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Assessment of hoki (*Macruronus novaezelandiae*) in 2017

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CONTENTS

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EXECUTIVE SUMMARY

McKenzie, A. (2018). Assessment of hoki (*Macruronus novaezelandiae*) in 2017.

***New Zealand Fisheries Assessment Report 2018/40.* 101 p.**

An updated 2017 assessment is presented for hoki, which was based on the 2016 assessment. The assessment uses the same program (CASAL), stock structure (two stocks in four fishing grounds), and estimation procedure (Bayesian, with multinomial and 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 data new to this assessment came from a November/December 2016 research trawl survey on the Sub-Antarctic. New proportions-at-age data came from the Sub-Antarctic research trawl survey, and four commercial fisheries in 2016.

The Ministry for Primary Industries Deepwater Fisheries Assessment Working Group agreed on a single base model run. In this base model, which was the same as the previous assessment, 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 Sub-Antarctic trawl series a single catchability was used, with an estimated process error.

In the base case model, the western stock was estimated to be 59 (40–84) %B_0 and the eastern stock 60 (44–79) %B_0, where the values in brackets are 95% confidence intervals. The western stock experienced an extended period of poor recruitment from 1995 to 2001 inclusive. Western recruitment was well above average in 2011 and 2014, and below average in 2015.

Sensitivity model runs were carried out to the base model run. These tested the sensitivity of the model to the process errors for trawl surveys, the western stock biomass indices (i.e., dropping the acoustic or the trawl surveys), assumptions about natal fidelity but still assuming adult fidelity, and domed spawning selectivity. Median biomass estimated for these sensitivity runs ranged from 41–79 (95% CI range 25–100% B_0) for the western stock and 53–66 (95% CI range 35–92% B_0) for the eastern stock.

Five-year projections were carried out for the base model. In the projections, future recruitments were selected at random from those estimated for 2006–2015, and future catch assumed to equal the current TACC of 150 000 t with 60 000 t for the east stock and 90 000 t for the west stock. 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. Hoki is widely distributed throughout New Zealand's Exclusive Economic Zone in depths of 50–800 m, but most hoki target 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, see p. 472).

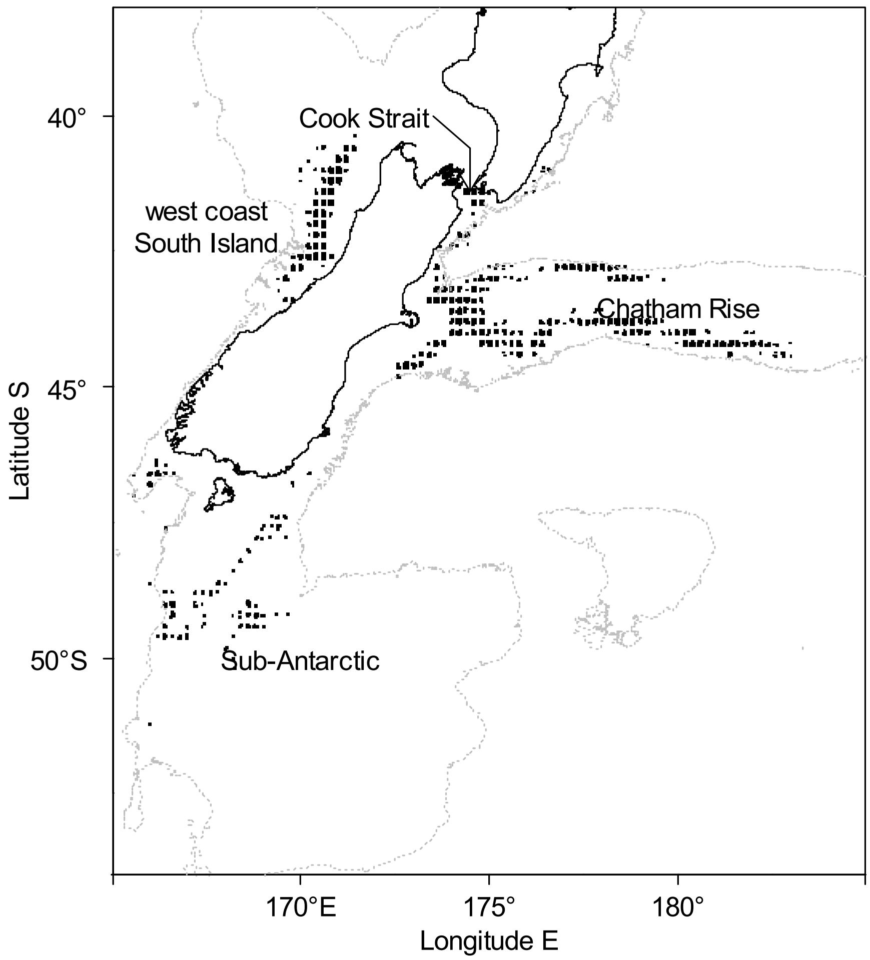

Figure 1: Southern New Zealand showing the main hoki fishing grounds, the 1000 m contour (broken grey line), and the position of all 2015–16 tows from TCEPRs (Trawl Catch and Effort Processing Returns) in which at least 10 t of hoki was caught (dots). Positions are rounded to the nearest 0.2 degrees and jittered.

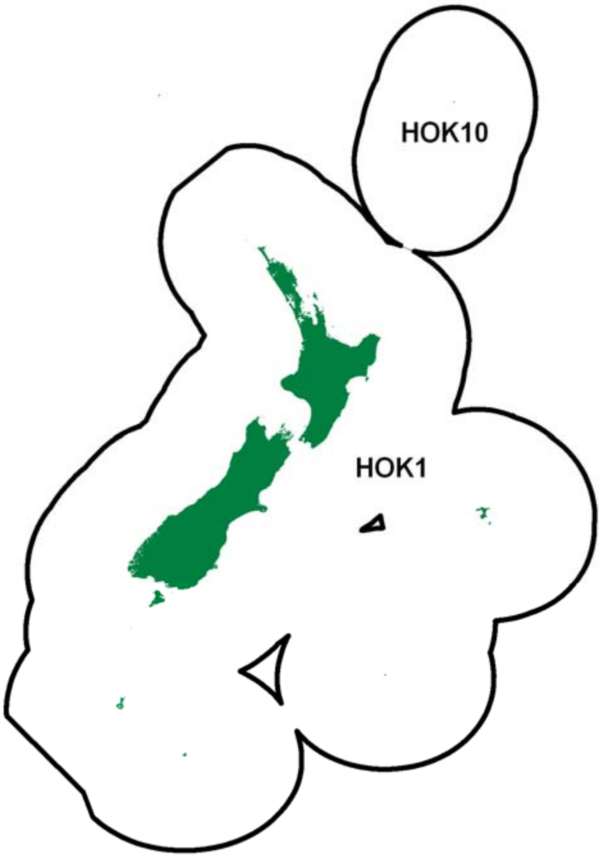

Figure 2: The Quota Management Areas for hoki.

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 2017 assessment of HOK 1, which is the sixteenth hoki assessment to use NIWA's general-purpose stock-assessment model CASAL (Bull et al. 2012). Since the last assessment in 2016 (McKenzie 2017) there has been another trawl survey on the Sub-Antarctic in November/December 2016 (O'Driscoll et al. 2018).

The work reported here addresses objective 1 of the Ministry for Primary Industries project DEE201608HOK: *To update the stock assessment of hoki including estimates of biomass, risk and yields.*

2. MODEL ASSUMPTIONS AND INPUTS FOR 2017

This section provides a summary of all model assumptions and inputs for the 2017 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. For the 2017 assessment the structure of the base case model is the same as the previous assessment.

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 that is the "best fit", 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 because they describe parameter uncertainty, but are 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 6), 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 2016 is referred to as the 2017 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 are assumed to 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.

Step	Approx. Months	Processes	*M* fraction	Age fraction	Observations Label	Observations 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 2016 the TACC was 150 000 with a catch split arrangement for 90 000 t to be taken from the western stock and 60 000 t from the eastern stock. However, the total estimated catch taken was 136 700 t.

For the current year (2017) the TACC and catch split remains unchanged from 2016. However it is intended to carry over 10 000 t quota from the previous year to give a total commercial catch of 160 000 t, with an estimated extra 10 000 t in the Sub-Antarctic, and the eastern stock catches remaining the same (Graham Patchell, pers. comm.). This equates to catches in the model: Wsp (83 200 t), Wnsp (16 700 t), Esp (19 600 t), Ensp (40 500 t). In the model the non-spawning fishery is split into two parts (see Table 4) and the assumed 2017 split proportions for this are the same as 2016.

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	32 300	12 500	9 100	7 300	19 800	80 600	161 600
2016	28 900	11 600	3 400	3 300	19 600	69 900	136 700
2017	28 900	11 600	8 500	8 200	19 600	83 200	160 000

Table 4: The assumed allocation of 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

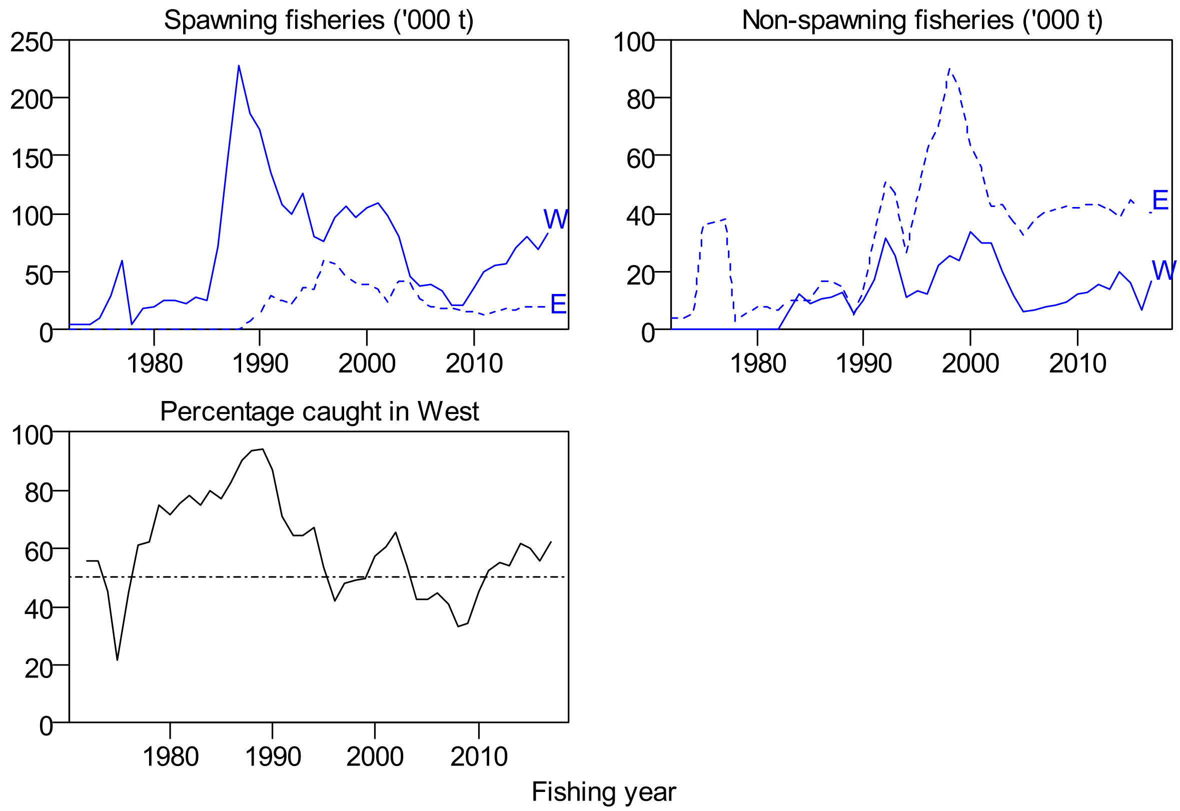

Figure 3: Annual catches by fishery for the spawning (top left panel) and non-spawning (top right panel) fisheries, and annual percentage of catch caught in western fisheries (Wsp, Wnsp1, Wnsp2) (bottom panel).

