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Assessment of hoki (*Macruronus novaezelandiae*) in 2016

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A. McKenzie

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PO Box 2526
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EXECUTIVE SUMMARY

McKenzie, A. (2017). Assessment of hoki (*Macruronus novaezelandiae*) in 2016.

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An updated 2016 assessment is presented for hoki, which was based on the 2015 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 (from autumn trawl surveys). The biomass indices new to this assessment came from a January 2016 research trawl survey on the Chatham Rise, a winter 2015 acoustic trawl survey on the Cook Strait spawning fishery, and revised acoustic indices for Cook Strait and west coast South Island. New proportions-at-age data came from the Chatham Rise research trawl survey, and three commercial fisheries (the 2015 Sub-Antarctic non-spawning fishery proportions-at-age was not used as it was not considered representative of the fishery).

The Ministry for Primary Industries Deepwater Fisheries Assessment 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 was dealt with by allowing natural mortality to be age dependent. For the previous assessment, the fits to the Sub-Antarctic trawl series were improved by using two catchabilities instead of two, but for the current assessment a single catchability was used, but with a higher estimated process error for the trawl survey.

The western stock was estimated to be 40–79% B_0 and the eastern stock 44–75% 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. Western recruitment was near or just below average from 2002 to 2009; below average in 2010, 2012 and 2013; and well above average in 2011 and 2014.

Five-year projections were carried out for the base model. In the projections, future recruitments were selected at random from those estimated for 2005–2014, and future catches for each fishery were assumed to be equal to those assumed for 2016. Under these projections the eastern and western biomasses are likely to increase 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 Sub-Antarctic) (Figure 1). Since the introduction of the QMS (Quota Management System), hoki has been managed as a single fishstock, HOK 1; HOK 10 is purely administrative (Figure 2). Before 2003–04, the TACC fluctuated between 200 000 t and its initial (1986–87) level of 250 000 t. In response to a series of poor recruitments the TACC was dropped to 180 000 t for 2003–04, to 100 000 t for 2004–05, and to 90 000 t in 2007–08 (Ministry of Fisheries 2010). More recent assessments indicated that stock status had improved, and consequently the TACC was increased, with the last increase being to 160 000 t for 2014–15, though it subsequently dropped to 150 000 t for 2015–16 (Ministry for Primary Industries (2016), p. 472).

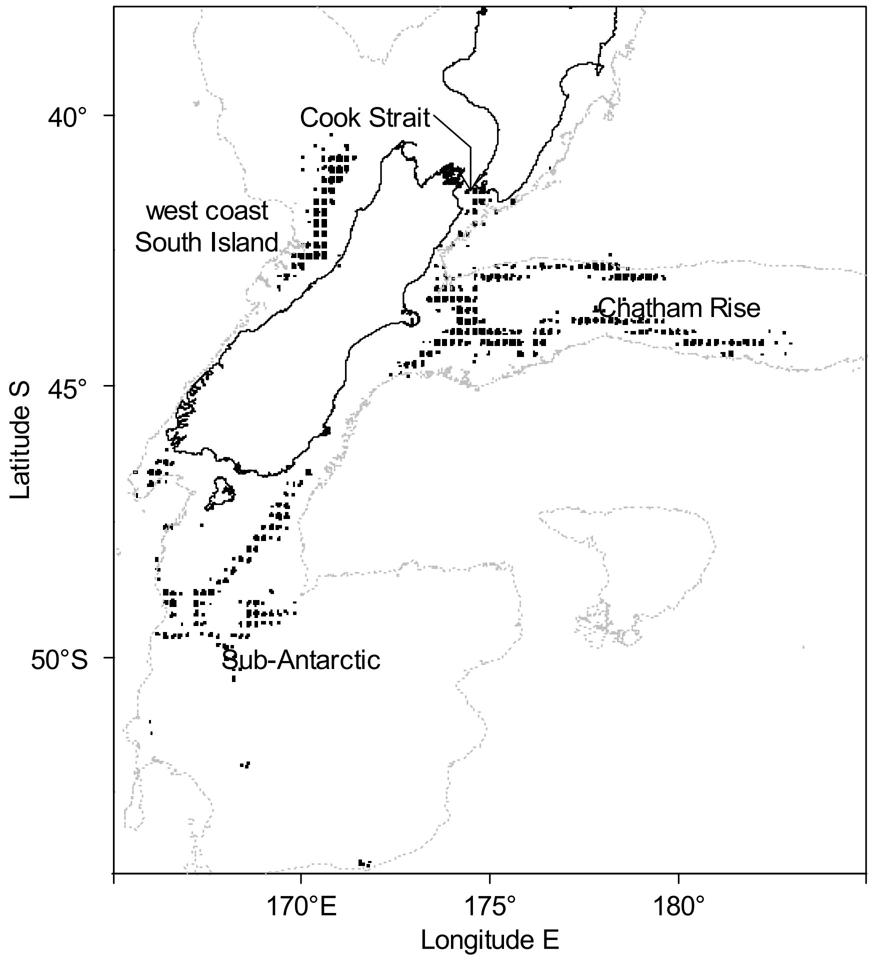

Figure 1: Southern New Zealand showing the main hoki fishing grounds, the 1000 m contour (broken grey line), and the position of all 2014–15 tows from TCEPRs (Trawl Catch and Effort Processing Returns) in which at least 10 t of hoki was caught (dots). Positions are rounded to the nearest 0.2 degrees and jittered.

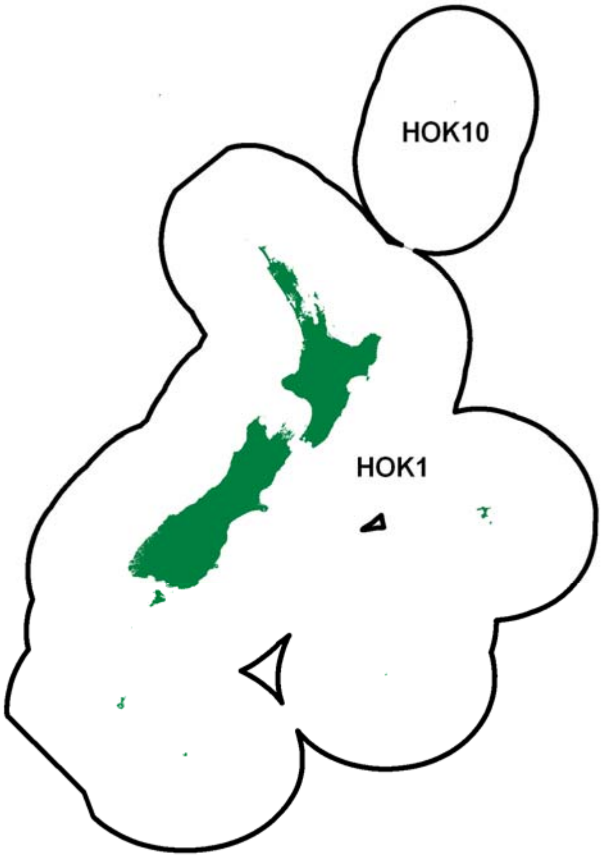

Figure 2: The Quota Management Areas for hoki.

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.

This report documents the 2016 assessment of HOK 1, which is the fifteenth hoki assessment to use NIWA's general-purpose stock-assessment model CASAL (Bull et al. 2012). Since the last assessment in 2015 (McKenzie 2016) there has been another trawl survey on the Chatham Rise in January 2016 (Stevens et al. 2017), and another acoustic survey of Cook Strait in winter 2015 (O'Driscoll et al. 2016).

The work reported here addresses objective 1 of the Ministry for Primary Industries project DEE20508HOK: *To update the stock assessment of hoki including estimates of biomass, risk and yields.*

2. MODEL ASSUMPTIONS AND INPUTS FOR 2016

This section provides a summary of all model assumptions and inputs for the 2016 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. Two changes from the 2015 assessment are: (i) the process error is estimated for the Chatham Rise and Sub-Antarctic trawl surveys, and (ii) for the MCMC runs there is an equality constraint for the last year class strength estimated (as in done in the MPD fits).

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 Sub-Antarctic 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	Sub-Antarctic
	WC	west coast South Island
Fishery	Esp	E spawning fishery
	Wsp	W spawning fishery
	Ensp1, Ensp2	first and second parts of E non-spawning fishery
	Wnsp1, Wnsp2	first and second parts of W non-spawning fishery
Observation	CSacous	CS acoustic biomass index
	WCacous	WC acoustic biomass index
	CRsumbio, CRsumage	biomass index and proportions-at-age from CR summer trawl survey
	SAsumbio, SAsumage	biomass index and proportions-at-age from SA summer trawl survey
	SAautbio, SAautage	biomass index and proportions-at-age from SA autumn trawl survey
	pspawn	proportion spawning (estimated from SA autumn trawl survey)
	Espage, Wnspage, etc	proportions-at-age in catch from given fishery (from otoliths)
	EnspOLF, WnspOLF	proportions-at-age in catch from given fishery (from OLF[1])
Migrations	Ertn, Wrtn	return migrations of E and W fish from spawning
	Whome	migration of juvenile fish from CR to SA
	Espmg, Wspmg	spawning migrations of E and W fish
Selectivity	Espsl, Wspsl, Enspsl, Wnspsl	selectivity in commercial fisheries
	CRsl, SAsl	selectivity in trawl surveys

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

2.1 Model structure and catches

Two stocks are assumed and assessed. Fish from the eastern (E) stock spawn in Cook Strait (CS) and have their home grounds in Chatham Rise (CR); the western (W) stock spawn on the west coast South Island (WC) and have their home grounds in the Sub-Antarctic (SA) (Figure 1). Soon after being spawned, all juveniles move to CR. In the assessment two alternative assumptions concerning the juveniles are modelled. One assumption is that the juveniles show natal fidelity – that is, they will 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.

	Approx.			Age	Observations	
Step	Months	Processes	*M* fraction	fraction	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 2015 the TACC was 160 000 t. For the current year (2016), the TACC is 150 000 t with a catch split arrangement for 90 000 t to be taken from the western stock and 60 000 t from the eastern stock. It was estimated that the 2016 catch would be (Graham Patchell, pers. comm.): Wsp (76 000 t), Wnsp (14 000 t), Esp (20 000 t), Ensp (40 000 t). In the model the non-spawning fishery is split into two parts (Table 4) and it is assumed that the 2016 split proportions for this are the same as 2015.

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	32 400	12 500	9 100	7 300	19 800	80 500	161 600
2016	28 900	11 100	7 800	6 200	20 000	76 000	150 000

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
Sub-Antarctic	Wnsp1	Wnsp2	Wnsp2
Cook Strait; Pegasus	Ensp1	Ensp2	Esp
Chatham Rise; east coasts of South Island and North Island; null[1]	Ensp1	Ensp2	Ensp2

[1] no area stated

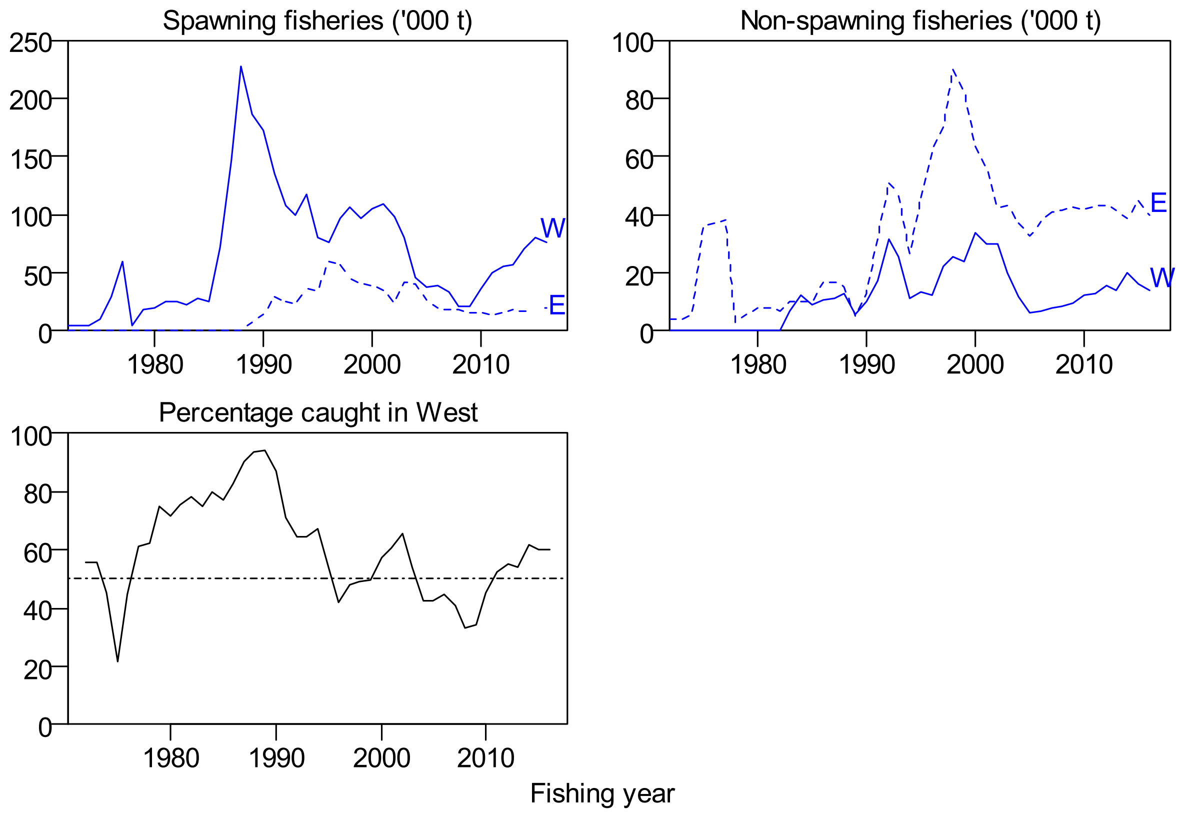

Figure 3: Annual catches by fishery for the spawning (top left panel) and non-spawning (top right panel) fisheries, and annual percentage of catch caught in western fisheries (Wsp, Wnsp1, Wnsp2) (bottom panel).

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

			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 a_{50} for the logistic 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). The further the median day is from the overall mean value for the median day, the greater the change in the selectivity, with the scale of the change estimated via a Wspsl shift parameter (see ahead to Table 12). 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 2016).

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	2015	Mean
298	300	301	300	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

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

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. Note there is no spawning ogive in the model, instead there are spawning areas (WC and CS), with the mid-season biomass in these defining spawning stock biomass.

Forty YCSs were estimated for each stock, for 1975 to 2014, inclusive. YCSs for the initial years (1970 to 1974) were fixed at 1. The E and W YCSs for 2014 were constrained (by a penalty function) to be equal for MPD runs (Francis 2006, p. 9) and, in a change for the current assessment, for the MCMC runs as well.

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 indices new to this assessment came from a January 2016 research trawl survey on the Chatham Rise, a winter 2015 acoustic trawl survey on the Cook Strait spawning fishery, and revised acoustic indices for Cook Strait and west coast South Island.

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 revised using a new target strength relationship (O'Driscoll et al. 2016). The asterisk value is new to the assessment (CRsumbio in 2016). Total CVs for trawl surveys (CRsumbio, SAsumbio, SAautbio) assume a process error of 0.20 (in some initial runs this is set to zero, for the final base run the process errors for CRsumbio and SAsumbio are estimated within the model).

	CRsumbio	SAsumbio	SAautbio	CSacous	WCacous
1988	–	–	–	–	**266** (0.22,0.60)
1989	–	–	–	–	**165** (0.15,0.38)
1990	–	–	–	–	**169** (0.06,0.40)
1991	–	–	–	**88** (0.13,0.41)	**227** (0.14,0.73)
1992	120 (0.08,0.21)	80 (0.07,0.21)	68 (0.08,0.22)	–	**229** (0.14,0.49)
1993	186 (0.10,0.22)	87 (0.06,0.21)	–	**283** (0.15,0.52)	**380** (0.07,0.38)
1994	146 (0.10,0.22)	100 (0.09,0.22)	–	**278** (0.06,0.91)	–
1995	120 (0.08,0.21)	–	–	**194** (0.12,0.61)	–
1996	153 (0.10,0.22)	–	89 (0.09,0.22)	**92** (0.09,0.57)	–
1997	158 (0.08,0.22)	–	–	**141** (0.12,0.40)	**445** (0.10,0.60)
1998	87 (0.11,0.23)	–	68 (0.11,0.23)	**80** (0.10,0.44)	–
1999	109 (0.12,0.23)	–	–	**114** (0.10,0.36)	–
2000	72 (0.12,0.23)	–	–	–	**263** (–,0.28)
2001	60 (0.10,0.22)	56 (0.13,0.24)	–	**102** (0.12,0.30)	–
2002	74 (0.11,0.23)	38 (0.16,0.26)	–	**145** (0.13,0.35)	–
2003	53 (0.09,0.22)	40 (0.14,0.24)	–	**104** (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)	–	**59** (0.11,0.32)	–
2006	99 (0.11,0.23)	21 (0.13,0.24)	–	**60** (0.17,0.34)	–
2007	70 (0.08,0.22)	14 (0.11,0.23)	–	**104** (–,0.46)	–
2008	77 (0.11,0.23)	46 (0.16,0.26)	–	**82** (–,0.30)	–
2009	144 (0.11,0.23)	47 (0.14,0.24)	–	**166** (–,0.39)	–
2010	98 (0.15,0.25)	65 (0.16,0.26)	–	–	–
2011	94 (0.14,0.24)	–	–	**141** (0.18,0.35)	–
2012	88 (0.10,0.22)	46 (0.15,0.25)	–	–	**283** (–,0.34)
2013	124 (0.15,0.25)	56 (0.15,0.25)	–	**168** (–,0.30)	**233** (–,0.35)
2014	102 (0.10,0.22)	–	–	–	–
2015	–	31 (0.13,0.24)	–	**204** (–,0.33)	–
2016	115* (0.14,0.24)	–	–	–	–

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

Area	Label	Data type	Years	Source of age data
WC	Wspage	Catch at age	1988–**2015**	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, 2012–13, 15	otoliths
	SAautage	Trawl survey	1992, 96, 98	otoliths
CS	Espage	Catch at age	1988–10, 2014–**15**	otoliths
CR	EnspOLF	Catch at age	1992, 94, 96, 98	OLF
	Enspage	Catch at age	1999–**2015**	otoliths
	CRsumage	Trawl survey	1992–2014, **2016**	otoliths

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

	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

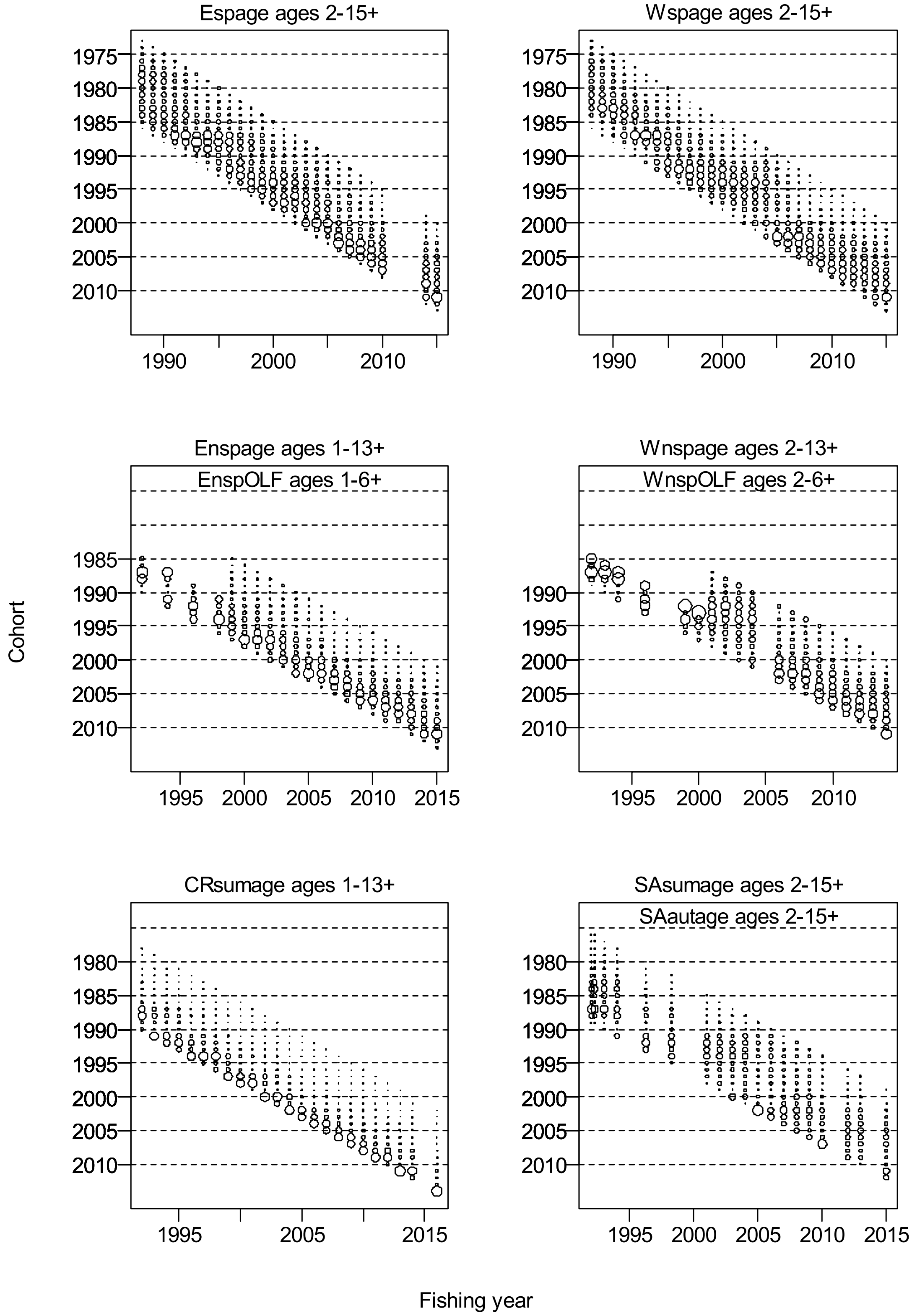

Figure 4: Proportions-at-age data, plotted by cohort and fishing year, with both sexes combined. The area of each circle is proportional to the associated proportion at age. Circle positions for the SAautage data in 1992 have been offset horizontally to allow them to be plotted on the same panel as the 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 (2011) the weighting of data in stock assessments was explored and one of the conclusions drawn was that proportions-at-age data are often over-weighted in assessments. Based on this, and explorations of reweighting for the 2011 assessment proportions-at-age data, it was decided by the Hoki Working Group to reweight the proportions-at-age data for the 2012 assessment using a multinomial error distribution (McKenzie 2013). This means that the weight assigned to each proportion-at-age datum is controlled by an effective sample size, these being calculated in MPD runs, then fixed for the full Bayesian runs. For the 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, although for the Chatham Rise and Sub-Antarctic trawl surveys it was decided for the current assessment to estimate this uncertainly within the model.

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. Note that CVs add as squares: $CV_{total}^2 = CV_{process}^2 + CV_{observation}^2$. The process error was set at 0.20 for some initial runs (Francis et al. 2001) , and estimated for the final base model run. 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 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 parameters and number estimated in the final model runs are shown in 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) with those for the acoustic surveys in Cook Strait and west coast South Island updated for the current assessment (Table 13), the proportion of the initial biomass 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).

Catchabilities are estimated as free parameters for both MPD and MCMC runs.

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.

Parameter(s)	Description	Distribution Type	Parameters		No. of 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	1	0.95	80
q[CSacous].q	catchability, CSacous	lognormal	0.55	0.90	1
q[WCacous].q	catchability, WCacous	lognormal	0.39	0.77	1
q[CRsum].q	catchability, CRsumbio	lognormal	0.15	0.65	1
q[SAsum].q	catchability, SAsumbio[b]	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	research trawl[c]	uniform	0.1	1	2
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

[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 some runs two catchabilities are estimated
[c] In some initial runs these process errors (CRsumbio, SAsumbio) were set at 0.00 and 0.20

Table 13: Old and new priors for CS and WCSI acoustic survey catchabilities. For CS the lognormal parameters are from Section 3.8 of O'Driscoll et al. (2016), and for WCSI from Appendix 3 in O'Driscoll et al. (2016).

Area	Version	Lognormal parameters mu	CV	Bounds lower	upper
Cook Strait	old	0.77	0.77	0.022	3.80
	new	0.55	0.90	0.010	4.53
west coast South Island	old	0.57	0.68	0.032	3.10
	new	0.39	0.77	0.010	3.35

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, 2016) (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 that 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 2015 which uses just the data up to 2015. In particular we look at the impact of the new Cook Strait and west coast South Island acoustic indices and priors, and sensitivity to the CV of the prior on the year class strengths.

3.1 New Cook Strait and west coast South Island acoustic indices and priors

New acoustic indices and catchability priors for Cook Strait (CS) and west coast South Island (WCSI) have been derived (see Table 8 and Table 13) for which the new catchability priors are to the left of the old priors (Figures 5–6).

To see how much impact the new indices and priors have, an MPD model run 1.7 is done using the base case run 1.1 from the 2015 assessment (Table 14), but with the new indices and priors. This is done with and without the new 2015 CS index (which was not part of the data inputs for the 2015 assessment). In effect this is a two-stage sensitivity run: revised indices and priors, plus one more index for the CS series.

For this new MPD run 1.7 the biomass trajectory and current 2015 biomass (%B_0) are very similar to the base run (Figure 7, Table 15). As expected with new indices and priors, catchability estimates are different, but well within the bounds of the new priors (Table 16). Fits to the old and new acoustic indices are shown in Figures 8–9. The new acoustic indices and catchability priors make little difference to the biomass trajectories.

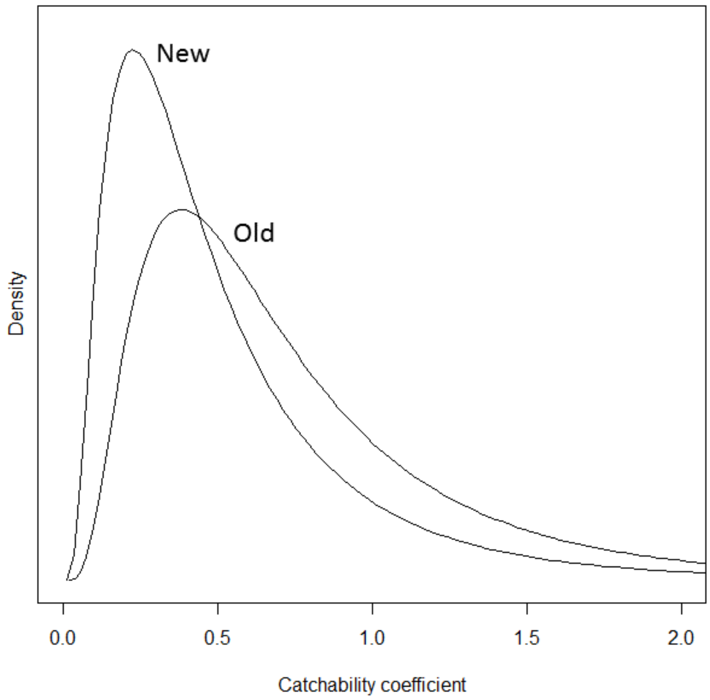

Figure 5: Estimated prior for acoustic q in Cook Strait estimated in this report ('New') and compared to existing prior ('Old'). Reproduced from figure 15 in O'Driscoll et al. (2016).

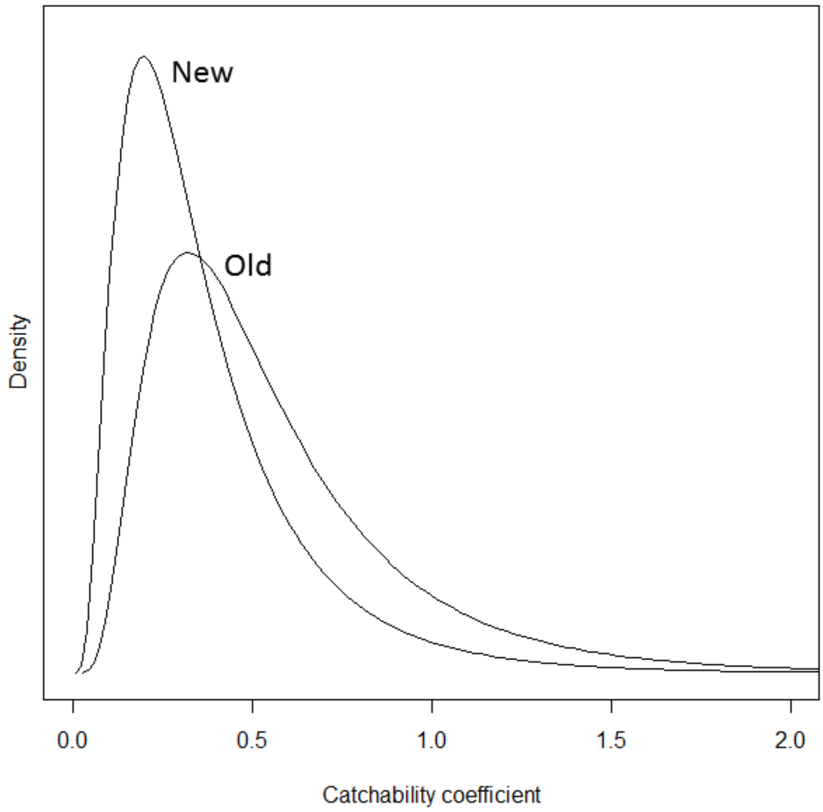

Figure 6: Estimated prior for acoustic q in WCSI estimated in this report ('New') compared to existing prior ('Old'). Reproduced from figure A3.3 in O'Driscoll et al. (2016).

Table 14: Distinguishing characteristics of MCMC final model runs for the 2015 hoki stock assessment, including sensitivity to the base run 1.1. Reproduced from table 22 in McKenzie (2016).

