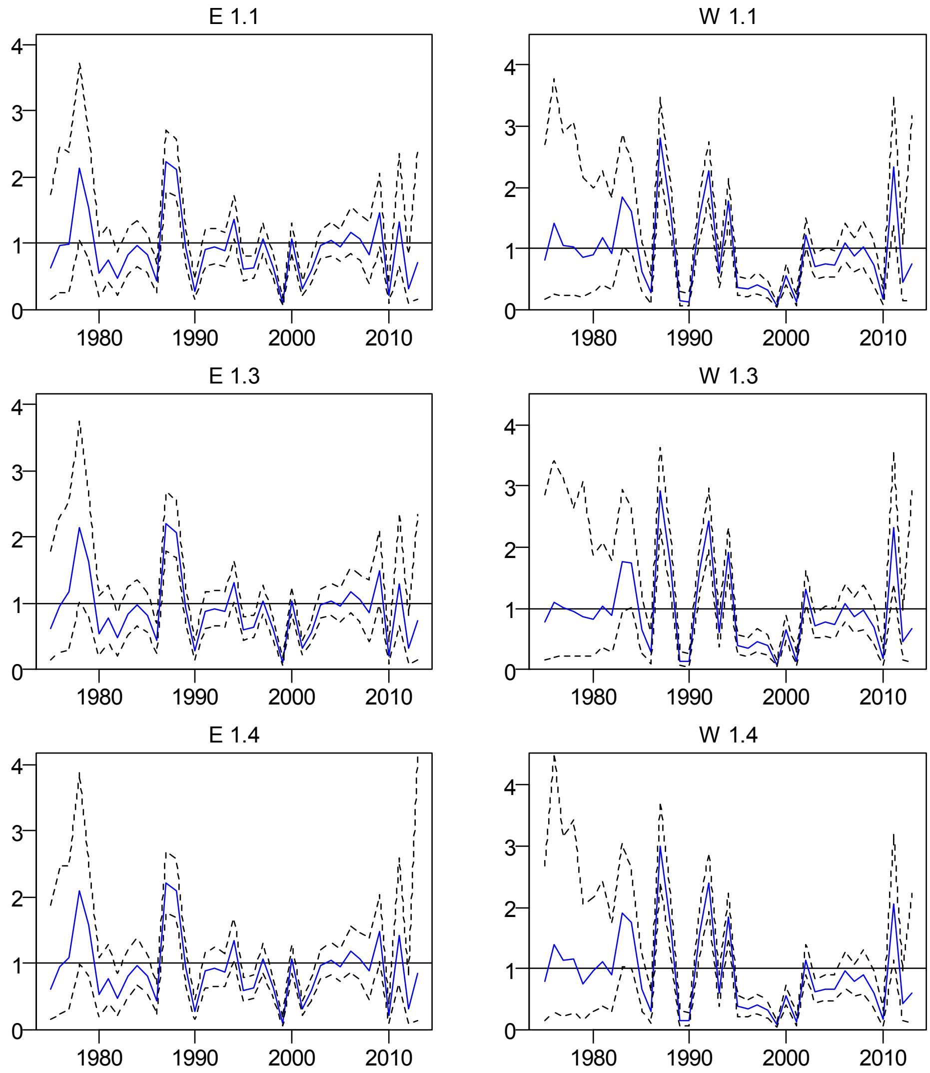


Figure 59: Estimated year-class strengths (YCSs) for runs 1.1, 1.3, and 1.4 showing medians (solid lines) and 95% confidence intervals (broken lines) by run for E (left panels), W (middle panels) and E + W (right panels).

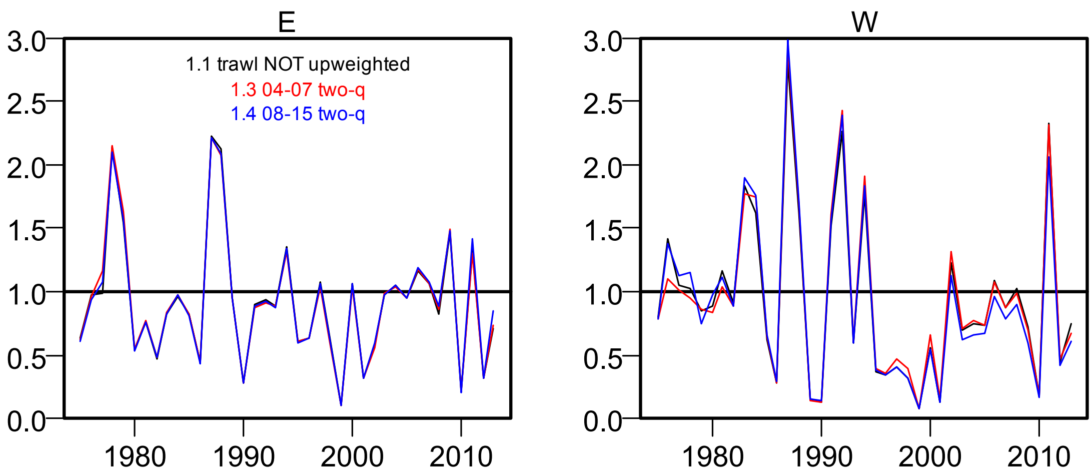


Figure 60: As in Figure 59 but showing just the medians.

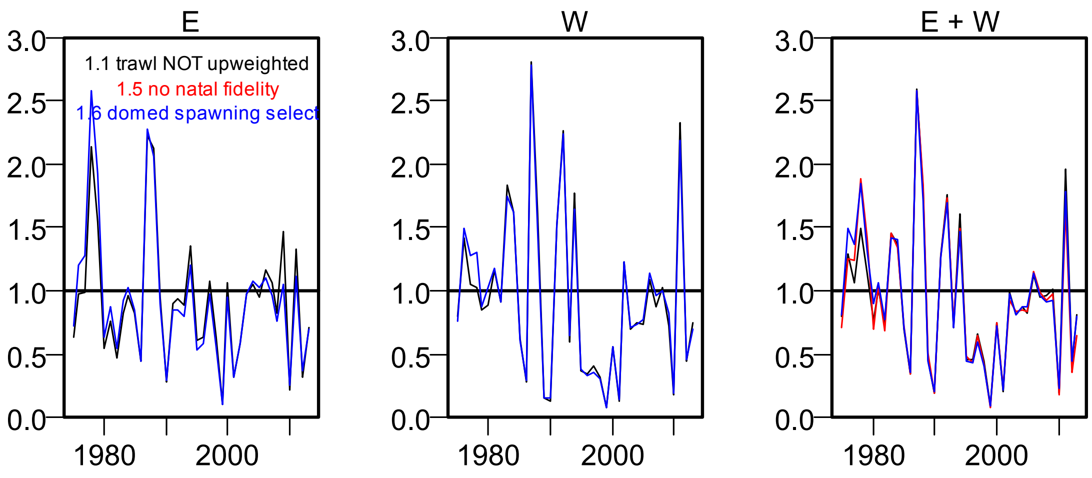


Figure 61: Estimated year-class strengths (YCSs) for the MCMC runs showing the medians (solid lines) by run for E (left panel), W (middle panel), E+W (right panel).

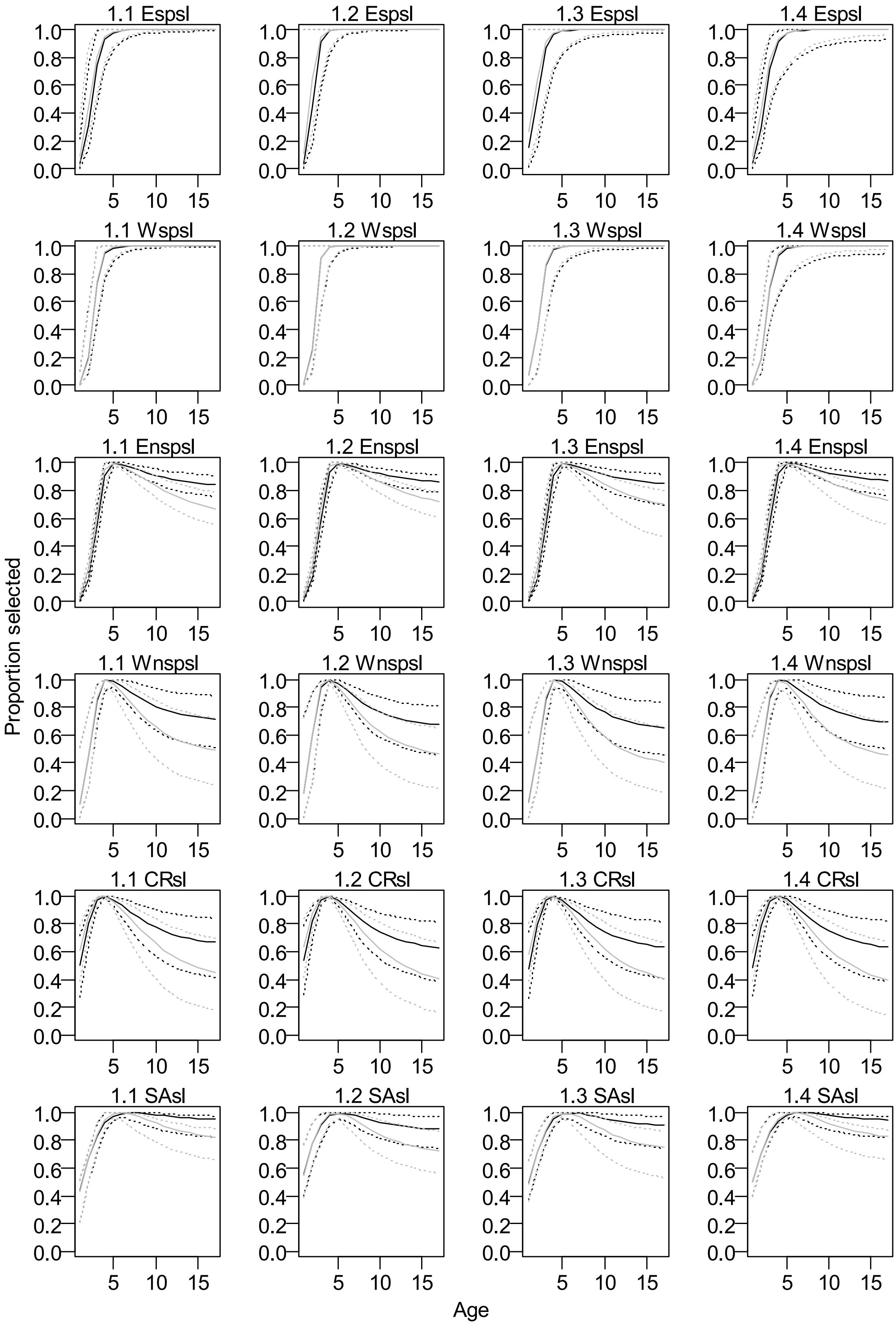


Figure 62: Posterior estimates of selectivity ogives for each for the four MCMC runs 1.1, 1.2, 1.3, and 1.4. Solid lines are medians; broken lines show 95% confidence intervals. Where ogives differ by sex they are plotted as black for males and grey for females. Where they differ by stock or time step the plotted curves are for one selected combination (E step 2 for Enspsl and CRsl, W step 2 for Wnspsl and SAsl).

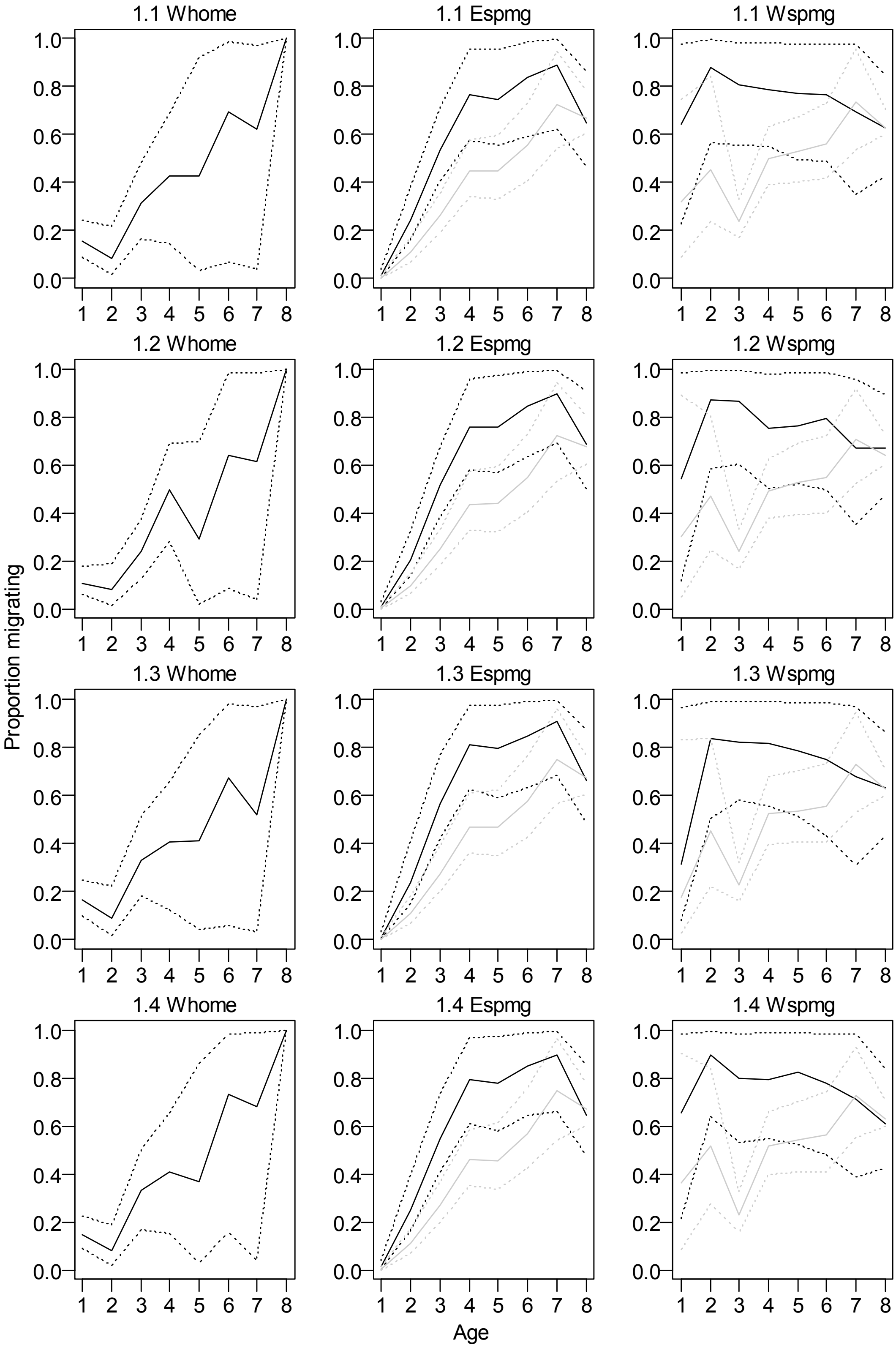


Figure 63: Migration ogives estimated in each of the four MCMC runs. Solid lines are medians, broken lines show 95% confidence intervals. Where ogives differ by sex they are plotted as black for males and grey for females.