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 selectivity 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 6 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 2017).

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	2016	Mean						
298	300	301	300	301	305						

2.3 Other structural assumptions

For each stock, the population at the start of the fishery was assumed to have a stable age structure with biomass, B_0, and constant recruitment, R_0. The Haist parameterisation of recruitment was used in final model runs (Bull et al. 2012, p. 32). Thus, recruitment at age 1 in year y in each stock was given by

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

where YCS_y is the year-class strength for fish spawned in year y, SR is a Beverton-Holt stock-recruit relationship with assumed steepness 0.75 (Francis 2009, p. 23), and SSB_y is the mid-season spawning stock biomass in year y. 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 one YCSs were estimated for each stock, for 1975 to 2015, inclusive. YCSs for the initial years (1970 to 1974) were fixed at 1. The E and W YCSs for 2015 were constrained (by a penalty function) to be equal for MPD runs (Francis 2006, p. 9) and in 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 data new to this assessment came from a November/December 2016 research trawl survey on the Sub-Antarctic. New proportions-at-age data came from the Sub-Antarctic research trawl survey, and four commercial fisheries in 2016.

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

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

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

The way the proportions-at-age data enter the model varies amongst data sets (Table 11). As in 2002 (and all subsequent years), all proportions less than 0.0001 were replaced by 0.0001 (for reasons, see Francis et al. (2003)). For the otolith-based data sets, the maximum ages were set as high as was possible without allowing the percentage of data points requiring their values to be replaced by 0.0001 to exceed 2%.

Table 8: Biomass indices ('000 t) used in the assessment, with observation and total CVs (respectively) in parentheses. Bold values are new to this assessment. Total CVs for trawl surveys (CRsumbio, SAsumbio, SAautbio) assume a process error of 0.20 (in some model runs 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 (0.14,0.28)
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 (0.26,0.46)	–
2008	77 (0.11,0.23)	46 (0.16,0.26)	–	82 (0.06,0.30)	–
2009	144 (0.11,0.23)	47 (0.14,0.24)	–	166 (0.13,0.39)	–
2010	98 (0.15,0.25)	65 (0.16,0.26)	–	–	–
2011	94 (0.14,0.24)	–	–	141 (0.14,0.35)	–
2012	88 (0.10,0.22)	46 (0.15,0.25)	–	–	283 (0.15,0.34)
2013	124 (0.15,0.25)	56 (0.15,0.25)	–	168 (0.15,0.30)	233 (0.13,0.35)
2014	102 (0.10,0.22)	–	–	–	–
2015	–	31 (0.13,0.24)	–	204 (0.17,0.33)	–
2016	113 (0.14,0.24)	–	–	–	–
2017	–	**38** (0.17,0.26)	–	–	–

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–**2016**	otoliths
SA	WnspOLF	Catch at age	1992–94, 96, 99–00	OLF
	Wnspage	Catch at age	2001–04, 06–14, **2016**	otoliths
	SAsumage	Trawl survey	1992–94, 2001–10, 12, 13, 15, **2017**	otoliths
	SAautage	Trawl survey	1992, 96, 98	otoliths
CS	Espage	Catch at age	1988–10, 2014–**2016**	otoliths
CR	EnspOLF	Catch at age	1992, 94, 96, 98	OLF
	Enspage	Catch at age	1999–**2016**	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

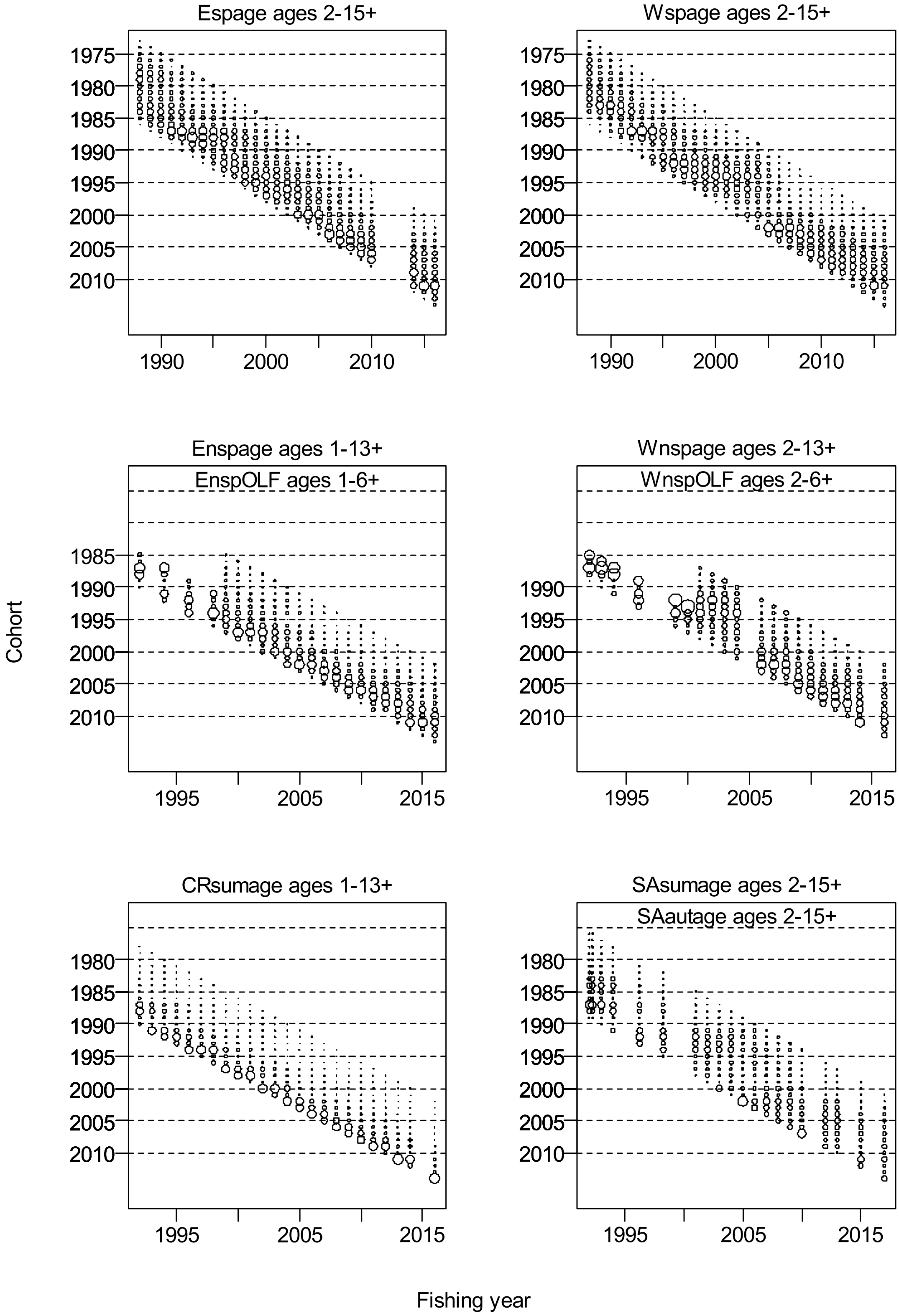

Figure 4: Proportions-at-age data, plotted by cohort and fishing year, with both sexes combined. The area of each circle is proportional to the associated proportion at age. Circle positions for the SAautage data in 1992 have been offset horizontally to allow them to be plotted on the same panel as the 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 (now called the Deepwater Fisheries Assessment Working Group, or Deepwater Working Group for short) 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.

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, 2016) 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).

The CASAL files defining the model runs can be accessed in Appendix 1, with changes to the stock assessment model over time documented in Appendix 2.

Table 12: Parameters estimated in the model runs, and their associated prior distributions. Where the number of parameters varied between model runs, the two values given are for runs where natural mortality is estimated or domed spawning selectivity is used instead (see Section 2.2 for an explanation of these model runs). Distribution parameters are: bounds for uniform and uniform-log; mean (in natural space) and CV for lognormal; and mean and s.d. for normal and beta.

		Distribution			No. of
Parameter(s)	Description	Type	Parameters		parameters
log_B0_total	$\log(B_{0,E} + B_{0,W})$	uniform	12.6	16.2	1
B0_prop_stock1 (=pE)	$B_{0,E}/(B_{0,E} + B_{0,W})$	beta[0.1,0.6][a]	0.344	0.072	1
recruitment.YCS	year-class strengths	lognormal	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

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. 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 (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 presented 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 were 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 now 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 2016 which uses just the data up to 2016. In particular we explore some aspects of estimating the process error for the Sub-Antarctic trawl survey.

3.1 Introduction

In the 2016 hoki stock assessment the process errors for the Sub-Antarctic and Chatham Rise trawl surveys were estimated in an MPD run (McKenzie 2017). These MPD process error estimates were then used in the MCMCs (i.e. fixed at these values) for the base case and sensitivity runs.

Prior to the 2016 assessment the process errors for both these surveys were fixed at 0.20 based on a meta-analysis of trawl surveys (Francis et al. 2001). The MPD estimated values were 0.15 (Chatham Rise) and 0.37 (Sub-Antarctic).

In the following sections we look at three aspects of this:

a) The process error for the Sub-Antarctic trawl survey is relatively high (0.37). Is the Sub-Antarctic trawl survey still influential on biomass trajectories with this process error?

b) What is driving the estimate of the Sub-Antarctic trawl survey process error? This is investigated with a posterior profile on the process error.

c) How uncertain are the process errors estimates for the Sub-Antarctic and Chatham Rise trawl surveys? An MCMC run is done where these are not fixed at the MPD values.

3.2 Influence of the Sub-Antarctic trawl survey

Three MPD model runs are compared:

i. Run 1.6 with process error of 0.20 for both the Chatham Rise trawl survey and Sub-Antarctic trawl survey.

ii. The base run 1.7 where the estimated process error is 0.15 (Chatham Rise) and 0.37 (Sub-Antarctic).

iii. A run 1.13 where the process error is set at 0.15 for the Chatham Rise and 2.0 for the Sub-Antarctic.

Even with a relatively high process error of 0.37 the Sub-Antarctic trawl survey is still influential on the fitted biomass trajectory, as can be seen by comparing the associated biomass trajectory with that where the process error is set at 2.0 (Figure 5).