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)

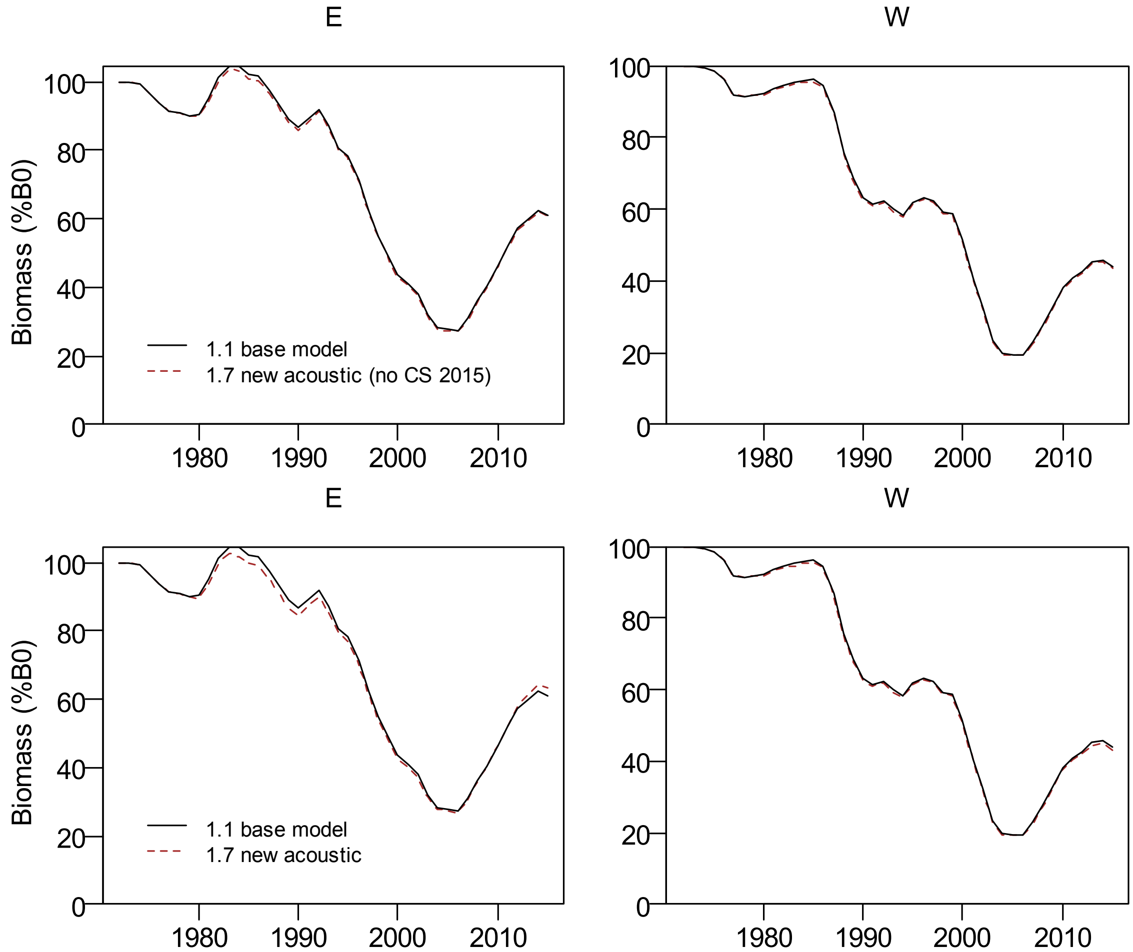

Figure 7: Comparison of MPD biomass trajectories for runs 1.1 and 1.7: E stock (left column), and W stock (right column). The top row show the trajectory without the new CS 2015 index, the bottom row including the new CS 2015 index.

Table 15: Comparison of MPD biomass estimates for runs 1.1 and 1.7 (including the new CS 2015 index).

Run	Description			$B_{2015}(\%B_0)$	
		E	W	E	W
1.1	Base model	444	774	61	44
1.7	New acoustic	437	768	63	43

Table 16: Comparison of MPD catchability estimates for runs 1.1 ("old") and 1.7 ("new" including the new CS 2015 index).

Area	Version	Estimated catchability
Cook Strait	old	1.25
	new	0.61
west coast South Island	old	0.91
	new	0.62

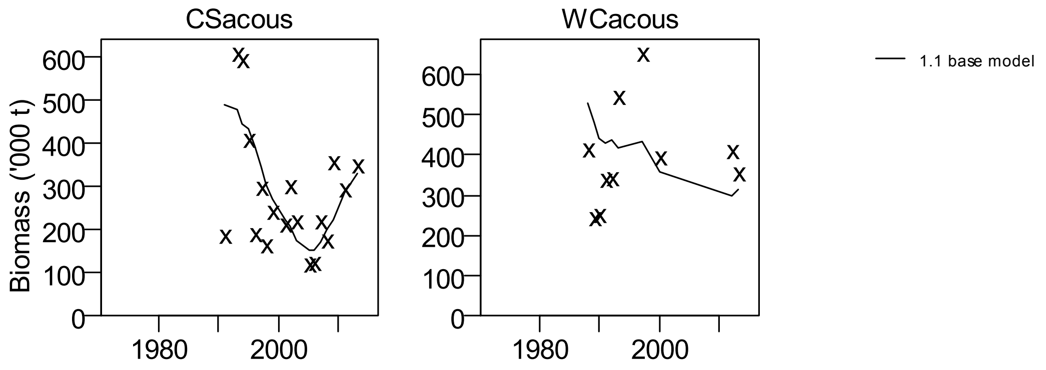

Figure 8: Fit to acoustic biomass indices for 2015 assessment base run 1.1. Shown are observed ('×') and expected values (lines).

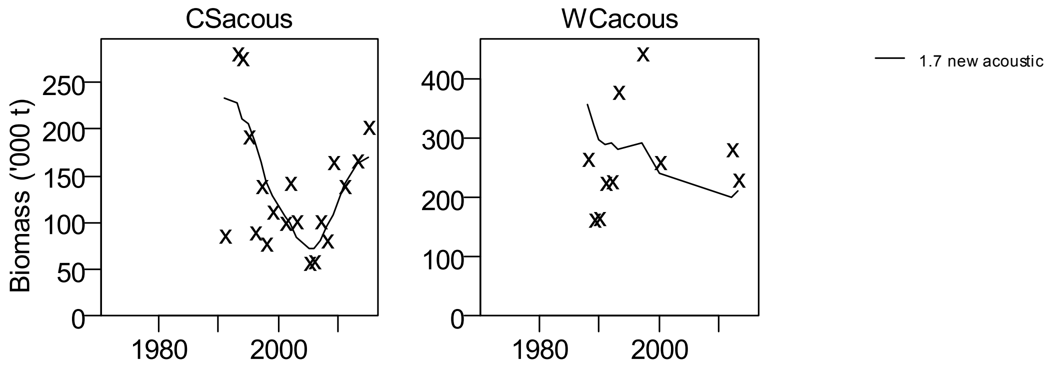

Figure 9: Fit to new acoustic biomass indices for run 1.7 including the new CS 2015 index, where CSacous and WCacous are new indices (with new priors). Shown are observed ('×') and expected values (lines).

3.2 Sensitivity runs for the CV of the prior on year class strengths

In the hoki assessment year class strengths are estimated for the east and west stocks separately. For the year class strengths lognormal priors are used with a mean of one and CV of 0.95 (McKenzie 2016). A CV of 0.95 is equivalent to $\sigma_R = 0.80$ for the log of the YCSs and came from (i) a consistency requirement with estimates found from the 2003 assessment, and (ii) the upper quantile in a compilation of estimated σ_R values (Francis 2004, p. 32). In MCMC runs estimates of pre-1985 YCSs are very uncertain as are those for the most recent years (Figure 10).

As part of the hoki review a recommendation **R-24** was made regarding the CV used for the prior (see below, and Butterworth et al. (2014) for further expansion on the recommendation).

R-24. *Attempt to improve the estimate of the most recent recruitment by means of a better relative weighting of the information provided by the Chatham Rise survey and the expectation from the stock-recruitment relationship. Given the amount of age data and length of some of the survey time series, this process might be assisted by estimating* σ_R *and using this to inform the prior on YCS instead of fixing it at a value that appears to be much larger than the empirical estimates obtained from the estimated year-class strengths coming from the assessment.*

We focus on the σ_R value used in base model run 1.1 from the 2015 assessment, a model with a single catchability for the Sub-Antarctic trawl series and age-varying natural mortality. First we look at the assessment MPD estimates of YCSs and their standard deviation, and secondly the impact of changing the prior σ_R value on biomass and YCS estimates.

YCSs for 1970–1974 inclusive are set to one in the 2015 assessment, with other YCSs up to 2013 estimated. Dropping the YCSs that are set to one and calculating the standard deviation in log space for the remainder of the MPD estimates gives: $sd_{west} = 0.64$ and $sd_{east} = 0.83$. The value of $\sigma_R = 0.80$ used for the prior seems quite comparable with these model estimates.

Two MPD runs are done, reducing the value of σ_R from 0.80 to 0.70 or 0.60. These have very little impact on YCS estimates, except for the last year (2013) which increases slightly towards one (Figures 11–12). In an MCMC run with $\sigma_R = 0.60$ the most noticeable impact was a reduction in the uncertainty in the earlier YCSs (Figure 13). MPD biomass estimates are very similar with a reduction in σ_R (Figure 14).

In summary, the value of $\sigma_R = 0.80$ used for the prior seems quite comparable with the model estimates, and reducing the value has little impact on YCSs or biomass estimates.

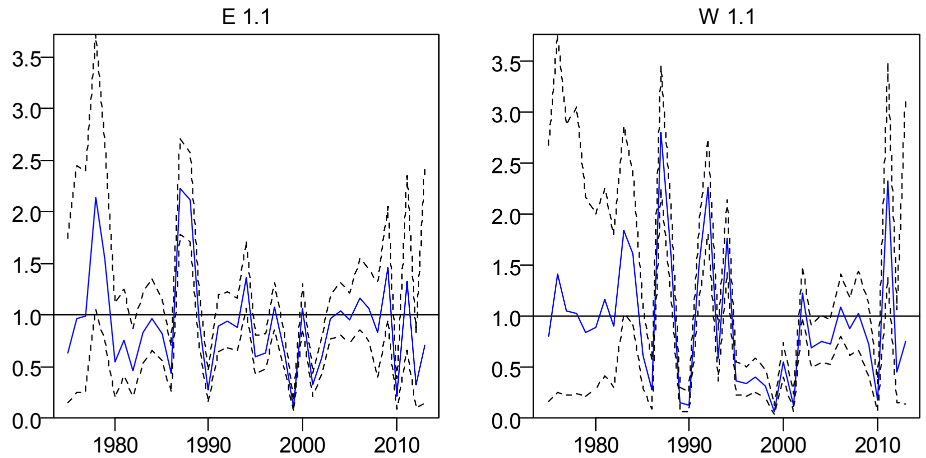

Figure 10: Estimated year-class strengths (YCSs) from the base run 1.1 for the 2015 assessment showing medians (solid lines) and 95% confidence intervals (broken lines) by run for E (left panels), W (right panels).

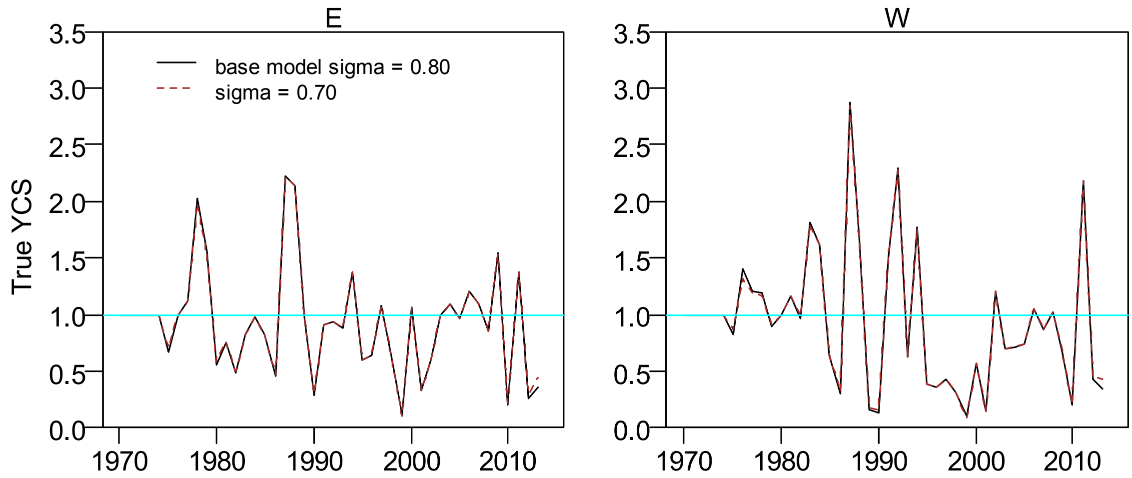

Figure 11: MPD estimates of YCSs using either a prior with σ_R = 0.80 (equivalent CV = 0.95) versus σ_R = 0.70 (equivalent CV = 0.80).

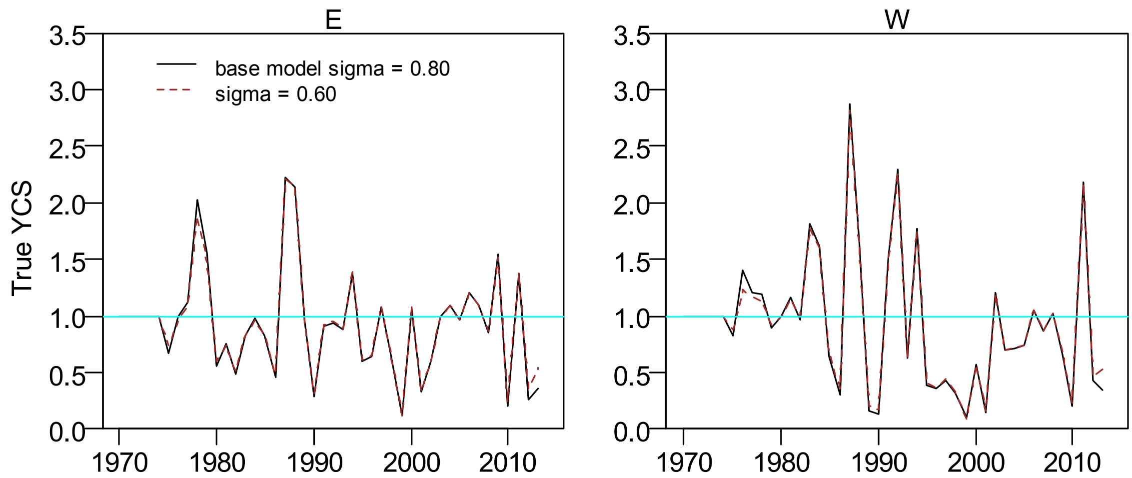

Figure 12: MPD estimates of YCSs using either a prior with σ_R = 0.80 (equivalent CV = 0.95) versus σ_R = 0.60 (equivalent CV = 0.66).

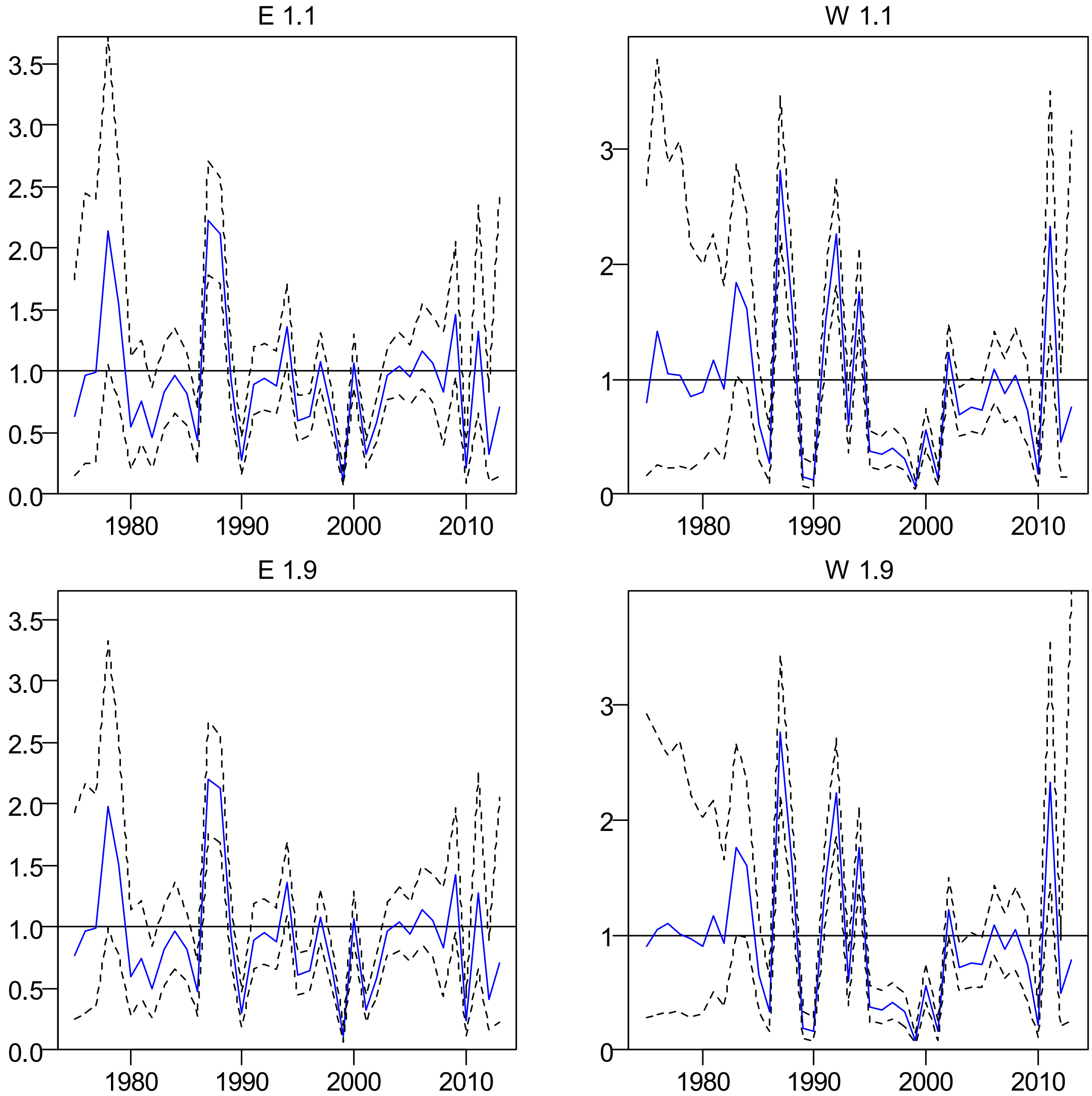

Figure 13: MCMC estimates of YCSs using either a prior with σ_R = 0.80 (equivalent CV = 0.95) – base run 1.1 (top row), or σ_{R} = 0.60 (equivalent CV = 0.66) – run 1.9 (bottom row).

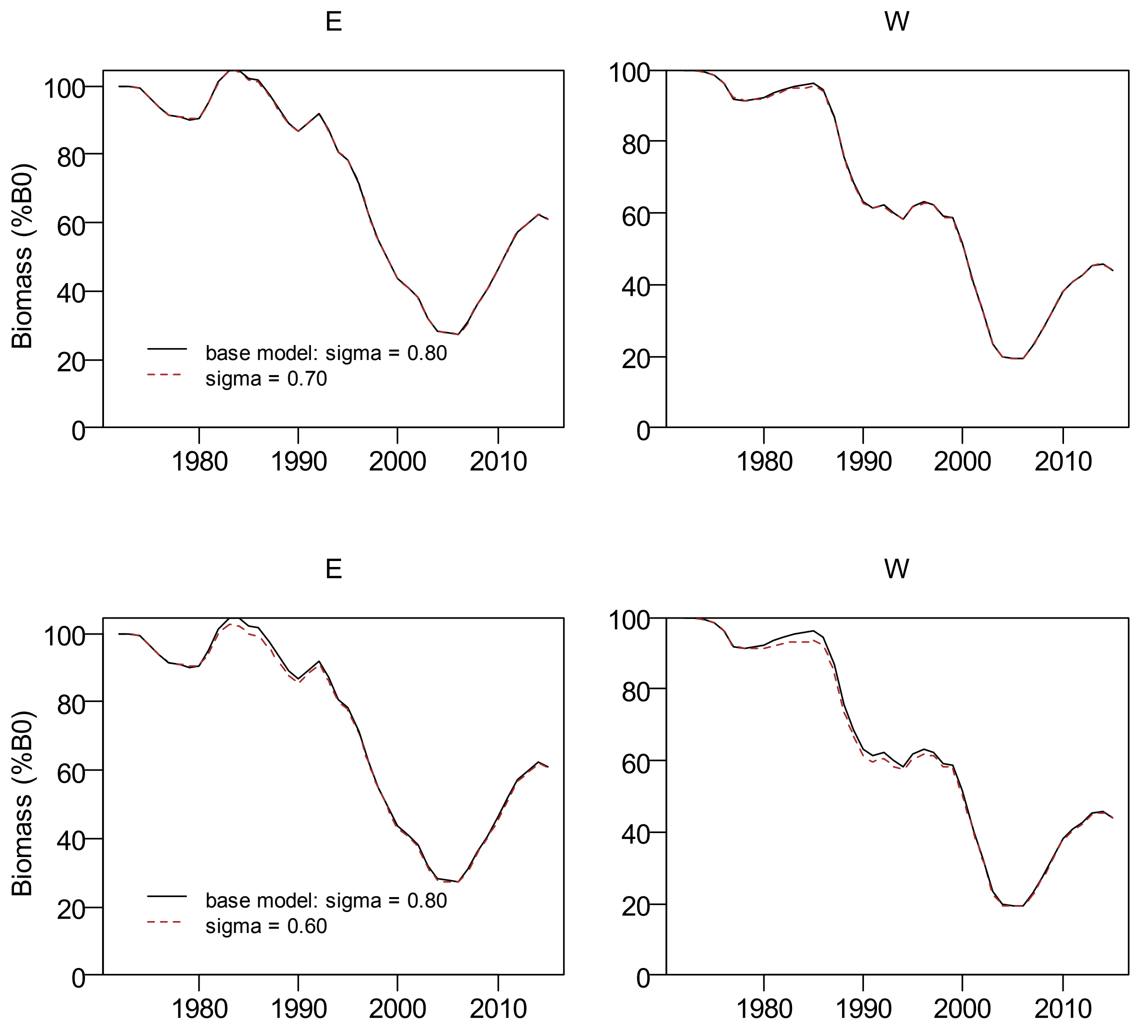

Figure 14: MPD biomass estimates using either a prior with $\sigma_R = 0.80$ (equivalent CV = 0.95) versus $\sigma_R = 0.70$ (equivalent CV = 0.80) (top row), or with $\sigma_R = 0.80$ versus $\sigma_R = 0.60$ (equivalent CV = 0.66) (bottom row).

4. INITIAL EXPLORATORY MODEL RUNS

4.1 Introduction

For the 2015 hoki stock assessment final model MCMC runs there was a single base run, and five sensitivity runs (see Table 14). The base run had age-varying natural mortality, a single catchability for the Sub-Antarctic trawl survey, assumed natal fidelity, and the trawl survey biomass indices were not upweighted.

The initial set of four MPD runs for the 2016 hoki stock assessment includes an update of the base model run from the 2015 assessment, a version where the trawl survey biomass indices are upweighted, and model runs where two catchabilities are used for the Sub-Antarctic trawl survey (Table 17).

A comparison of the updated base model with the 2015 base model is given in Section 4.2 and more results from the initial four MPD runs in Sections 4.3 and 4.4.

Subsequent to these four initial runs, three additional runs were done in which the process error was estimated for CRsumbio and SAsumbio (Section 4.5), the impact of a revision to the 2016 Chatham Rise trawl survey data looked at (Section 4.6), and lastly the process error estimated while incorporating the revised Chatham Rise trawl survey data (Section 4.7). These three additional runs are summarised in Table 18.

The observation error for the at-age data was used to determine an initial effective sample size for the assumed multinomial error distribution for the at-age data. Following this, the reweighting procedure was used for the at-age data to give a model run 1.1, with reweighting results summarised in Appendix 3. The effective sample sizes from this reweighting are used in the four initial MPD runs, and subsequent runs 1.5 and 1.6, but the data is reweighted for all other model runs (including the final model runs in Section 5).

Biomass estimates for the four initial model runs are summarised in Table 19. Details are given for the other model runs in the sections that follow. The model run 1.7 with process error estimated was chosen by the Deepwater Working Group as the base model for the assessment (see ahead in Section 5).

Table 17: Initial MPD model runs for the 2016 hoki stock assessment.

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 - 2008–16 two-*q*	as 1.1 but with a different q for 2008–16

Table 18: Further MPD model runs for the 2016 hoki stock assessment.

Run	Main assumptions
1.5 est process error	as 1.1 but estimate process error
1.6 revised CR 2016 data	as 1.1 but revised Chatham Rise 2016 data
1.7 est and revised	as 1.1 but estimate process error and revised Chatham Rise 2016 data

Table 19: Comparison of MPD biomass estimates for the four initial model runs.

Run	Description	B_0('000 t)		$B_{2016}(\%B_0)$	
		E	W	E	W
1.1	trawl not upweighted	445	792	60	41
1.2	trawl upweighted	437	714	60	27
1.3	2004–07 two-*q*	452	850	61	45
1.4	2008–16 two-*q*	445	773	61	33

4.2 Comparison to base model from the last assessment in 2015

Using the 2016 model run 1.1 with a single catchability for the Southern Plateau trawl survey, the biomass trajectory is compared to the comparable model runs from last year's assessment (Table 20, Figure 15). For the updated assessment model the eastern and western virgin biomasses are very similar to those from the 2015 assessment, while 2015 western biomass is slightly less ($\%B_0$).

The year class strengths differ in 2011, with the new model run 1.1 estimating the east YCS to be somewhat higher and the west YCS somewhat lower (Figure 16). Other graphs show selectivities, migration ogives, and fitted age-varying natural mortality, and they are very similar between the new and last assessment (Figures 17–19).

Table 20: Comparison of old and new biomass estimates for the individual stocks, E and W, and the combined E + W stock. The label 2015.1 refers to run 1.1 from the 2015 assessment (see Table 14), while run 1.1 is for the 2016 assessment (see Table 17).

	B_0('000 t)		$B_{2015}(\%B_0)$		$B_{2016}(\%B_0)$	
Run	E	W	E	W	E	W
2015.1	444	774	61	44	NA	NA
1.1	445	792	61	40	60	41

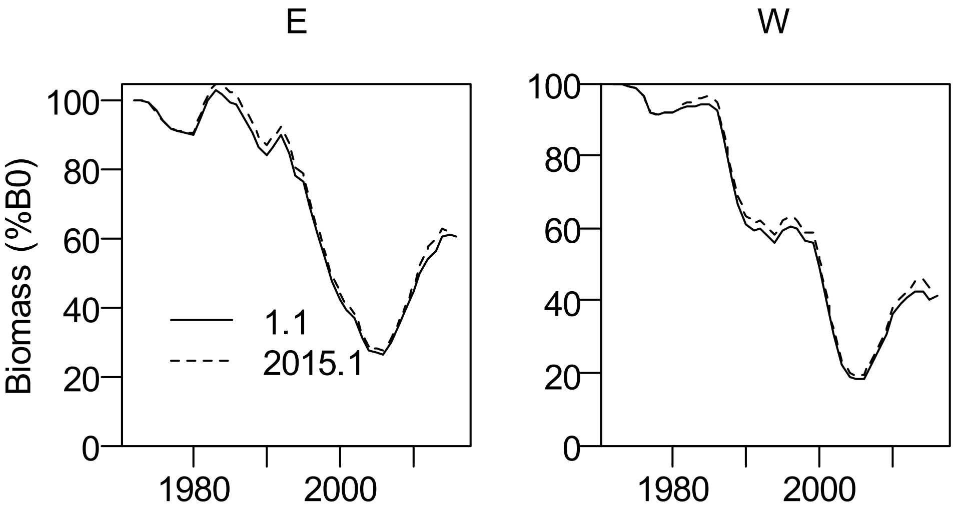

Figure 15: Comparison of biomass trajectories from different runs: E stock (left column), W stock (middle column), and E + W stocks combined (right column). The graphs compare run 1.1. from 2016 (solid lines) with the corresponding run from 2015 (broken lines). The label 2015.1 denotes run 1.1 from the 2015 assessment.

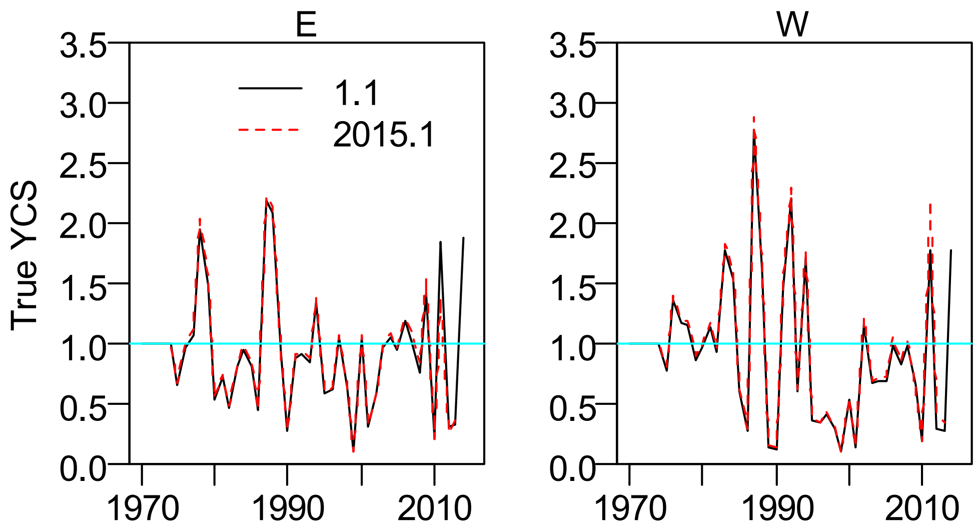

Figure 16: True YCS estimates for new run 1.1 from 2016 (solid lines) compared to the comparable run from last year's assessment. The label 2015.1 denotes run1.1 from the 2015 assessment.