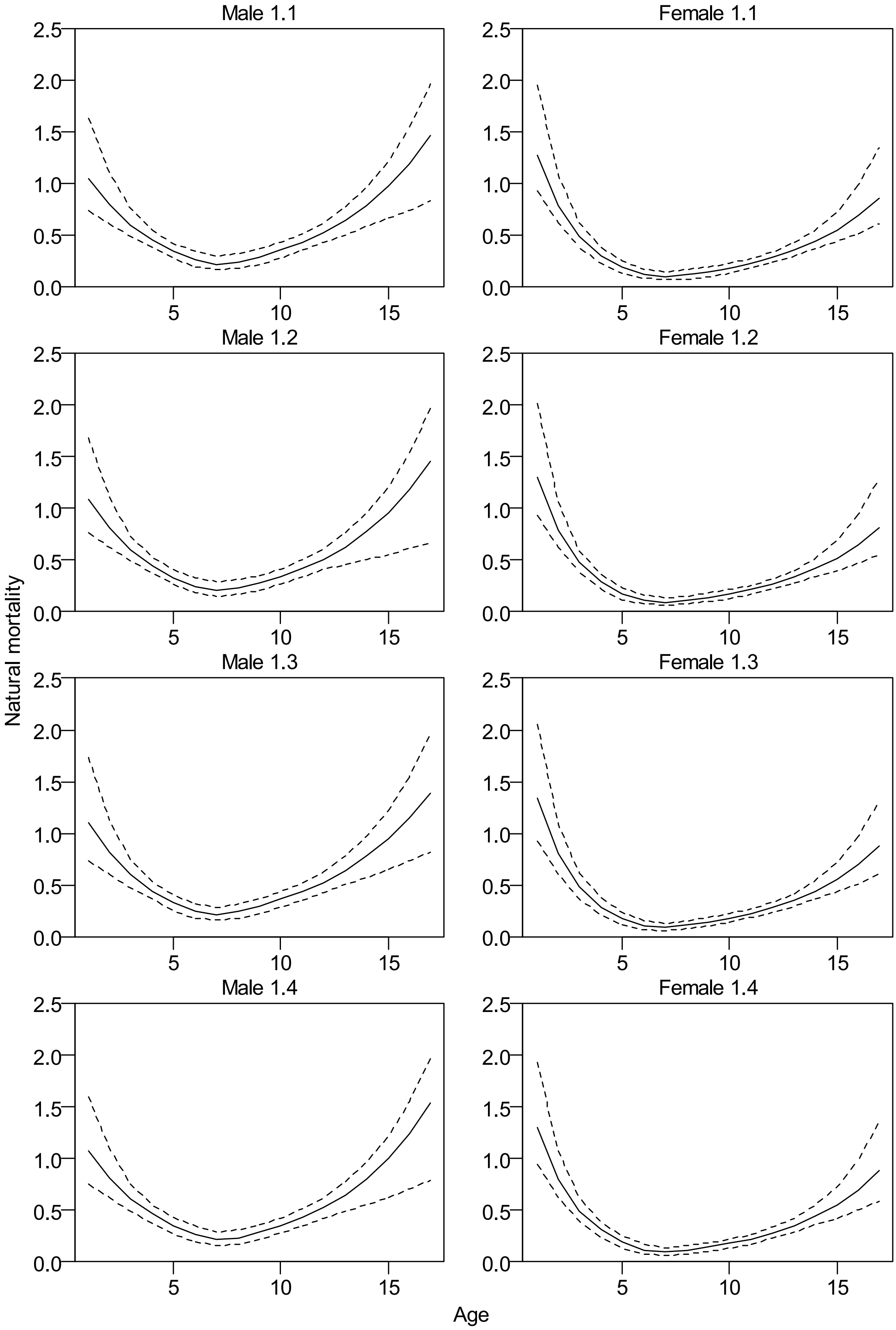


Figure 64: Assessment estimates of age-dependent natural mortality ogives in each of the four MCMC runs showing median estimates (solid lines) and 95% confidence intervals (broken lines) for each sex.

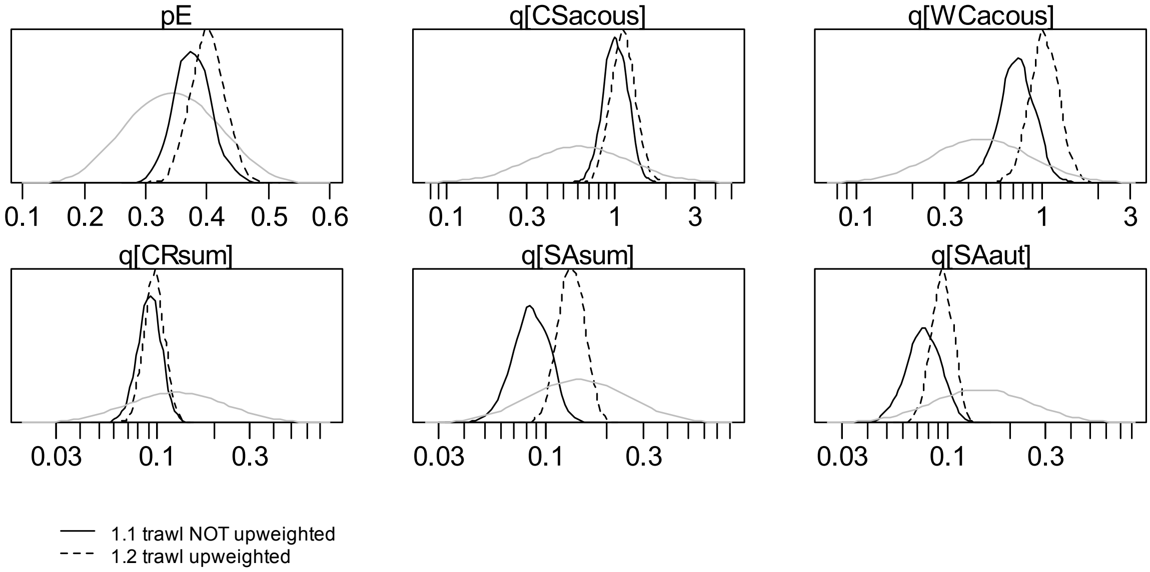


Figure 65: 2015 assessment prior (grey lines) and estimated posterior (black lines) distributions for the following parameters: pE (proportion of B_0 in E stock), and survey catchabilities (acoustic and trawl).

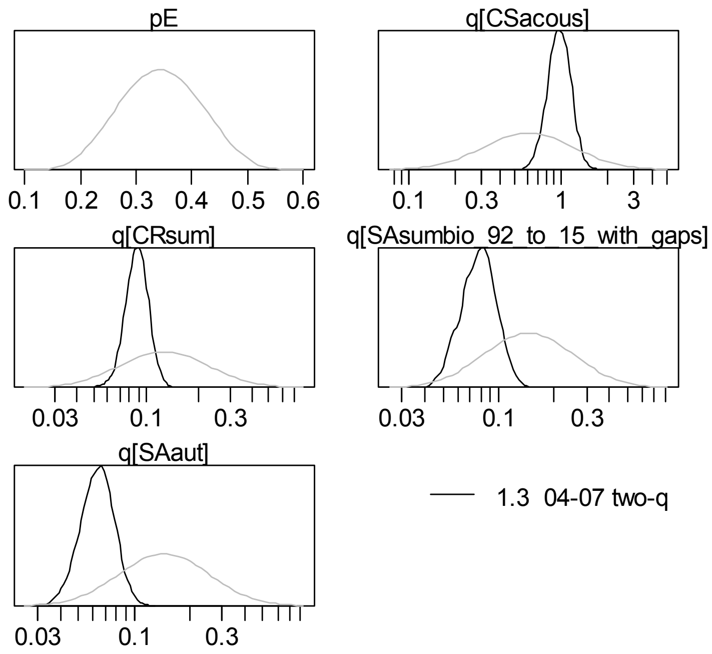


Figure 66: 2015 assessment prior (grey lines) and estimated posterior (black lines) distributions for the following parameters: pE (proportion of B_0 in E stock), and survey catchabilities (acoustic and trawl). The catchability *q*[SAsumbio_04_07] refers to the years 2004–07, and *q*[SAsumbio_92_15_with_gaps] to the other years. In both cases the catchability is bounded on [0.020, 0.51].

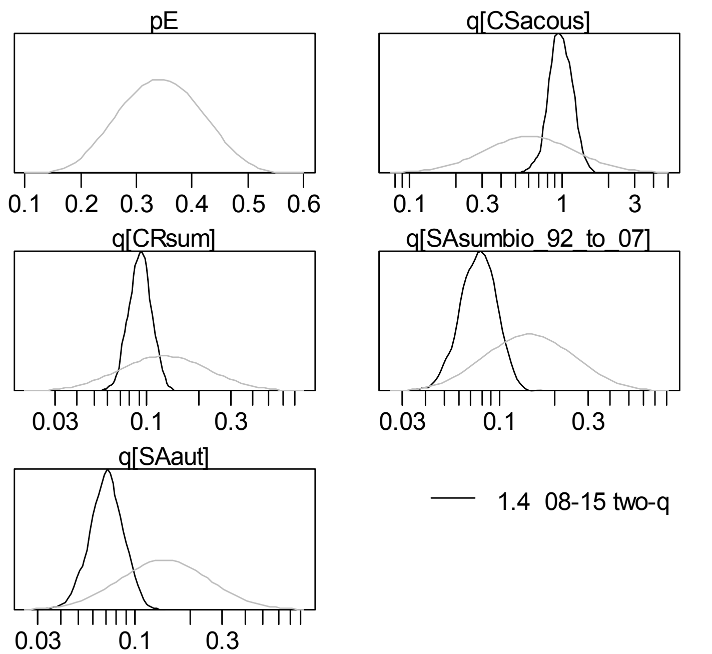


Figure 67: 2015 assessment prior (grey lines) and estimated posterior (black lines) distributions for the following parameters: pE (proportion of B_0 in E stock, and survey catchabilities (acoustic and trawl). The catchability *q*[SAsumbio_08_15] refers to the years 2008–15, and *q*[SAsumbio_92_07] to the years 1992–2007.

5.2 Traces and density plots for parameters that hit bounds in the base model

In model 1.1 a number of selectivity and migration parameters are estimated, some of which hit the bounds in the MPD estimation (Table 24–25). In previous assessments these parameters have been fixed at the bounds for the MCMCs, but they are kept free for the MCMCs in 2015. In this section we examine how well the posterior densities for some parameters of these are estimated, and compare selectivities between assessments.

A primary selectivity parameter is the position of the peak for the Chatham Rise trawl survey (CRsl.a1) which in the MPD hits the bound of 64 cm (for the length-based ogive). The trace for this exhibits some movement away from what may be a stationary distribution concentred from 64 cm to 66 cm, with a resultant extended tail in the density distribution (Figures 68–69). Visually there is little difference between the trawl selectivity estimated for the 2014 assessment (where CRsl.a1 was fixed at 64 cm in the MCMC) and that for the 2015 assessment where this parameter was not fixed (Figure 70).

For the Southern Plateau trawl selectivity, all three parameters of this double normal selectivity run into the bounds in the MPD. The trace for the peak of this selectivity (SAsl.a1) displays a downward trend for the first chain (of the three concatenated together), and for the other two chains stays near the bound of 84 cm (Figures 71–72). The medians for the selectivity look similar between the 2014 assessment (where SAsl.a1 was fixed at 84 cm) and the 2015 assessment (Figure 73).

The parameter Whome7 (proportion of males/females of age 7 that make a home migration from the Chatham Rise to the Southern Plateau) has a uniform prior on [0,1] and in the MPD hits the bound of one. The trace and posterior indicate a broad distribution for this parameter with a median at about 0.60 (Figures 74–76).

In general the selectivities are little changed by freeing up the parameters in the MCMCs, but are estimated with more uncertainty.

Table 24: Ogive assumptions for run 1.1. In the ogive constraints, $O_{7,F,E}$ refers to the ogive value at age 7 for female fish from the E stock, etc.

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

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

Table 25: Migration and selectivity parameters that hit bounds in MCMC run 1.1 (one-q). 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; ato95 the increment from a50 to reach the 0.95 value for a logistic curve (Bull et al. 2012). Lower and upper bounds for the parameter are shown, with an asterisk indicating which bound is hit in the MPD.