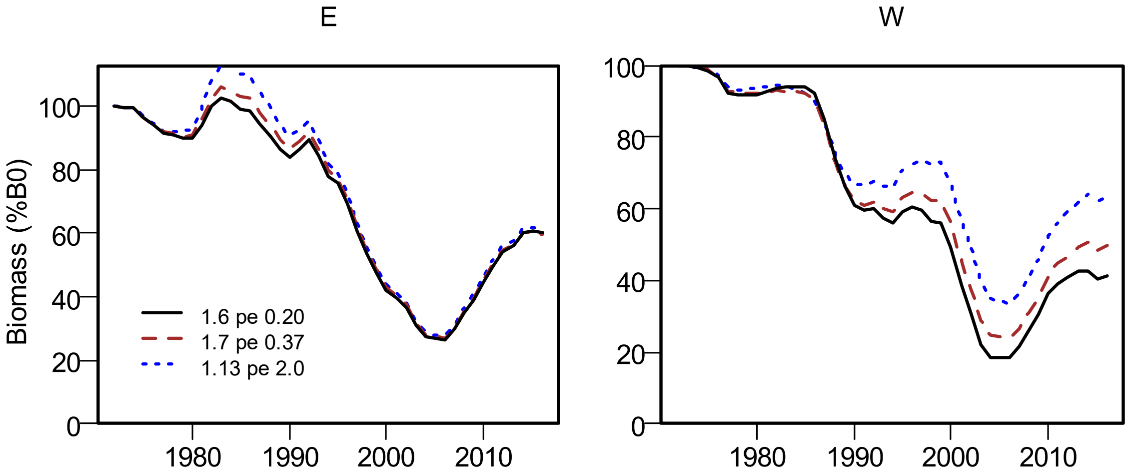

Figure 5: Comparison of biomass trajectories from different runs: E stock (left column) and W stock (right column). See text above the figure for a description of the model runs.

3.3 Estimating the Sub-Antarctic trawl survey process error

The question here is what is driving the MPD estimate of the Sub-Antarctic trawl survey process error? This is addressed by doing a posterior profile for run 1.7 on the process error, and breaking the objective function up into the various components that contribute to it (Figure 6).

It is evident from the posterior profile that: (i) the process error is not strongly estimated, and (ii) the main contributions to the fitted value are the composition data and Sub-Antarctic trawl survey.

The composition data encourages a higher estimate of process error (compared to 0.37) whereas the Sub-Antarctic trawl survey data encourages a lower value (Figure 7).

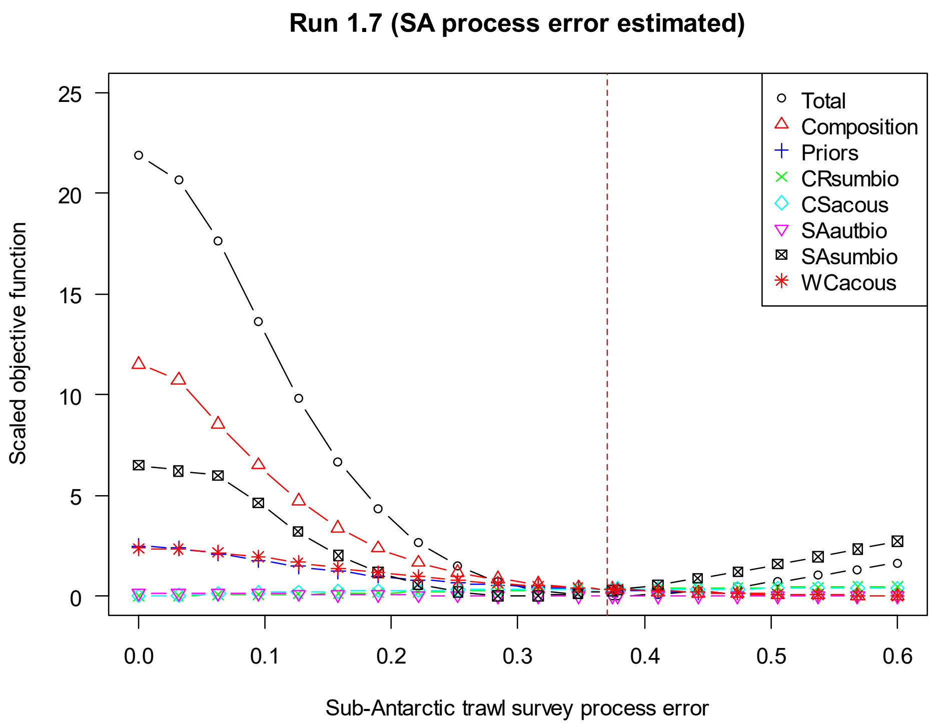

Figure 6: Posterior profile for run 1.7 on the Sub-Antarctic trawl survey process error. Objective function components are scaled so that they are zero at their minimum. The vertical dashed line is at the MPD estimate of 0.37.

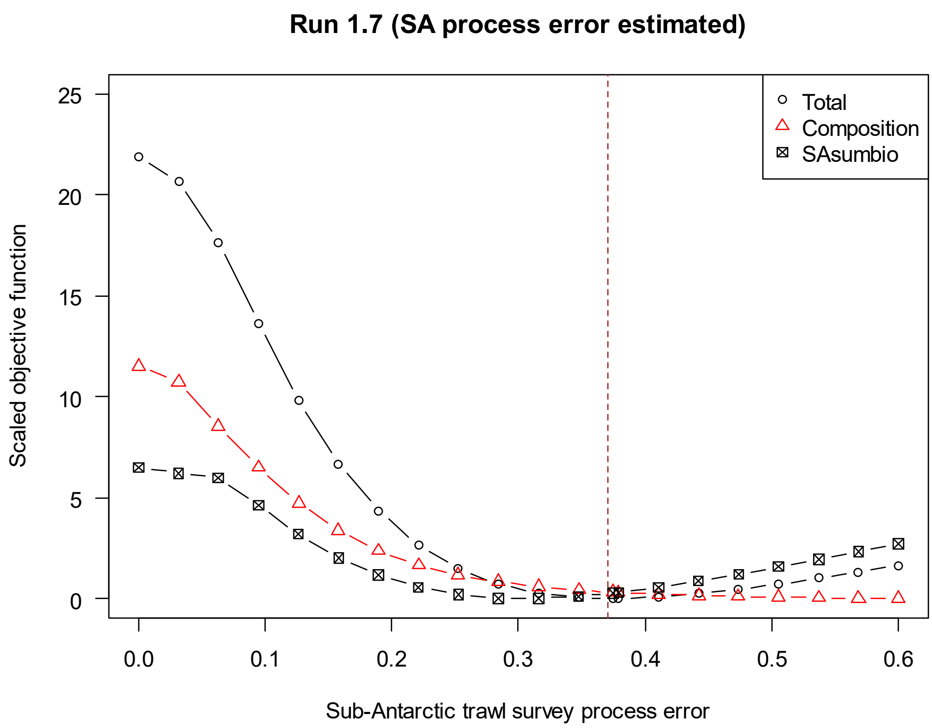

Figure 7: As in Figure 6, but showing only the total objective function value, and contributions from the composition and Sub-Antarctic trawl survey.

3.4 Uncertainty in the CR and SA trawl process error estimates

This is investigated by doing an MCMC run in which the process errors are not fixed at the MPD estimates. Note there is some debate as to whether or not this is an appropriate thing to do.

The new MCMC run 1.14 is the same as the base model run 1.7, except the process errors for the Chatham Rise and Sub-Antarctic trawl survey are not fixed at the MPD estimates. Diagnostics are similar for the two runs (Figures 8–9). Estimate of biomass (virgin and current) are slightly higher for run 1.14 (Figure 10).

The posterior distribution for the process errors is shown in Figures 11–12 and the median with confidence intervals in Table 13. From the posteriors a default value of 0.20 looks plausible for the Chatham Rise trawl survey, but not for the Sub-Antarctic trawl survey.

One concern with estimating the process error is that it may be highly correlated with virgin biomass estimates, leading to problems with chain convergence. However, the diagnostic plots indicate that there is no problem with chain convergence, and plotting the SA process error against western virgin biomass does not show a strong correlation (Figure 13). Note that in the assessment the western virgin biomass is a derived quantity – estimates are made for the total virgin biomass (east and west) and a proportion of this is in the east.

Table 13: Estimates of process error for the Chatham Rise (CR) and Sub-Antarctic trawl surveys from the MCMC.

Area	Median (with 95% CI)	CV
CR	0.16 (0.10,0.25)	0.24
SA	0.45 (0.28,0.77)	0.27

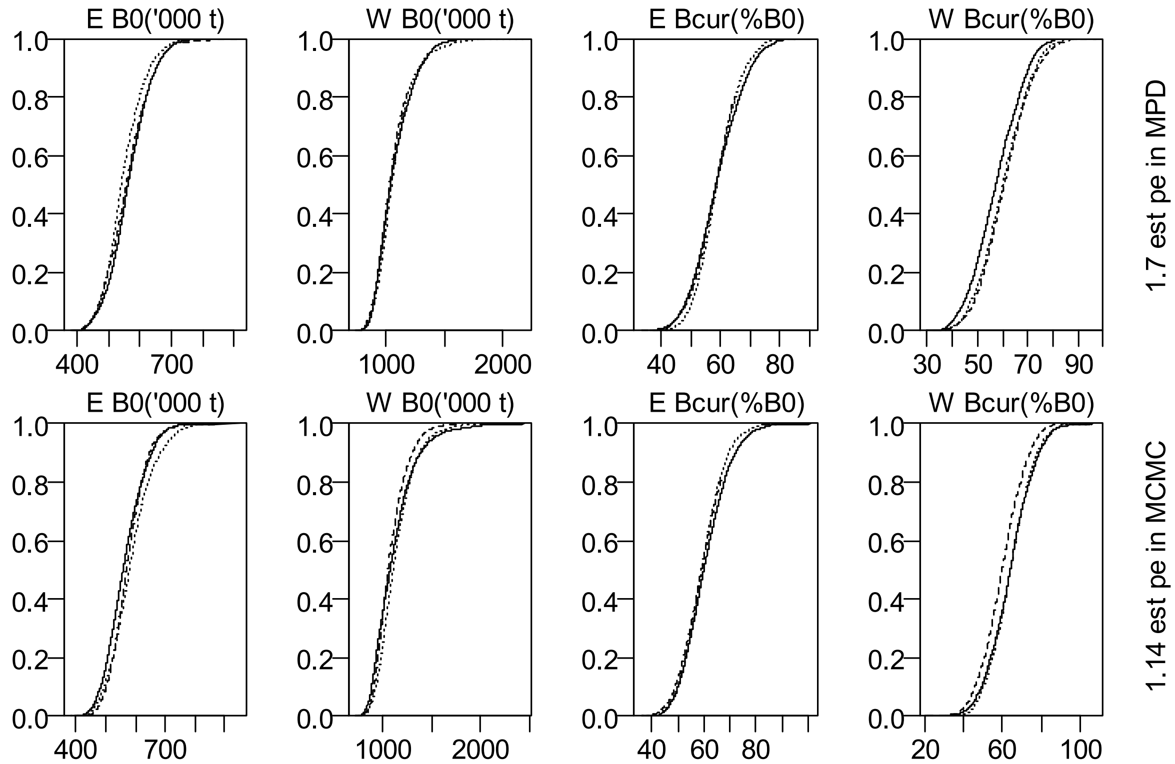

Figure 8: Diagnostics for MCMC chains for the two runs: 1.7 and 1.14. Each panel contains cumulative probability distributions, for B_0 or $B_{current}$, for three chains from the same model run. Samples from the burn in period are discarded for these results.