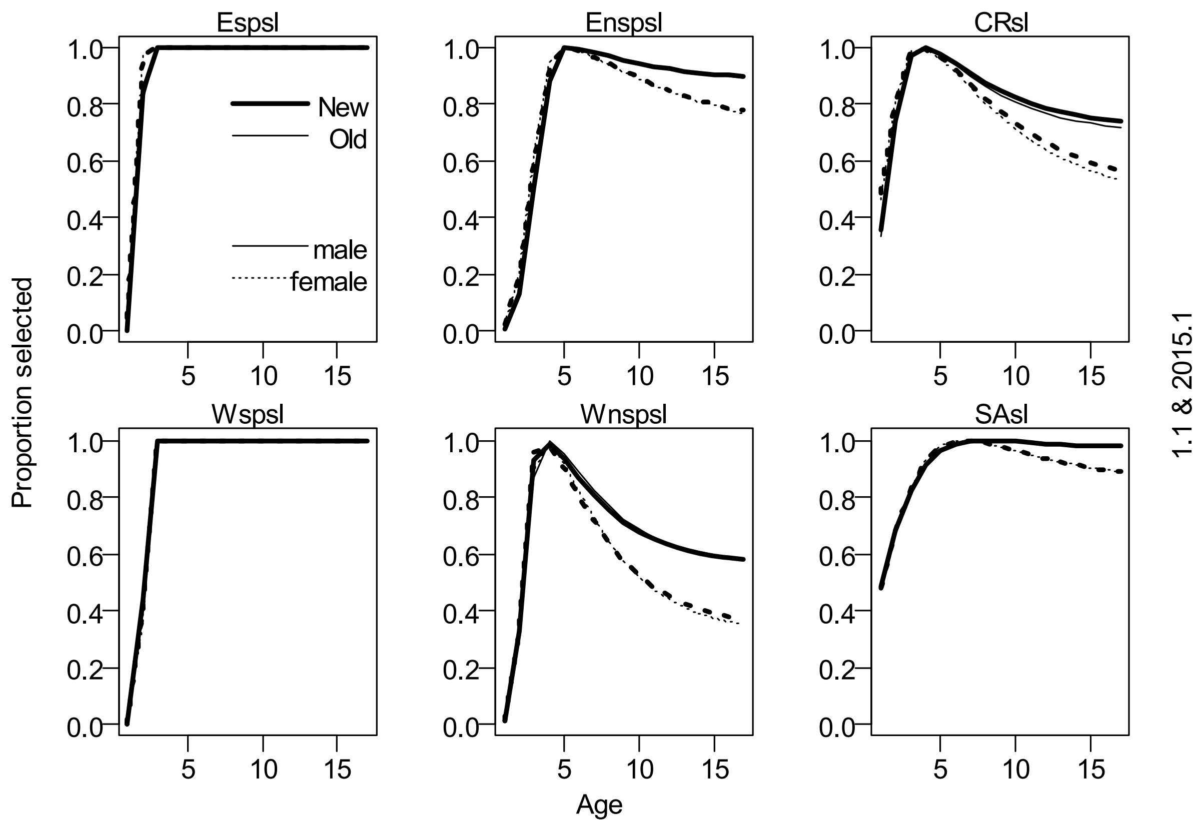

Figure 17: Estimated selectivity curves for the new model run 1.1 from new 2016 (thick lines) and analogous model run from the previous assessment (thin lines). Males are shown by a solid line, females by a dotted line. The label 2015.1 denotes run 1.1 for the 2015 assessment.

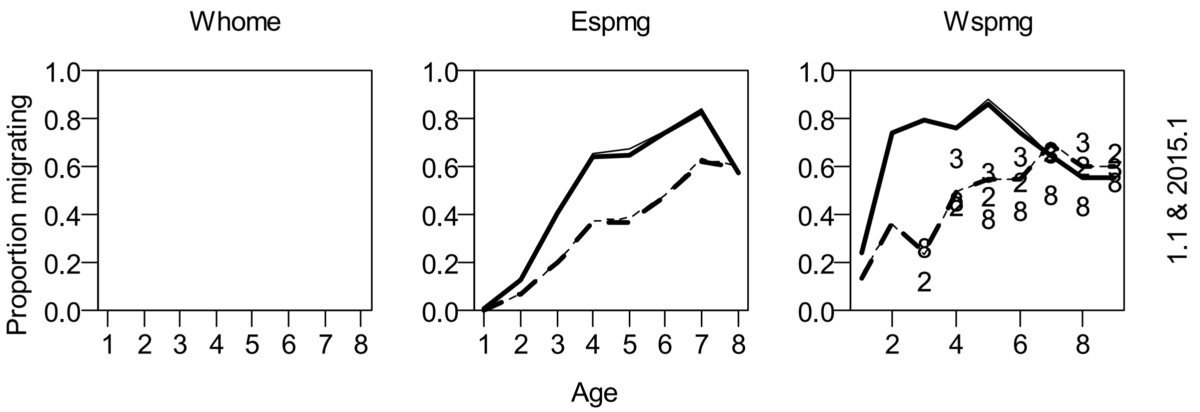

Figure 18: Estimated migration ogives for new run 1.1 from 2016 (thick lines) and the analogous model run from the previous assessment (thin lines). Each row of plots compares ogives from the new run (thick lines) with that from the previous assessment (thin lines). Where ogives differ by sex, female 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 2015.1 denotes run 1.1 for the 2015 assessment.

Figure 19: Comparison between age-dependent natural mortality estimated in the new run 1.1 from 2016 (thick lines) and the analogous model run from the previous assessment (thin lines). Males are shown by a solid line, females by a dotted line. The label 2015.1 denotes run 1.1 for the 2015 assessment.

4.3 Trawl survey upweighting

In run 1.2 the trawl survey biomass indices are upweighted, unlike run 1.1. Upweighting slightly improves the fit for the last six years of CRsumbio, and about half the years for SAsumbio (Table 21, Figures 20–22). There is little difference in the fits to the other biomass data sets SAautbio, CSacous, and WCacous.

With trawl survey biomass index upweighting, current western biomass is estimated to be less and there is a more pronounced decline in recent years (Figure 23). The trawl surveys have little impact on the estimated YCSs (Figure 24).

Table 21: 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 indices data sets).

run	Trawl surveys upweighted?	CRsumbio	SAsumbio	SAautbio	CSacous	WCacous
1.1	No	0.81	1.45	0.66	0.92	0.98
1.2	Yes	0.78	1.18	0.67	0.92	1.10

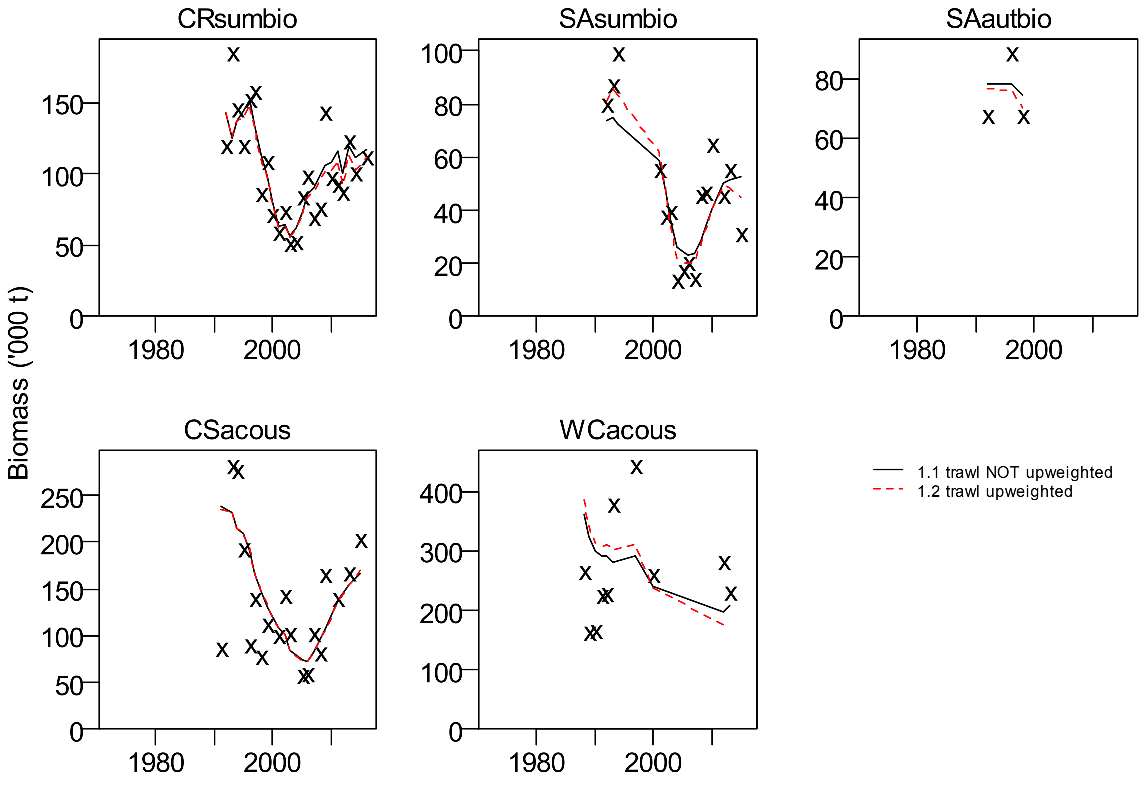

Figure 20: Fit to biomass indices for 2016 assessment run 1.1 (trawl surveys not upweighted) and 1.2 (trawl surveys upweighted). Shown are observed ('×') and expected values (lines).

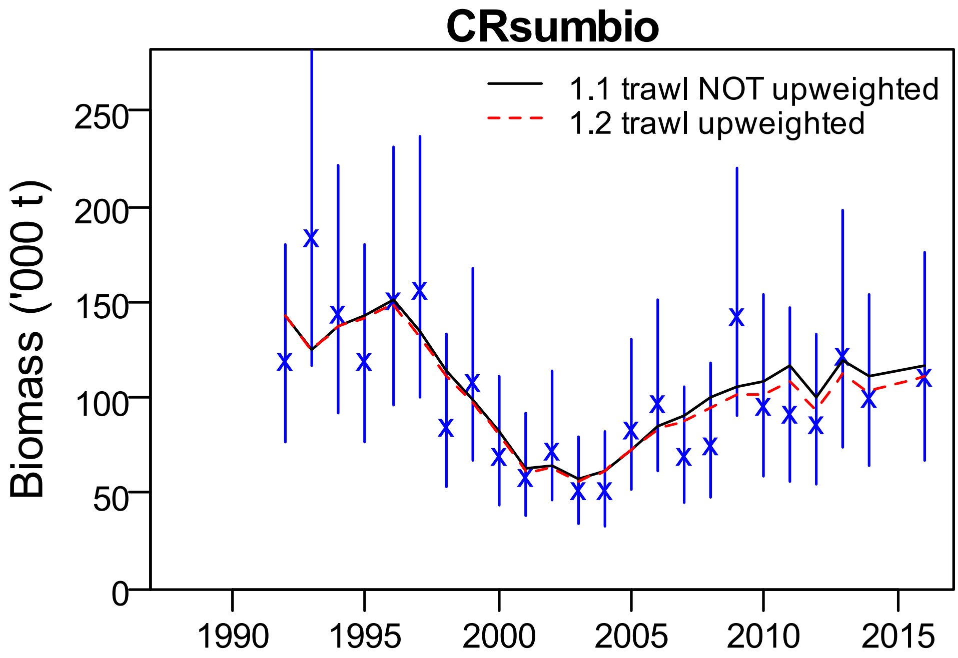

Figure 21: Fits to CRsumbio for 2016 runs 1.1 and 1.2, showing observed ('×', with vertical lines showing 95% confidence intervals including 0.20 process error) and expected values (lines). Plotted years are as in the model (so the last survey is plotted at 2016). The trawl survey expected values are shown for the not upweighted (solid lines) and upweighted (dashed lines) runs.

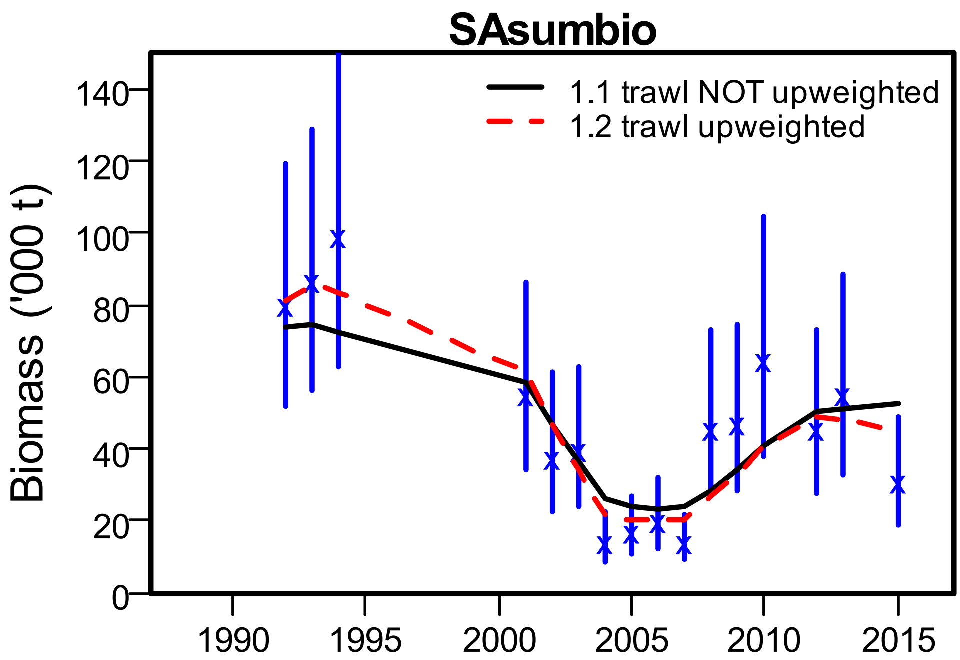

Figure 22: Fits to SAsumbio for 2015 runs 1.1 and 1.2, showing observed ('×', with vertical lines showing 95% confidence intervals including 0.20 process error) and expected values (lines). Plotted years are as in the model (so the last survey is plotted at 2015). The trawl survey expected values are shown for the not upweighted (solid lines) and upweighted (dashed lines) runs.

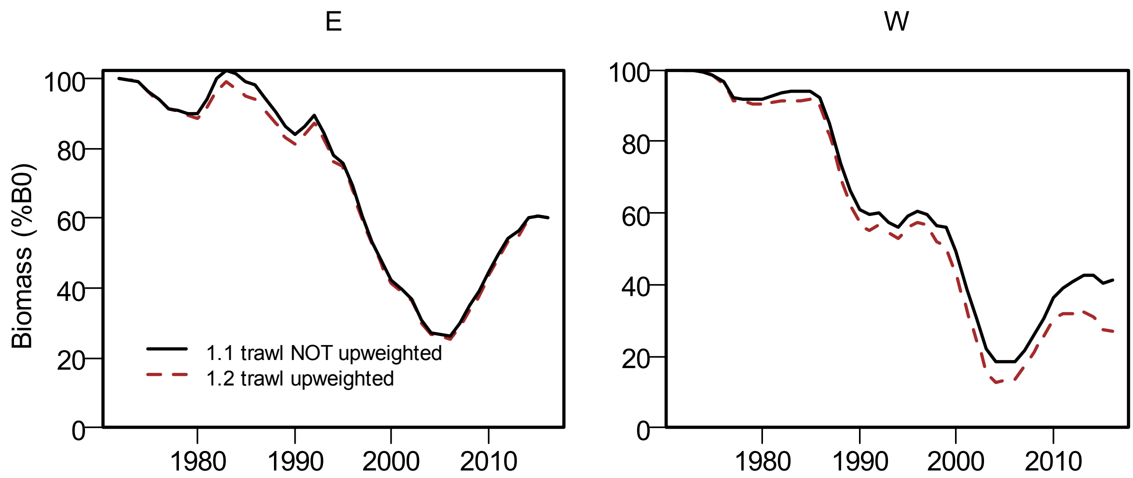

Figure 23: Comparison of biomass trajectories for runs 1.1 and 1.2: E stock (left panel), W stock (right panel).

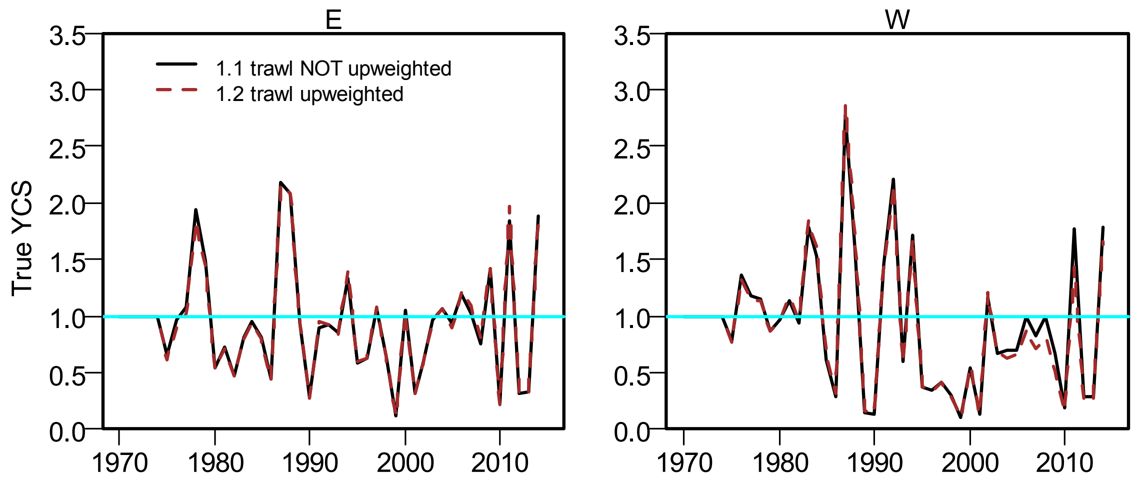

Figure 24: True YCS estimates for 2016 runs 1.1 and 1.2.

4.4 Using two catchabilities for the Sub-Antarctic trawl survey

The numbers-at-age data for the Sub-Antarctic summer trawl survey indicate that there has 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 25–26). 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 15). 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 27, Table 22), with the catchability for 2004–2007 estimated to be half that for the other years or 50% more for 2008–2016 (Table 23). The improvement in fit and estimated catchabilities are similar to the analogous model runs of the 2015 assessment.

Biomass trajectories differ for the western stock between the single and two catchability models (Figure 28).

Table 22: Objective function values for selected model runs.

		Trawl surveys	Objective function	
Run		upweighted?	SAsumbio	Total
1.1	single q	N	-7.5	2864.8
1.3	04-07q different	N	-14.7	2853.9
1.4	08-16q different	N	-11.6	2859.9

Table 23: Estimated catchability for the model runs.

	catchability		
run	1992–2003	2004–2007	2008–16
1.1	0.10	0.10	0.10
1.3	0.10	0.05	0.10
1.4	0.09	0.09	0.14

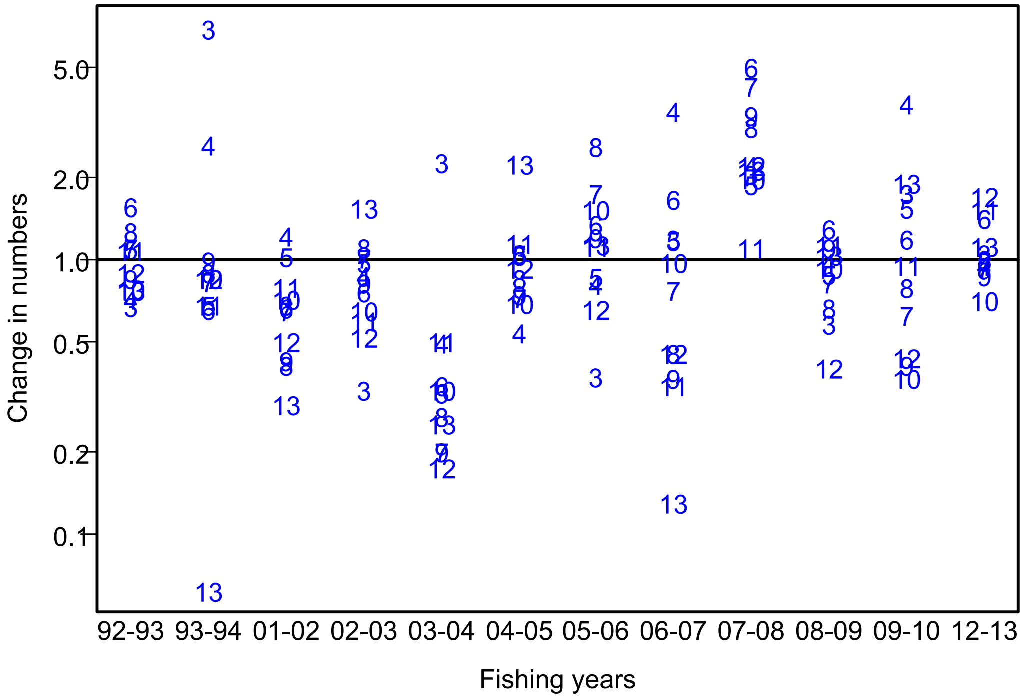

Figure 25: Changes, between surveys one year apart in the Sub-Antarctic summer series, in estimated numbers of selected cohorts. Each plotted point indicates how the estimated number in a cohort changed between the two surveys; the plotting symbol is the age of the cohort in the earlier survey. For example, for the 06-07 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.

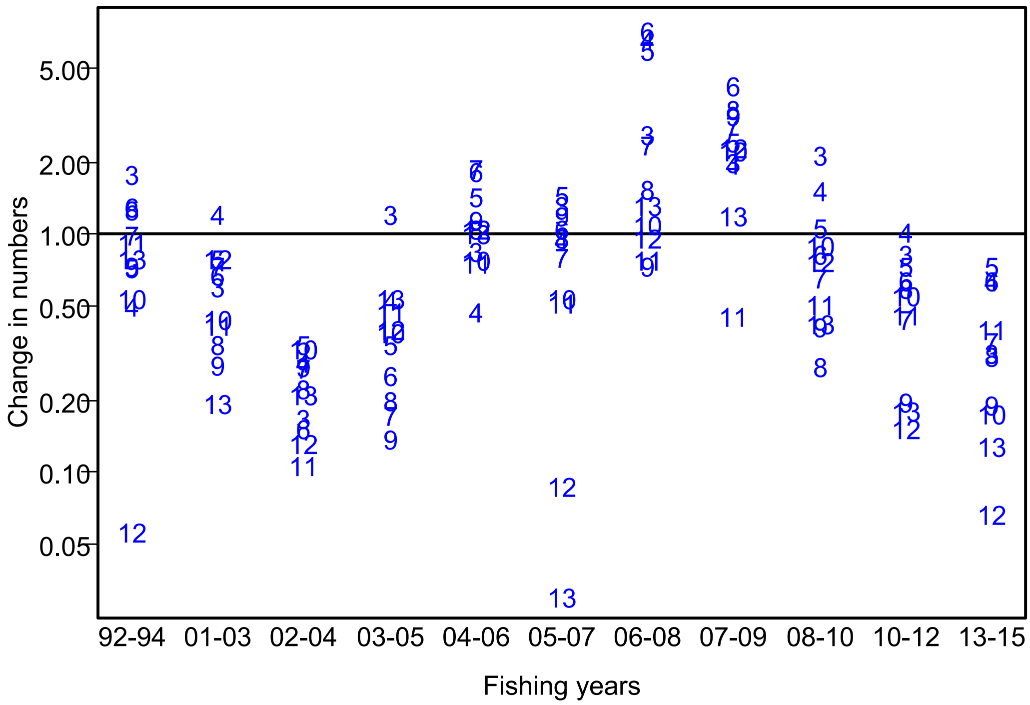

Figure 26: As Figure 25, but changes between surveys two years apart.

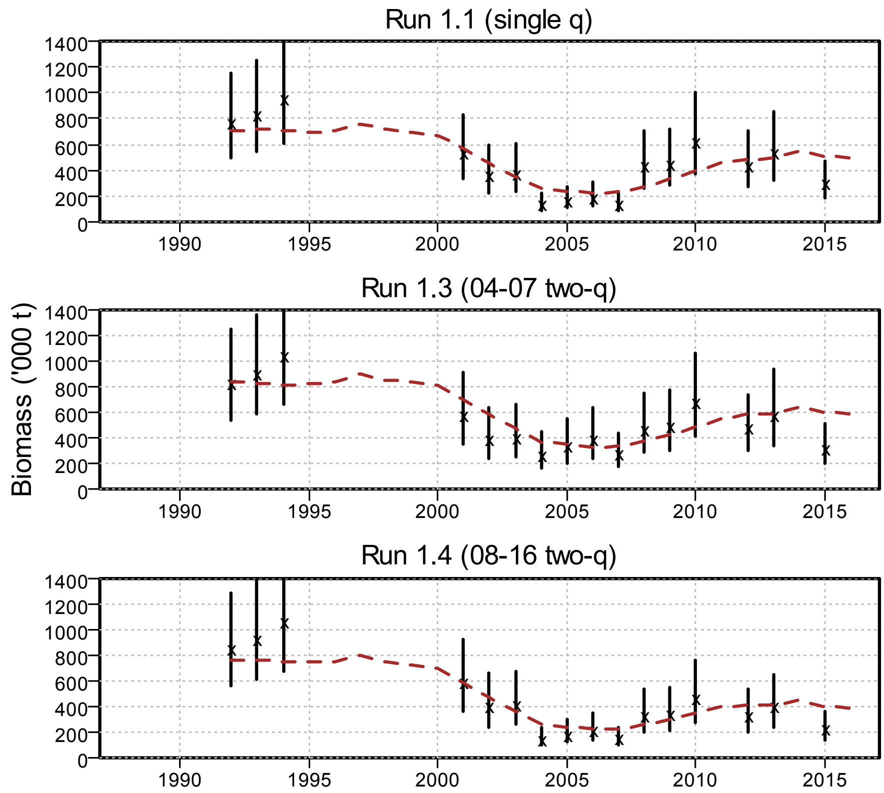

Figure 27: Fits to SAsumbio for runs 1.1, 1.3, and 1.4 showing observed values scaled to model biomass by dividing by catchability ('x', with vertical lines showing 95% confidence intervals) and expected values (dashed lines). Plotted years are as in the model (so the last survey is plotted at 2015). The trawl survey indices are not upweighted for all runs.

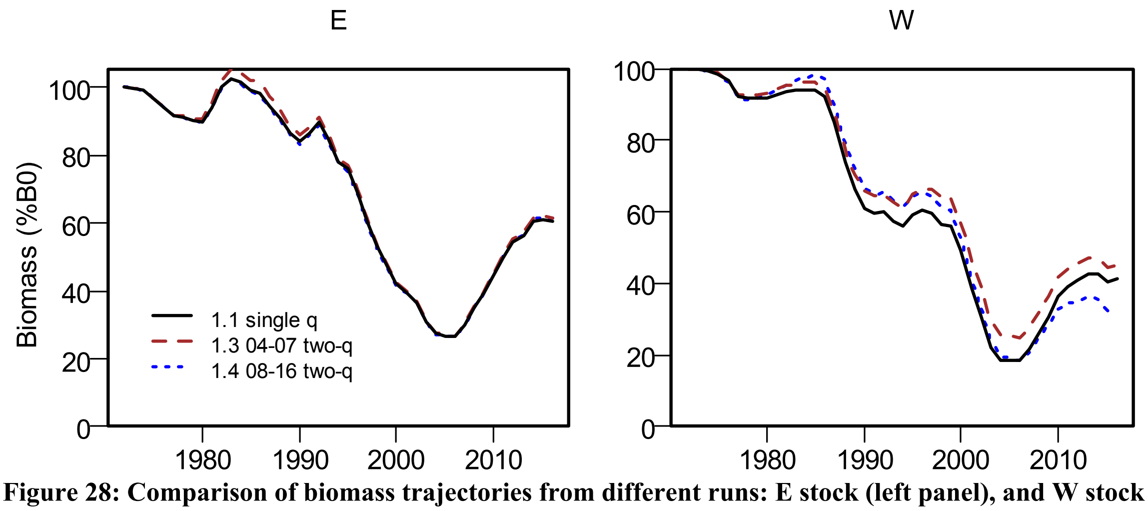

Figure 28: Comparison of biomass trajectories from different runs: E stock (left panel), and W stock (right panel).

4.5 Estimating process error for the research trawl surveys: part I

Four initial MPD model runs were undertaken for the 2016 hoki stock assessment (see Table 17).

In the starting model 1.1 the trawl surveys from the three series (CRsumbio, SAsumbio, SAautbio) all have a process error of 0.20 to account for varying trawl catchabilities, this coming from a meta-analysis of trawl surveys (Francis et al. 2001). In an alternative model run 1.2 the trawl survey biomass indices are upweighted by setting the process error to zero for all three trawl survey series.

A suggestion from the Deepwater Working Group was that the process error for CRsumbio and SAsumbio should be estimated in a model run (but not SAautbio due to the short length of the series). The fits in this model run to SAsumbio should then be compared to runs 1.1 and 1.2, which have process errors of 0.20 and 0.00 respectively.

For the new run 1.5 this gave estimated process errors of 0.15 (CRsumbio) and 0.36 (SAsumbio). The fits to SAsumbio are shown in Figures 29–31, where the confidence intervals for the observations have no process error (Figure 29), estimated process error of 0.36 (Figure 30), assumed process error of 0.20 (Figure 31). The fits are similar for run 1.5 and run 1.1, though in both cases more consistent with a process error of 0.36 for the observations (see Figure 30).

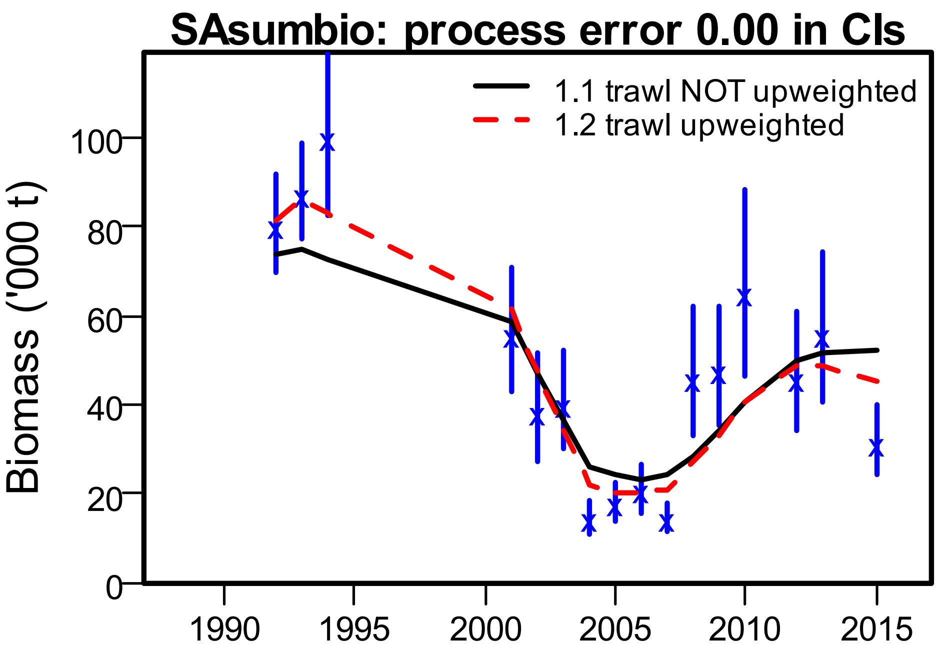

Figure 29: Fits to SAsumbio for 2016 runs 1.1 and 1.2, showing observed ('×', with vertical lines showing 95% confidence intervals (with no process error) and expected values (lines). Plotted years are as in the model (so the last survey is plotted at 2015). The trawl survey indices are not upweighted (solid lines), and upweighted (dashed lines).