Parameter	Lower	Upper
Whome7	0	1*
EspmgF1	0*	1
EspmgF8	0.6*	1
WspmgF8	0.6*	1
Enspsl.sR	4	44*
Espsl.ato95	4*	60
CRsl.a1	64*	84
SAsl.a1	64	84*
SAsl.sL	4	44*
SAsl.sR	4	44*

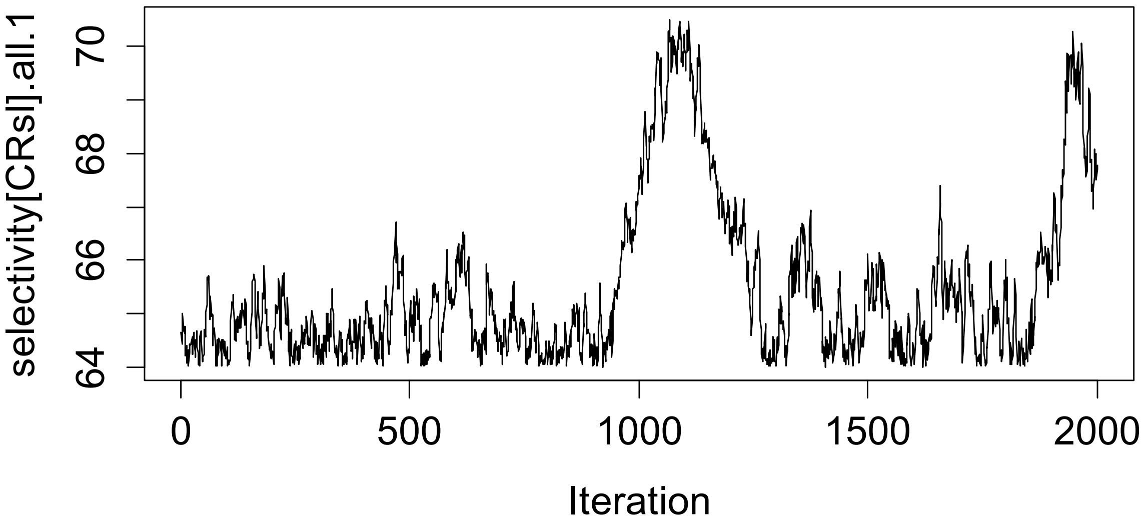


Figure 68: Trace for model 1.1 and the parameter CRsl.a1.

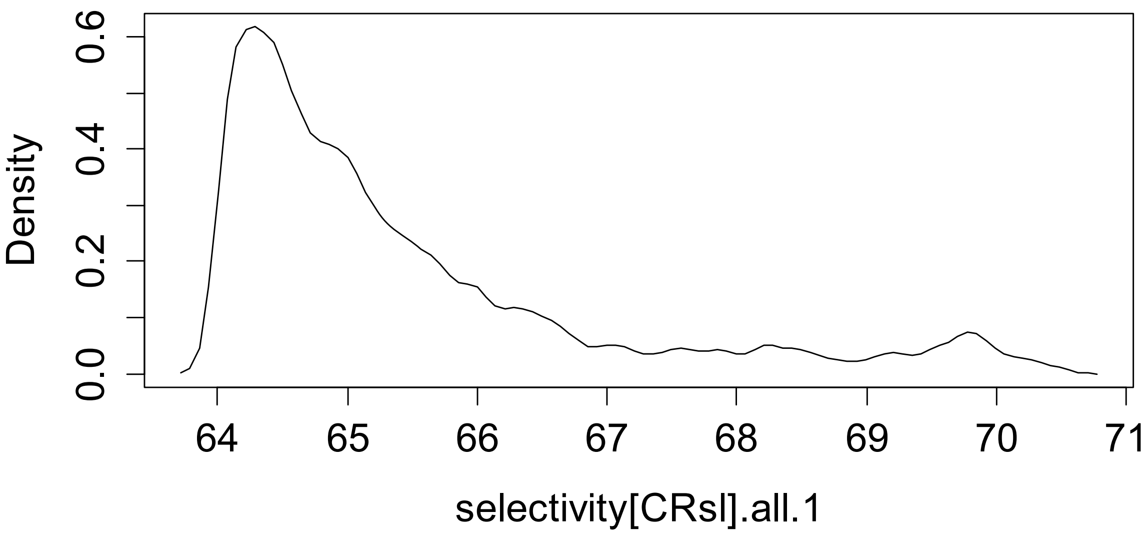


Figure 69: Estimated posterior density for the parameter CRsl.a1 (constructed via kernel density estimation with a Gaussian kernel).

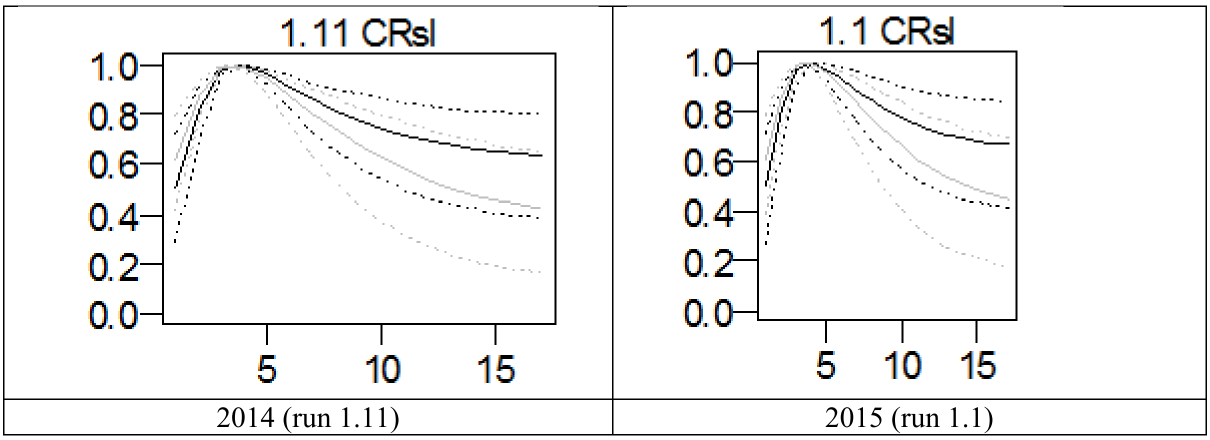


Figure 70: Chatham Rise trawl selectivity between assessments.

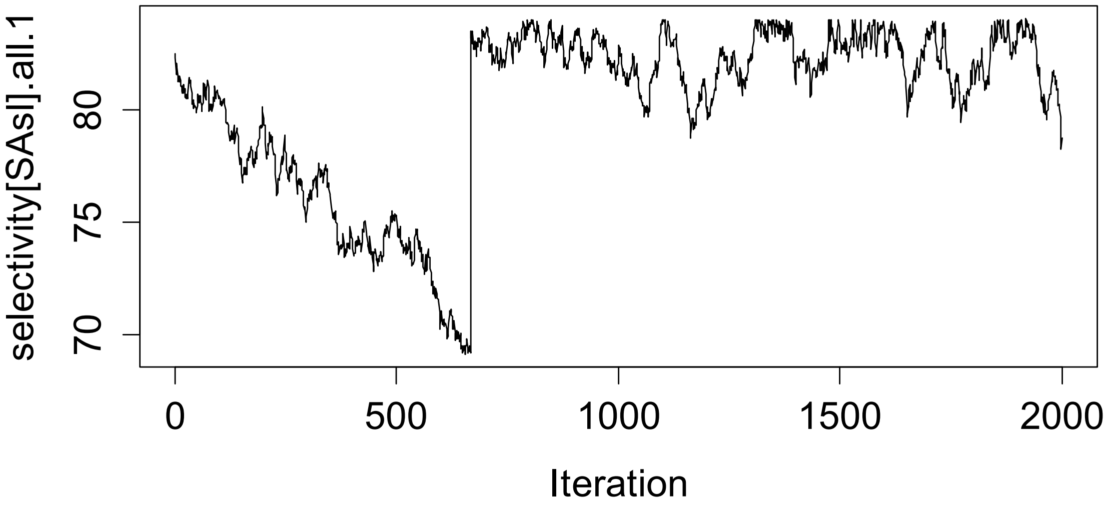


Figure 71: Trace for the parameter SAsl.a1.

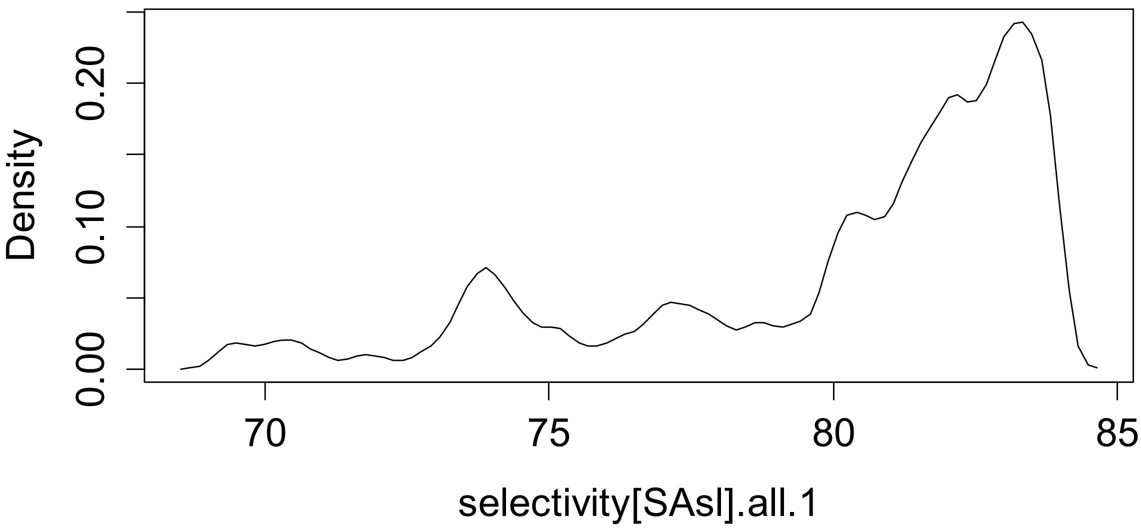
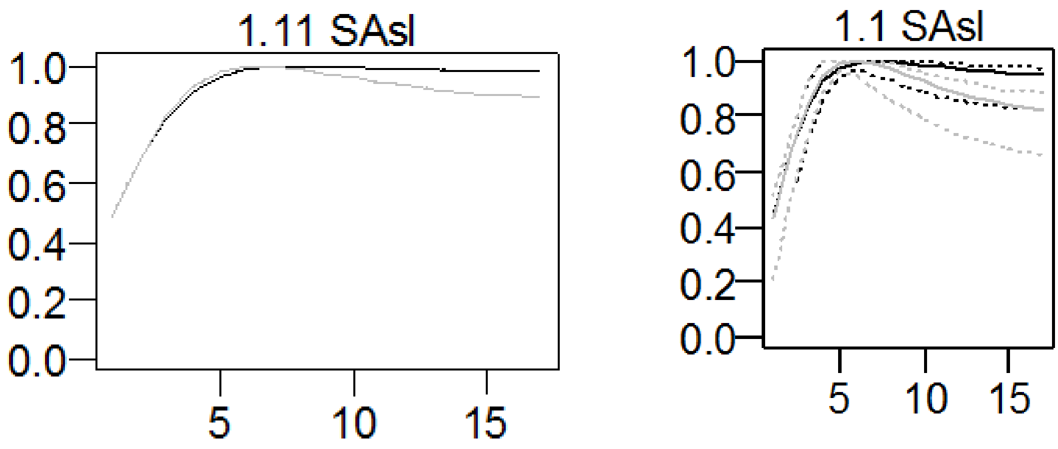


Figure 72: Posterior density for the parameter SAsl.a1.



2014 (run 1.11) 2015 (run 1.1)

Figure 73: Southern Plateau trawl selectivity between assessments.

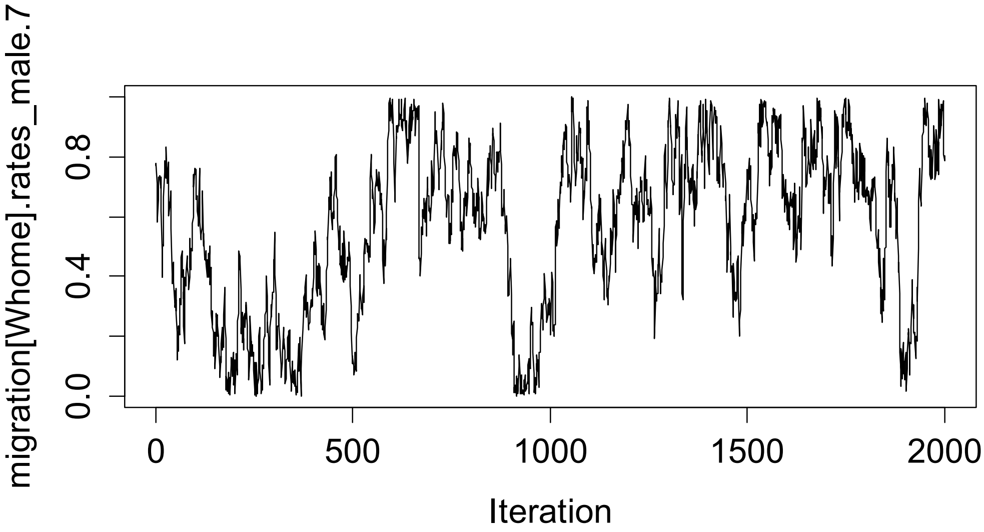


Figure 74: Trace for the parameter Whome7 (proportion of males/females of age 7 that make a home migration from the Chatham Rise to the Southern Plateau).