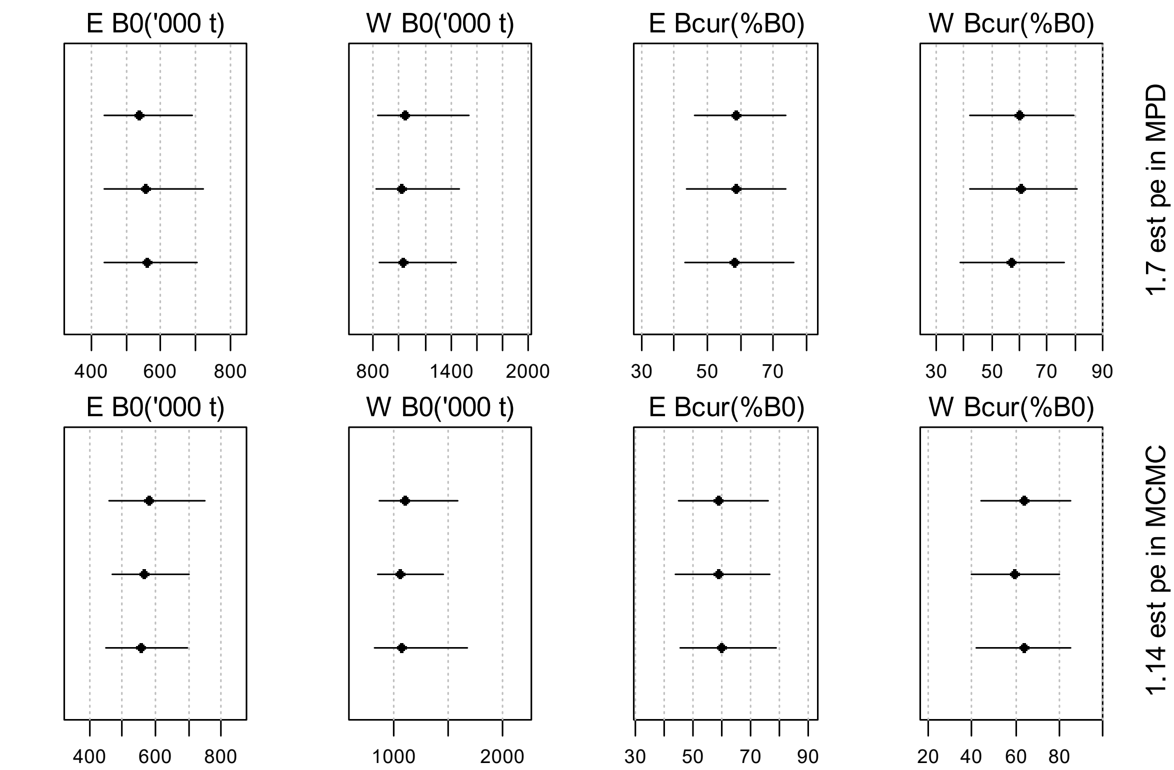

Figure 9: Further diagnostics for MCMC chains for the two runs: 1.7 and 1.14. Each panel contains the median (solid dot) and 95% confidence interval, for B_0 or $B_{current}$, for three chains from the same model run.

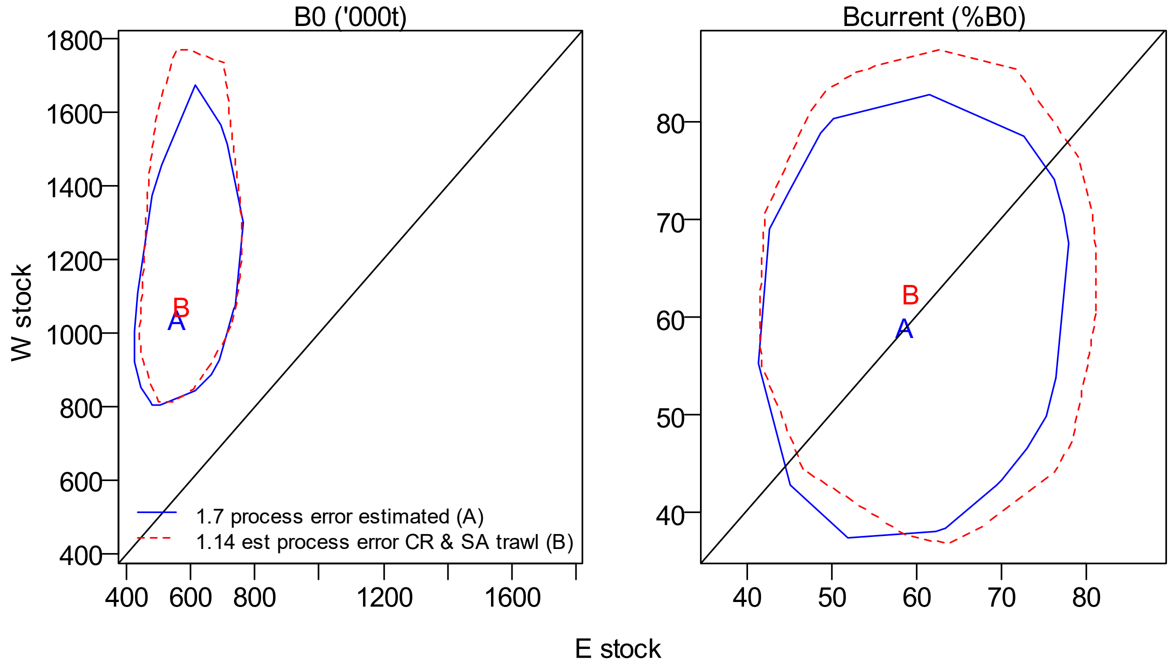

Figure 10: Estimates and approximate 95% confidence intervals for virgin (B_0) and current ($B_{current}$ as $\%B_0$) biomass by stock for the two runs 1.7 and 1.14. In each panel the points 'A', 'B' indicate best estimates (median of the posterior distribution) for these two runs, and the polygons (with solid, and broken lines, respectively) enclose approximate 95% confidence intervals. Diagonal lines indicate equality (y = x).

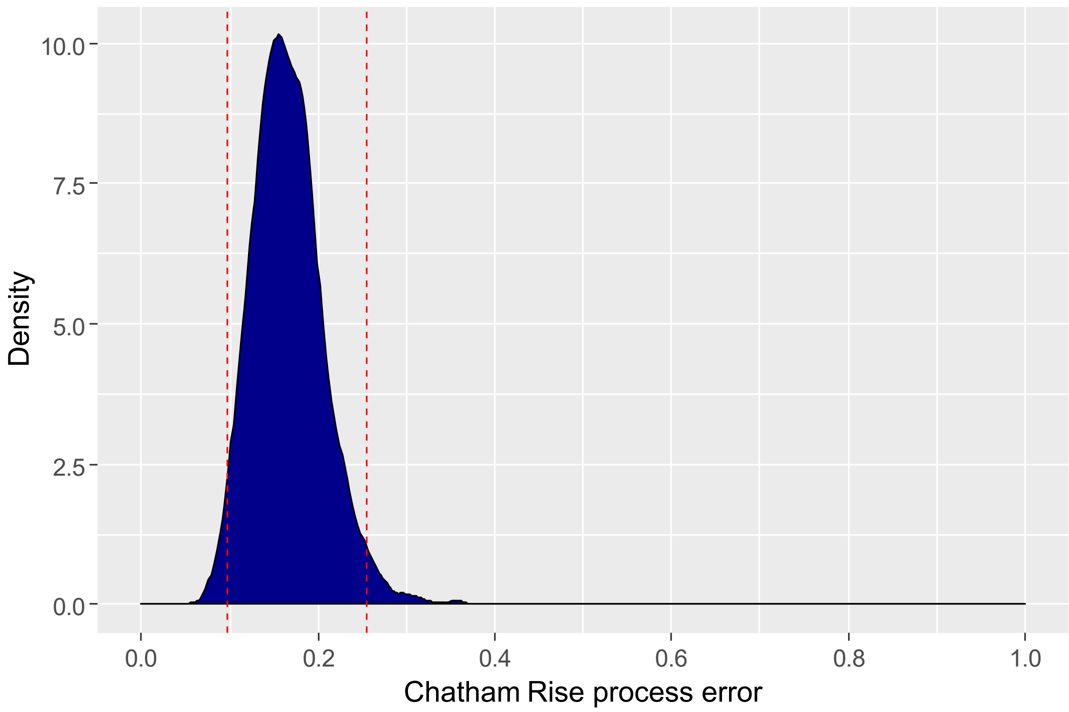

Figure 11: Posterior distribution for the Chatham Rise trawl process error and run 1.14, with vertical dashed lines showing the 95% confidence interval.

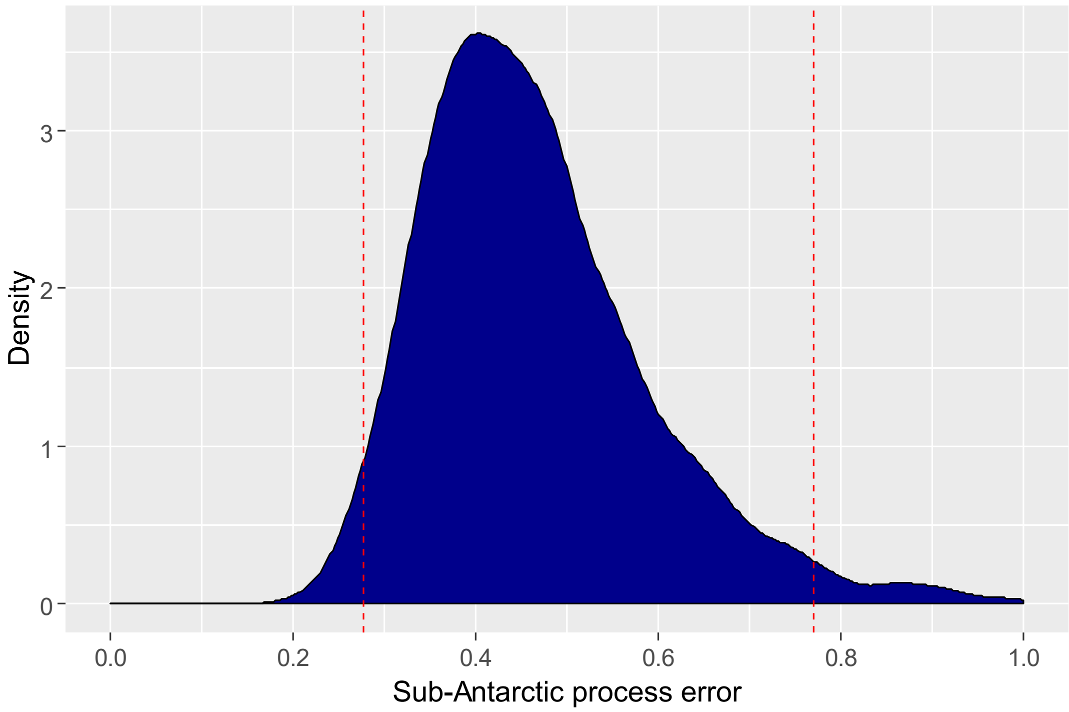

Figure 12: Posterior distribution for the Sub-Antarctic process error and run 1.14, with vertical dashed lines showing the 95% confidence interval.