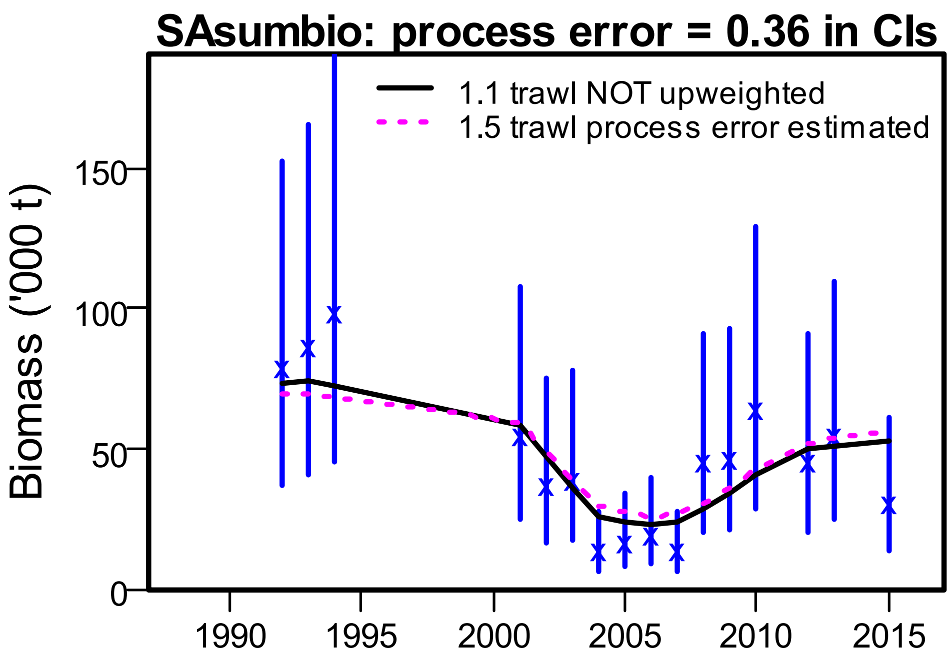

Figure 30: As in Figure 29 but showing run 1.5, and including a process error of 0.36 for the confidence intervals for the observations.

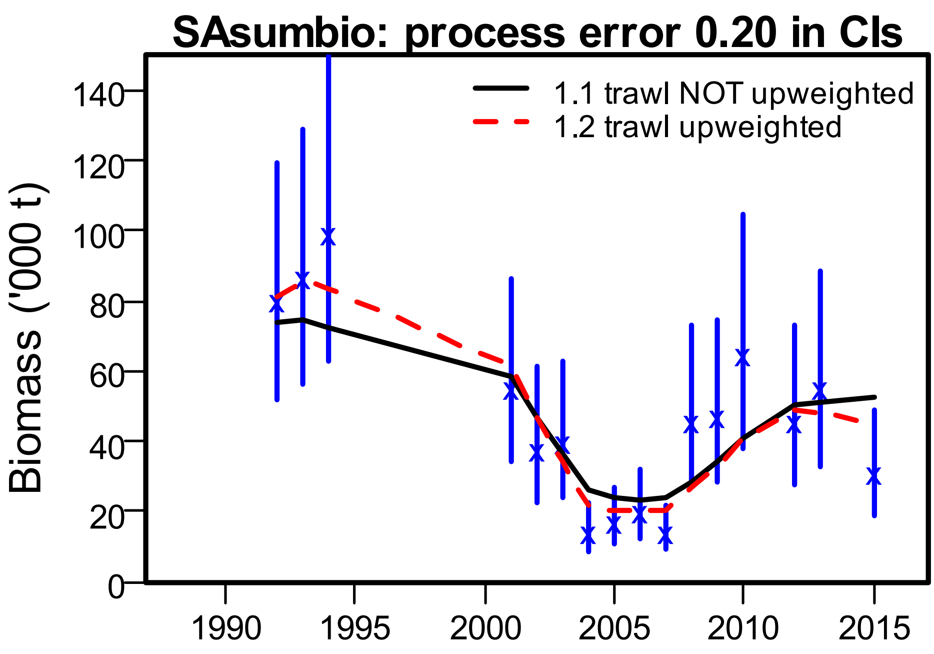

Figure 31: As in Figure 29, but including a process error of 0.20 for the confidence intervals for the observations.

4.6 Revised Chatham Rise trawl survey data

Subsequent to the initial MPD model runs the 2016 Chatham Rise trawl survey biomass estimate and age-frequency were revised, as a single tow distance has been input incorrectly. The revised 2016 CRsumbio value is 114.5 thousand tonnes (CV 14.2%) versus the previous value of 112.4 thousand tonnes (CV 13.8%). There is little difference between the revised and previous 2016 age frequencies (Figure 32). A new model run 1.6 where the revised value are used shows a biomass trajectory (%B_0) that is indistinguishable from when the previous values were used in model run 1.1 (Figure 33). As incorporating the revised 2016 Chatham Rise data made very little difference to the MPD run, the same effective sample sizes were retained for the at-age data in run 1.6 as were used in run 1.1.

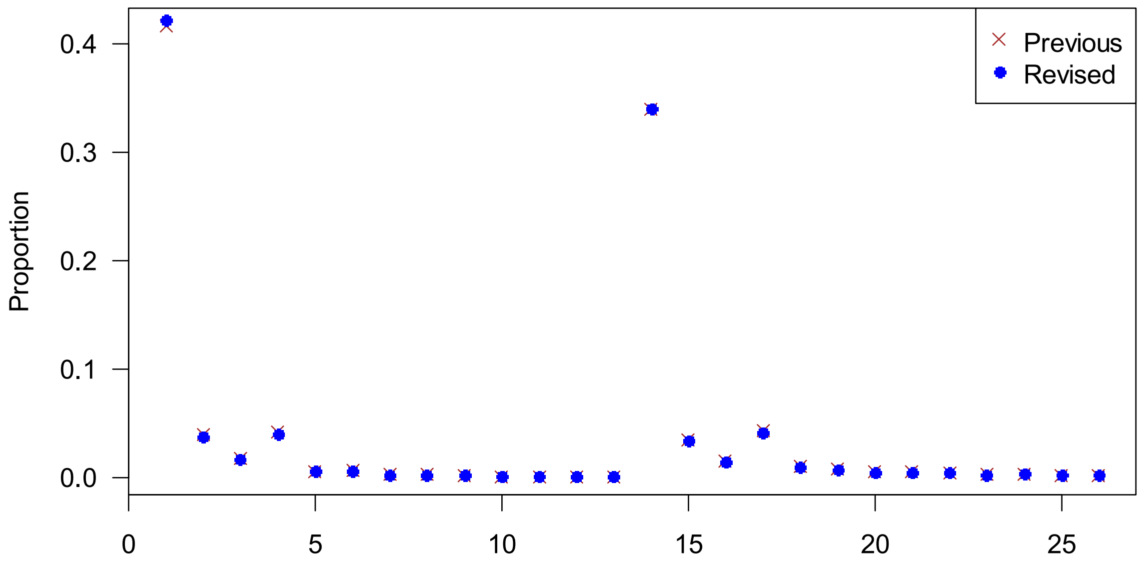

Figure 32: Revised versus previous age frequencies for the 2016 Chatham Rise trawl survey, as used in the hoki stock assessment (CRsumage). The age groups are 1-13+ with male first (entries 1 to 13 on the x-axis), followed by female (entries 14 to 26).

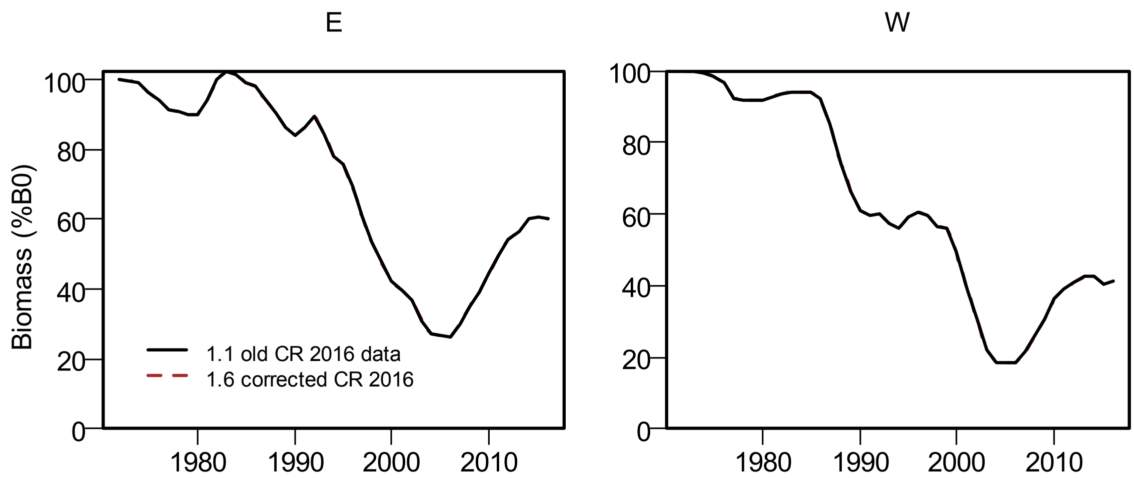

Figure 33: Comparison of biomass trajectories from different runs: E stock (left column), W stock (middle column). Both runs have a process error of 0.20 for the trawl surveys. Note that the trajectory for run 1.6 is almost indistinguishable from that for run 1.1, hence the lines overlap substantially.

4.7 Estimating process error for the research trawl surveys: part II

The process errors for CRsumbio and SAsumbio were estimated in run 1.5 (Section 4.5). Subsequent to this run the Chatham Rise trawl survey data for 2016 were revised for run 1.6 (Section 4.6). In this section we conduct a new run 1.7 incorporating the revised Chatham Rise data and estimating the process error for CRsumbio and SAsumbio. For the new run the at-age data was reweighted again, though the effective sample sizes were very similar to the run where the process error was not estimated (Table 24). Fits for the new run are compared to run 1.6 where the process error is set at 0.20 for both CRsumbio and SAsumbio.

For the new run 1.7 the estimated process errors are 0.37 (SAsumbio) and 0.15 (CRsumbio). The fits to SAsumbio and CRsumbio are shown in Figures 34–35, and slow a slightly flatter fit relative to run 1.6 for SAsumbio and very little difference for CRsumbio.

When process error is estimated, the biomass trajectory for the eastern stock shows some changes in the early years, but the current biomass (%B_0) is little changed (Table 25, Figure 36). For the western stock the biomass trajectory is flatter after 1990, and current biomass (%B_0) is estimated to be higher (50% versus 41% B_0).

For the model runs, virgin biomass is parameterised in terms of log_B0_tot, for which a posterior profile is done, and this parameter transformed to total virgin biomass for plotting. The objective function components (e.g., CRsumage, SAsumbio) were scaled to be zero at their minimum value. All the at-age data components were summed under the label "Composition" and similarly for the prior components under the label "Priors". The total objective function value along with the profiles attributable to total priors, total composition data, and biomass indices are shown in Figures 37–38. The profiles are similar to each other, and to that from the 2014 assessment (Figure 39).

Fits and Pearson residuals are shown for the CRsumage and SAsumage data (Figures 40–44) and Pearson residuals for the rest of the at-age data (Figures 45–52).

Table 24: Iterative reweighting for multinomial sample sizes using method TA1.8 of Francis (2011). Shown are the mean values of N for the at age data sets in the model: initial (based on observation error), run 1.6, and run 1.7

	Espage	Wspage	EnspOLF	Enspage	WnspOLF	Wnspage	CRsumage	SAsumage	SAautage
Initial	660	906	89	334	80	193	1351	574	829
Run 1.6	77	23	12	39	55	13	67	14	14
Run 1.7	77	21	12	38	58	15	66	16	15

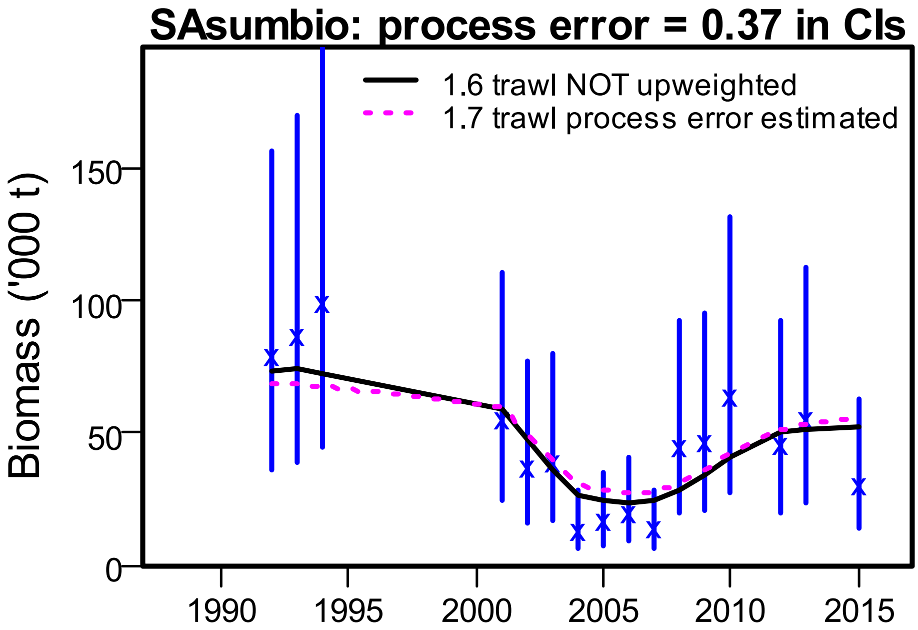

Figure 34: Fits to SAsumbio for 2016 runs 1.6 and 1.7, showing observed ('×', with vertical lines showing 95% confidence intervals (including process error of 0.37) and expected values (lines). Plotted years are as in the model (so the last survey is plotted at 2015).

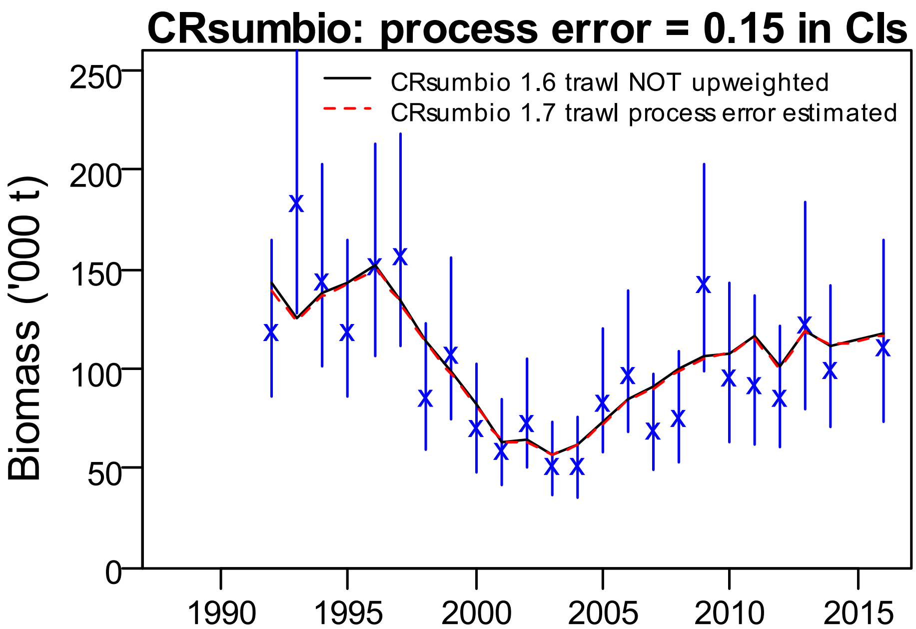

Figure 35: Fits to CRsumbio for 2016 runs 1.6 and 1.7, showing observed ('×', with vertical lines showing 95% confidence intervals (including process error of 0.15) and expected values (lines). Plotted years are as in the model (so the last survey is plotted at 2016).

Table 25: Comparison of MPD biomass estimates for some model runs.

Run	Description	B_0('000 t)		B_{2016}(%B_0)	
		E	W	E	W
1.6	trawl not upweighted	445	792	60	41
1.7	process error estimated	452	858	59	50

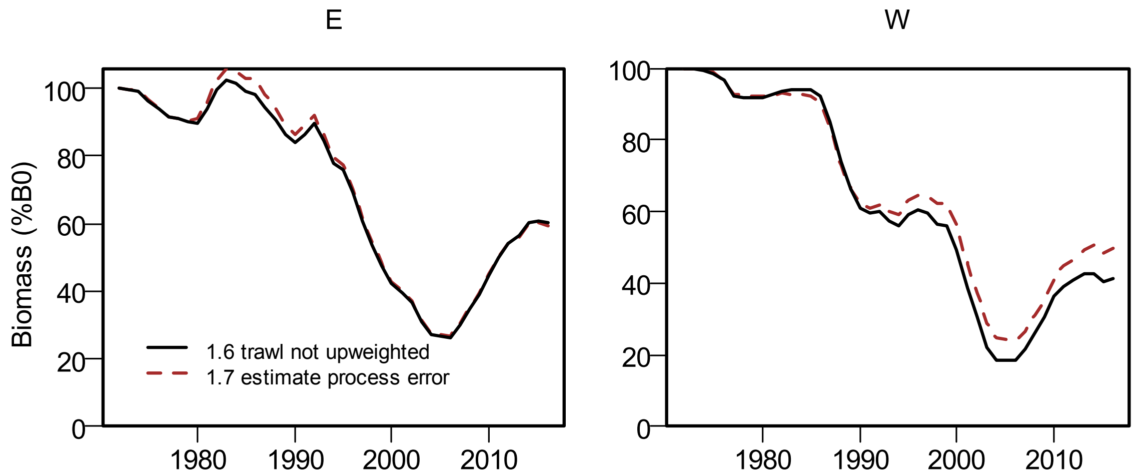

Figure 36: Comparison of biomass trajectories from different runs: E stock (left column), W stock (right column).

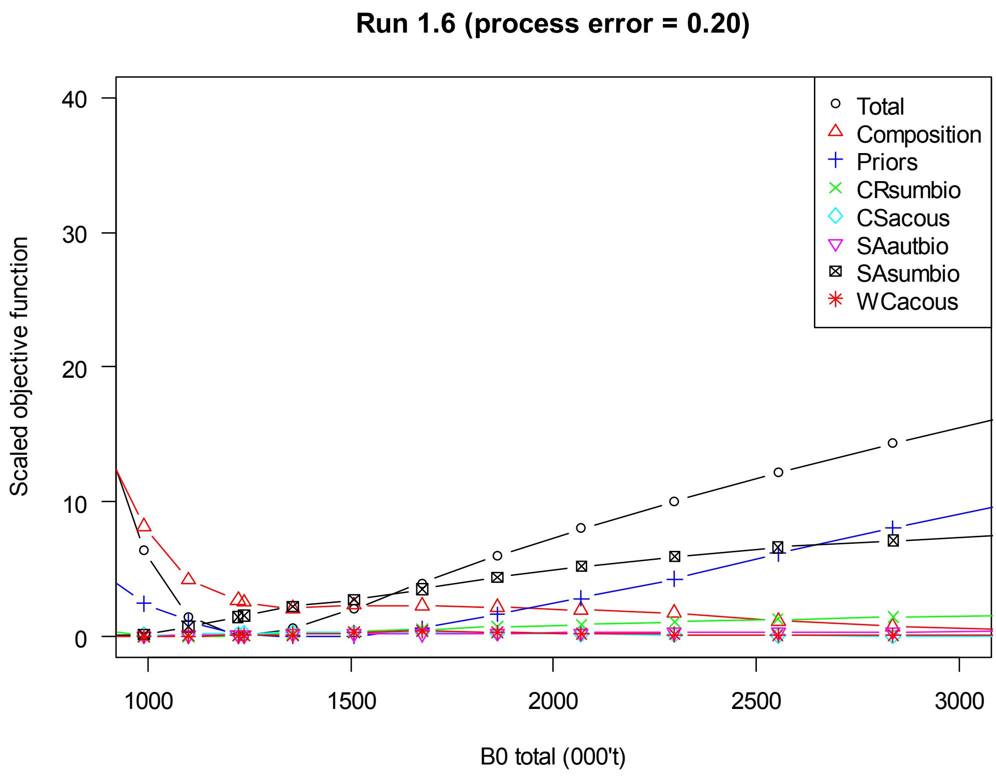

Figure 37: Posterior profile for run 1.6 on B_0 total.

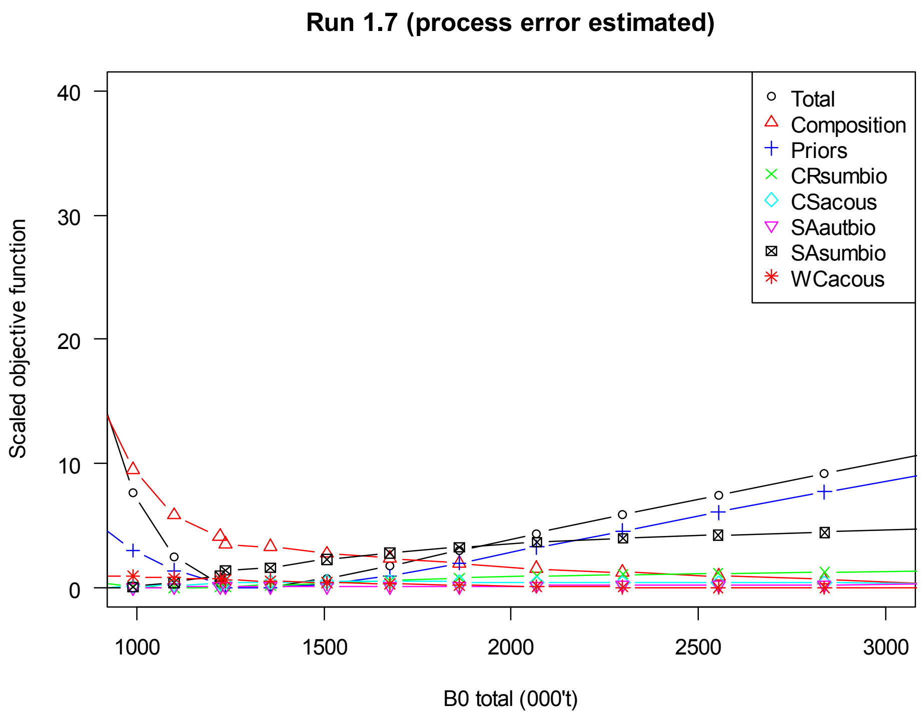

Figure 38: Posterior profile for run 1.7 on B_0 total.

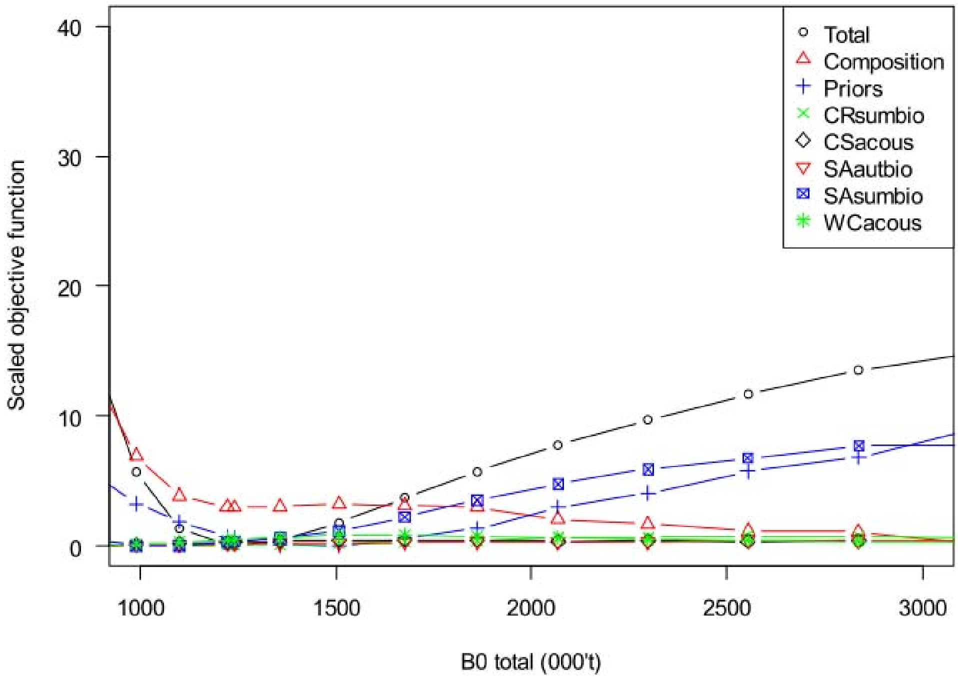

Figure 39: Posterior profile on B_0 total from the 2014 assessment (using the Haist parameterisation with a lognormal prior). Reproduced from figure 16 in McKenzie (2015b).

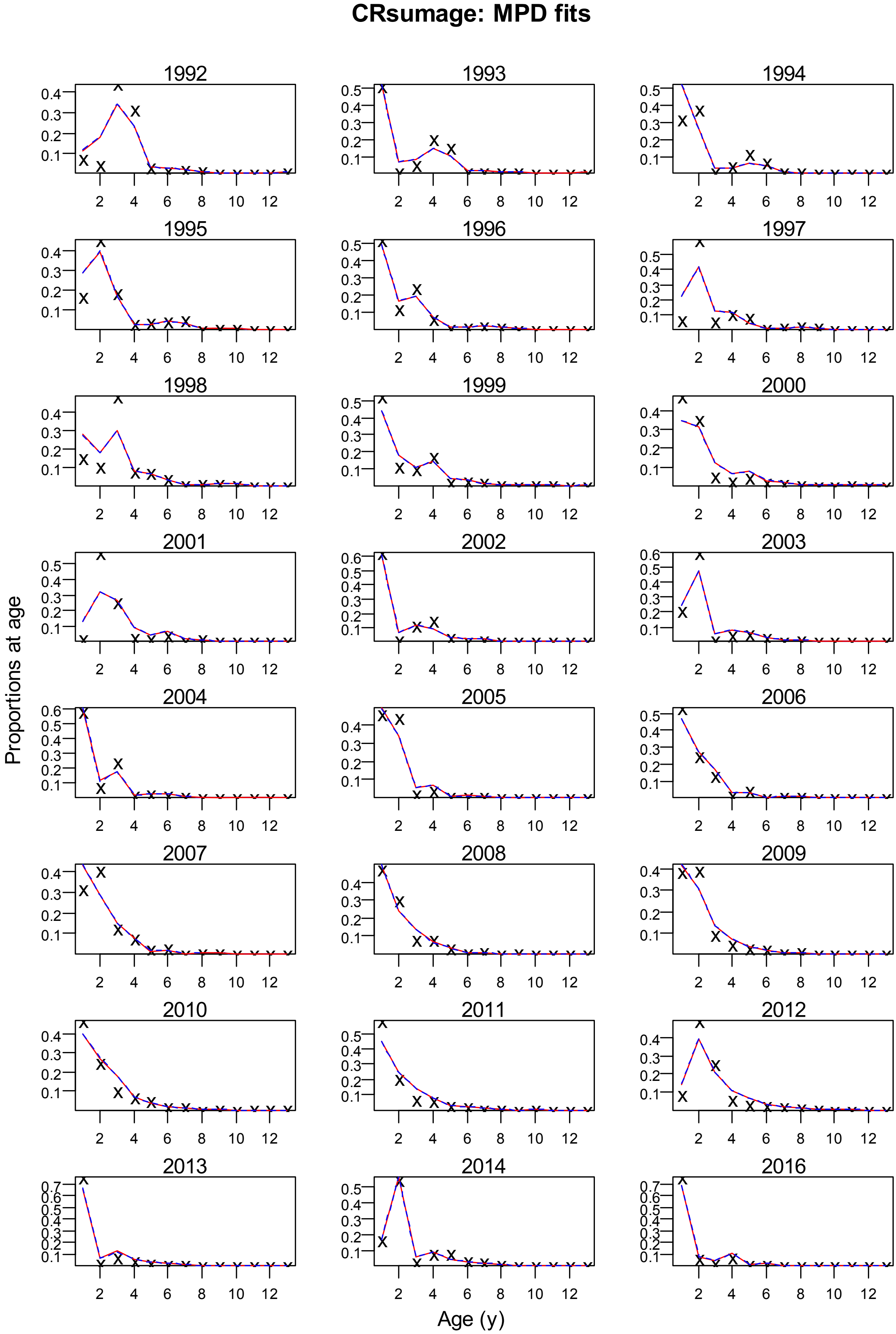

Figure 40: MPD fits to CRsumage. Observed ('×') and expected (lines) for runs 1.6 (red solid lines) and 1.7 (blue broken lines). Note that the expected value lines overlap substantially. Male and female observed and expected proportions are summed for an age group.