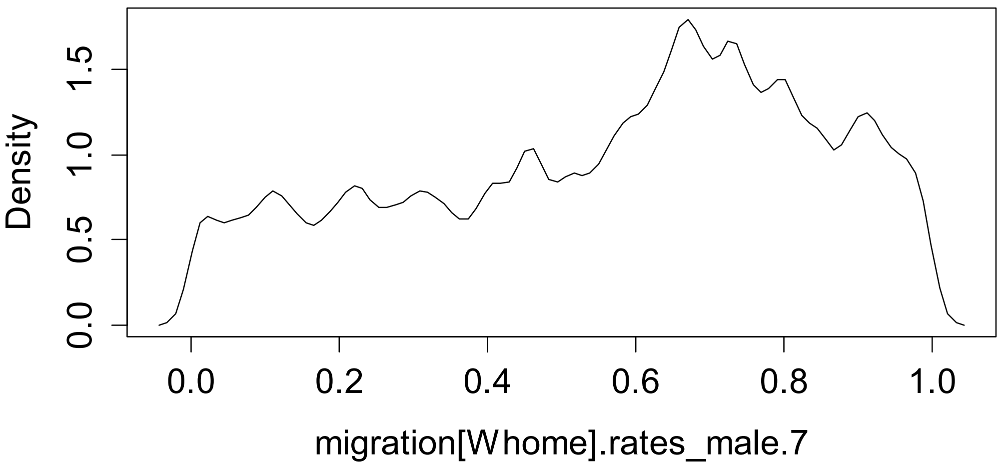


Figure 75: Posterior density for the parameter Whome7.

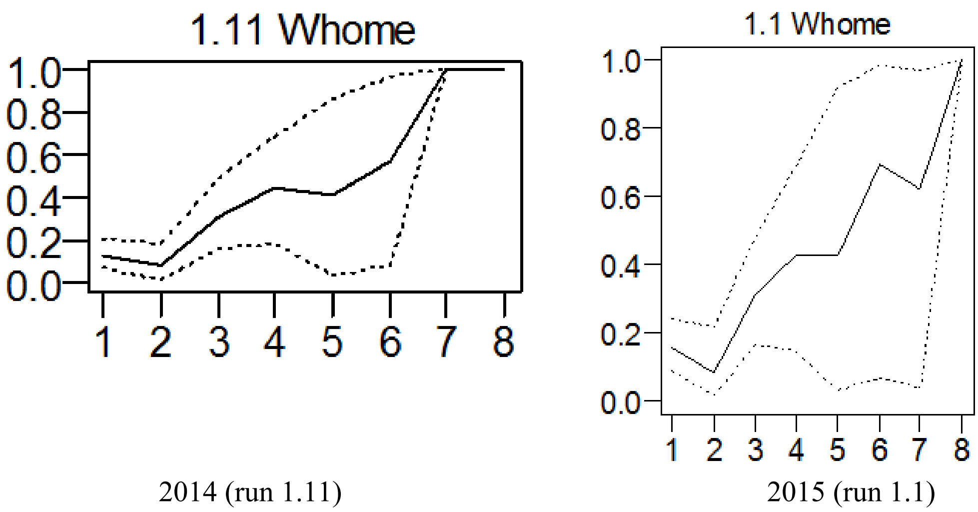


Figure 76: Whome selectivity between assessments, and in particular Whome7 the selectivity at age 7.

6. PROJECTIONS

Five-year projections were carried out for two models: the base model with a single catchability for the SAsumbio series (1.1), and the model where the trawl surveys are upweighted (1.2).

In all projections, future recruitments were selected at random from those estimated for 2004–2013, and the future catches in each fishery were assumed to be the same as for 2015. The projections indicate that with these assumed catches, the E and W biomasses are likely to remain flat or decline slightly over the next 5 years (Figure 77).

The probabilities of the current (2015) 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 Table 26 for the case where future catches remain at 2015 levels. The probability of either stock being less than either the soft or the hard limit over the five year projection period is negligible for the E stock, but 0.34 or less for the W stock when trawl surveys are upweighted (run 1.2). Both stocks are projected to be within or above the 35–50% B_0 target range at the end of the projection period, except for the W stock when trawl surveys are upweighted.

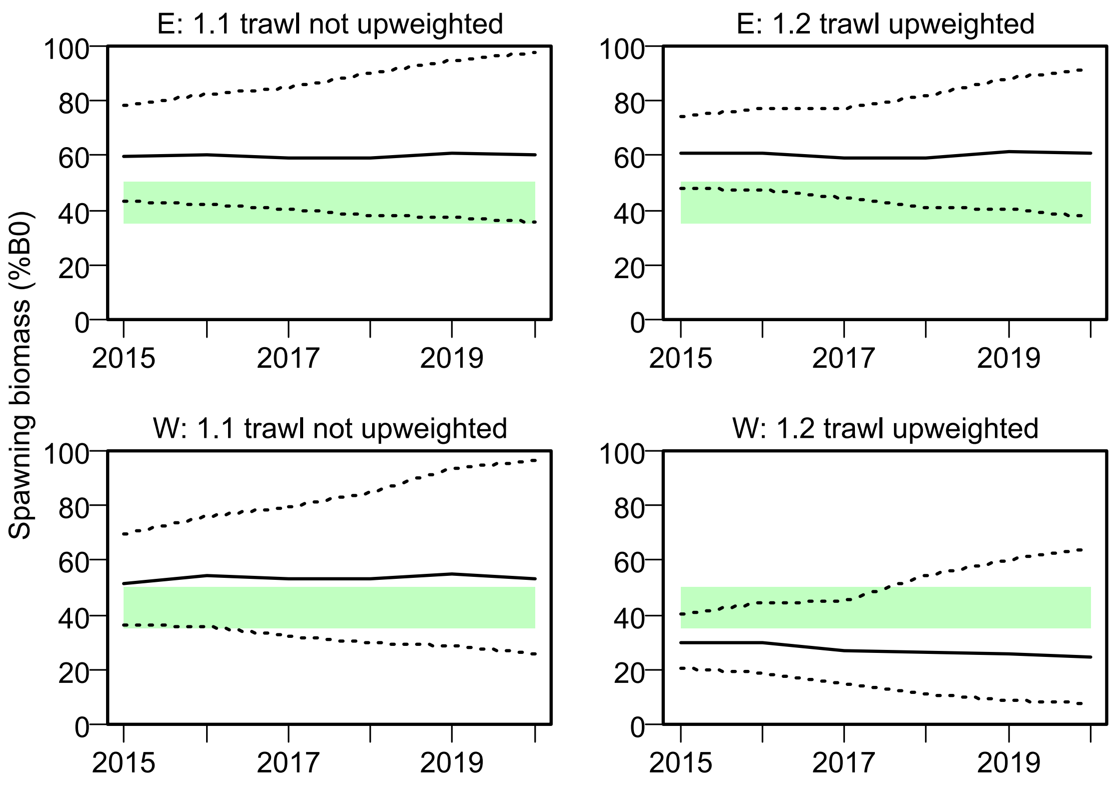


Figure 77: Projected spawning biomass (as %B_0): median (solid lines) and 95% confidence intervals (broken lines) for the base case (1.1) and a sensitivity run with the trawl surveys upweighted (1.2). The shaded green region represents the target management range of 35–50% B_0.

Table 26: Probabilities (to two decimal places) associated with projections for SSB (%B_0) for the base case (1.1) and the sensitivity run with trawl surveys upweighted (1.2) for 2015 and 2020.

	2015		2020	
	1.1	1.2	1.1	1.2
EAST				
P (SSB<10%B_0)	0	0	0	0
P (SSB<20%B_0)	0	0	0	0
P (SSB<35%B_0)	0	0	0.02	0.01
P (SSB<50%B_0)	0.13	0.04	0.24	0.20
WEST				
P (SSB<10%B_0)	0	0	0	0.07
P (SSB<20%B_0)	0	0.02	0	0.34
P (SSB<35%B_0)	0.02	0.84	0.11	0.77
P (SSB<50%B_0)	0.44	1.00	0.43	0.92

7. 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_0 or 50% B_0, respectively, assuming deterministic recruitment and individual fishery exploitation rates that are multiples of those in the current year. These reference pressures were calculated by simulating fishing using a harvest strategy in which the exploitation rate for fishery f was $mU_{f,\mathrm{current}}$, where $U_{f,\mathrm{current}}$ 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 $m_{x\%}U_{\mathrm{current}}$, 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 78).

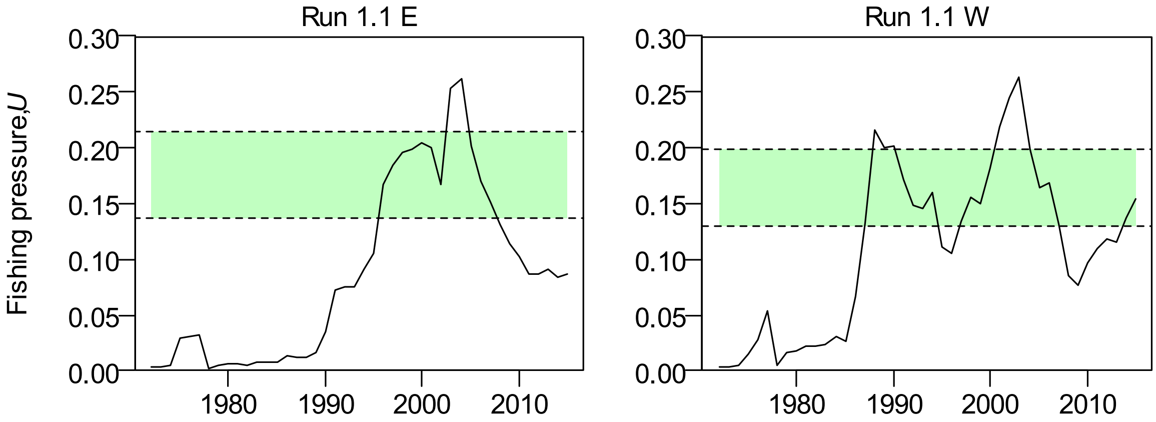


Figure 78: Fishing intensity, U (from MPDs), plotted by run and stock. Also shown (as broken lines) are the reference levels $U_{35\%B_0}$ (upper line) and $U_{50\%B_0}$ (lower line), which are the fishing intensities that would cause the spawning biomass to tend to 35% B_0 and 50% B_0, respectively.

8. CALCULATION OF B_{MSY}

B_{MSY} was calculated, for each stock, assuming a harvest strategy in which the exploitation rate for fishery f was $mU_{f,2015}$, where $U_{f,2014}$ is the estimated 2015 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 the base run 1.1 (one-q), estimates of B_{MSY} were 25% for the E stock, and 26% for the W stock.

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

9. DISCUSSION

The western stock is estimated to have been increasing since about 2006, but flattening and declining in recent years if the trawl surveys are upweighted. The eastern biomass is estimated to have been increasing since about 2006, but declining slightly in recent years if a domed spawning selectivity is used.

Current biomass are 36–69%B_0 for the western stock and 43–78%B_0 for the eastern stock (values are 95% CI for the base case). 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 in 2010, 2012 and 2013 when it was likely to have been below average (although estimated with high uncertainty). Projections indicate that with the current catch the eastern and western biomasses are likely to remain stable or decline slightly over the next 5 years.

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.

10. ACKNOWLEDGMENTS

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Appendix 1: Files defining the final runs

Each of the final model runs is completely defined, in the context provided by the CASAL manual (Bull et al. 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).

Appendix 2: Changes in stock-assessment model assumptions

Table A1: Changes in stock-assessment model assumptions and input data for each year since the first CASAL assessment of hoki in 2002.

Year	Changes
2003	Changed timing of spawning migrations from the middle to the end of the non-spawning fisheries (and after the autumn SA surveys)
	Earliest estimated YCS changed to 1977 from 1980
	Assumed Beverton-Holt stock-recruit relationship
	Disallowed annual variation in selectivities for Wnsp fishery
	Allowed for ageing error (expected to reduce bias in estimates of YCSs)
	Process errors for at-age data sets estimated within the model
	Non-uniform prior on pE
	Max. age of otolith-based at-age data increased from 10 (plus group) to 12 (no plus group)
	First use of otolith-based at-age data for non-spawning fisheries (Enspage & Wnspage)
	Forced equality of recent W and E YCSs extended from 2 y to 3 y
	Improvements in methods of converting ogives from size-based to age-based and implementing annual variation in selectivities
2004	First use of age-dependent natural mortality and domed spawning selectivities to cope with lack of old fish
	Maximum age in partition increased from 13 y to 17 y
	New parameterisation for YCSs
	Earliest estimated YCS changed to 1975 from 1977
	Change in priors for CSacous catchability and pE
	Max. age of otolith-based at-age data increased from 12 (no plus group) to 13/15 (plus group)
2005	For runs with domed spawning selectivities, spawning selectivities (rather than migrations) constrained to be equal
	Some at-age data revised
2006	Annual variation in Wsp selectivity restricted to years with significant data and constrained by non-uniform prior on controlling parameter
	Forced equality of recent W and E YCSs reduced from 3 y to 1 y
	Added smoothing penalty for age-dependent natural mortality
	First model run without the assumption of natal fidelity
2007	New parameterisation (double-exponential) and prior for age-dependent natural mortality
2008	Models runs without natal fidelity dropped
	Stock recruitment steepness reduced from 0.90 to 0.75
	1998 proportions spawning data re-analysed
2009	Median catch day re-calculated using a new first year
	1992 and 1993 proportions spawning data re-analysed
2010	Allow two catchabilities for the Southern Plateau trawl survey in sensitivity model runs
2011	Reduce to one base model (age-varying natural mortality) from two base models (for the other base model there were domed shaped fishing selectivities in the spawning fishery)
2012	Re-weight the proportions-at-age data (the procedure giving them a substantial down-weighting)
	Re-introduce a sensitivity model run without natal fidelity
2013	Of the three final model runs, two have a time-varying catchability for the Southern Plateau trawl survey biomass series
2014	Use the Haist year class strength parameterisation (instead of the Francis parameterisation)
2015	Three changes in MCMC procedure:
	(i) estimate catchabilities as free parameters instead of analytical,
	(ii) leave as free those migration and selectivity parameters that hit bounds in MPDs
	(instead of fixing them to the bounds), and
	(iii) increase chain length from two million to four million.