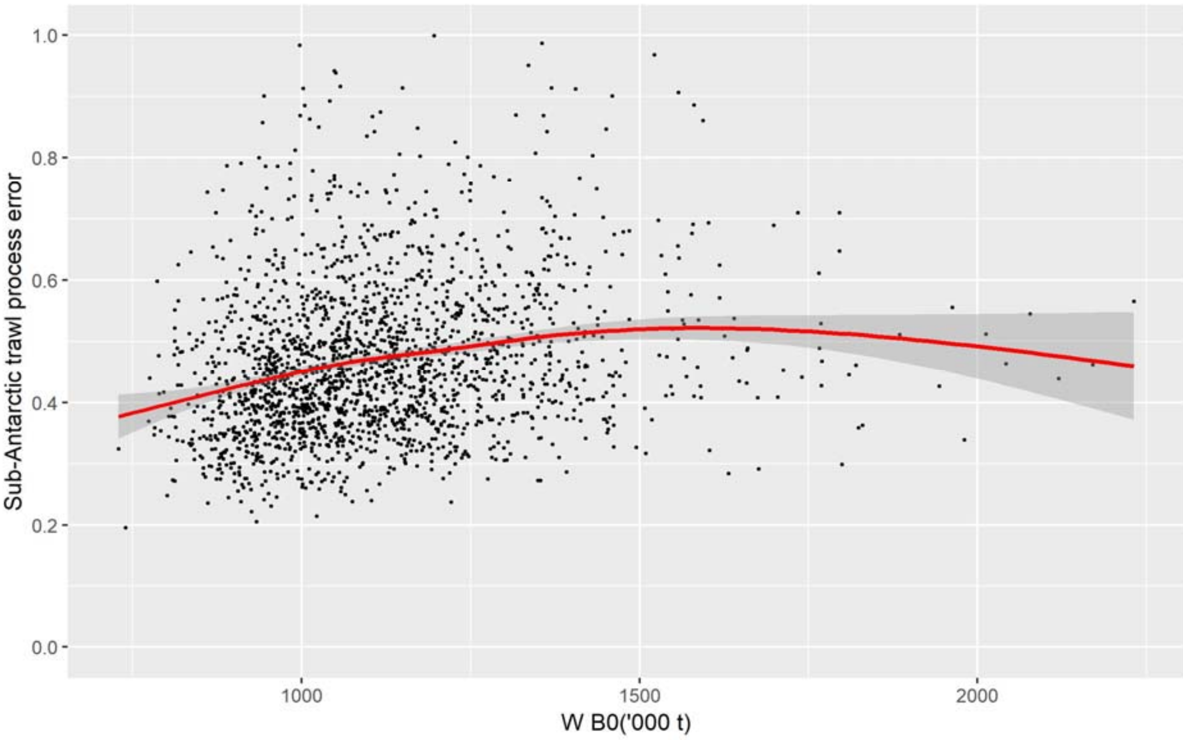

Figure 13: Sub-Antarctic process error versus western virgin biomass (from the MCMC samples), with the red line the fitted loess smooth curve, with the shaded grey a 95% confidence interval for the mean value of the loess curve.

4. INITIAL EXPLORATORY MODEL RUNS

4.1 Introduction

For the 2016 hoki stock assessment final model MCMC runs there was a single base run, and three sensitivity runs (McKenzie 2017, Table 14). The base run had age-varying natural mortality, a single catchability for the Sub-Antarctic trawl survey, assumed natal fidelity, and the process errors for the Chatham Rise and Sub-Antarctic trawl surveys were estimated.

The initial set of MPD runs for the 2017 hoki stock assessment includes an update of the base model run from the 2016 assessment, a version where the process error for the Chatham Rise and Sub-Antarctic trawl surveys is set at 0.20, and two model runs where the west coast acoustic indices (WCacous) are dropped (Table 15).

The YCSs are parameterised using the Haist parameterisation with lognormal priors. There is an equality penalty for the last year of east and west YCSs estimated in the model (the 2015 YCSs), which is also used in MCMC runs. Biomass survey catchabilities are estimated as free parameters.

The observation error for the at-age data was used to determine initial effective sample sizes for the assumed multinomial error distribution for the at-age data. Following this, a reweighting procedure for the effective sample sizes was undertaken for model 1.1, with reweighting results summarised in Appendix 3. The resulting effective sample sizes from model 1.1 were used for all the other initial model runs.

Biomass estimates for initial model runs are summarised in Table 16. For the initial model run 1.1 the process errors for the Chatham Rise and Sub-Antarctic trawl survey were estimated to be 0.15 and 0.38 respectively (compared to 0.15 and 0.37 respectively for the previous assessment). Appendix 4 shows fits to the proportions-at-age data for runs 1.1 and 1.2.

In the next section the updated model 1.1 is compared to the analogous model run from the 2016 assessment, comparing selectivities, ogives, and biomass estimates. In Section 5 more detailed analyses are presented exploring the data reweighting procedure, changes to selectivities between assessments, data weighting for the Sub-Antarctic trawl survey, and the impact of the west coast acoustic survey.

Table 14: 2016 hoki stock assessment. 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

Table 15: 2017 hoki stock assessment initial MPD model runs.

Run	Main assumptions
1.1	natal fidelity *M* is age-dependent single q for Sub-Antarctic trawl series process error of CRsumbio and SAsumbio estimated in MPD run
1.2	as 1.1 but process error fixed at 0.20 for CRsumbio and SAsumbio
1.3	as 1.1 but drop WCacous and with process error same as 1.1
1.4	as 1.1 but drop WCacous and with process error fixed at 0.20

Table 16: Comparison of MPD biomass estimates for all initial model runs.

Run	Description	B_0('000 t)		B_{2017}(%B_0)	
		E	W	E	W
1.1	Estimate process error	449	869	63	48
1.2	Process error 0.20	442	786	65	37
1.3	Drop WCacous, use est pe	444	804	64	39
1.4	Drop WCacous, pe 0.20	439	754	65	31

4.2 Comparison to the base model from the previous assessment in 2016

Using the 2017 model run 1.1, the biomass trajectory is compared to the analogous model run from last year's assessment (Table 17, Figure 14). For the updated assessment model the eastern and western virgin biomasses are very similar to those from the previous assessment, and the estimate of biomass in 2016 (%B_0) is slightly higher.

For the updated assessment the western stock 2011 and 2014 YCS peaks are lower compared to the previous assessment (Figure 15).

Other graphs show selectivities, migration ogives, and fitted age-varying natural mortality, and compare the updated and previous assessment (Figures 16–18). These are very similar with the only notable difference being the eastern and western spawning selectivities (Espsl, Wspsl) which are now flat in the 2017 model (see Figure 16). The difference in Espsl and Wspsl between the assessments is looked at in more detail in section 5.3.

Another difference is that the parameter used to estimate annual changes in the selectivity ogive for the western spawning fishery (a_shift) was estimated to be zero in 2017, meaning that in contrast to the previous assessment there were no annual changes. This change is investigated in more detail in Section 5.4.

Table 17: Comparison of old and new biomass estimates for the individual stocks, E and W, and the combined E + W stock. The label 2016.7 refers to run 1.7 from the 2016 assessment (see McKenzie 2017), while run 1.1 is for the 2017 assessment (see Table 15).

	B_0('000 t)		B_{2016}(%B_0)		B_{2017}(%B_0)	
Run	E	W	E	W	E	W
2016.7	452	858	59	50	NA	NA
1.1	449	869	62	51	63	48

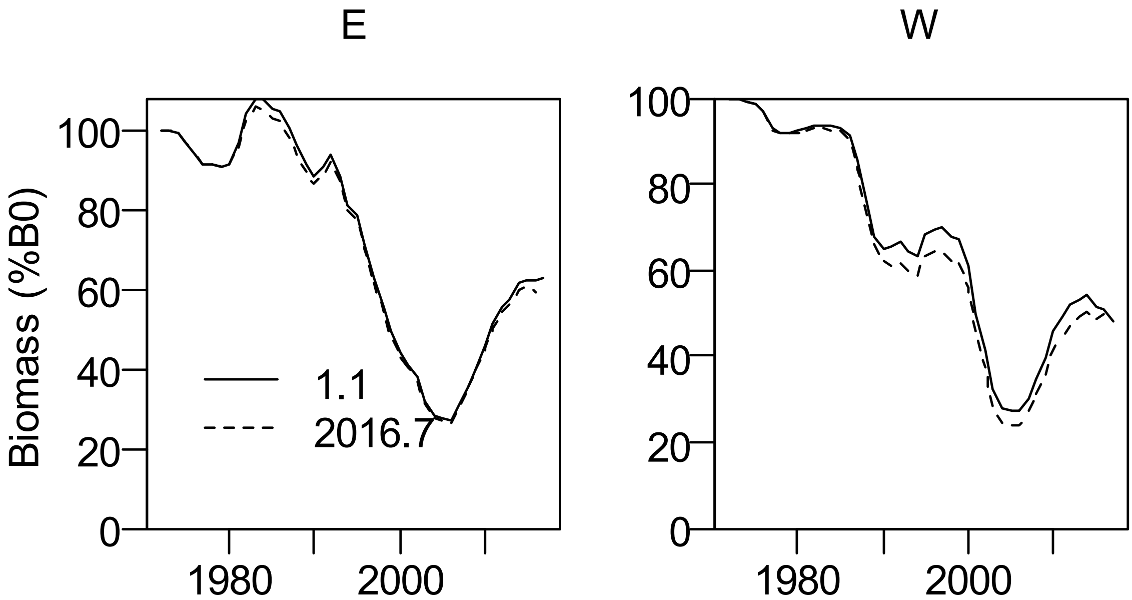

Figure 14: Comparison of biomass trajectories from different runs: E stock (left column), W stock (middle column), and E + W stocks combined (right column). The graphs compare run 1.1 from 2017 (solid lines)

with the corresponding run from 2016 (broken lines). The label 2016.7 denotes run 1.7 from the 2016 assessment.

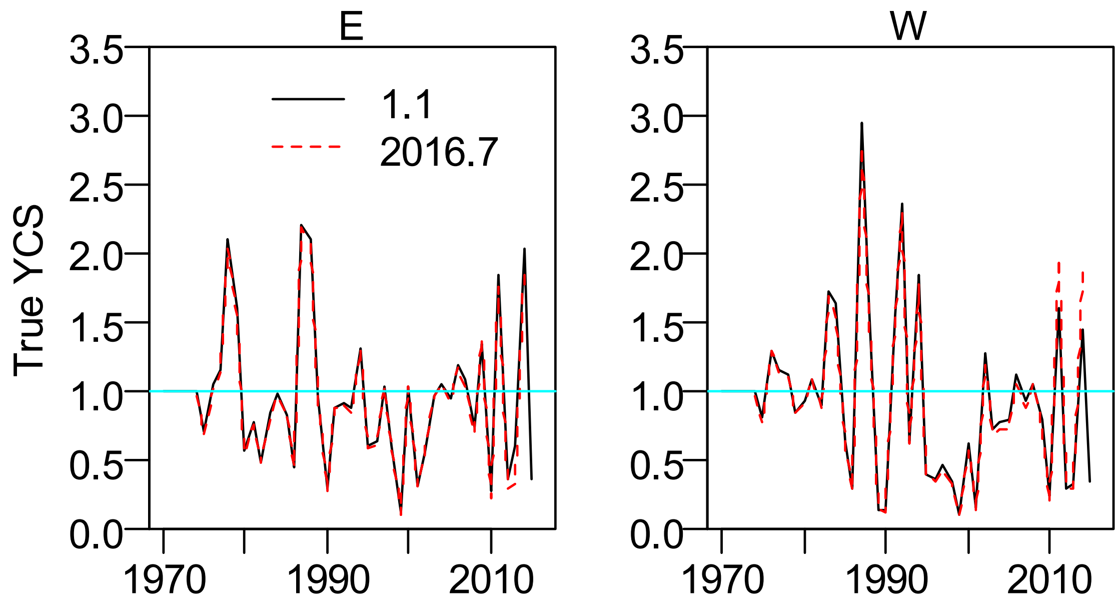

Figure 15: True YCS estimates for new run 1.1 from 2017 (solid lines) and the analogous run from last year's assessment. The label 2016.7 denotes run1.7 from the 2016 assessment.