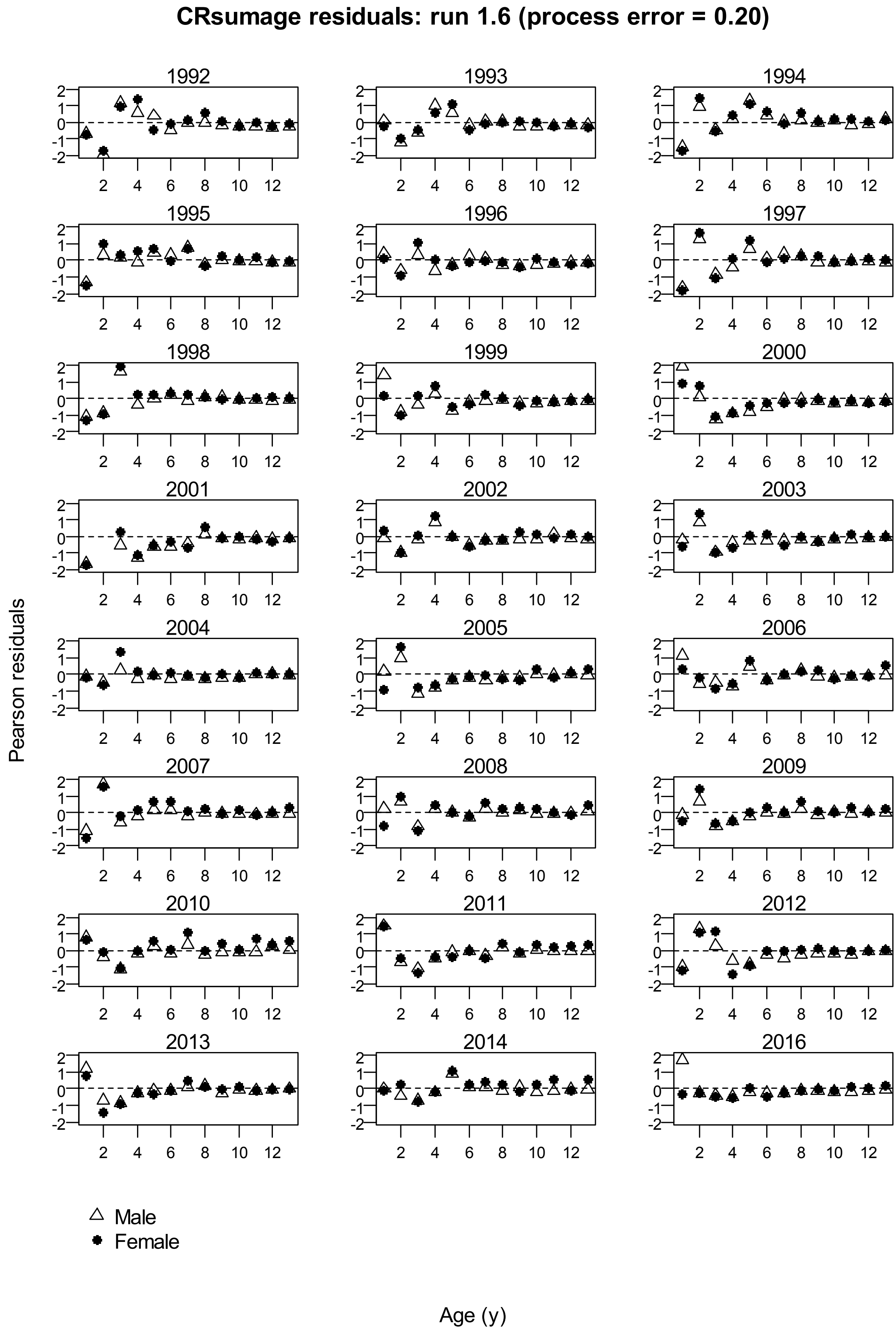

Figure 41: MPD Pearson residuals for the fit to CRsumage (run 1.6 with process error 0.20).

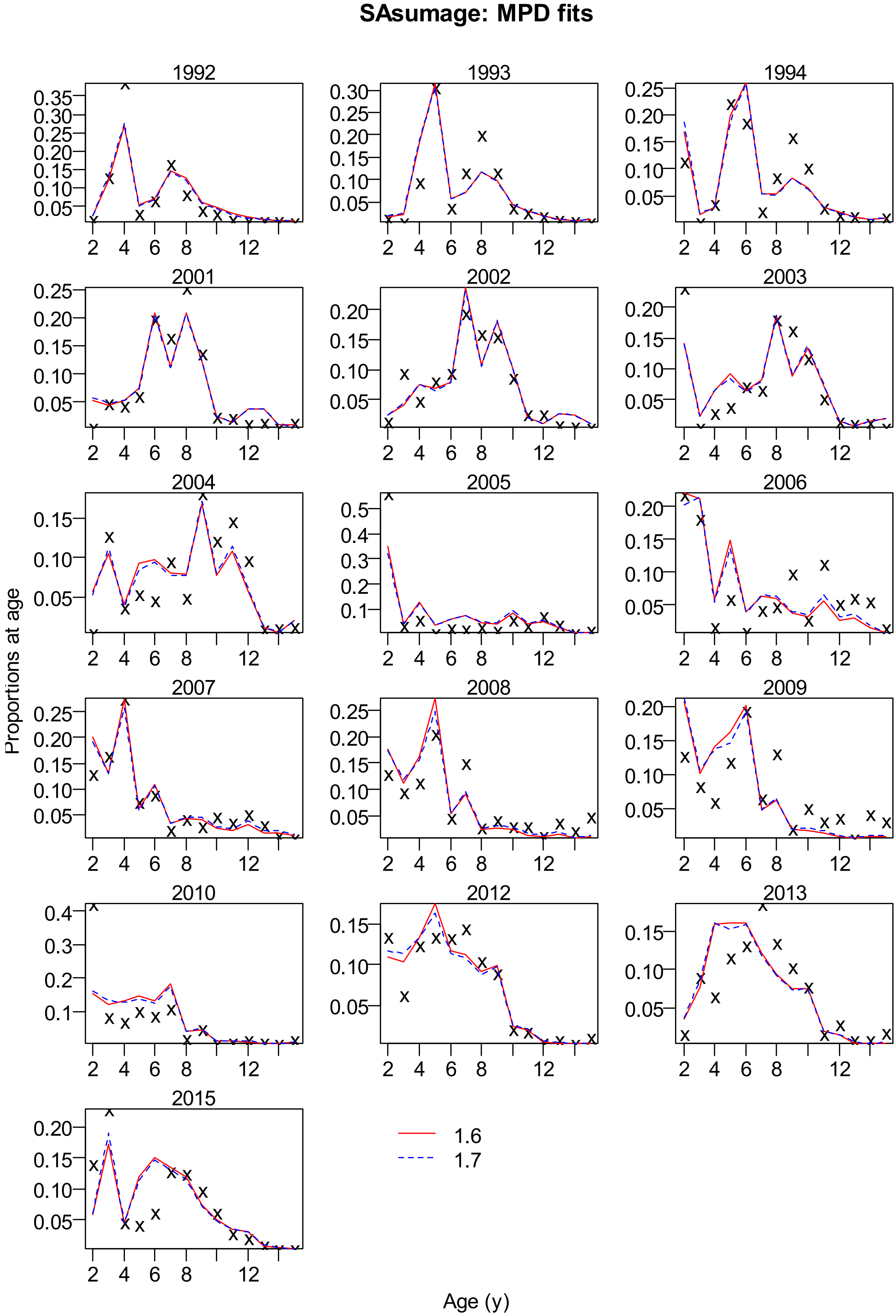

Figure 42: MPD fits to the SAsumage data. Observed ('×') and expected (lines) for runs 1.6 (red solid lines) and 1.7 (blue broken lines). Male and female observed and expected proportions are summed for an age group.

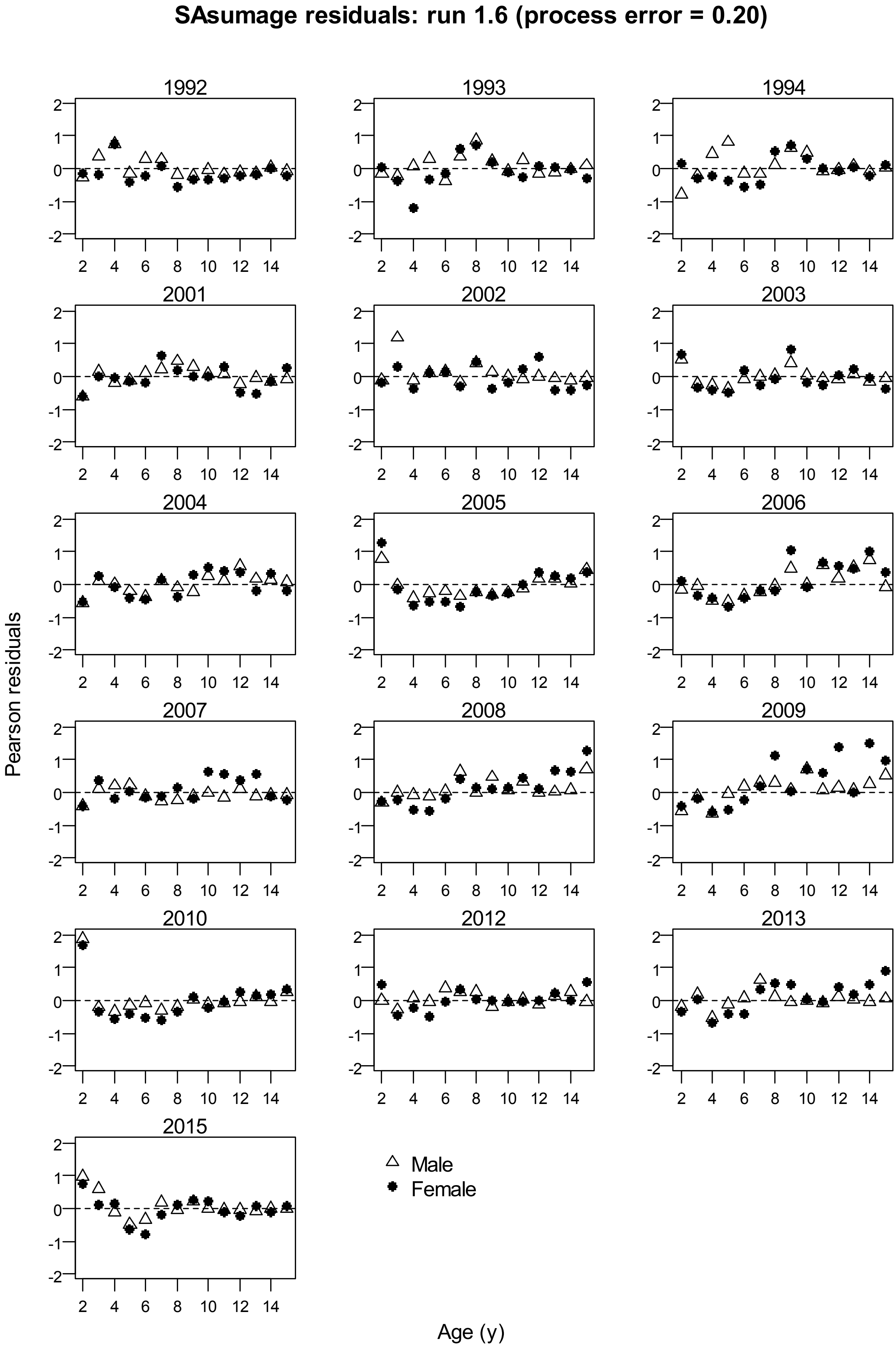

Figure 43: MPD Pearson residuals for the fit to SAsumage (run 1.6 with process error 0.20).

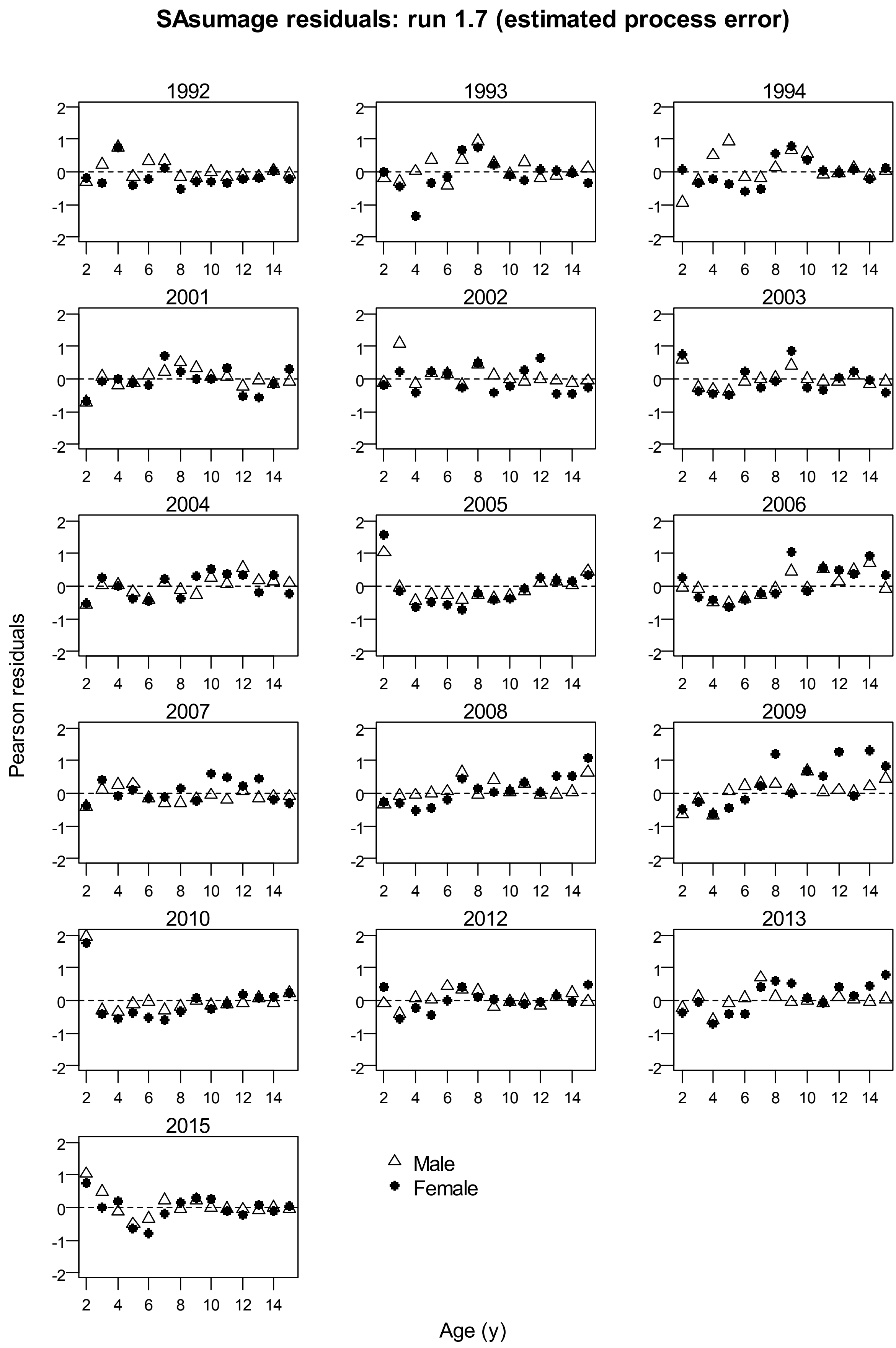

Figure 44: MPD Pearson residuals for the fit to SAsumage (run 1.7 with estimated process error).

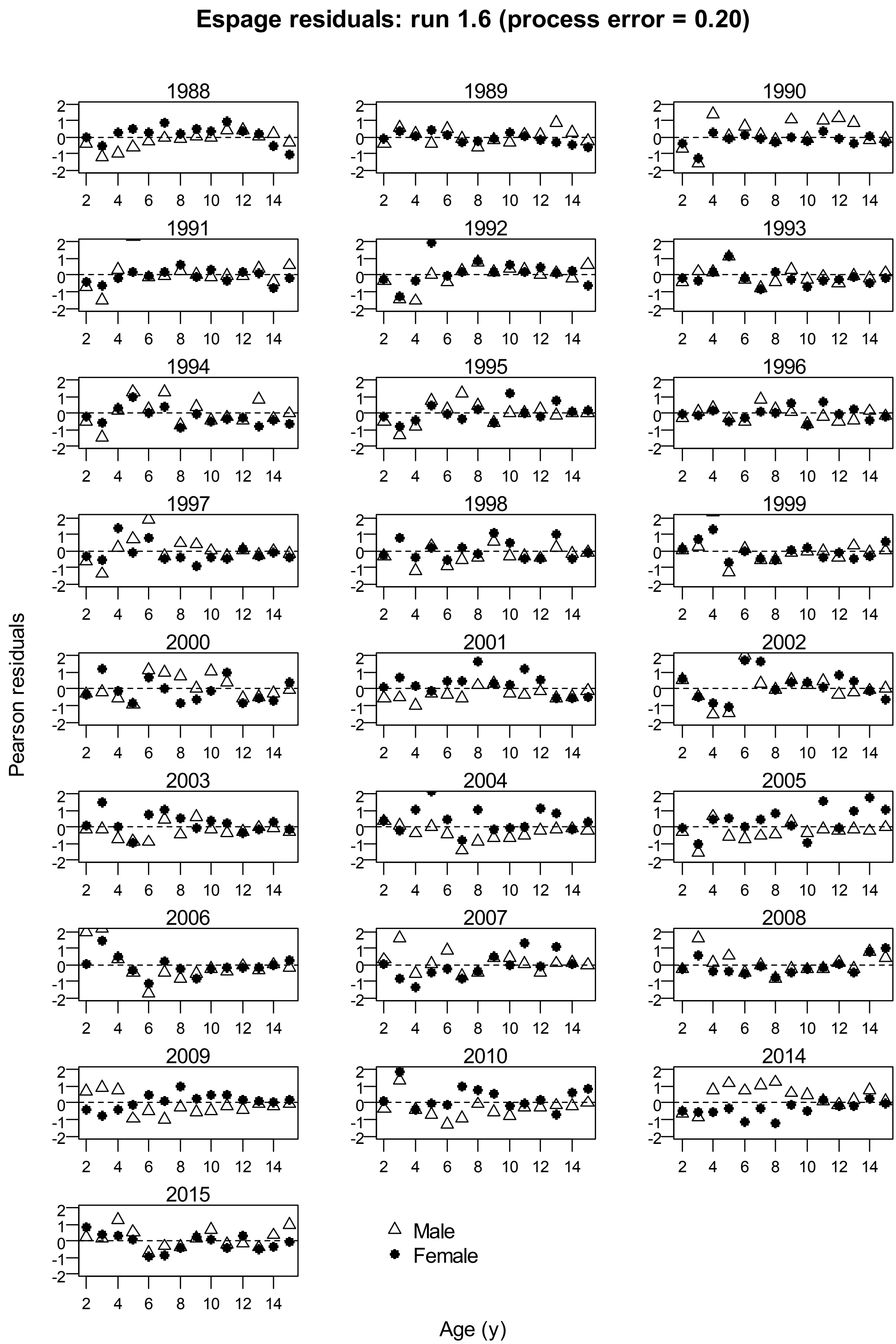

Figure 45: MPD Pearson residuals for the fits to Espage data in run 1.6.

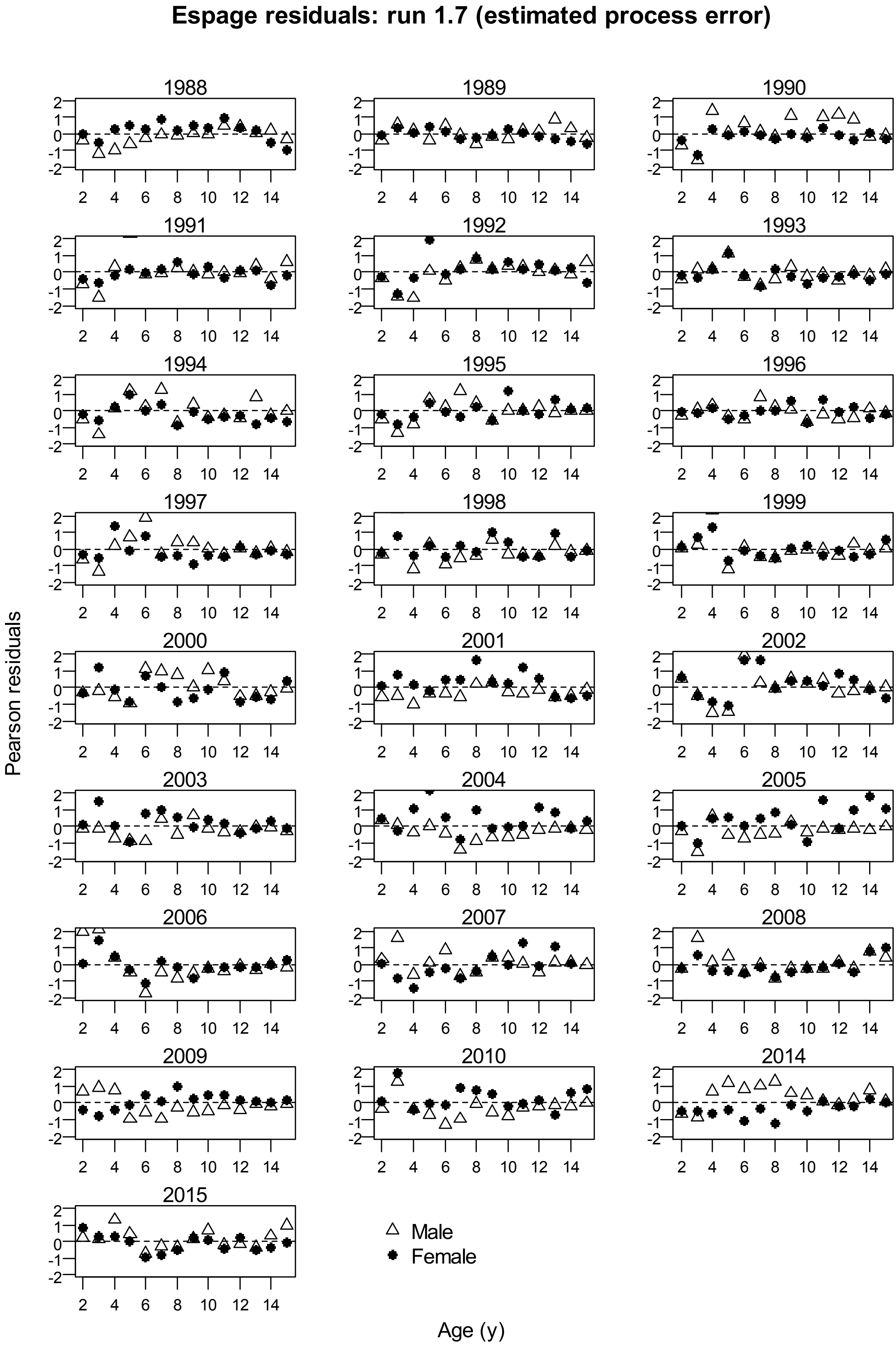

Figure 46: MPD Pearson residuals for the fits to Espage data in run 1.7.

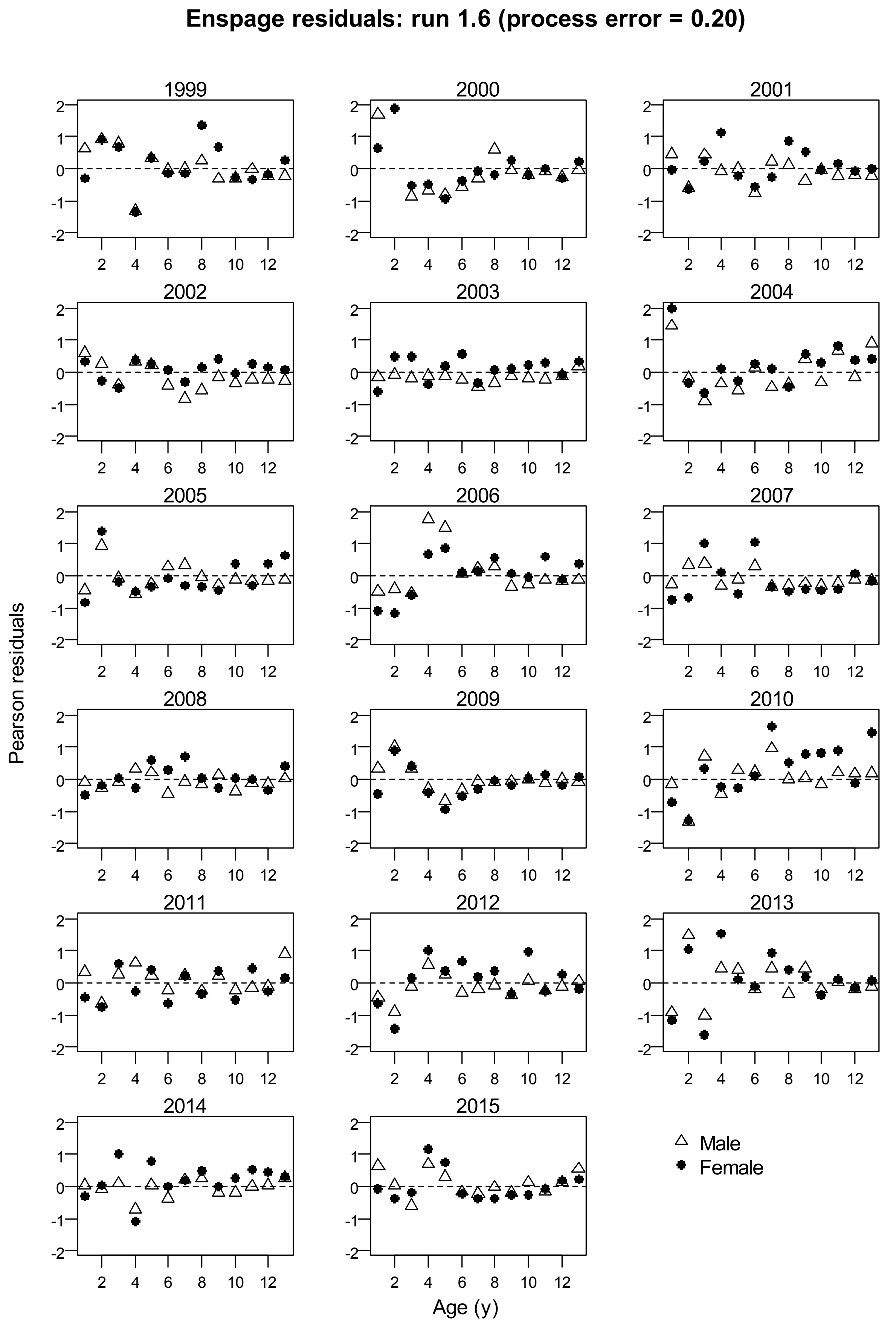

Figure 47: MPD Pearson residuals for the fits to Enspage data in run 1.6.

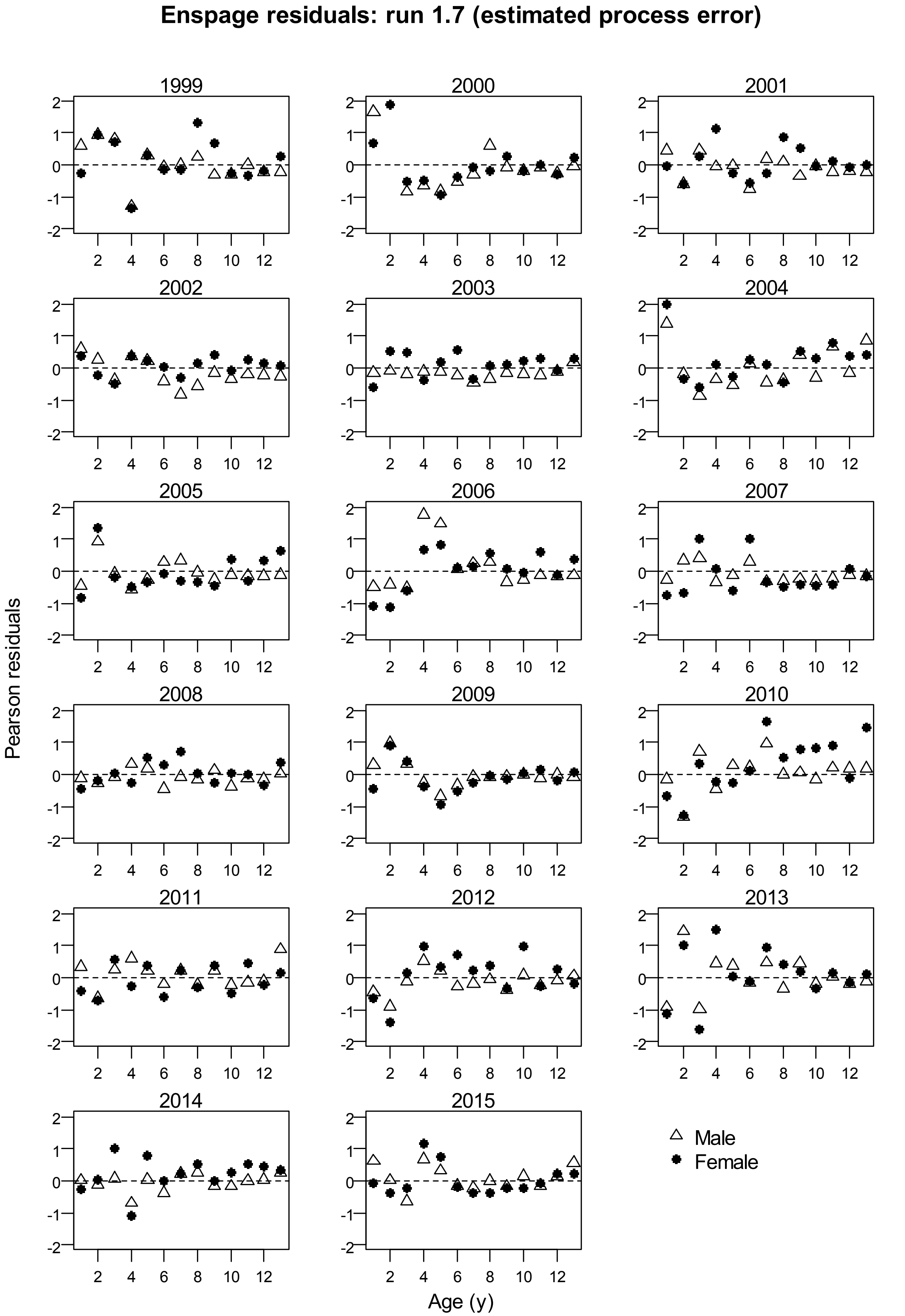

Figure 48: MPD Pearson residuals for the fits to Enspage in run 1.7.