Appendix 3: Traces for previous base model run 1.11 (2014 assessment)

In the 2014 assessment migration and selectivity parameters that hit bounds are held fixed in the MCMC, and will have flat traces.

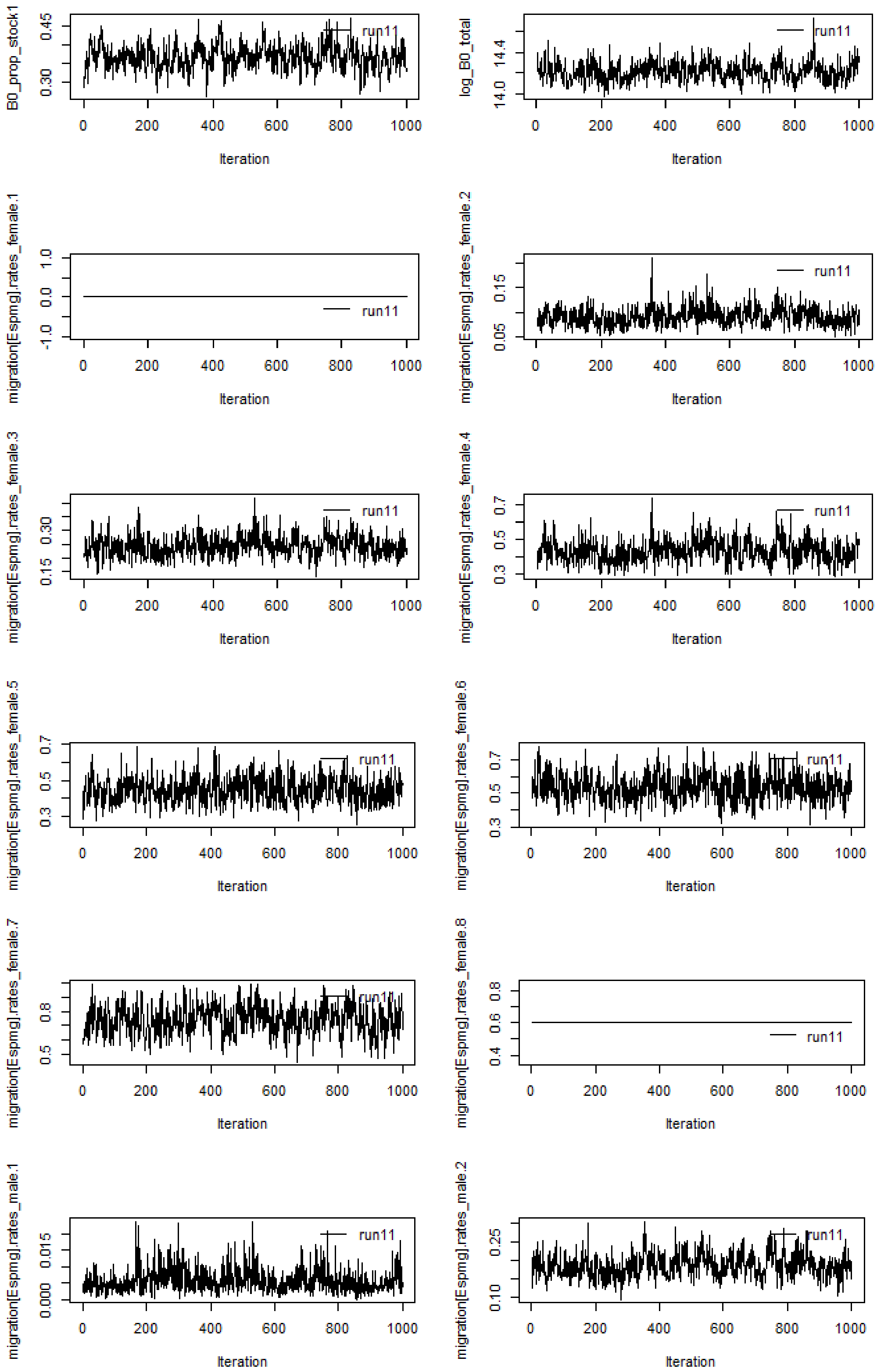
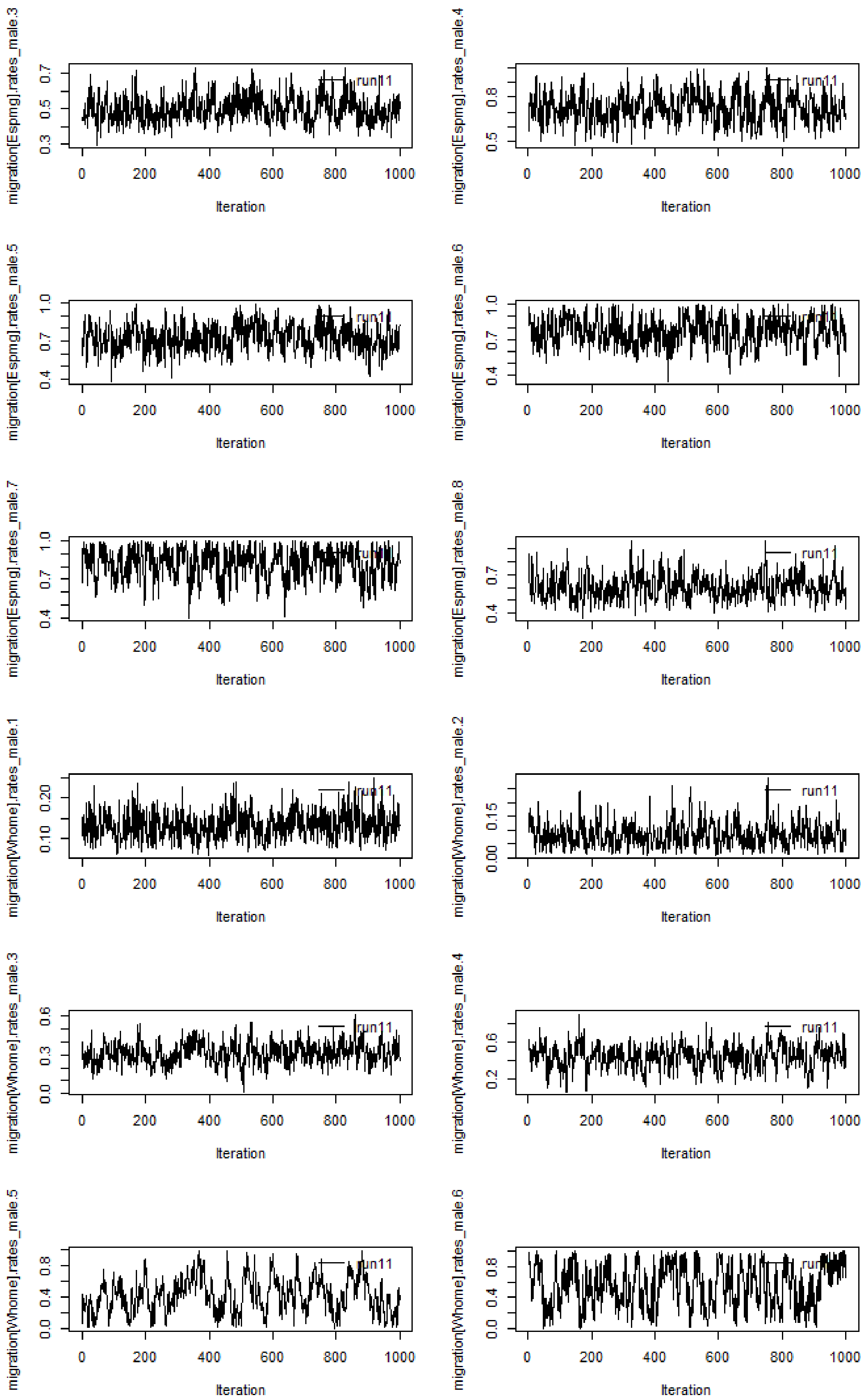


Figure A1: Traces for the 2014 base model run 1.11



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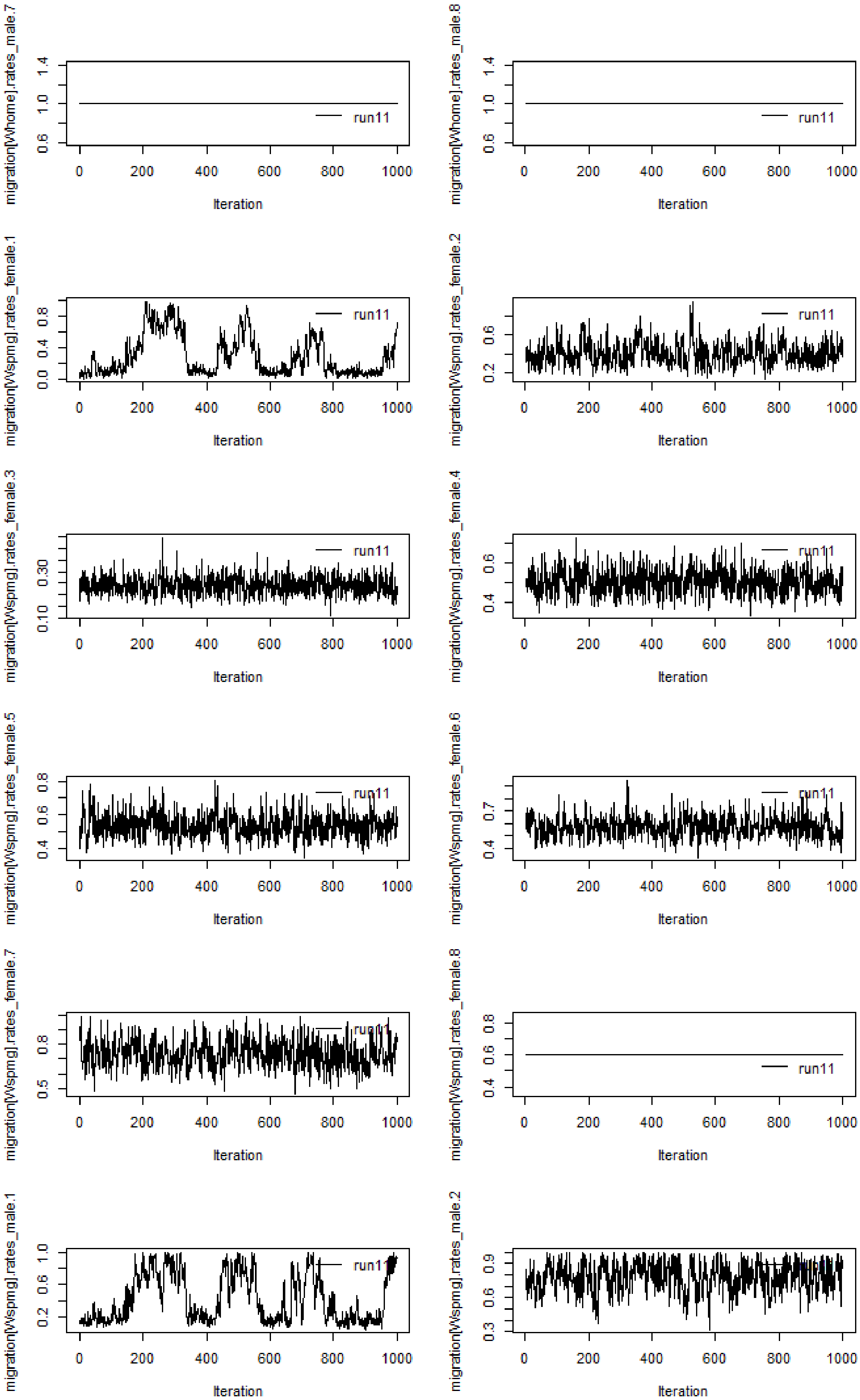