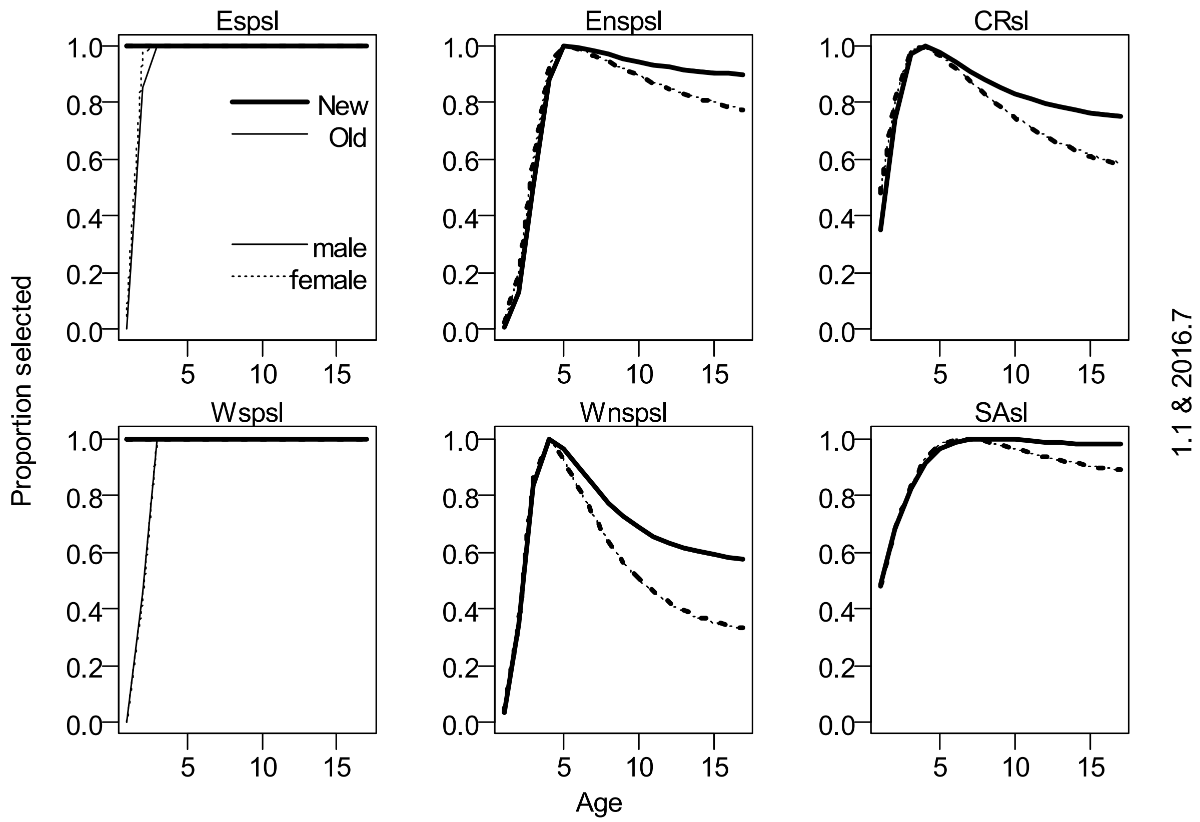

Figure 16: Estimated selectivity curves for the new model run 1.1 from new 2017 (heavy lines) and analogous model run from the previous assessment (light lines). Males are shown by a solid line, females by a dotted line. The label 2016.7 denotes run 1.7 for the 2016 assessment.

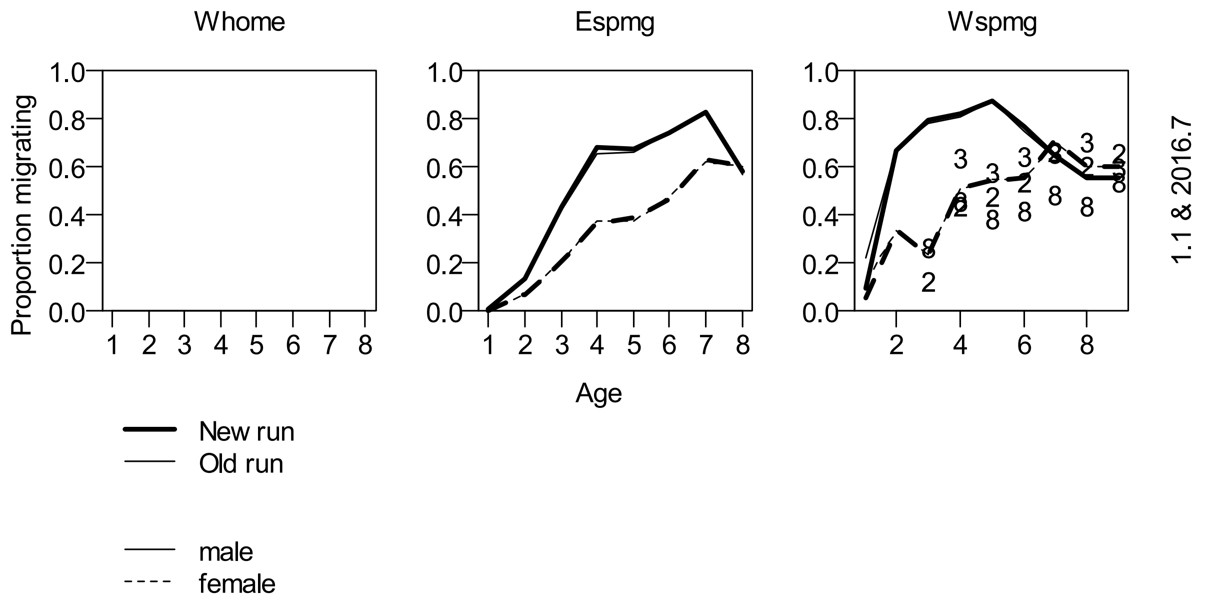

Figure 17: Estimated migration ogives for new run 1.1 from 2017 (heavy lines) and the analogous model run from the previous assessment (light lines). Each row of plots compares ogives from the new run (heavy lines) with that from the previous assessment (light lines). Where ogives differ by sex, female ogives are plotted as broken lines. The observations pspawn are also plotted in the rightmost panel, with the plotting symbol identifying the year of sampling ('2' = 1992, '3' = 1993, '8' = 1998). The label 2016.7 denotes run 1.7 for the 2016 assessment.

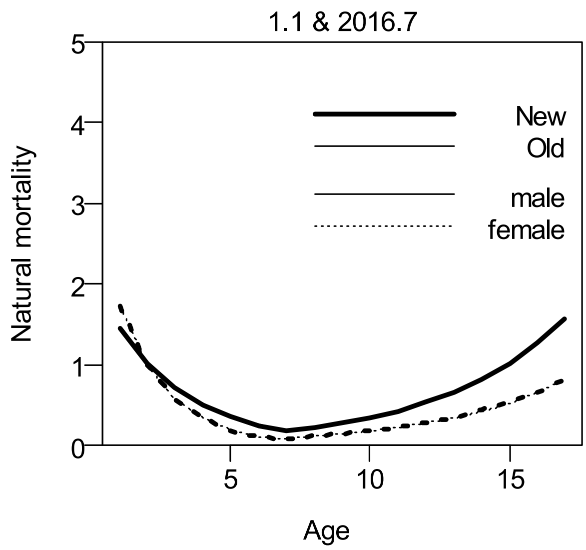

Figure 18: Comparison between age-dependent natural mortality estimated in the new run 1.1 from 2017 (heavy lines) and the analogous model run from the previous assessment (light lines). The label 2016.7 denotes run 1.7 for the 2016 assessment.

5. FOLLOW-UP WORK FOR INITIAL MODEL RUNS

5.1 Introduction

Some more detailed analyses of the initial model runs are presented in this section looking at the data reweighting procedure, changes to selectivities, data weighting for the Sub-Antarctic trawl survey, and the impact of the west coast acoustic survey.

5.2 Order for reweighting procedure

For the initial MPD model run 1.1 the at-age data was reweighted, with the resulting effective sample size for the at-age data used for all initial MPD runs (Table 27). The reweighting procedure is an iterative process, starting with initial effective sample sizes determined by observation error, and the process error of the Chatham Rise and Sub-Antarctic trawl surveys estimated at each iteration.

One question is what affect does the ordering of components (i.e. reweighting of sample size, estimating process error) have on the estimate of process error? This is investigated by doing a reweighting for the same model as run 1.1, but having the process error fixed at 0.20 for both surveys during the reweighing of the at-age data, then estimating the process error at the end.

The final effective sample sizes changed little (Table 18), nor did the process errors for Chatham Rise and Sub-Antarctic trawl surveys: run 1.1 (0.15, 0.38), new ordering (0.15, 0.36).

Table 18: Comparing final mean values of N for at age data sets in the model: Run 1.1 and the same model but a new ordering for estimating the process error.

Model	Espage	Wspage	EnspOLF	Enspage	WnspOLF	Wnspage	CRsumage	SAsumage	SAautage
1.1	84	19	12	38	57	16	63	18	14
New ordering	83	21	12	38	54	14	66	15	14

5.3 Changes to the spawning selectivities from 2016 to 2017 assessment

For the initial model run 1.1 the spawning selectivities Espsl and Wspsl were estimated to be flat, in contrast to the previous assessment (see Figure 16).

Espsl and Wspsl are length-based logistic selectivities which are set to be the same for male and female, as well as east and west stocks. The associated commercial proportions-at-age (Espage, Wspage) are entered into the model with an age range from 2 to 15++. Ages are incremented at the start of the spawning fishery step in the model (see Table 2).

In the previous assessment the logistic parameters were estimated to be 44.8 cm (a_{50}) and 4 cm (a_{to95}) with the a_{to95} at a bound (note that a hoki of length 44.8 cm is about 1.5 years old). In the current assessment both values are estimated to be 6.7 cm with neither of them at a bound. Note that in the previous assessment the left tail of the selectivity (in the age domain) was not well estimated (Figure 19).

Using the previous assessment logistic parameters (44.8, 4) in the current assessment run 1.1 has a miniscule impact on estimated biomass (Figure 20). Using the previous parameters decreases the fit to Wspage by about four likelihood points, which is most noticeable for two year old fish, and in more recent years (e.g. 2004, 2006, 2008) (Figures 21–22).

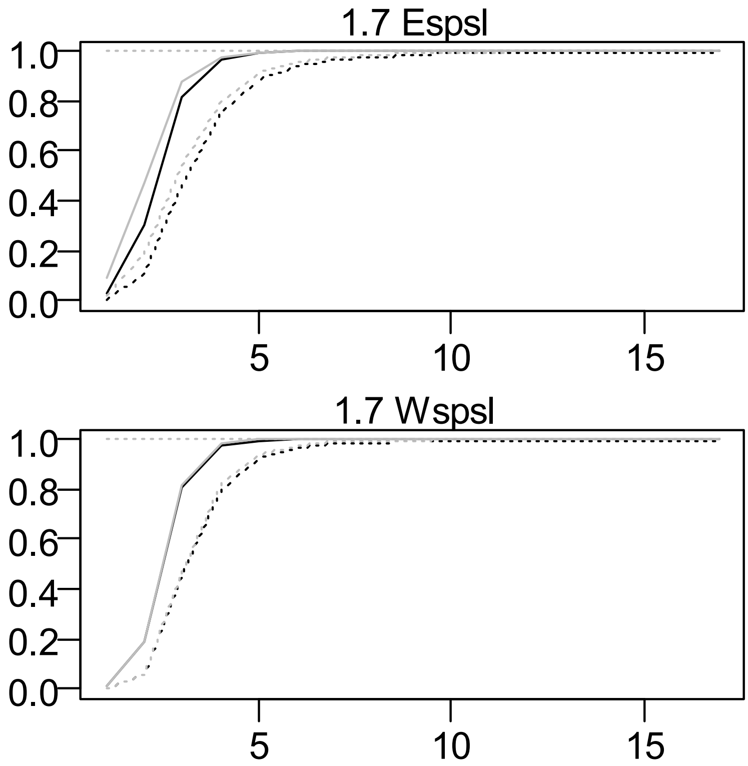

Figure 19: Posterior estimates of selectivity ogives for base case MCMC run 1.7 from the 2016 assessment. Solid lines are medians; broken lines show 95% confidence intervals. Age in years is along the x-axis. Where ogives differ by sex they are plotted as black for males and grey for females.