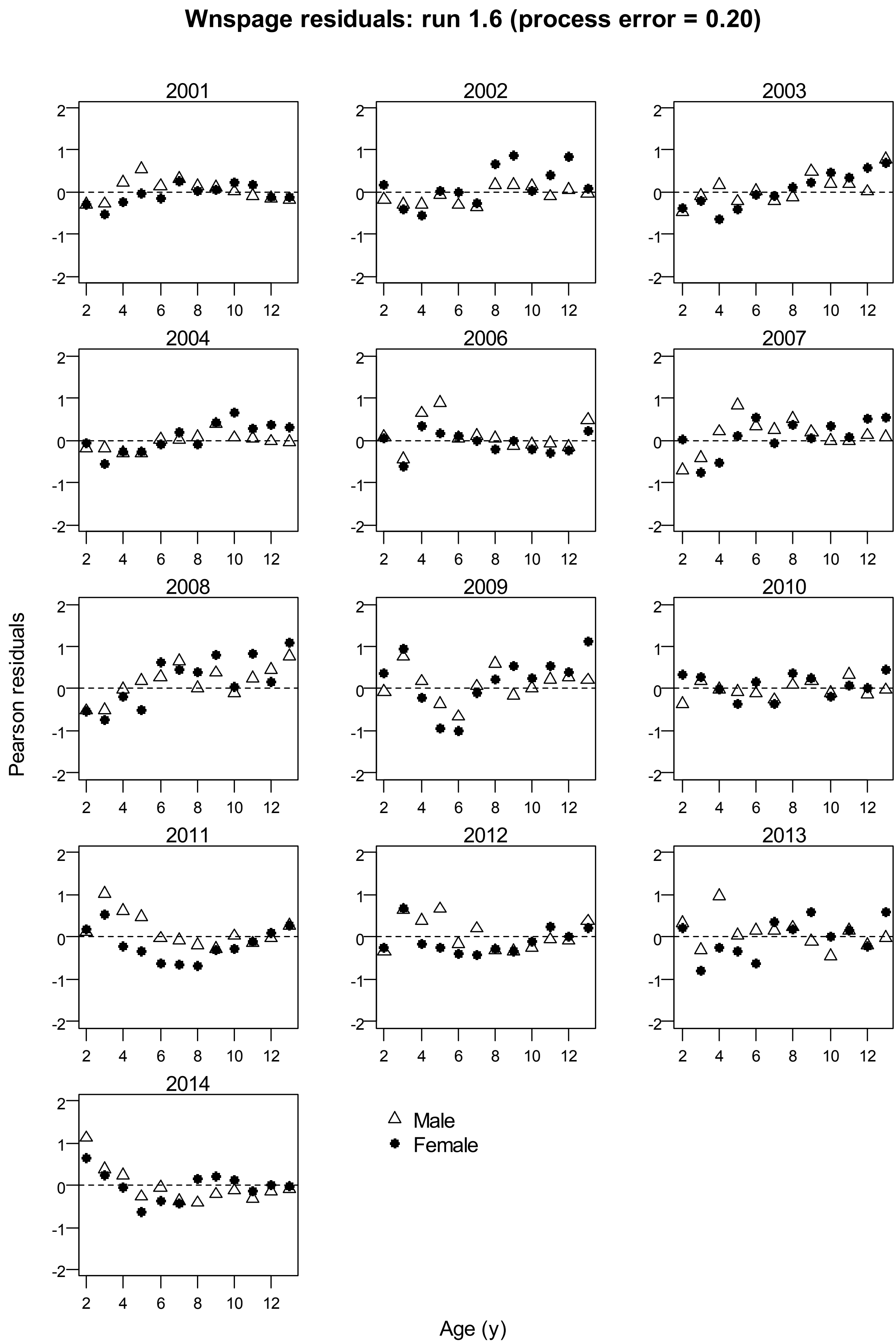

Figure 49: MPD Pearson residuals for the fits to Wnspage data in run 1.6.

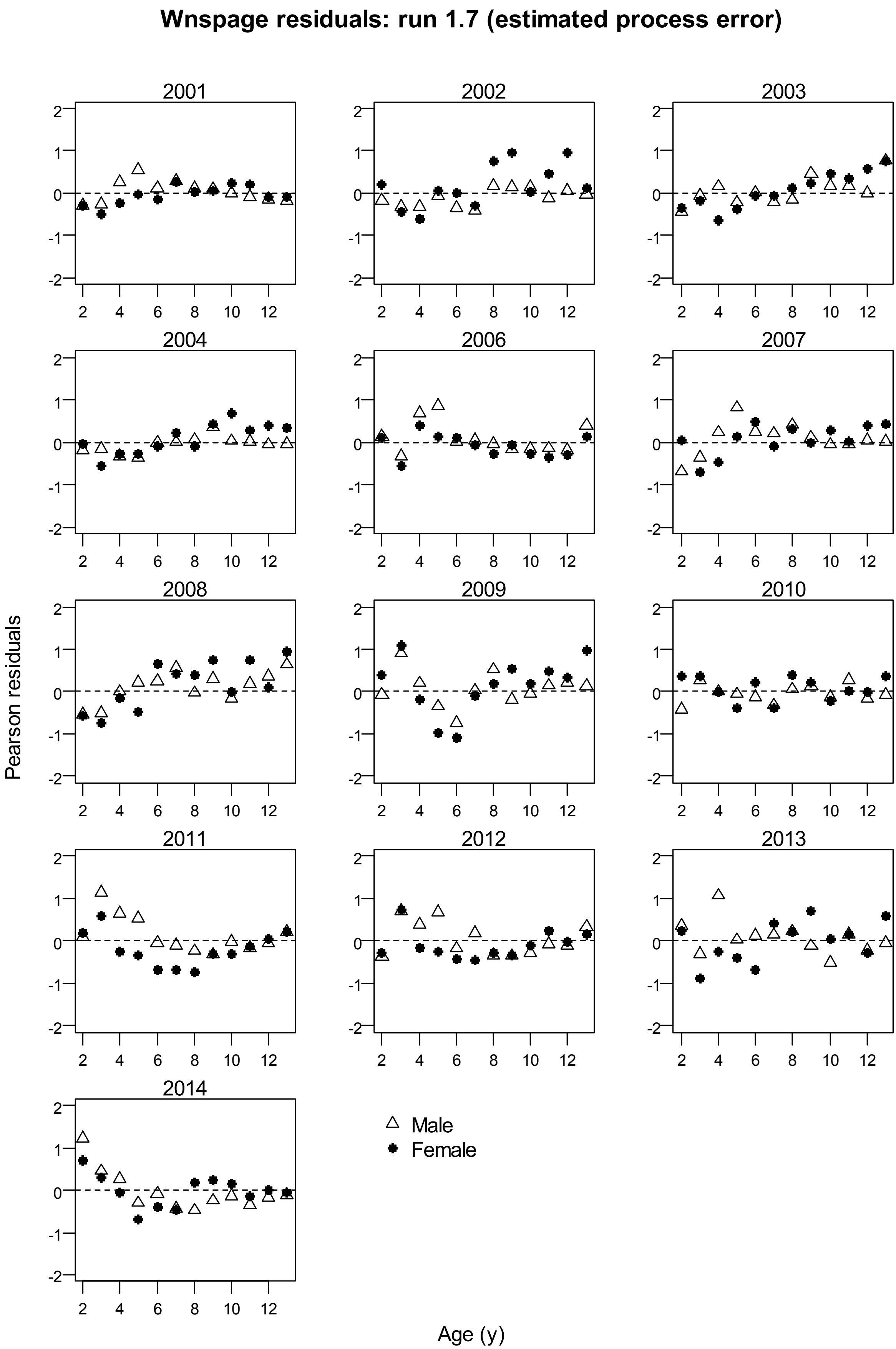

Figure 50: MPD Pearson residuals for the fits to Wnspage data in run 1.7.

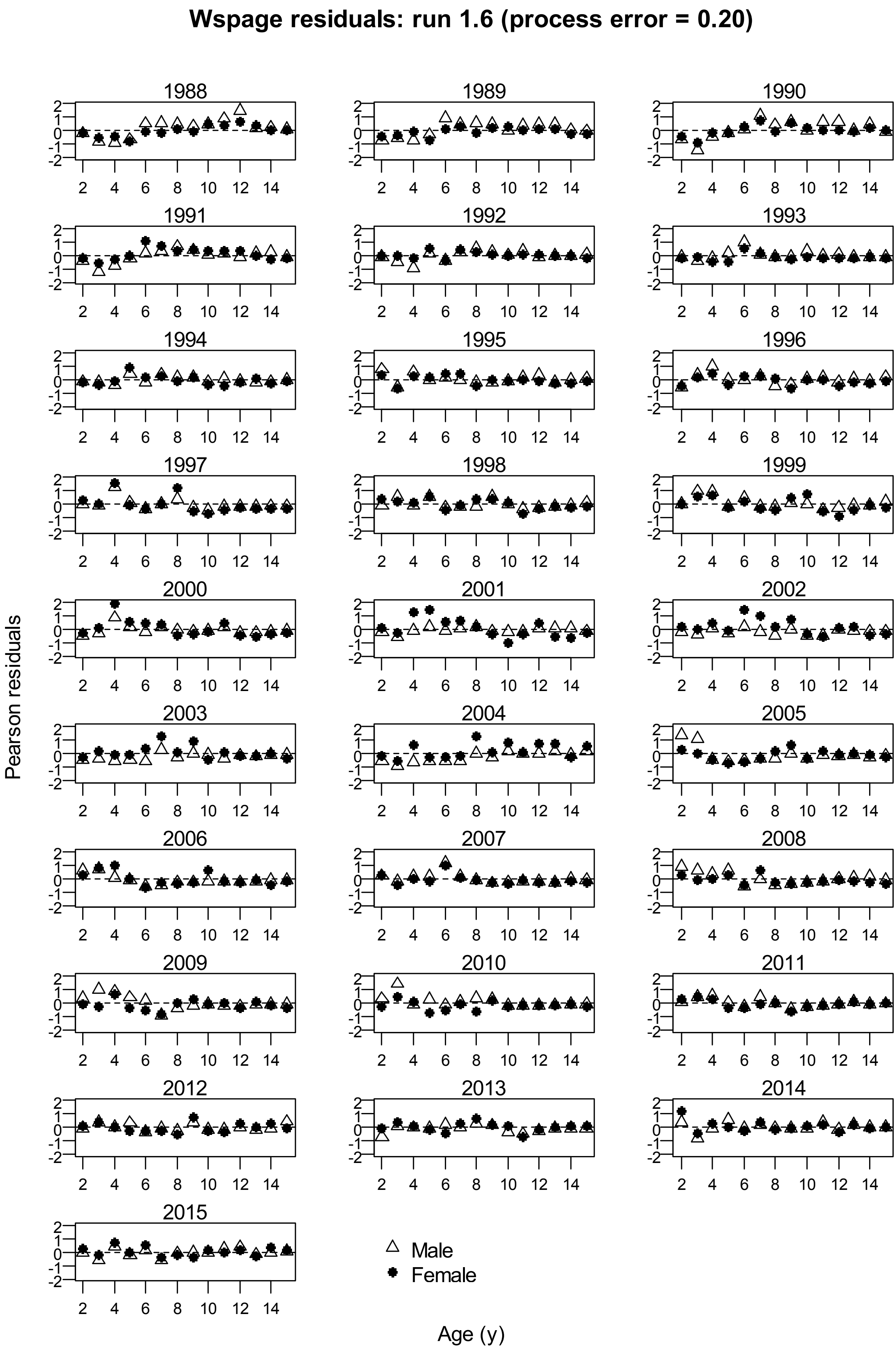

Figure 51: MPD Pearson residuals for the fits to Wspage data in run 1.6.

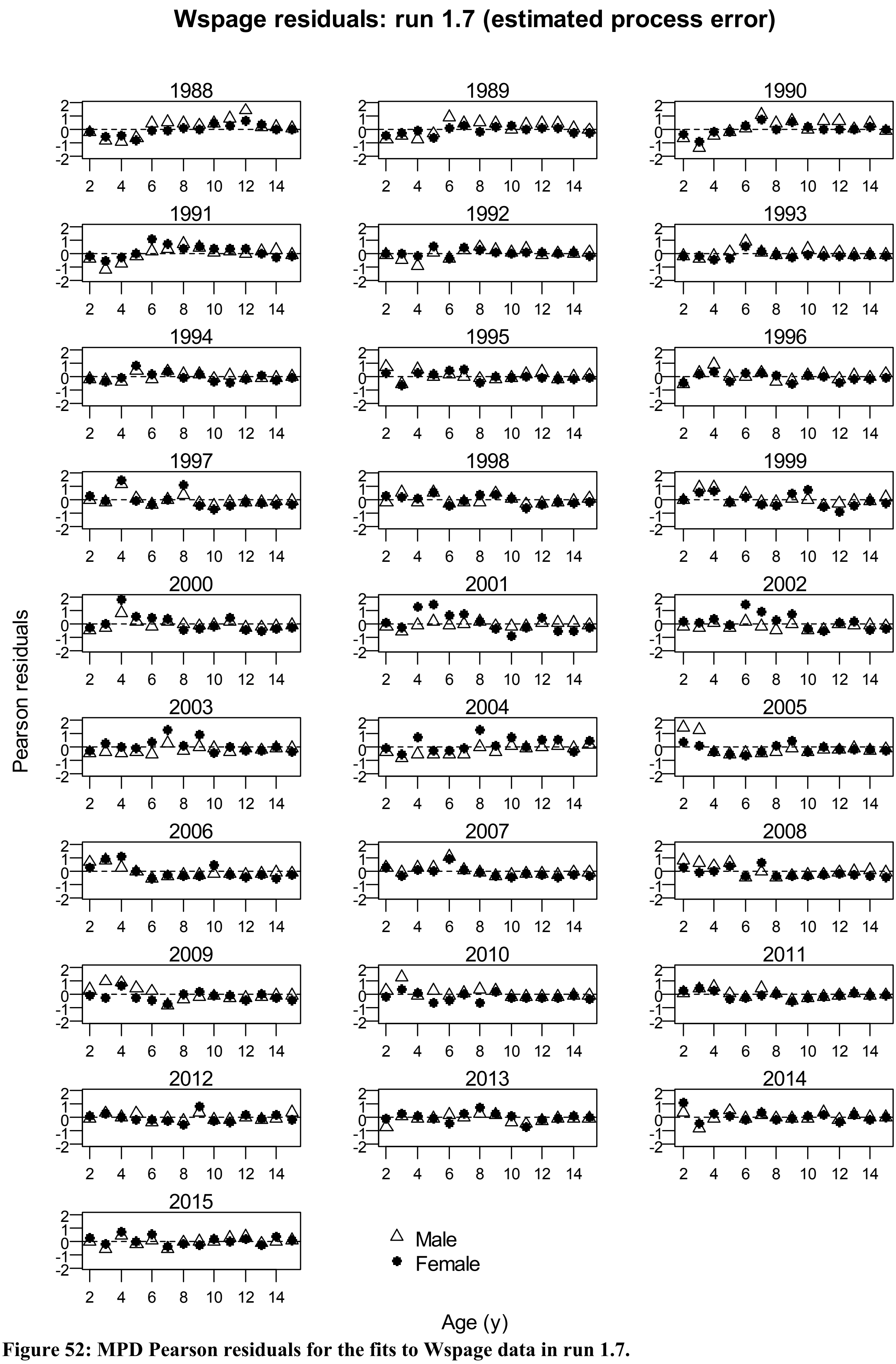

Figure 52: MPD Pearson residuals for the fits to Wspage data in run 1.7.

5. FINAL MODEL ASSESSMENT RESULTS

It was decided by the Deepwater Working Group to take four runs through to the MCMC stage (Table 26). The base run 1.7 uses a single catchability for the Sub-Antarctic trawl survey (SAsumbio), and the process error is estimated for this survey and the Chatham Rise trawl survey (CRsumbio). All other model runs are sensitivity analyses to this base run. Model run 1.6 is a continuity run from the previous assessment, and the process error is set at 0.20 for both the Sub-Antarctic and Chatham Rise trawl surveys. In the last two model runs natal fidelity is not assumed but adult fidelity is (run 1.8), or a domed spawning selectivity is used instead of an age-dependent natural mortality (run 1.9). The process error estimated for CRsumbio and SAsumbio in run 1.7 is used for the other runs.

Run 1.7 was preferred over run 1.6 as the base case by the Deepwater Working Group because the residual patterns for the fits to SAsumbio and CRsumbio were better. The higher SAsumbio process error for run 1.7 (0.38) compared to run 1.6 (0.20) means that the estimate of western stock biomass is more uncertain.

Table 26: Distinguishing characteristics for all MCMC final model runs, including all sensitivities to the base run 1.7.

Run	Main assumptions
1.7 - base case	natal fidelity *M* is age-dependent single q for Sub-Antarctic trawl series process error of CRsumbio and SAsumbio estimated in MPD run
1.6	as 1.7 but process error fixed at 0.20 for CRsumbio and SAsumbio
1.8	as 1.7 but natal fidelity is not assumed
1.9	as 1.7 but with M fixed and a one sex model

Following the practice of the previous assessment, catchability parameters are estimated as free parameters instead of calculated analytically (McKenzie 2015b, p. 47). 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 2015 assessment and the MCMC runs in the current assessment no parameters are set at their bounds (McKenzie 2016, pages 28 and 62).

In a change from the 2015 assessment, the equality constraint for the 2014 east and west year class strengths in the MPD runs is kept for the MCMC runs (previously it was dropped for the MCMC runs).

For each MCMC model run, the at-age data is reweighted. This was done separately and independently for each model.

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, after removing the first $^1/_8$ of each chain ("burn-in"), are shown in Figures 53–54. They suggest that convergence was problematic in that not all three chains have the same distributional quantities, however they are adequate to estimate key quantities and their uncertainty. 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), the three chains concatenated, and the resulting chain thinned by systematic sub-sampling to produce a posterior sample of length 2000.

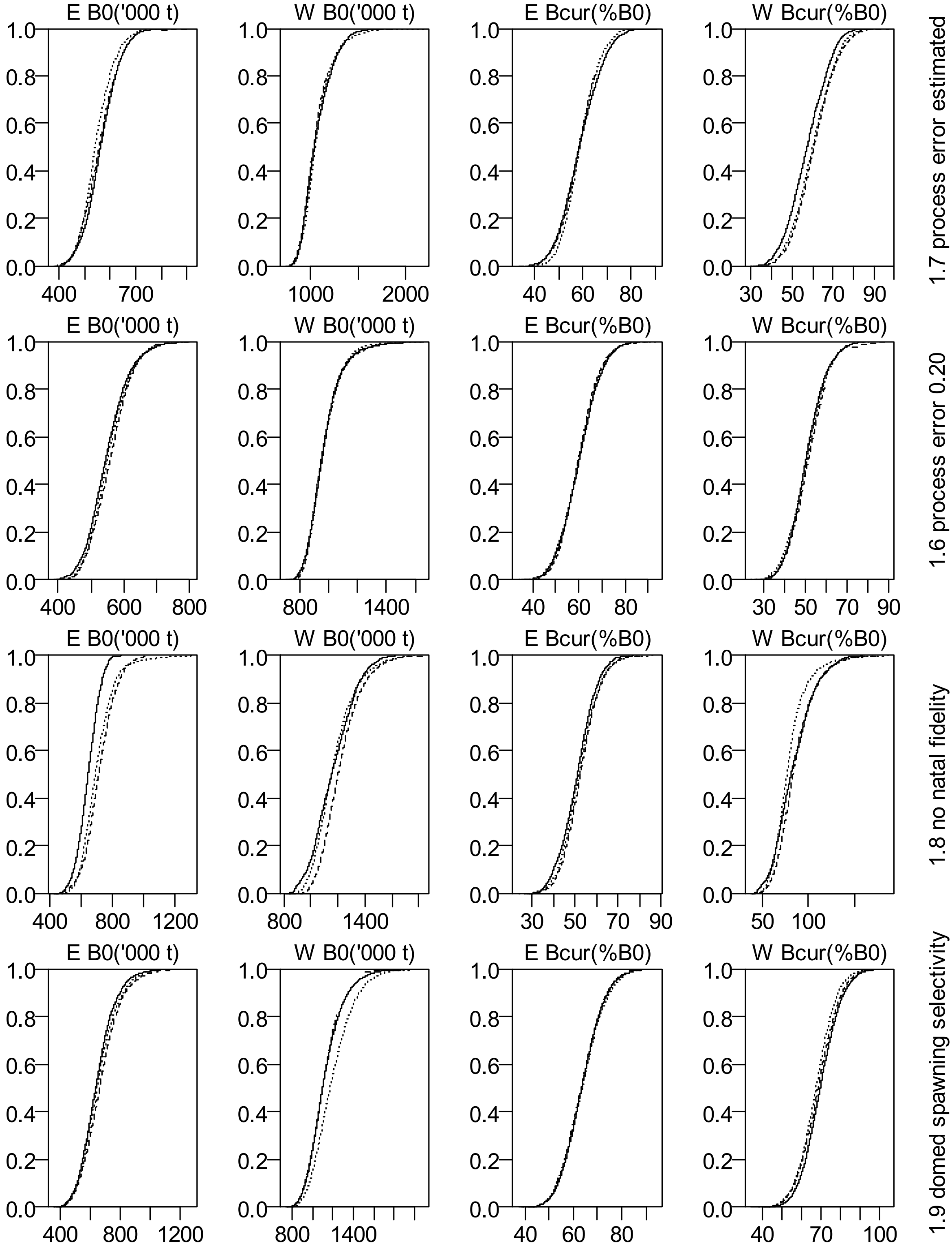

Figure 53: Diagnostics for MCMC chains for the four runs: 1.6 to 1.9. Each panel contains cumulative probability distributions, for B_0 or $B_{current}$, for three chains from the same model run. Samples from the burn in period are discarded for these results.

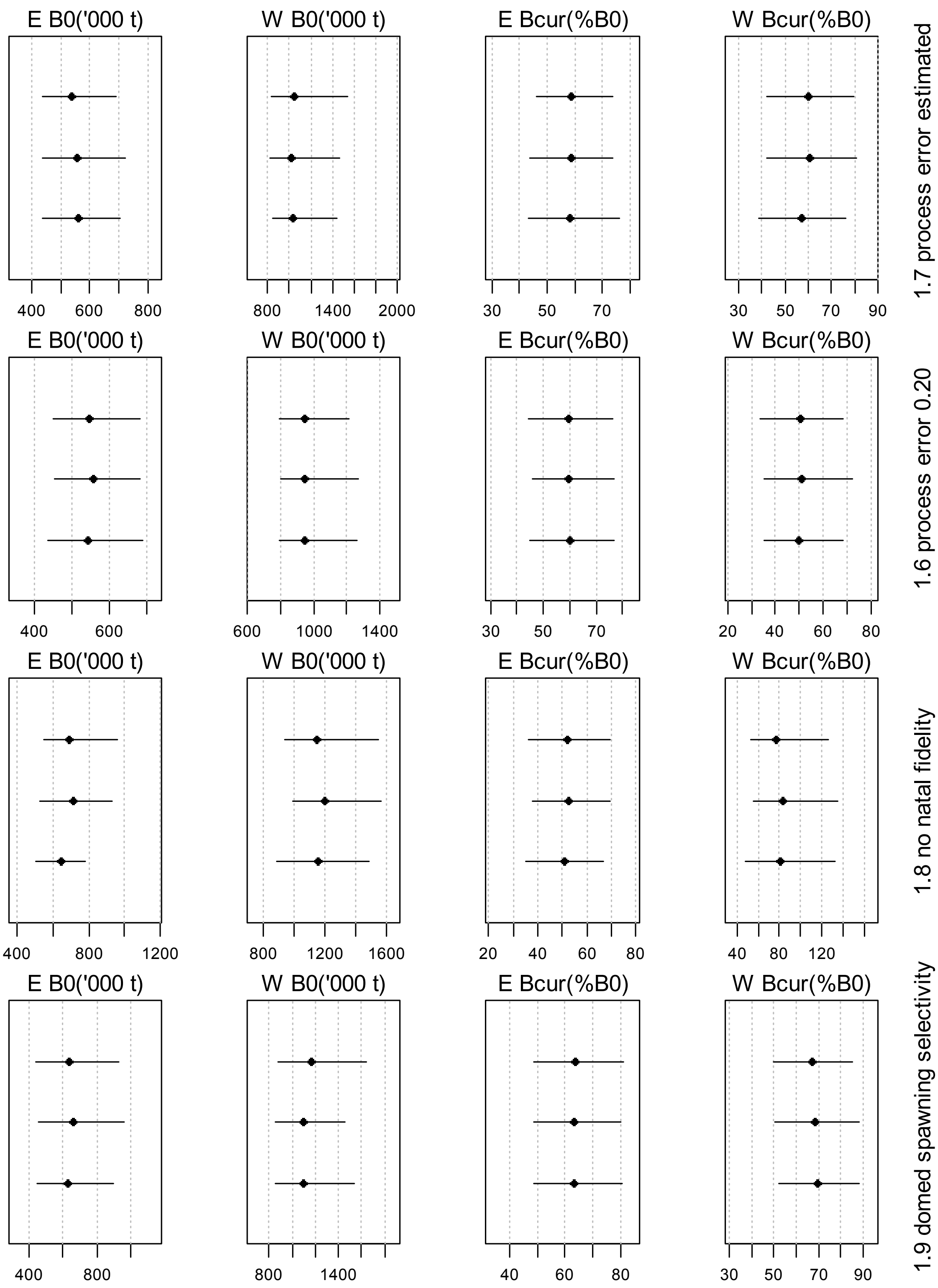

Figure 54: Further diagnostics for MCMC chains for the four runs: 1.6 to 1.9. Each panel contains the median (solid dot) and 95% confidence interval, for B_0 or $B_{current}$, for three chains from the same model run.

The MCMC results for all runs show that the western spawning stock was originally larger than the eastern spawning stock (Table 27). The models estimate the current spawning biomass for the eastern stock to be at 52–63% B_0, and for the western stock 51–80% B_0 (values are ranges for the medians).

When trawl survey process error is estimated, the estimate of eastern stock current biomass is little changed (see Table 27, Figure 55). For the western stock, the estimate of current biomass increases from 51%B_0 to 59%B_0 with increased uncertainty.

Fits to the Sub-Antarctic trawl survey are better for run 1.7 compared to run 1.6 (Figures 56–59). As the estimated process error of 0.15 for CRsumbio is close to 0.20 then there is little difference between the fits in runs 1.7 and 1.6 (Figures60–63). Based on the better fits of model 1.7, and that a sequence of four low biomass estimates from a series of this length is not uncommon statistically (Patrick Cordue, pers. comm.), it was decided by the Deepwater Working Group to choose model 1.7 as the base case.

Estimates of 2015 biomass are very similar between run 1.6 and the analogous model run 1.1 from the previous assessment (Figure 64).

The model runs indicate that both eastern and western biomass has been increasing since about 2006 (Figures 65–66). The estimate of the 2014 year class strength is very uncertain for both east and west stocks, and for runs 1.6 and 1.7 (Figures 67–68).

The estimated selectivities are similar for the first four models, as are the migration ogives and natural mortality estimates (Figures Figure 69–Figure 71), and are similar to those for the 2015 assessment.

Posteriors are within the bounds of the priors (Figure 72). One difference from the 2015 assessment is that the posterior for the proportion of the total virgin biomass that is in the east stock (pE) has shifted to the left of the mode of the prior, whereas previously it was to the right.

Table 27: Estimates of spawning biomass (medians of marginal posterior, with 95% confidence intervals in parentheses) for the four final runs. $B_{current}$ is the biomass in mid-season 2016.

	B_0(‘000 t)		$B_{current}$(‘000 t)		$B_{current}$(%B_0)		
Run	E	W	E	W	E	W	E+W
1.7 (Base)	556 (439.712)	1039 (838,1473)	325 (214,477)	616 (355,1082)	58(44,75)	59 (40,79)	59 (46,73)
1.6	551 (450,685)	953 (797,1254)	330 (221,488)	483 (292,837)	60(45,77)	51 (35,69)	54 (43,68)
1.8	679 (518,905)	1170 (926,1521)	355 (216,546)	957 (510,1761)	52(36,68)	80 (52,132)	70 (53,103)
1.9	645 (450,936)	1116 (859,1565)	406 (254,644)	772 (464,1206)	63(49,81)	68 (51,88)	67 (54,80)

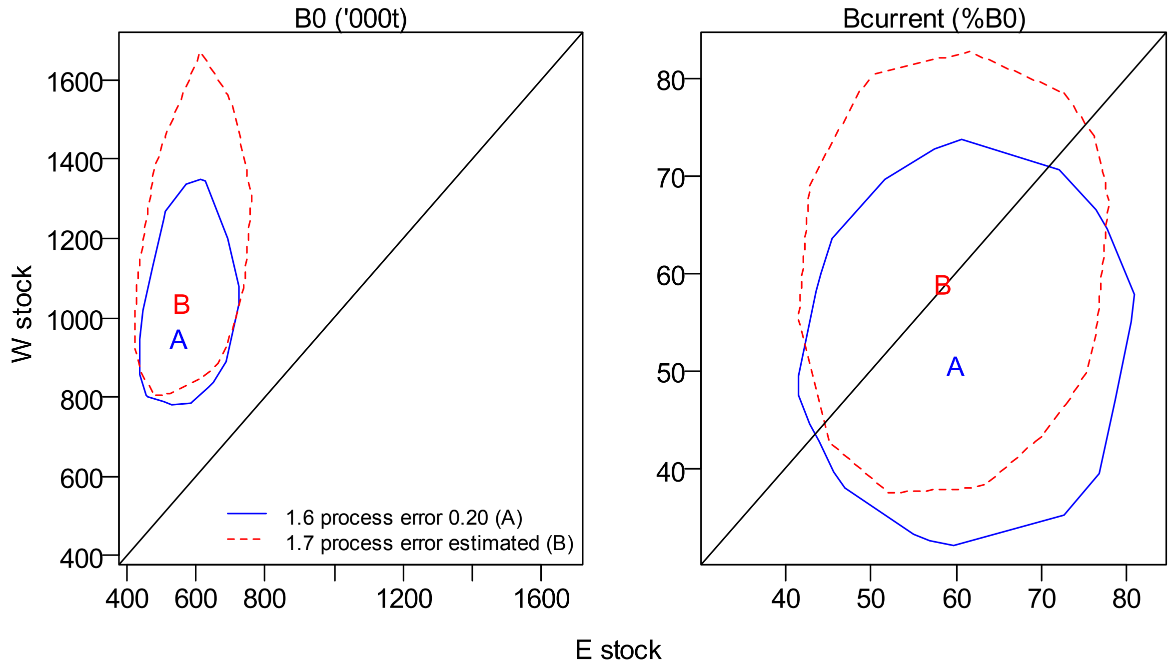

Figure 55: Estimates and approximate 95% confidence intervals for virgin (B0) and current ($B_{current}$ as %B0) biomass by stock for the two runs 1.6 and 1.7. In each panel the points 'A', 'B' indicate best estimates (median of the posterior distribution) for these two runs, and the polygons (with solid, and broken lines, respectively) enclose approximate 95% confidence intervals. Diagonal lines indicate equality (y = x).