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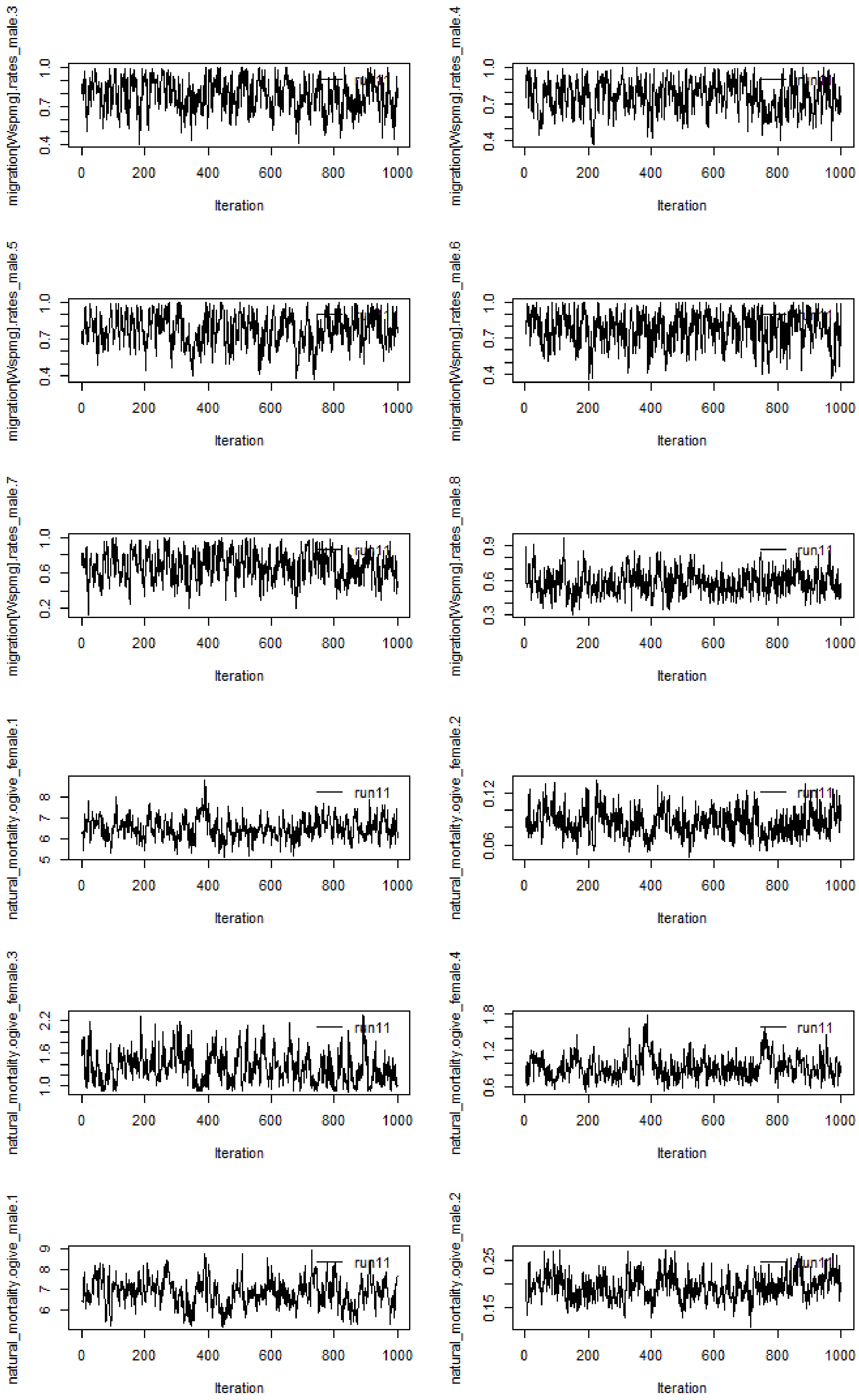

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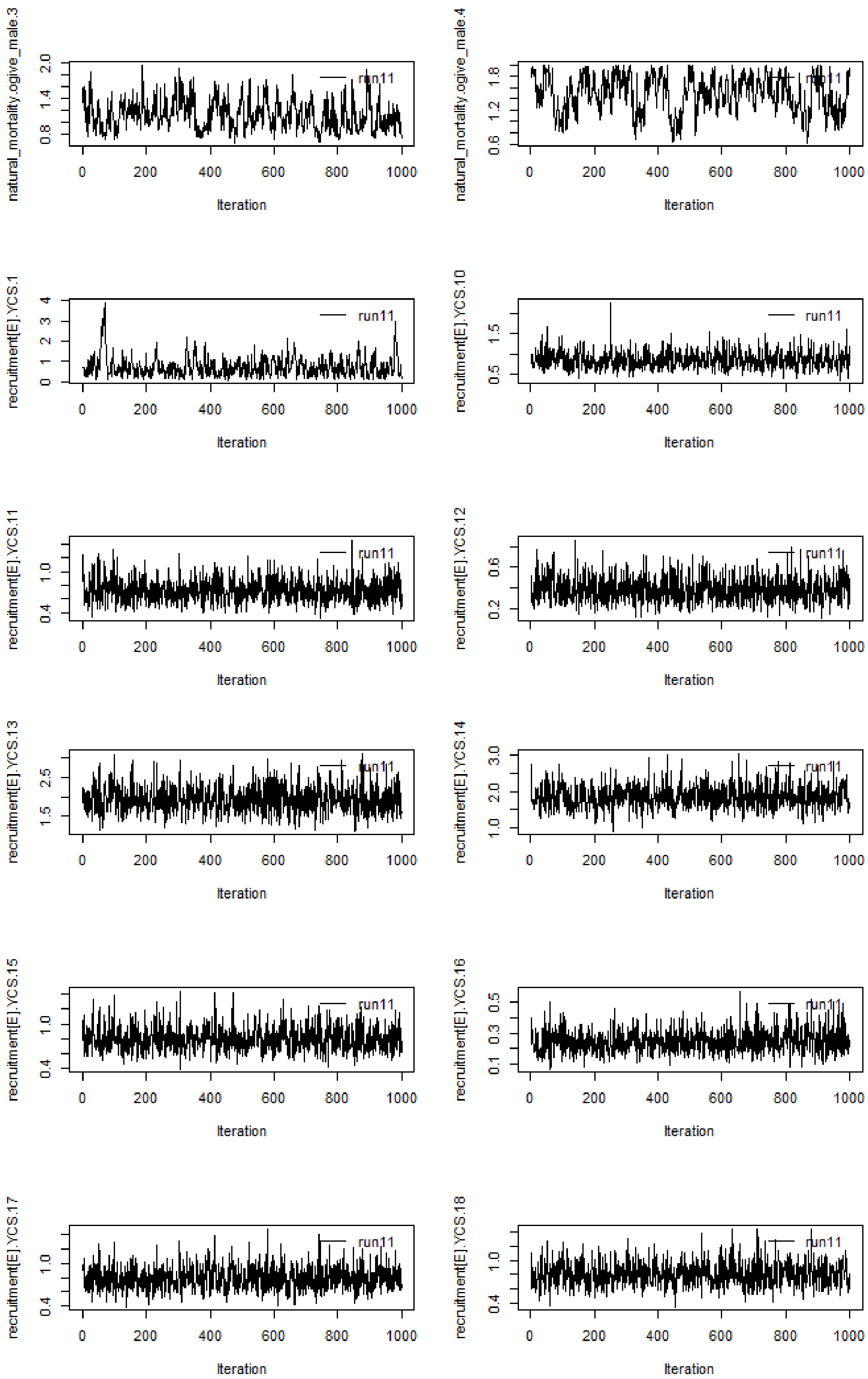

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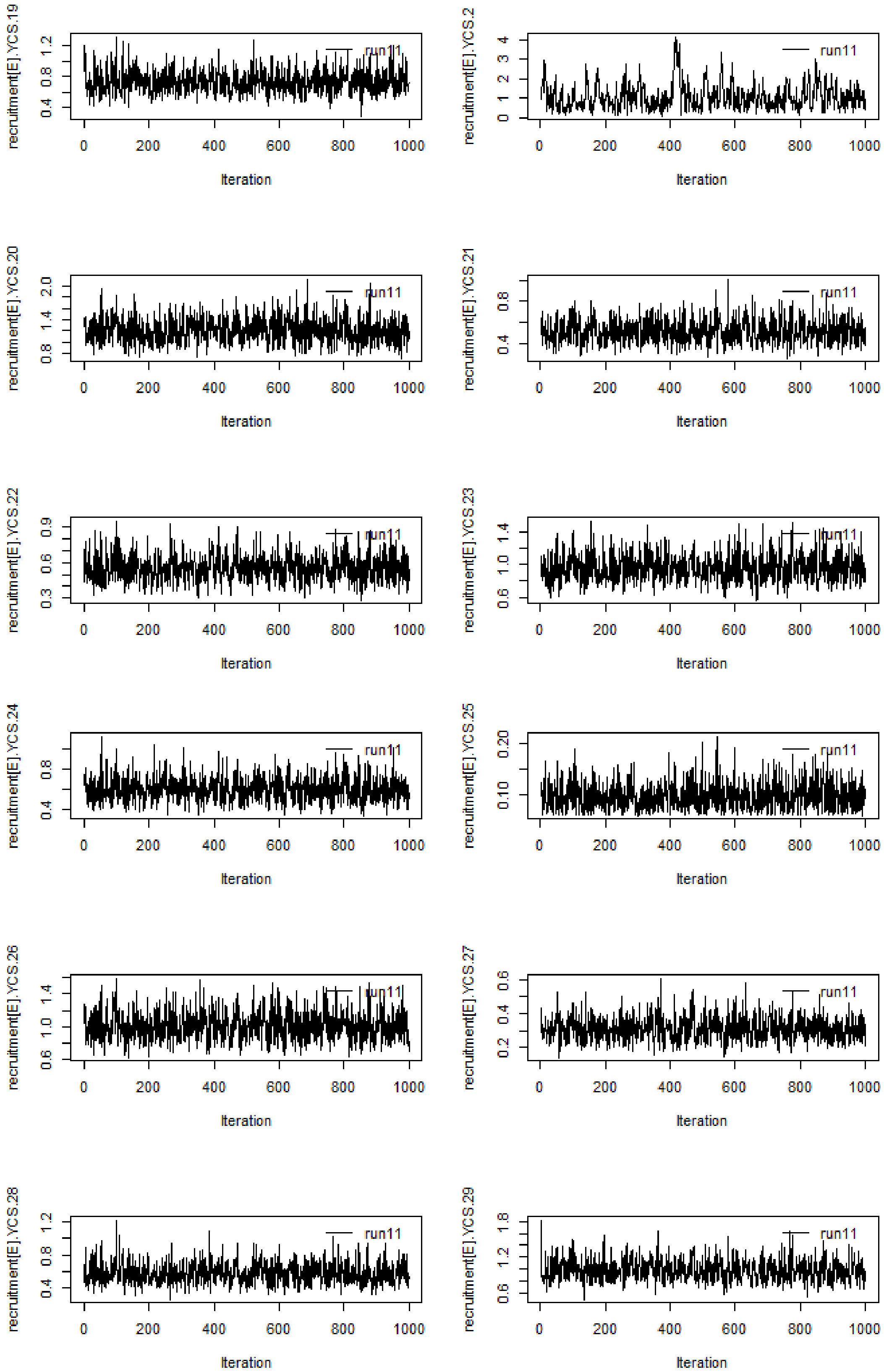

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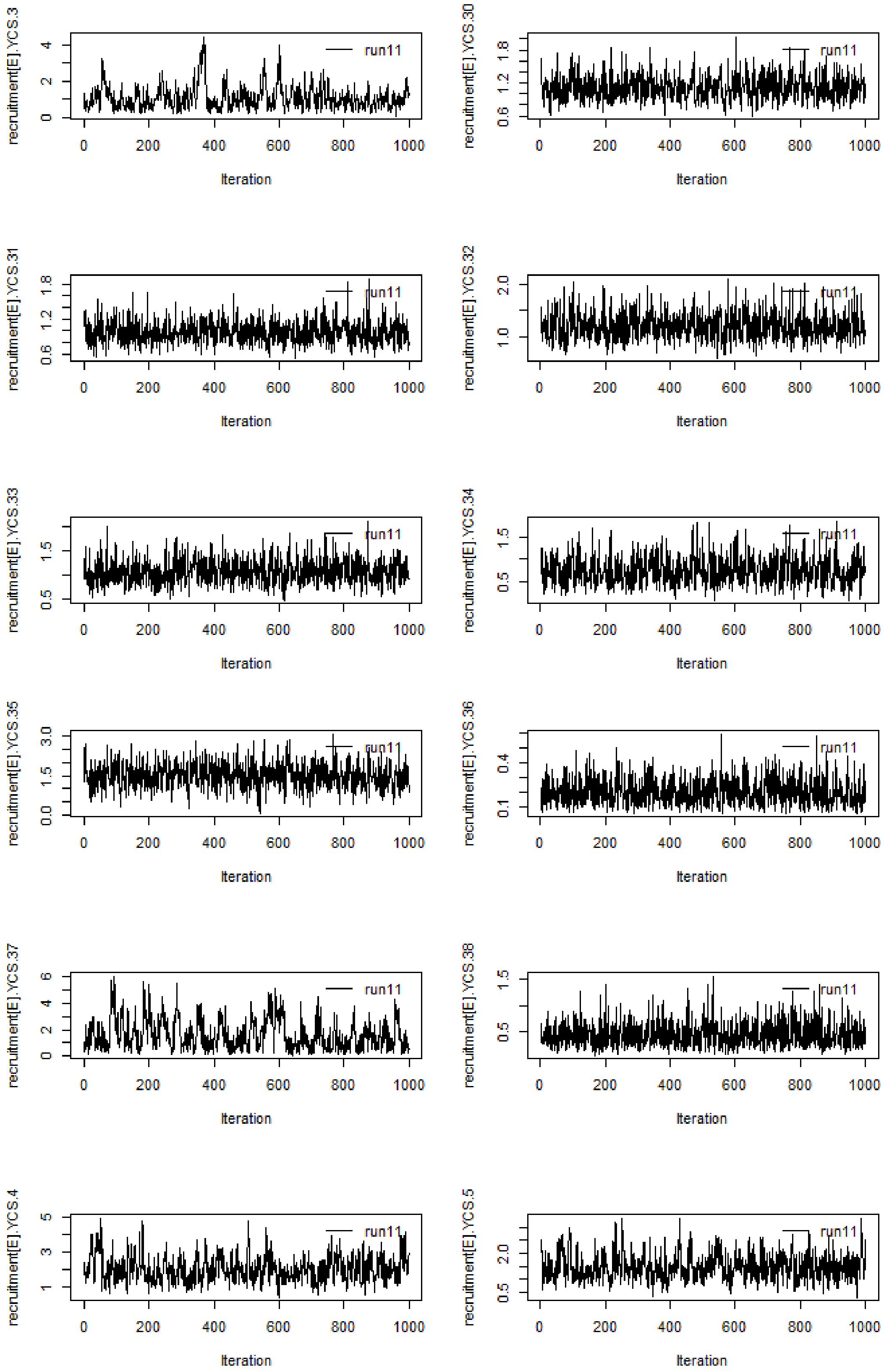
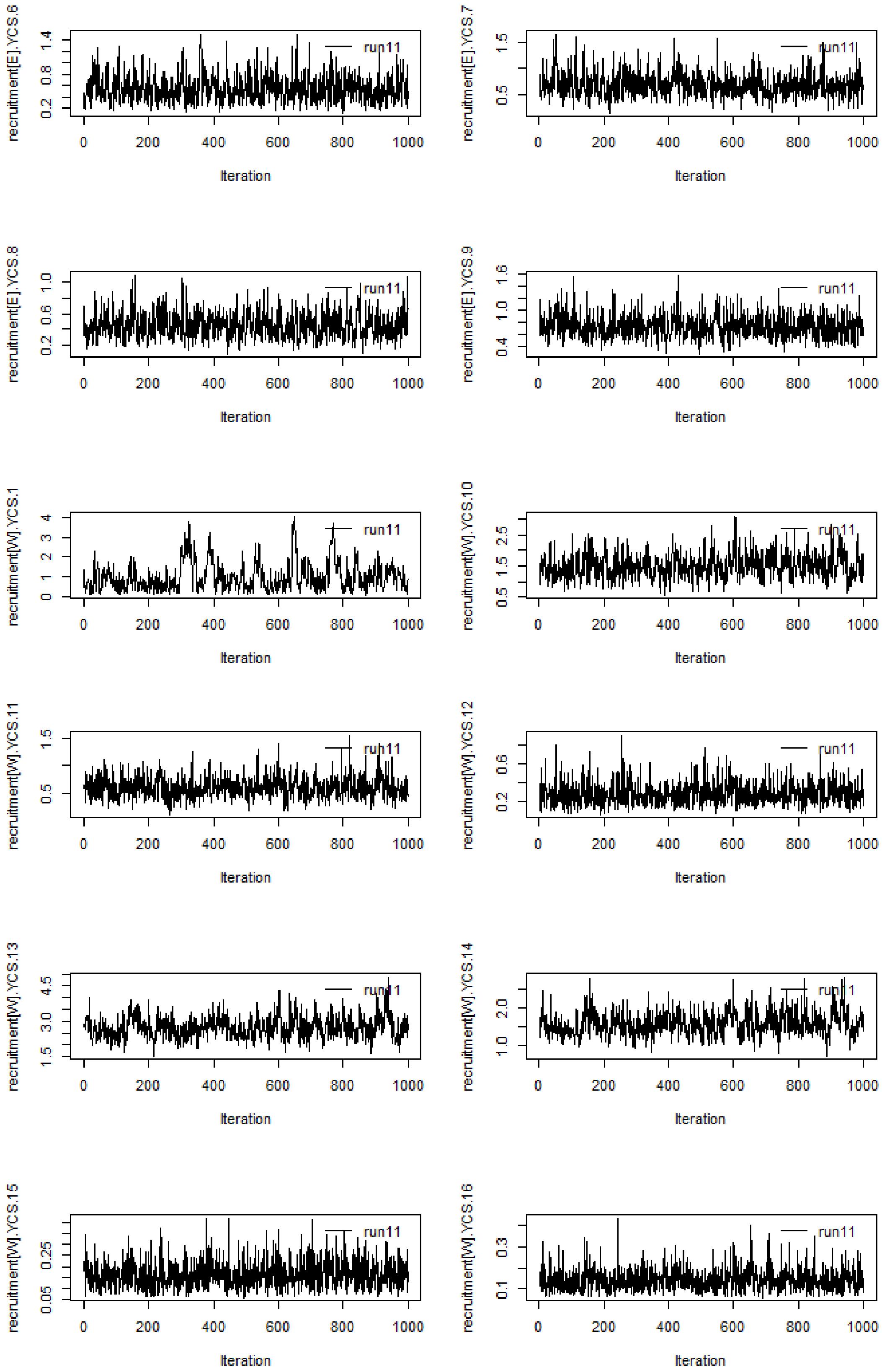