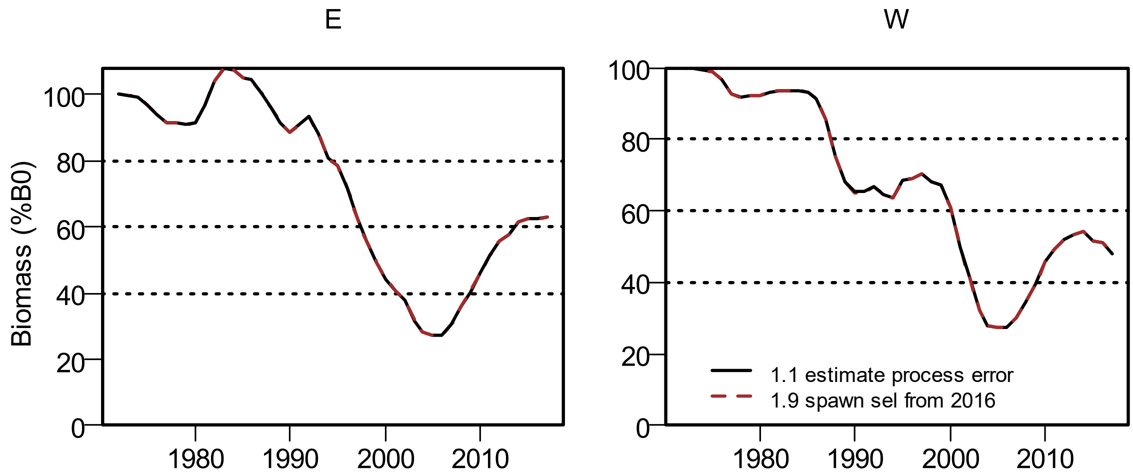

Figure 20: Comparison of biomass trajectories for runs 1.1 and 1.9: E stock (left column), W stock (right column). In model run 1.9 the same estimated model parameter values are used as run 1.1, except the logistic spawning selectivity parameters are set at the values estimated in the 2016 assessment (44.8 cm, 4 cm). Note the curves overlap substantially.

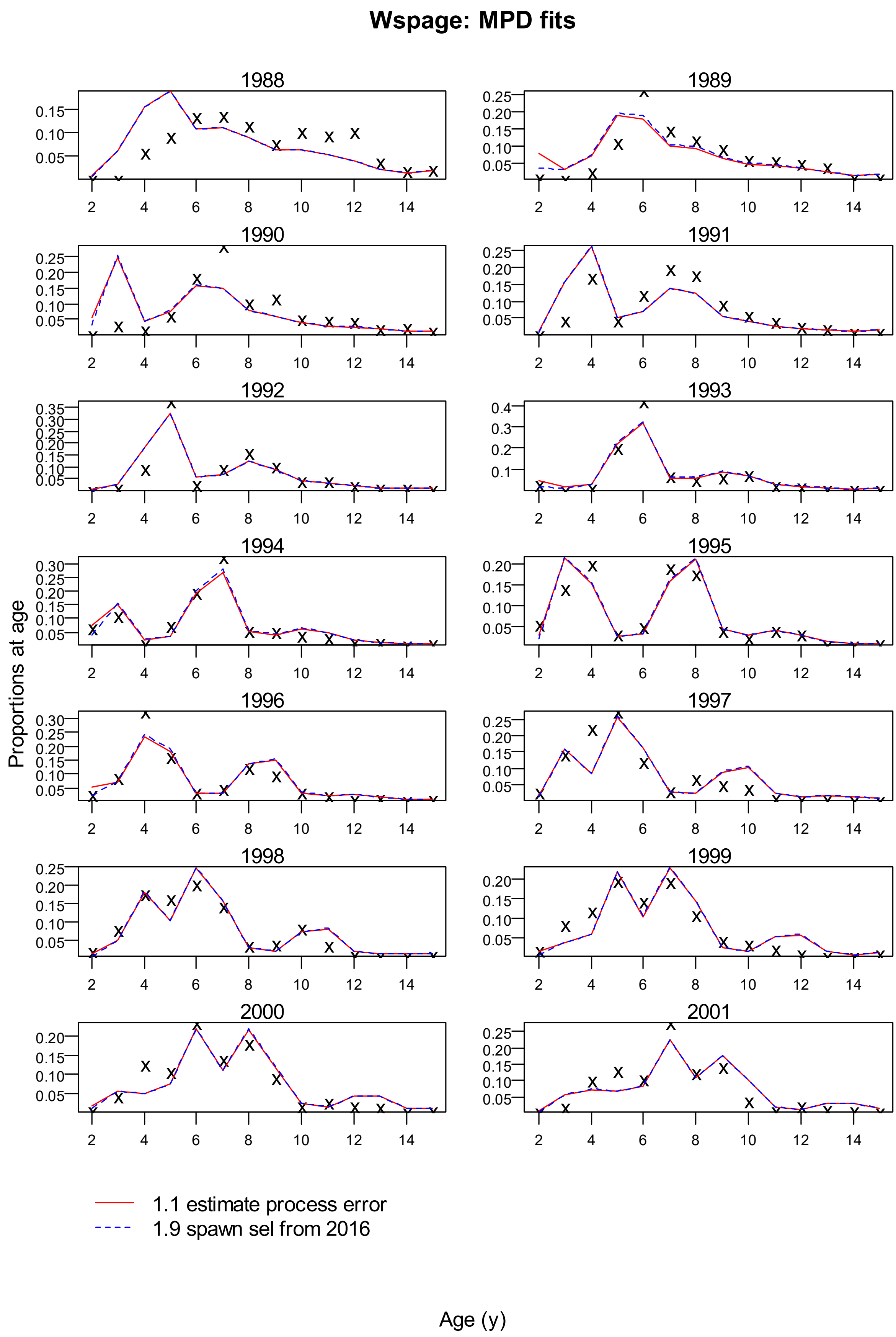

Figure 21: MPD fits to the Wspage data for 1988 to 2001. Observed ('×') and expected (lines) for runs 1.1 (red solid lines) and 1.0 (blue broken lines). Male and female observed and expected proportions are summed for an age group.

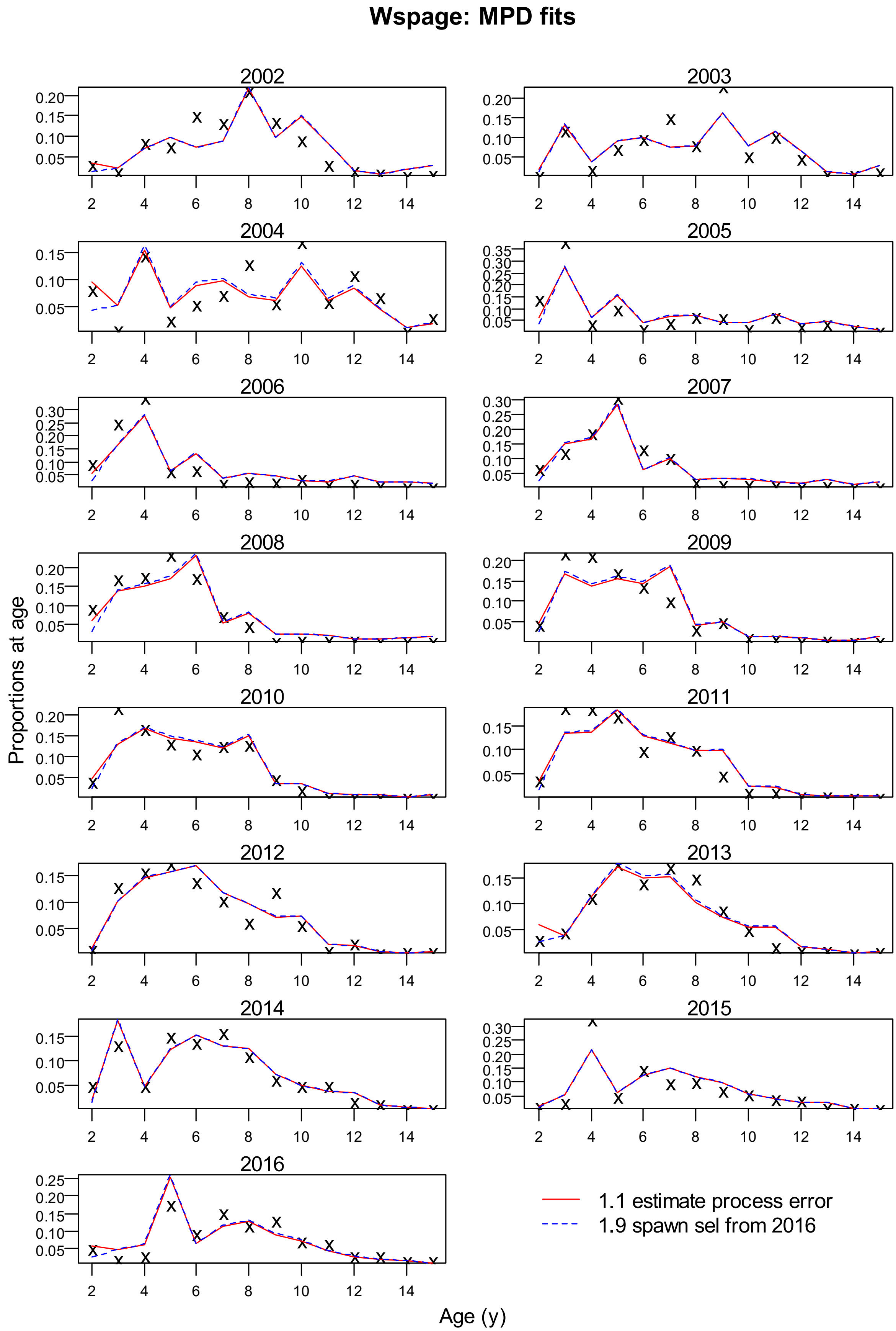

Figure 22: MPD fits to the Wspage data for 2002 to 2016. Observed ('×') and expected (lines) for runs 1.1 (red solid lines) and 1.0 (blue broken lines). Male and female observed and expected proportions are summed for an age group.

5.4 No annual changes for the western spawning fishery in 2017

The model attempts to estimate annual changes in a_{50} for the logistic western spawning selectivity (a length-based selectivity). The changes are driven by the median day of the fishery, this being the day when half of the year's catch had been taken. 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 an estimated Wspsl shift parameter: a_shift*(median – mean).