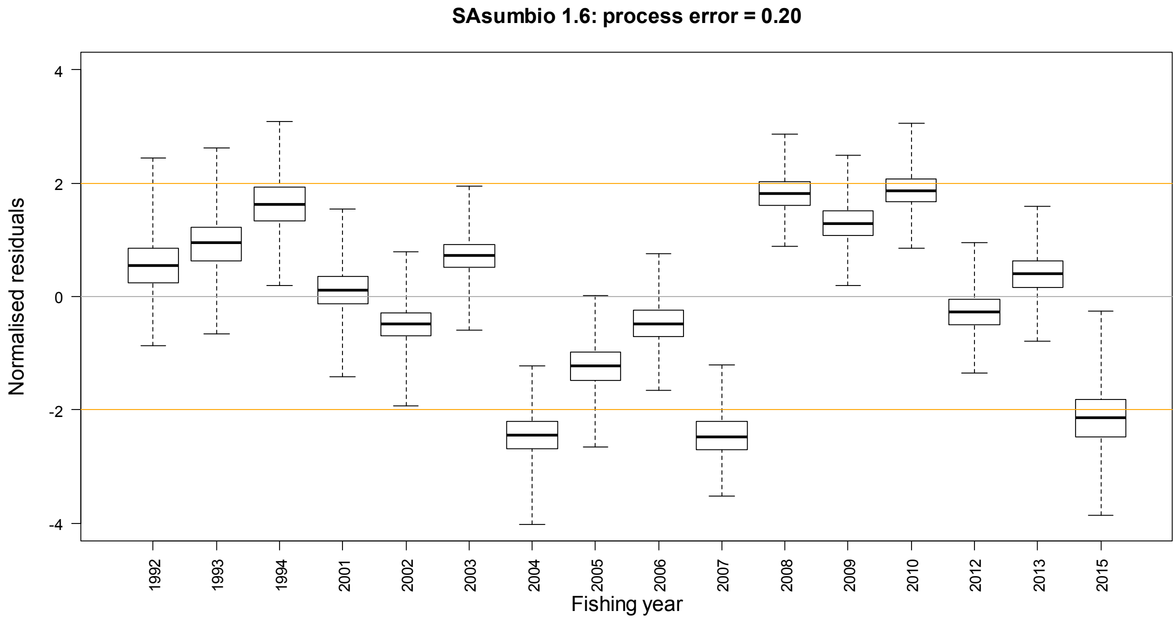

Figure 56: MCMC normalised residuals for model 1.6 and the fit to the Sub-Antarctic trawl survey. The central rectangle of the boxplots has horizontal lines (from bottom to top) at the quartiles: 25% (lower quartile), 50% (median), and 75% (upper quartile). The interquartile range (IQR) is equal to the 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.

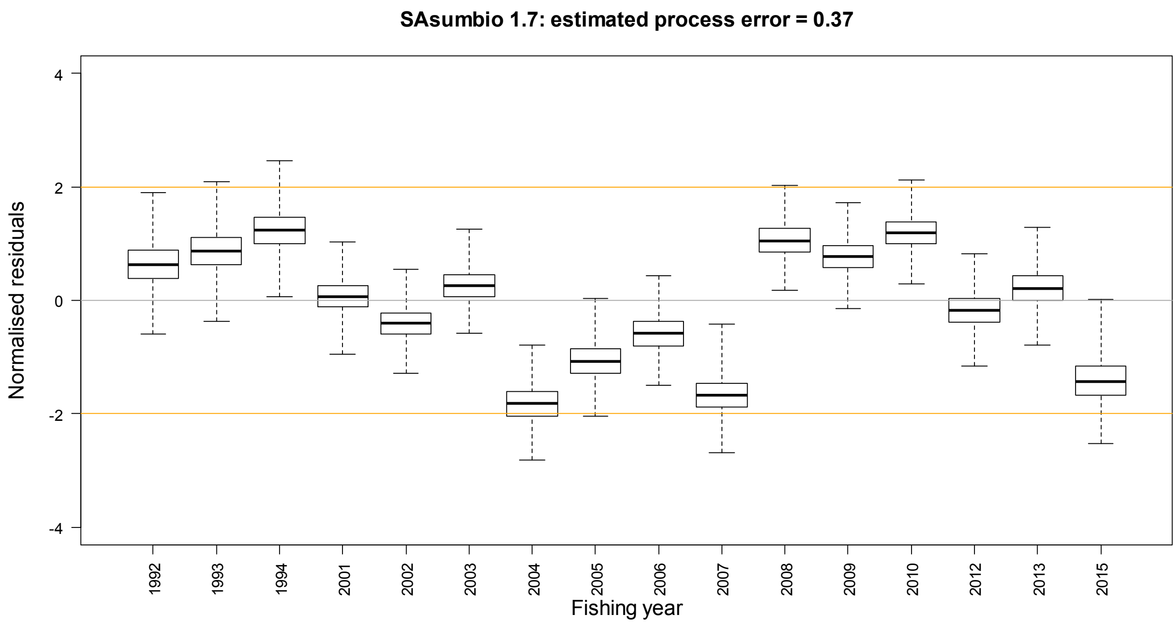

Figure 57: As in Figure 56 but for model 1.7 and the fit to the Sub-Antarctic trawl survey.

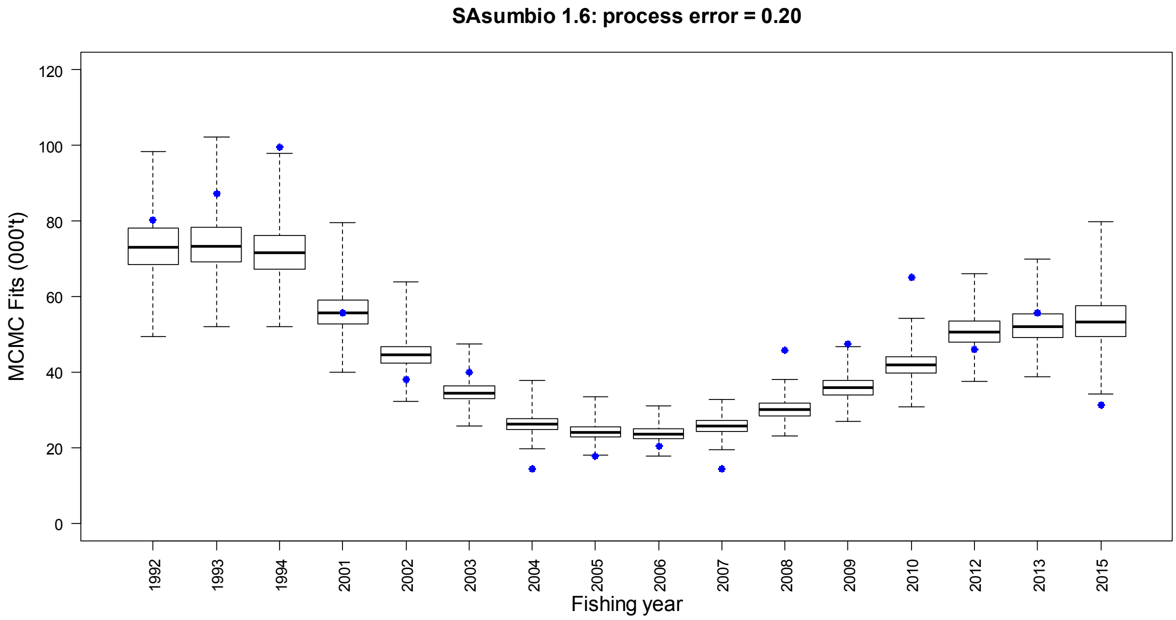

Figure 58: MCMC fits (boxplots) to the Sub-Antarctic trawl survey for run 1.6 (blue dots). The boxplots are defined as in Figure 56.

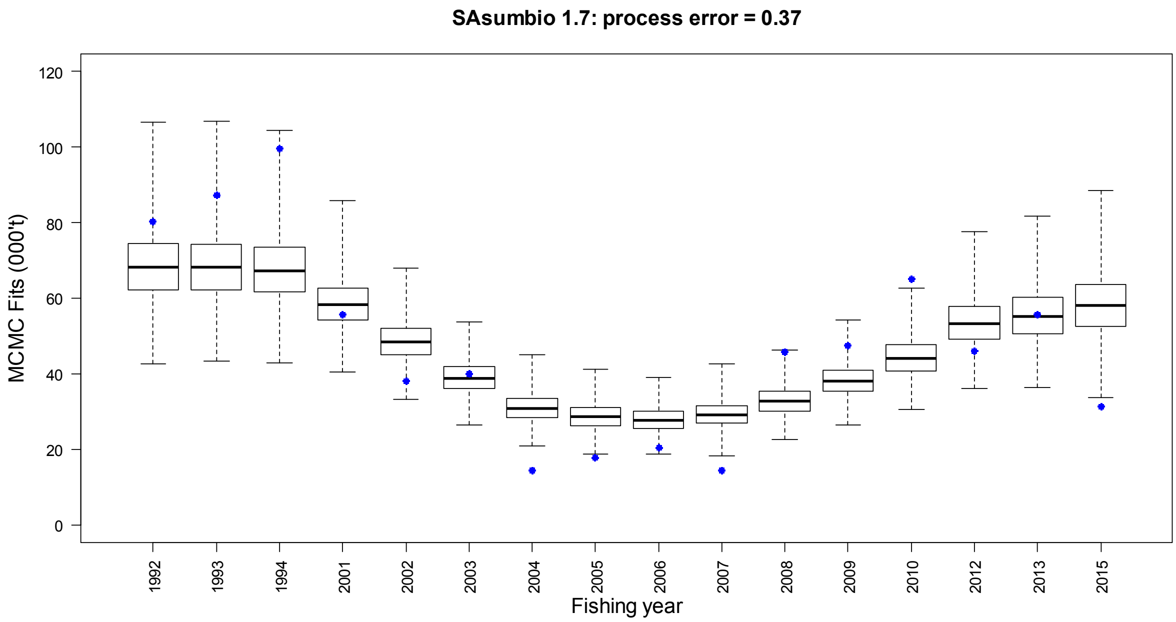

Figure 59: As in Figure 58 but for the Sub-Antarctic trawl survey for run 1.7 (blue dots). The boxplots are defined as in Figure 56.

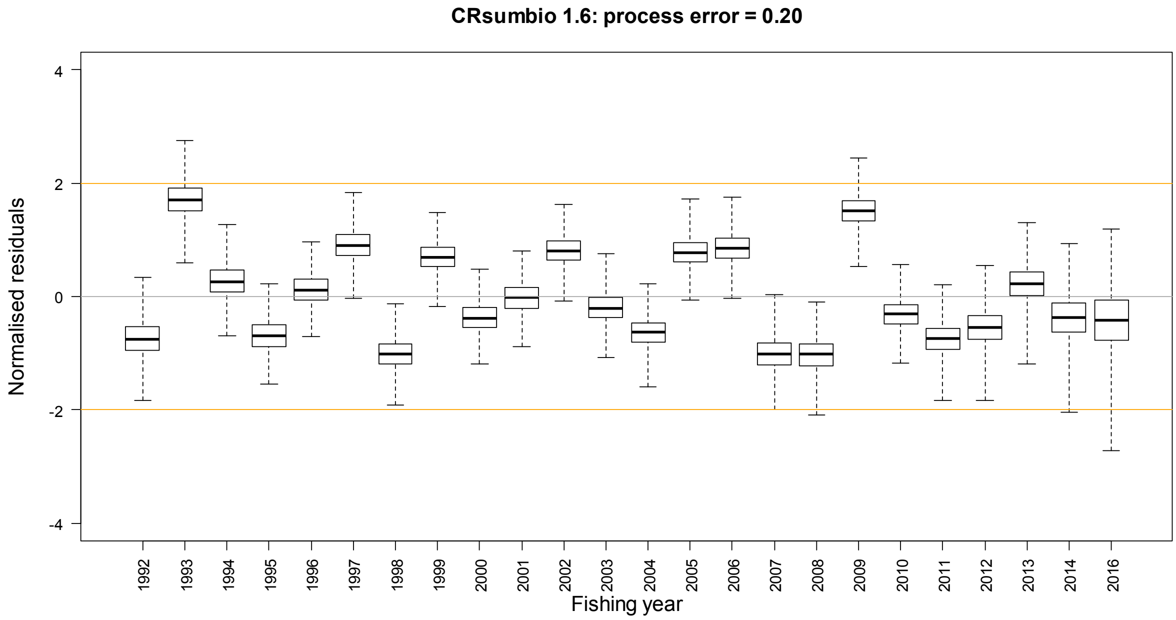

Figure 60: MCMC normalised residuals for model 1.6 and the fit to the Chatham Rise trawl survey. The boxplots are defined as in Figure 56.

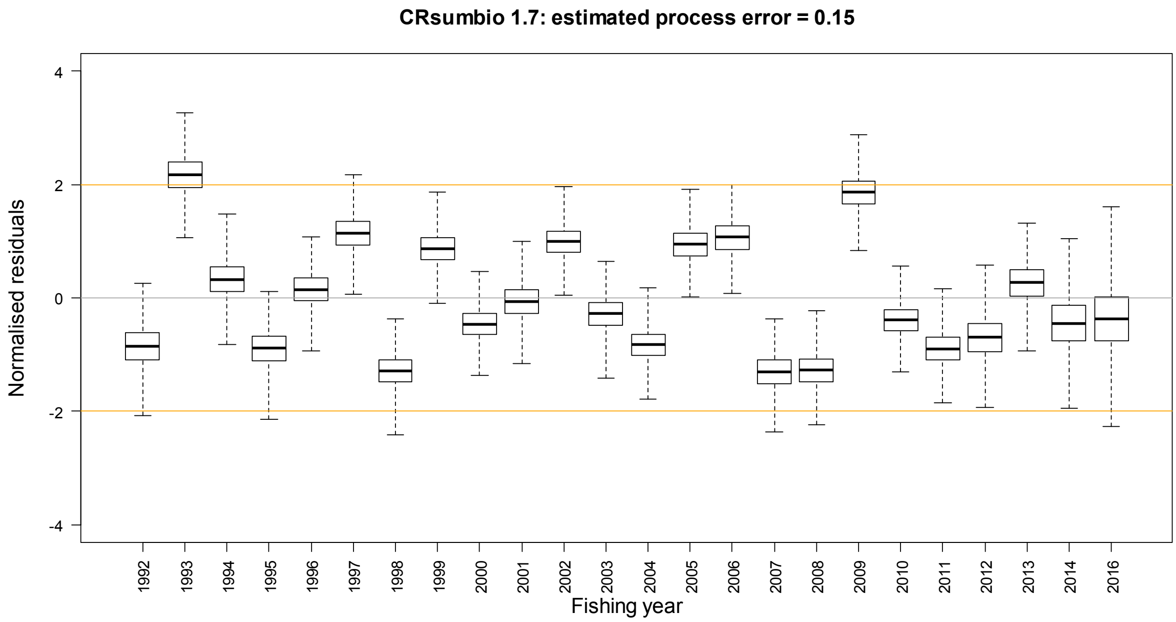

Figure 61: MCMC normalised residuals for model 1.6 and the fit to the Chatham Rise trawl survey. The boxplots are defined as in Figure 56.

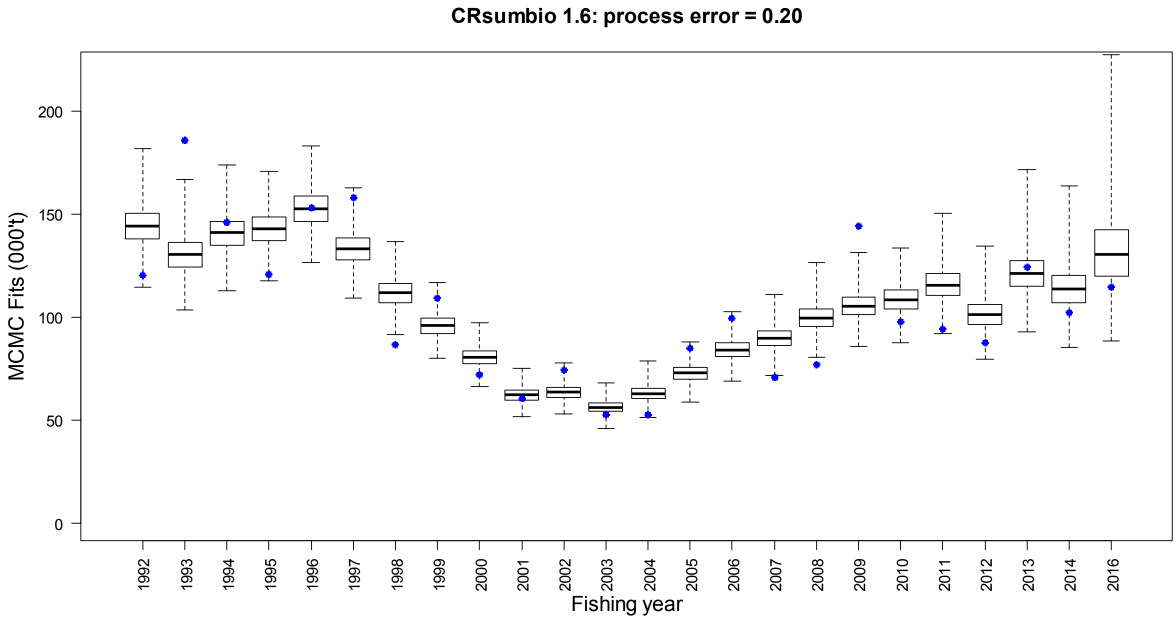

Figure 62: MCMC fits (boxplots) to the Chatham Rise trawl survey for run 1.6 (blue dots). The boxplots are defined as in Figure 56.

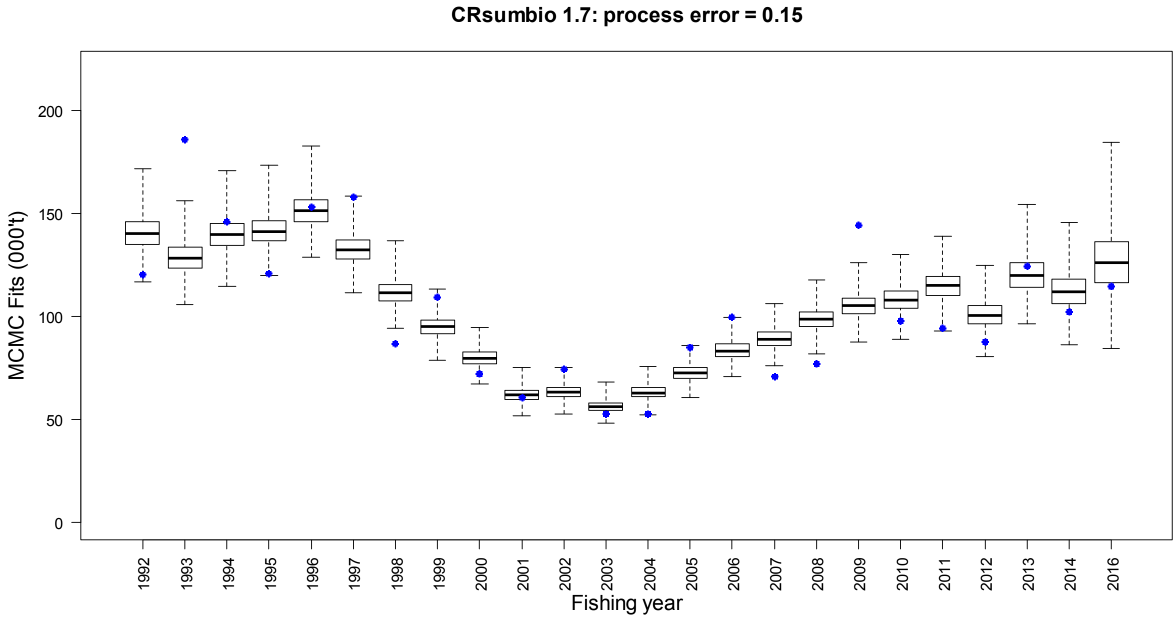

Figure 63: MCMC fits (boxplots) to the Chatham Rise trawl survey for run 1.7 (blue dots). The boxplots are defined as in Figure 56.

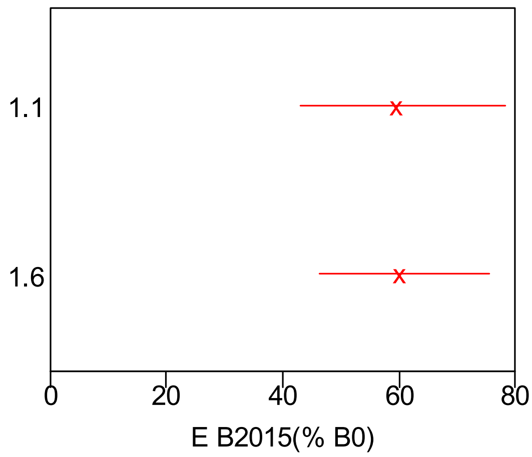

Figure 64: Comparison of 2016 continuity run 1.6 (single q) with the comparable run from 2015 (1.1): estimates of stock status in 2015 (B_{2015} as $\%B_0$), with 95% confidence intervals shown as horizontal lines.

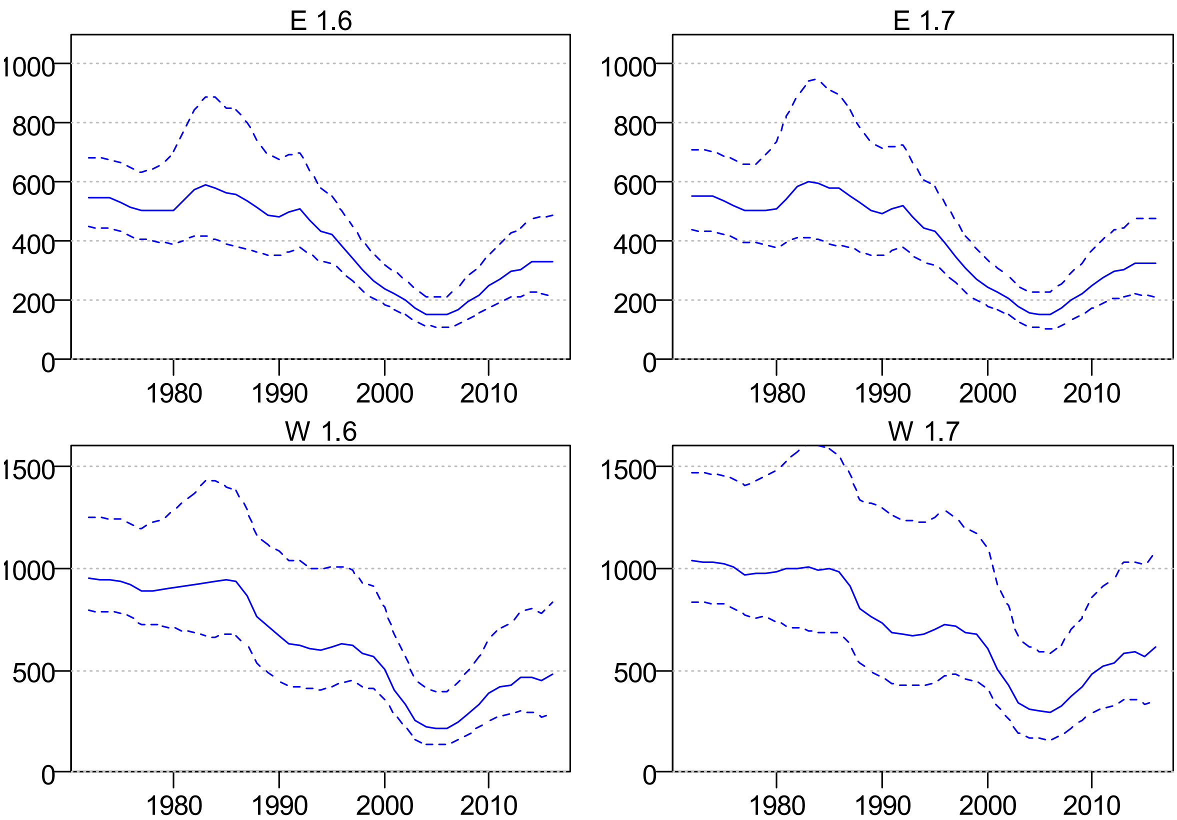

Figure 65: Estimated spawning-biomass trajectories in thousands of tonnes from the MCMC runs, showing medians (solid lines) and 95% confidence intervals (broken lines) by run for E (upper panels) and W (lower panels).

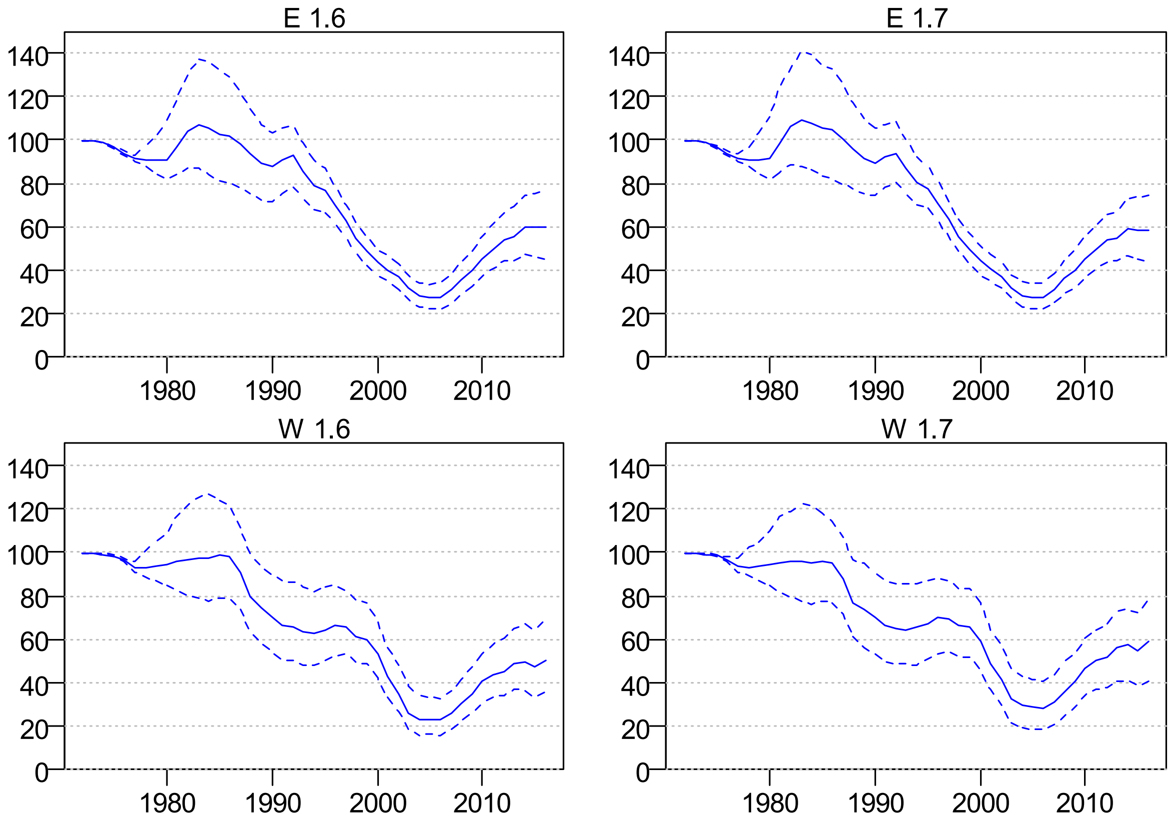

Figure 66: As in Figure 65, but plotted as %B_0.

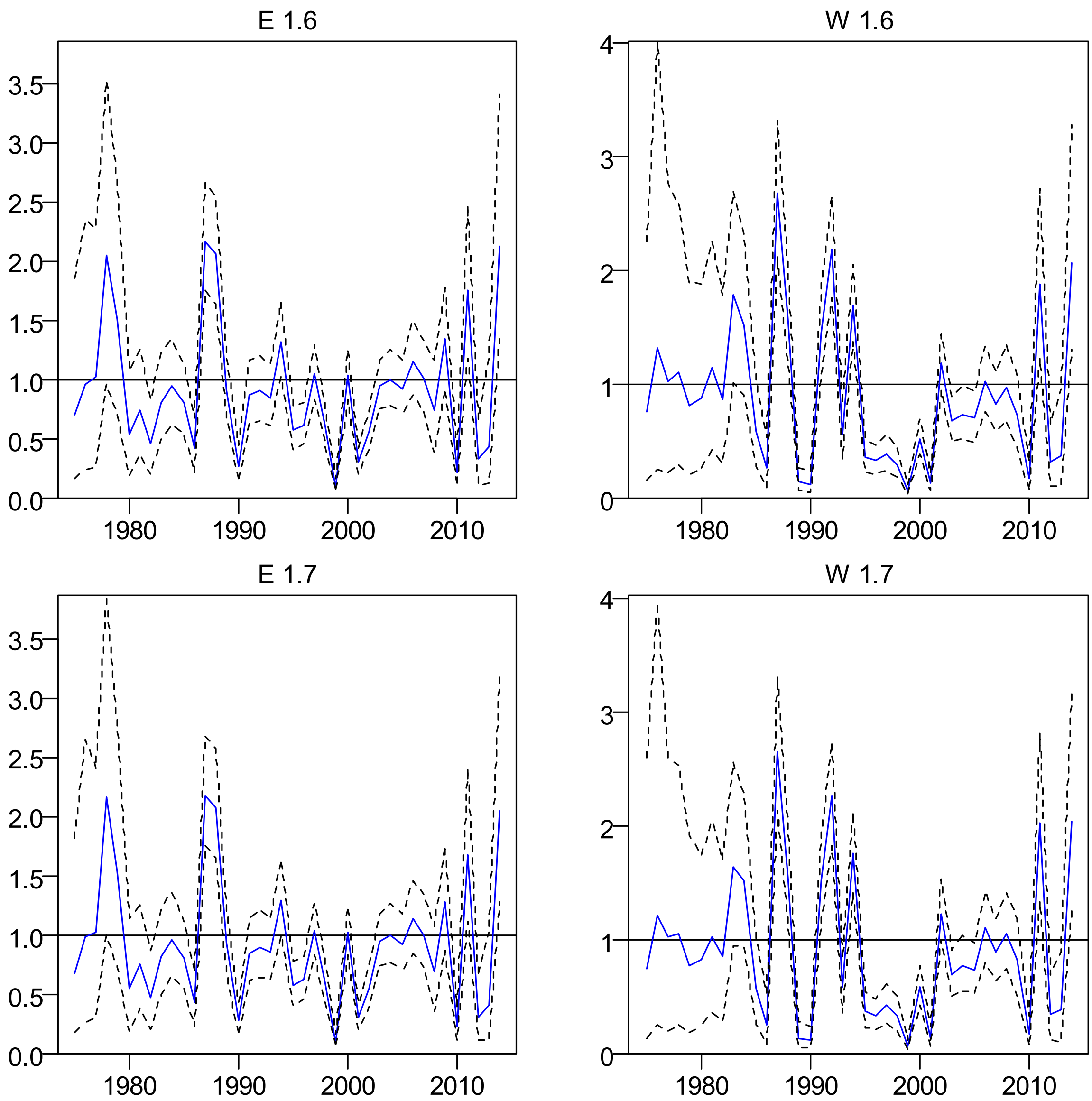

Figure 67: Estimated year-class strengths (YCSs) from the runs 1.6 and 1.7 showing medians (solid lines) and 95% confidence intervals (broken lines) by run for E (left panels) and W (right panels).