Figure A1 continued



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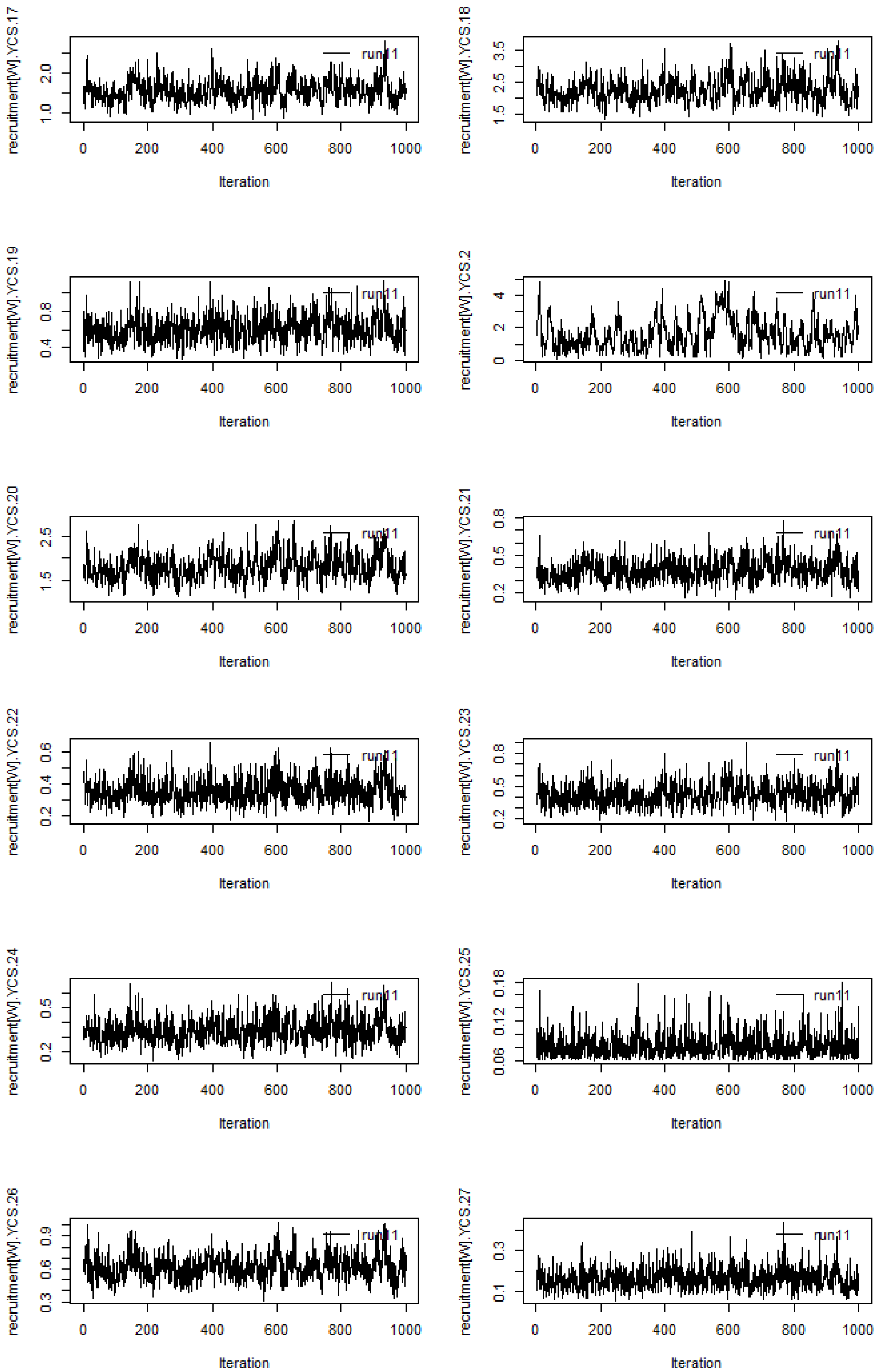

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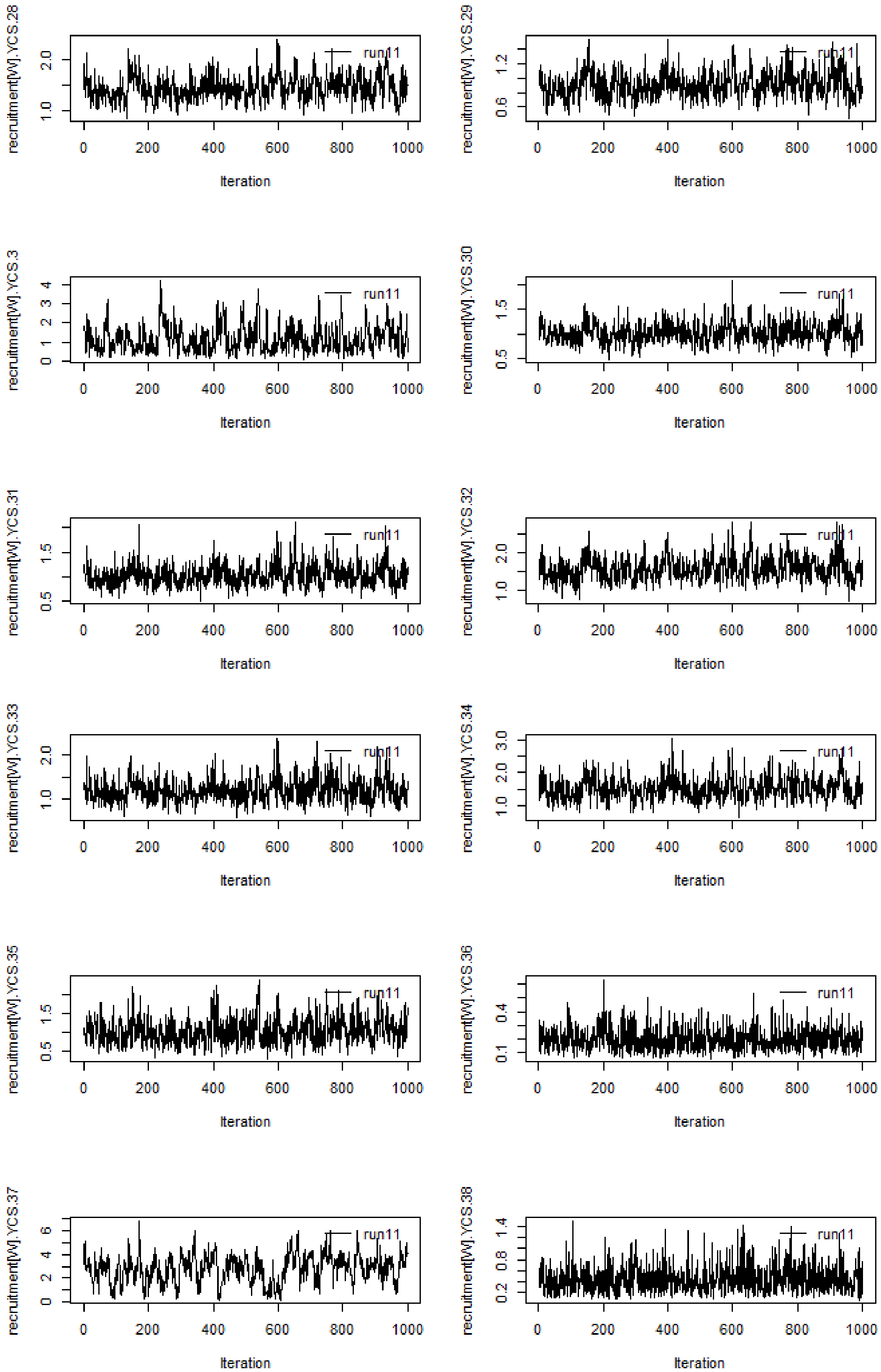

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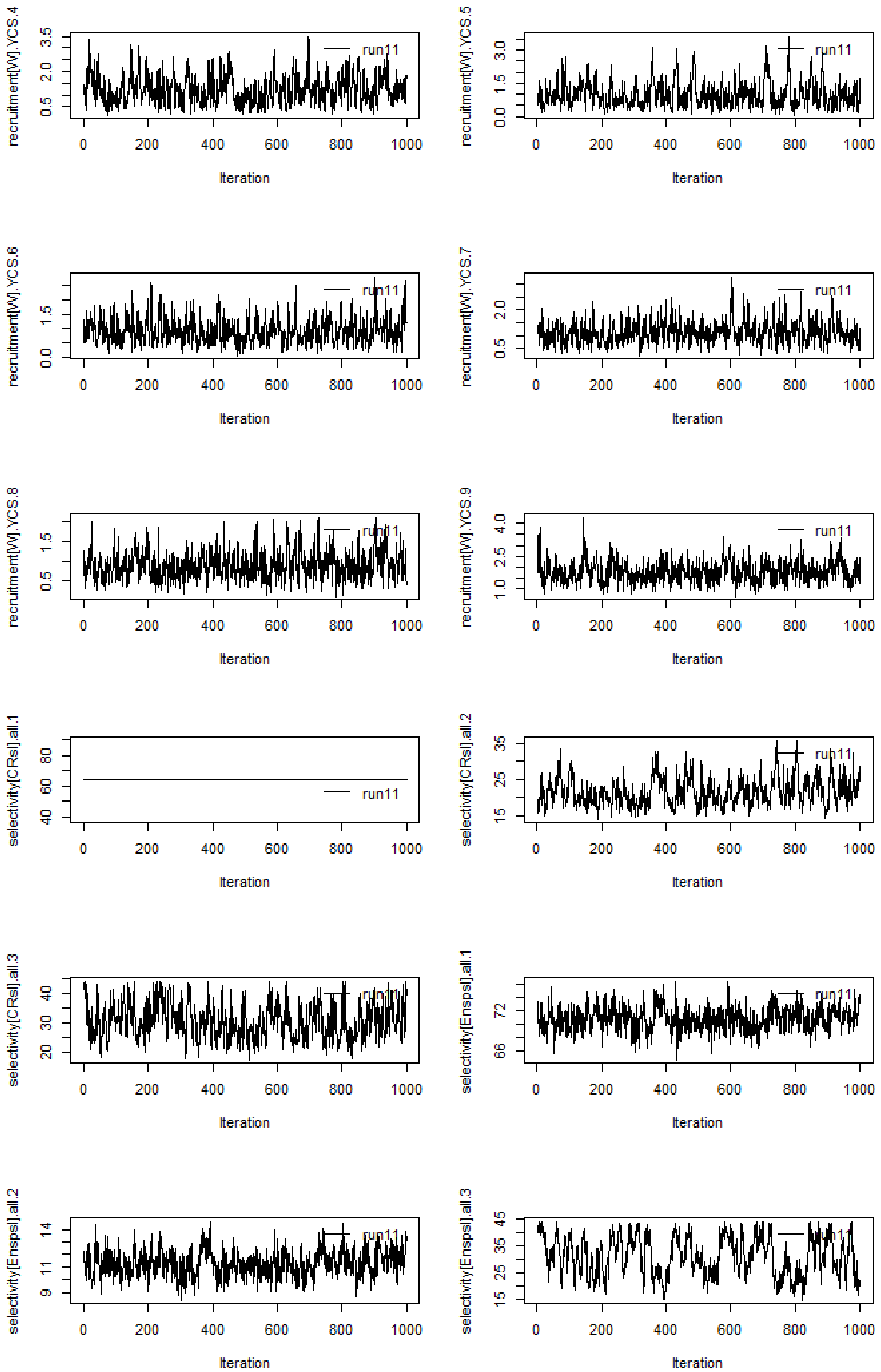