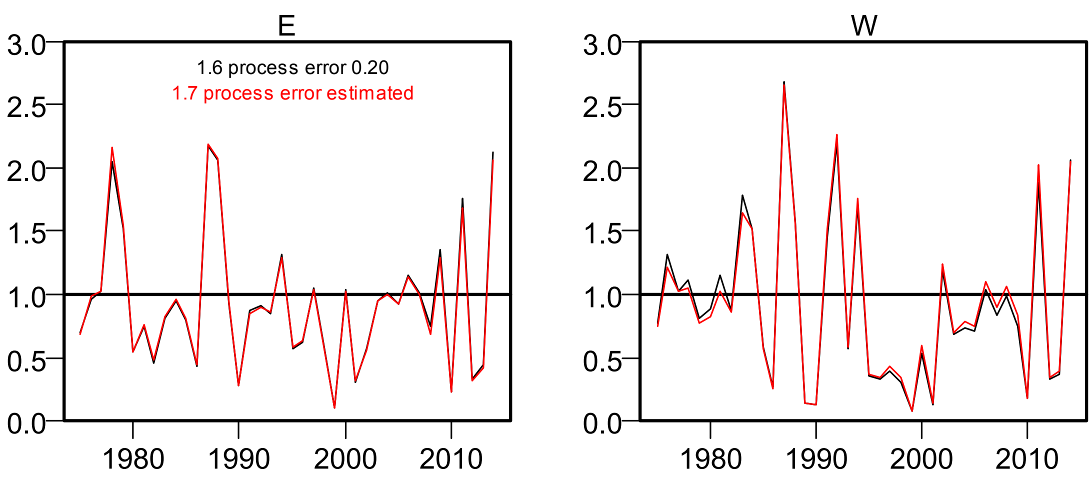

Figure 68: As in Figure 67 but showing just the medians.

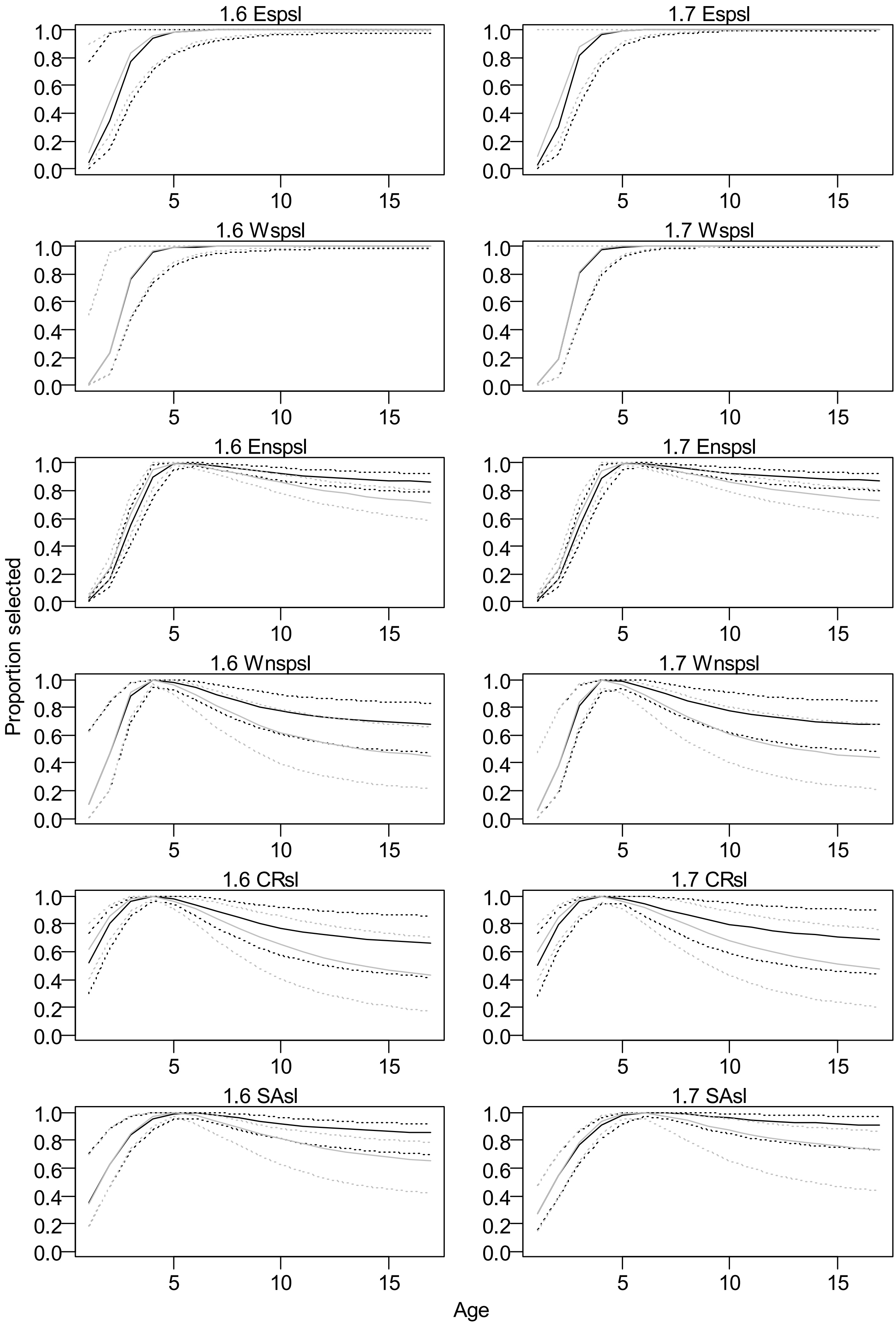

Figure 69: Posterior estimates of selectivity ogives for each for the two MCMC runs 1.6 and 1.7. Solid lines are medians; broken lines show 95% confidence intervals. Where ogives differ by sex they are plotted as black for males and grey for females. Where they differ by stock or time step the plotted curves are for one selected combination (E step 2 for Enspsl and CRsl, W step 2 for Wnspsl and SAsl).

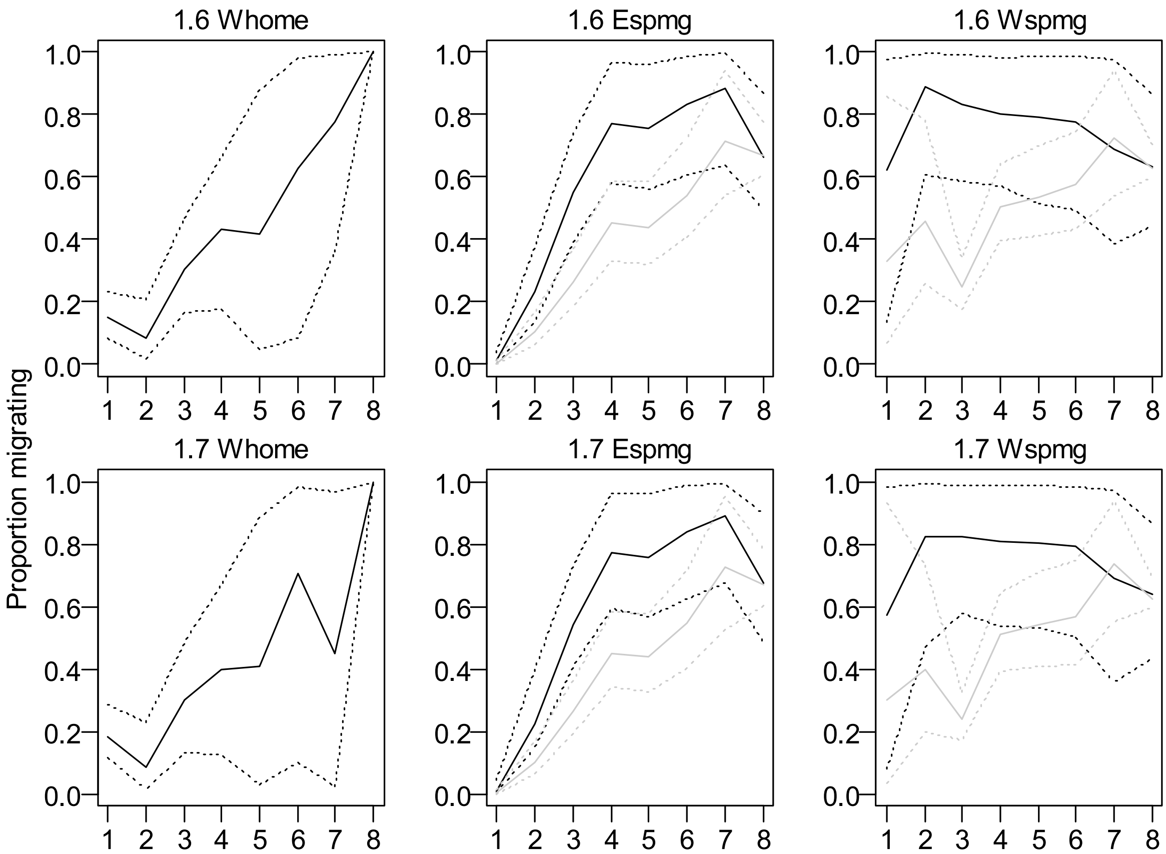

Figure 70: Estimated migration ogives. Solid lines are medians, broken lines show 95% confidence intervals. Where ogives differ by sex they are plotted as black for males and grey for females. Age is along the x-axis.

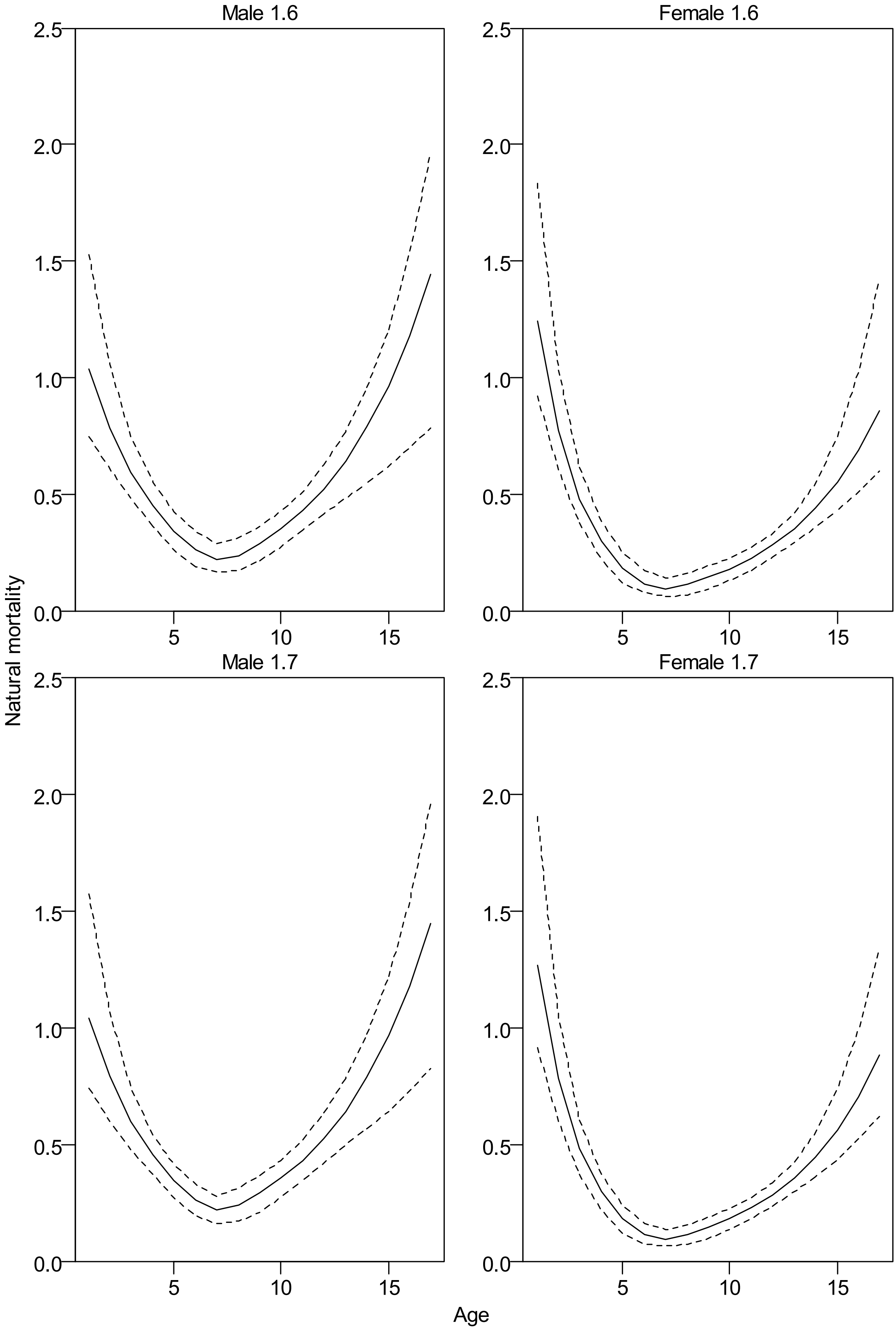

Figure 71: Assessment estimates of age-dependent natural mortality ogives for the MCMC runs showing median estimates (solid lines) and 95% confidence intervals (broken lines) for each sex.

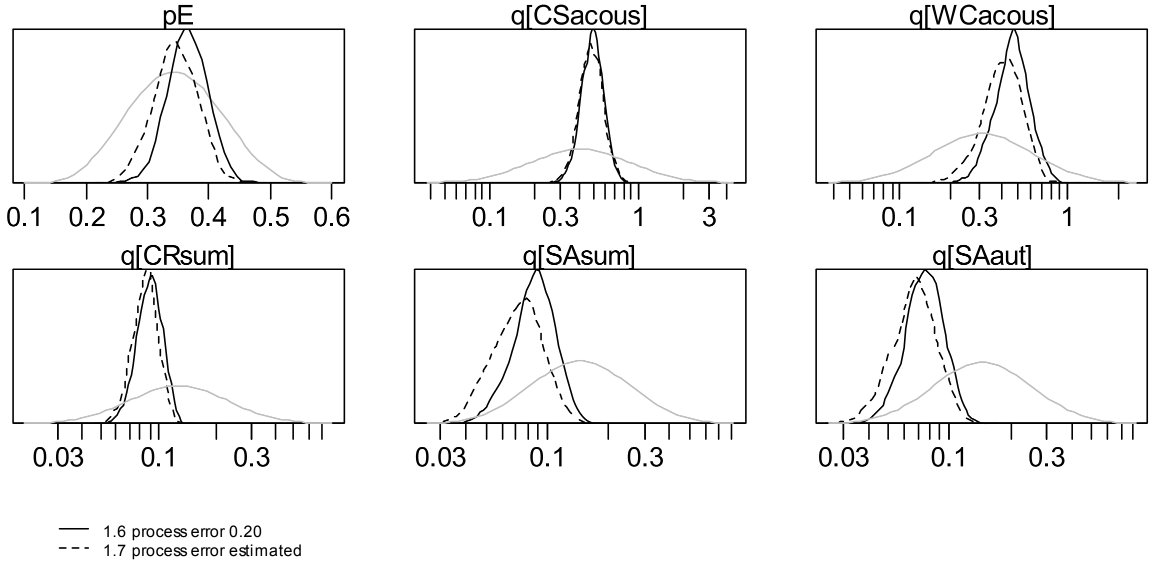

Figure 72: 2016 assessment prior (grey lines) and estimated posterior (black lines, solid for run 1.6, broken for run 1.7)) distributions for the following parameters: pE (proportion of B_0 in E stock), and survey catchabilities (acoustic and trawl). Note that the priors for CSacous and WCacous were changed for the 2016 assessment.

6. PROJECTIONS

Five-year projections were carried out for the base model (1.7), with future recruitments selected at random from those estimated for 2005–2014, and future catches in each fishery assumed to be the same as in 2016. The projections indicate that the E and W biomass are likely to slightly increase over the next five years.

The probabilities of the current (2016) 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 28. The probability of either stock being less than either the soft or the hard limit over the five year projection period is negligible. Both stocks are projected to be above the 35–50% B_0 target range at the end of the projection period.

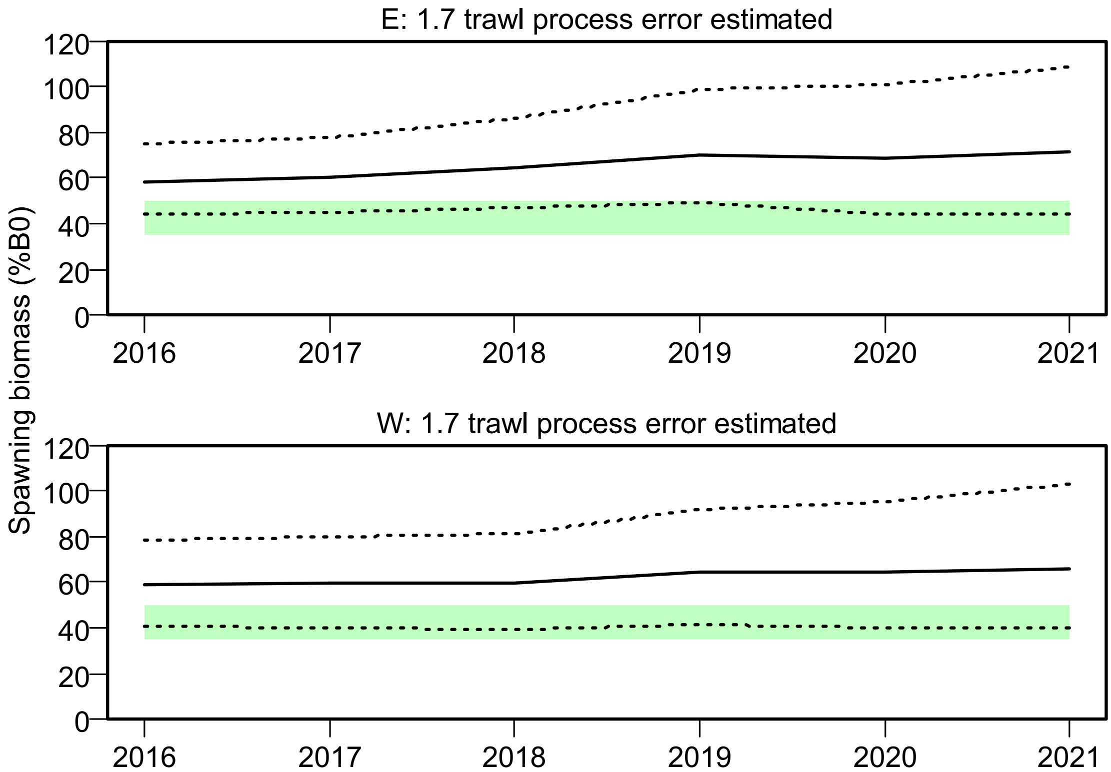

Figure 73: Projected spawning biomass (as %B_0): median (solid lines) and 95% confidence intervals (broken lines) for the base case (1.7). The shaded green region represents the target management range of 35–50% B_0.

Table 28: Probabilities (to two decimal places) associated with projections for SSB (%B_0) for the base case (1.7) for 2016 through to 2021.

	2016	2017	2018	2019	2020	2021
EAST 1.7						
P (SSB<10%B_0)	0	0	0	0	0	0
P (SSB<20%B_0)	0	0	0	0	0	0
P (SSB<35%B_0)	0	0	0	0	0	0
P (SSB<50%B_0)	0.13	0.10	0.06	0.03	0.06	0.06
WEST 1.7						
P (SSB<10%B_0)	0	0	0	0	0	0
P (SSB<20%B_0)	0	0	0	0	0	0
P (SSB<35%B_0)	0	0.01	0	0	0.01	0.01
P (SSB<50%B_0)	0.17	0.19	0.18	0.12	0.14	0.12

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 74).

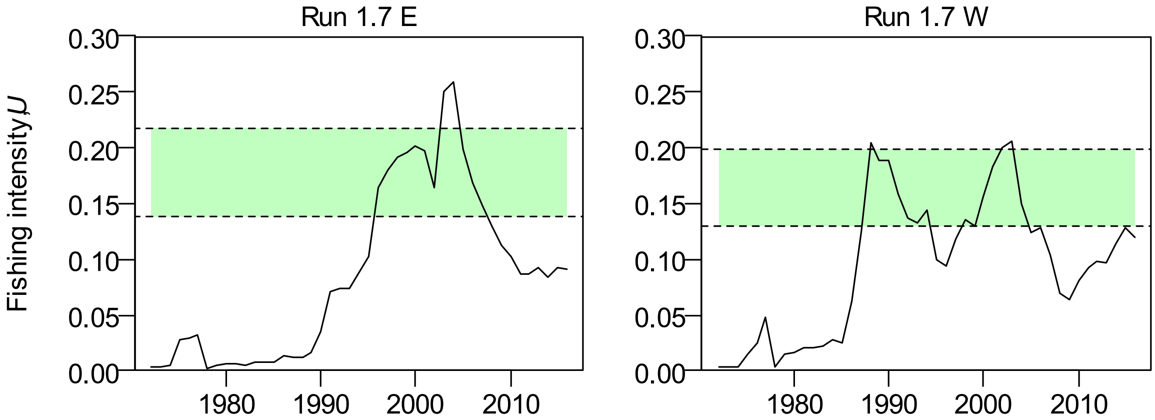

Figure 74: Fishing intensity, *U* (from MPDs), plotted by stock for run 1.7. Also shown (as broken lines) are the reference levels $U_{35\%B_0}$ (upper line) and $U_{50\%B_0}$ (lower line), which are the fishing intensities that would cause the spawning biomass to tend to 35% B_0 and 50% B_0, respectively.

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 $mU_{f,2016}$, where $U_{f,2016}$ is the estimated 2016 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 1.7, estimates of B_{MSY} were 29% for the E stock, and 25% 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 an extended period 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 eastern and western stocks are estimated to have been increasing since about 2006. Current biomass is estimated to be 40–79% B_0 for the western stock and 44–75% B_0 for the eastern stock (values are 95% CIs for the base case). The western stock experienced an extended period of poor recruitment from 1995 to 2001 inclusive. Western recruitment has been near or just below average from 2002 to 2009; below average in 2010, 2012 and 2013; and well above average in 2011 and 2014. Projections indicate that with the current catch the eastern and western biomasses are likely to increase 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 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 Sub-Antarctic trawl survey in sensitivity model runs
2011	Reduce to one base model (age-varying natural mortality) from two base models (for the other base model there were domed shaped fishing selectivities in the spawning fishery)
2012	Re-weight the proportions-at-age data (the procedure giving them a substantial down-weighting)
	Re-introduce a sensitivity model run without natal fidelity
2013	Of the three final model runs, two have a time-varying catchability for the Sub-Antarctic 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.
2016	Process error estimated for Chatham Rise and Sub-Antarctic trawl surveys
	Equality constraint in MCMC for last year class strength (2014 for 2016 assessment)

Appendix 3: Reweighting the 2016 assessment at-age data

The same procedure as in McKenzie (2016) 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. Final mean N values are very similar to those for the analogous model run 1.1 for the 2015 assessment.

Table 29: Model run 1.1. Iterative reweighting for multinomial sample sizes using method TA1.8 of Francis (2011). 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	660	906	89	334	80	193	1351	574	829
2	60	32	13	41	104	17	90	13	23
3	66	24	12	41	59	13	72	14	15
4	74	23	12	40	56	13	70	14	14
5	76	23	12	39	55	13	68	14	14
Final	77	23	12	39	55	13	67	14	14
Initial/Final	9	39	7	9	1	15	20	41	59

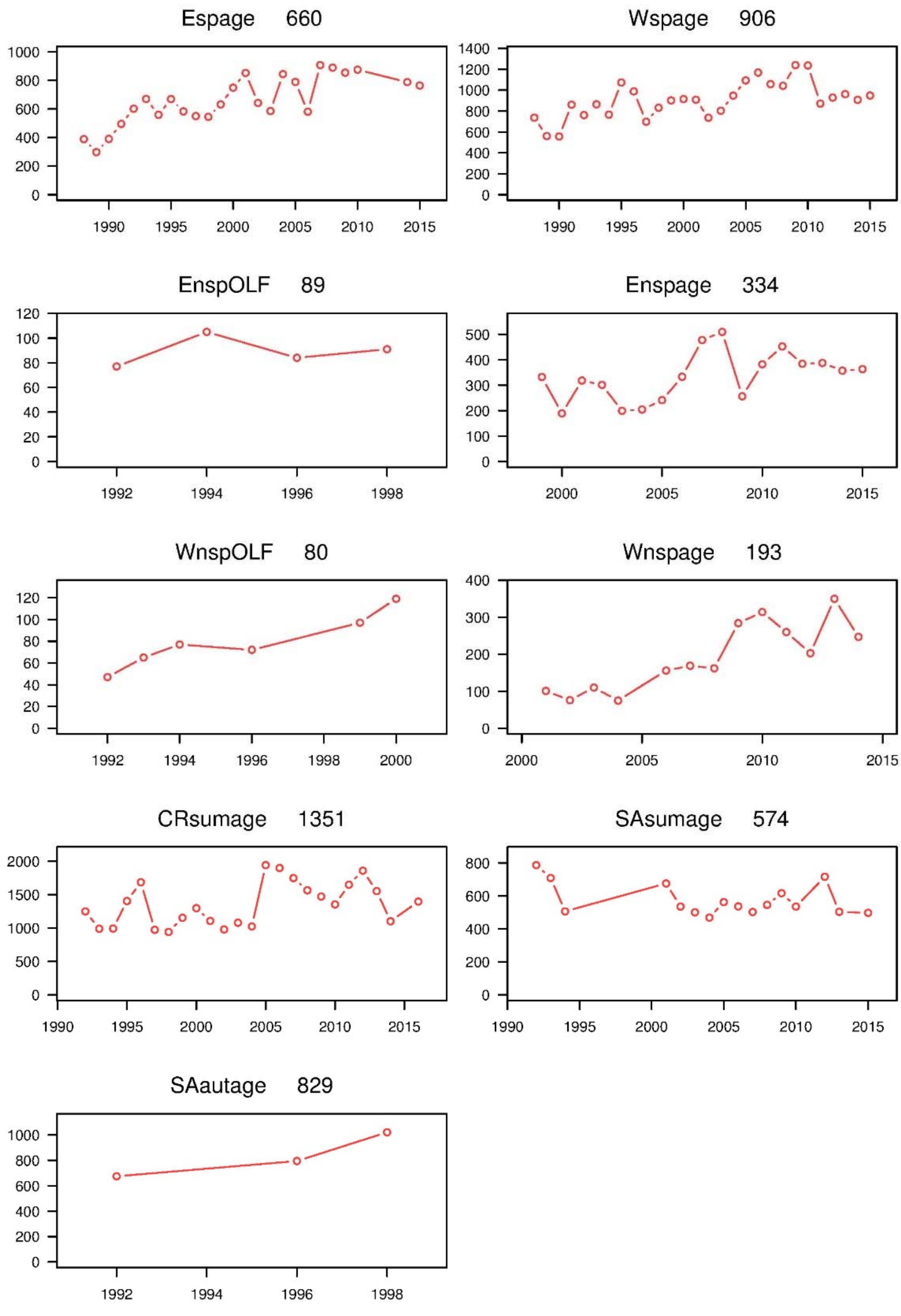

Figure 75: Model 1.1. Equivalent multinomial N values for the observational error. The number above each panel is the mean value over the fishing years.

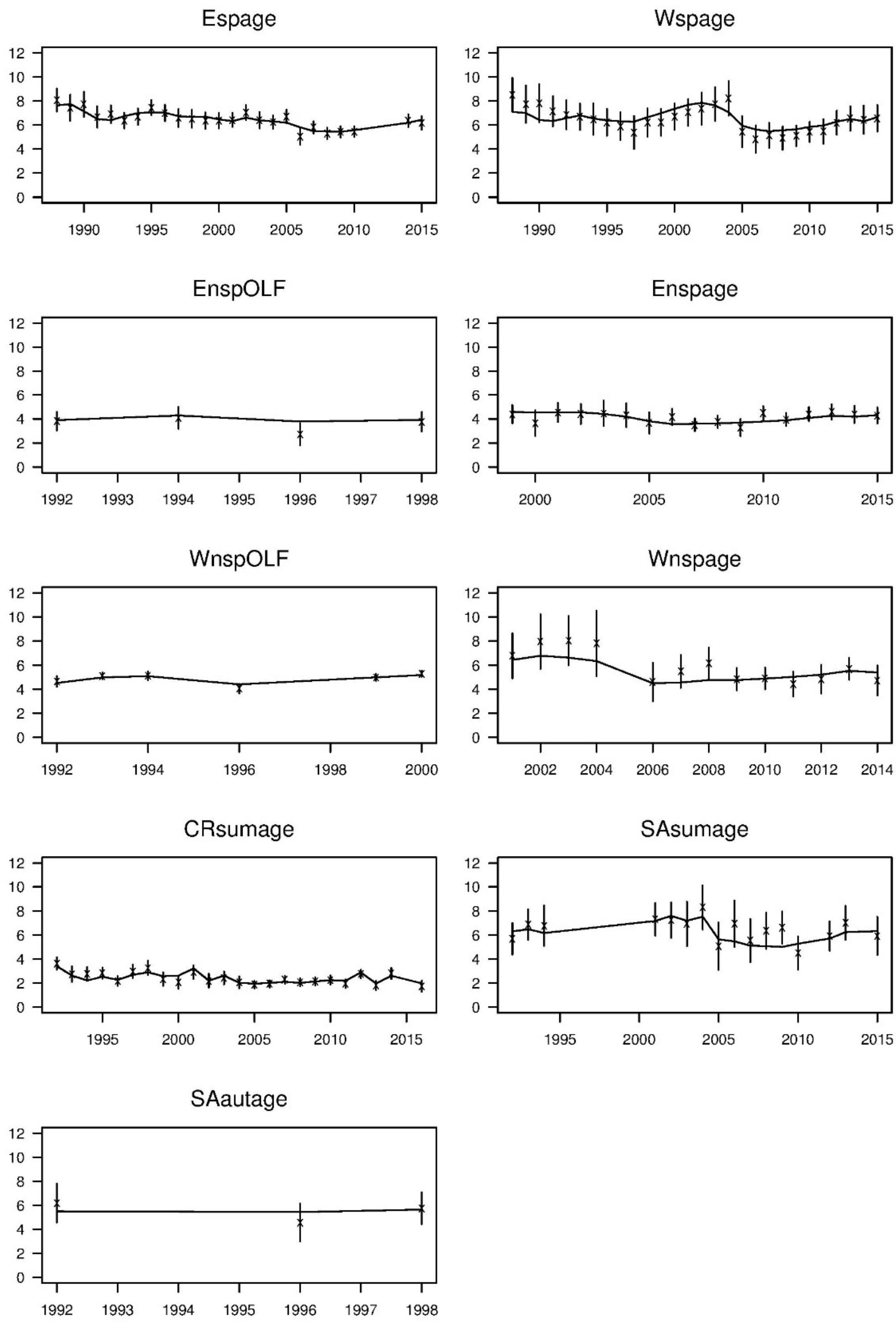

Figure 76: Model 1.1. Observed ('×', with 95% CIs. as vertical lines) and expected (lines) for the at-age data sets in run 1.1 after reweighting.