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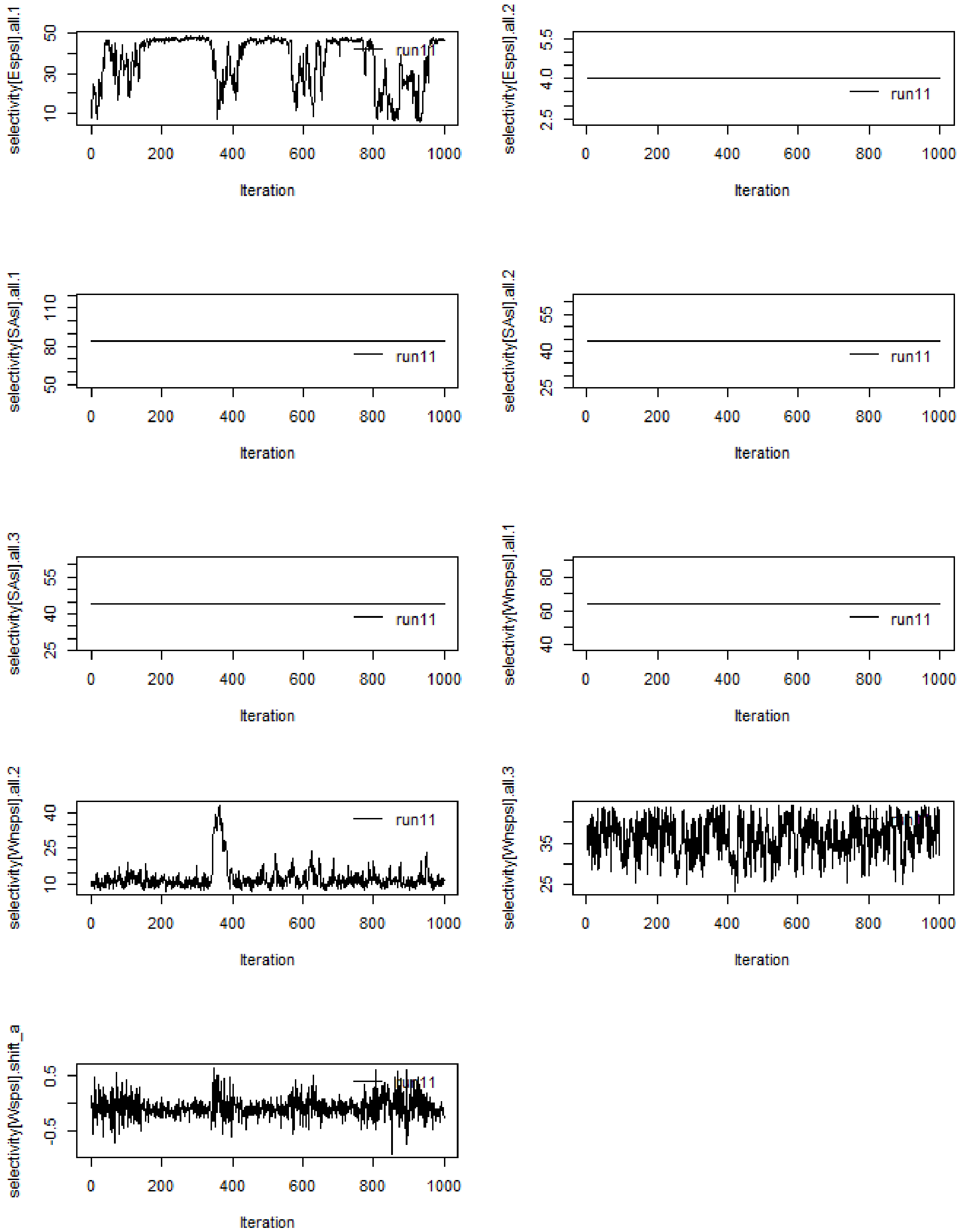

Figure A1 continued.

Appendix 4: Reweighting the 2015 assessment at-age data

The same procedure as in McKenzie (2015a) was used to reweight the at-age data for the model run 1.1 Summary results from the reweighting are shown in the tables and figures below.

Table A2: Model run 1.1. Iterative reweighting for multinomial sample sizes using method TA1.8 (Francis 2011a) Shown are the mean values of N for the at age data sets in the model.

Stage	Espage	Wspage	EnspOLF	Enspage	WnspOLF	Wnspage	CRsumage	SAsumage	SAautage
Initial	656	904	89	333	80	193	1349	574	829
2	57	32	13	37	104	17	88	13	24
3	67	24	12	39	58	14	72	13	15
4	74	22	12	38	54	14	68	14	14
5	77	21	12	37	53	14	66	14	14
Final	79	21	12	36	53	14	66	14	14
Initial/Final	8	43	7	9	2	14	20	41	59

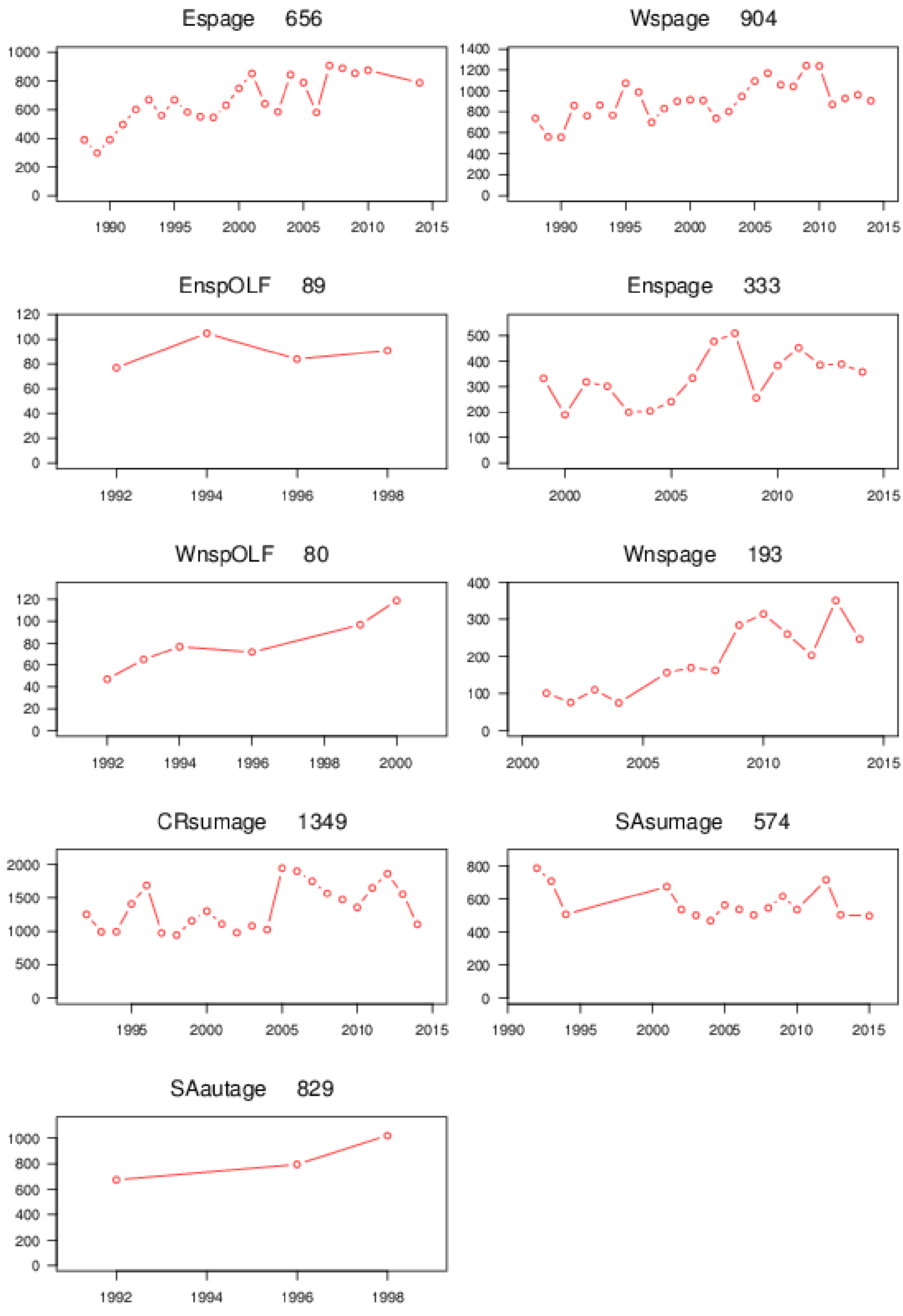

Figure A2: Model 1.1. Equivalent multinomial N values for the observational error. The number above each panel is the mean value over the fishing years.

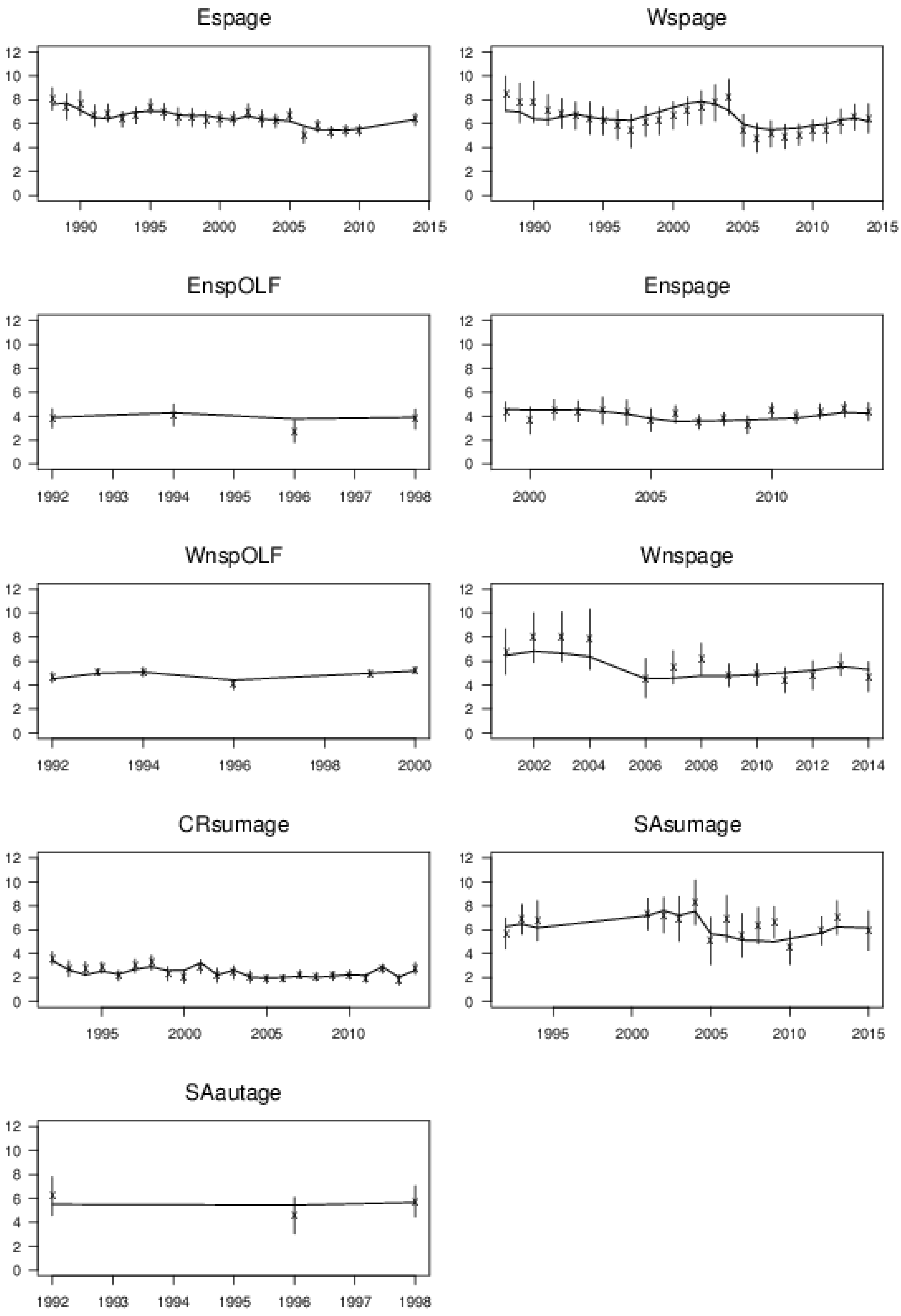

Figure A3: Model 1.1. Observed ('×', with 95% CIs. as vertical lines) and expected (lines) for the at-age data sets in run 1.1 after reweighting.