The value of the estimated a_shift has been low for recent stock assessments, and for the 2017 assessment was estimated to be zero (Table 19). Annual changes in the western spawning selectivity were last looked at for the 2011 assessment (Figure 23), and this is compared to annual changes for the 2016 assessment (Figures 24–25). Compared to the 2011 assessment, annual changes were small for the 2016 assessment, and presumably also for 2014 and 2015 given the small a_shift values for those years.

Table 19: Estimated value of the a_shift parameter in some recent hoki stock assessments. All model runs have the same basic model structure: sexed, age-varying natural mortality, and a single catchability for the Sub-Antarctic trawl survey.

Assessment year	Model run	MPD estimated a_shift
2011	1.1	-0.289
2014	1.11	-0.079
2015	1.1	-0.086
2016	1.7	-0.091
2017	1.1	0.000

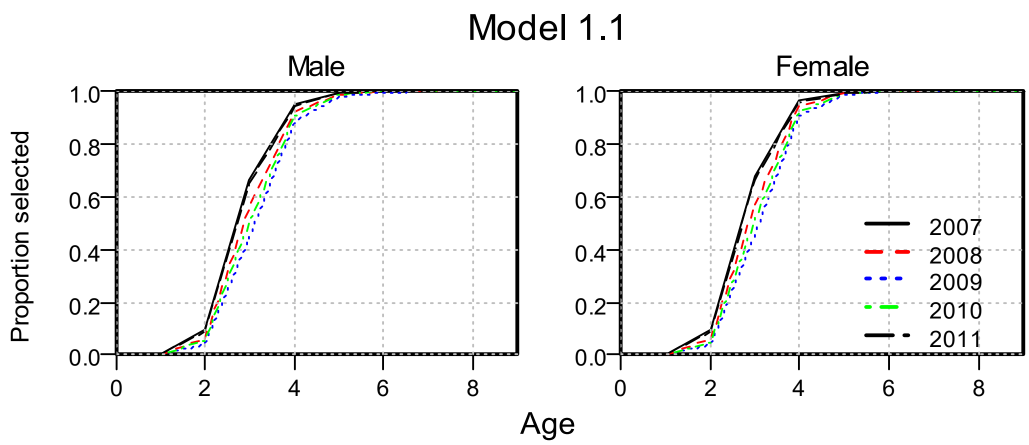

Figure 23: Wspsl selectivity from 2007 to 2011 (model 1.1 from 2011 assessment). The ages go to 17+ but are truncated at 9. Reproduced from figure 20 in McKenzie (2011).

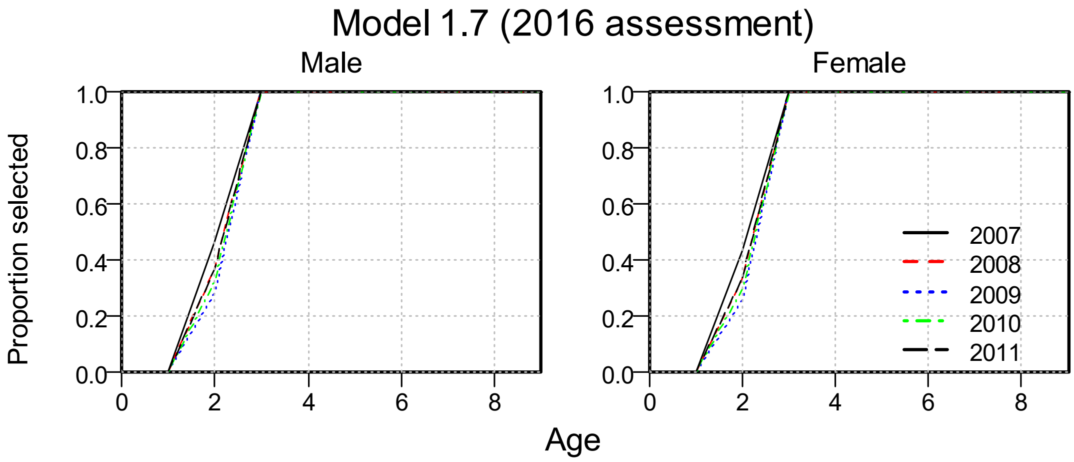

Figure 24: Wspsl selectivity from 2007 to 2011 (model 1.7 from 2016 assessment). The ages go to 17+ but are truncated at 9.

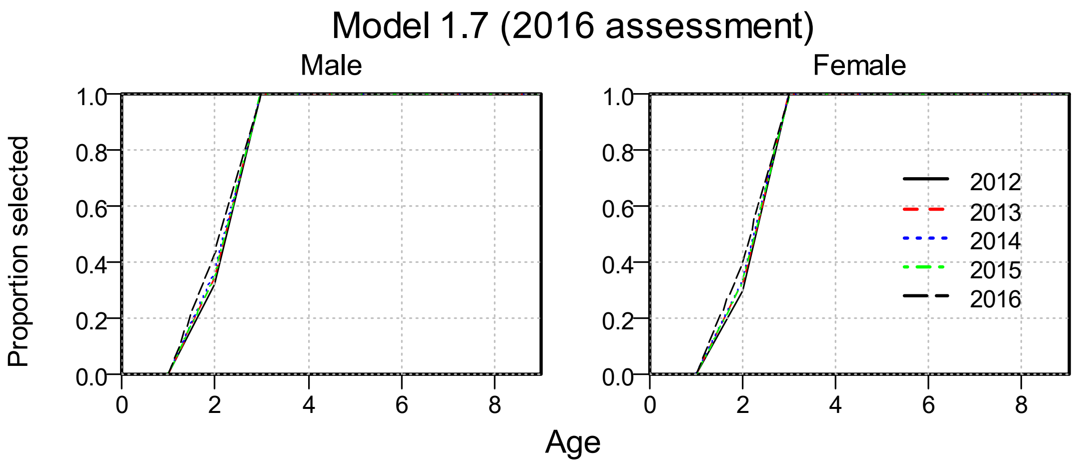

Figure 25: Wspsl selectivity from 2012 to 2016 (model 1.7 from 2016 assessment). The ages go to 17+ but are truncated at 9.

5.5 Implications of different data weightings for the Sub-Antarctic trawl survey

In this section we look at the implications of different data weightings for the Sub-Antarctic trawl survey, where the weightings are set by the process error associated with this survey. We concentrate on model run 1.1 (estimated process error 0.38) and run 1.2 (process error set at 0.20 for both the Sub-Antarctic and Chatham Rise trawl survey).

The most pertinent difference is in the estimate of western current biomass. With a process error of 0.20 this is estimated to be 37%B_0, whereas with the higher estimated process error of 0.38 it is estimated to be 48%B_0 (Figure 26). This difference is driven by a closer fit to the Sub-Antarctic trawl survey, with little difference in the fit to the Chatham Rise trawl survey (Figures 27–29). With a process error of 0.20 the fit to WCacous has a steeper decline, and the fit for CSacous is little changed (Figures 30–31)

With a process error of 0.20 the peak values for YCSs in 2011 and 2014 are less for the eastern stock, and greater for the western stock (Figure 32, Table 20).

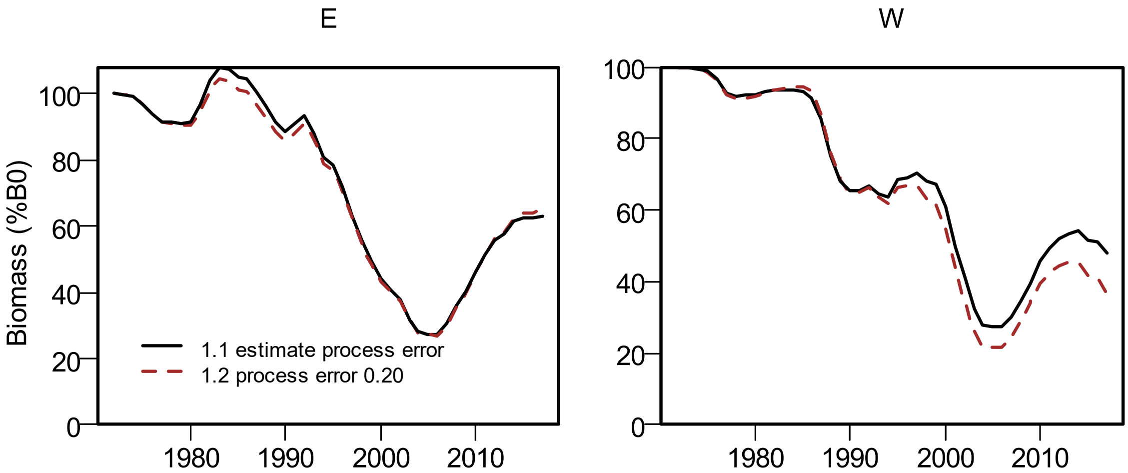

Figure 26: Comparison of biomass trajectories for runs 1.1 and 1.2: E stock (left column), W stock (right column).

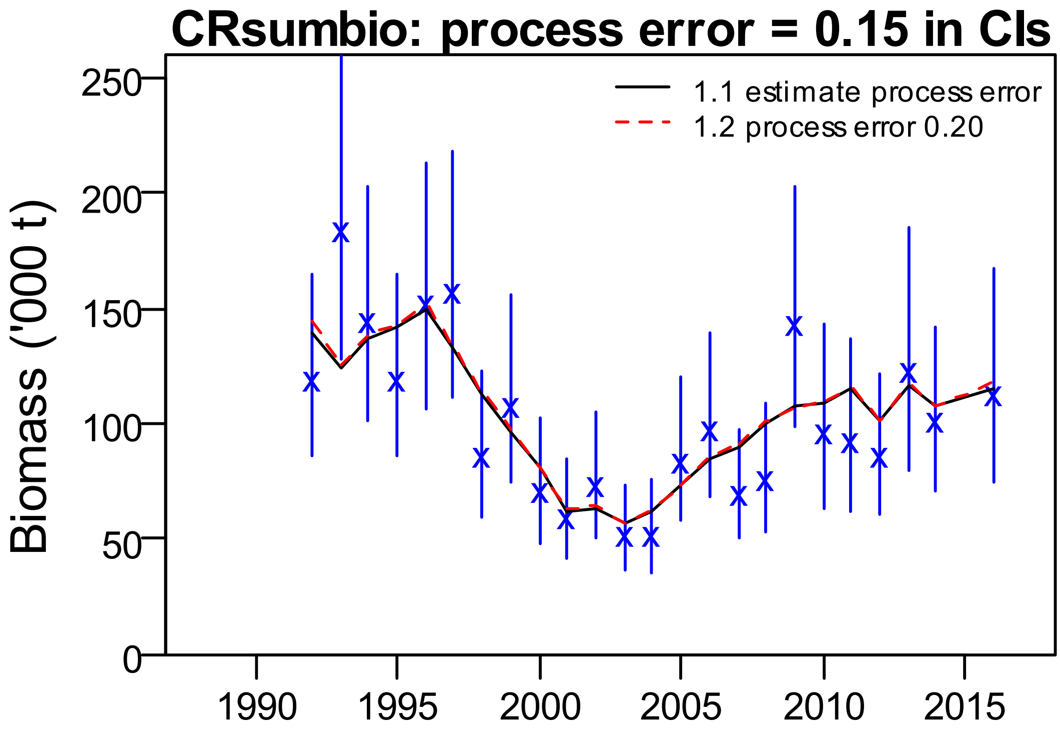

Figure 27: Fits to CRsumbio for 2017 runs 1.1 and 1.2, showing observed ('x', with vertical lines showing 95% confidence intervals including estimated process error) and expected values (lines). Plotted years are as in the model (so the last survey is plotted at 2016).

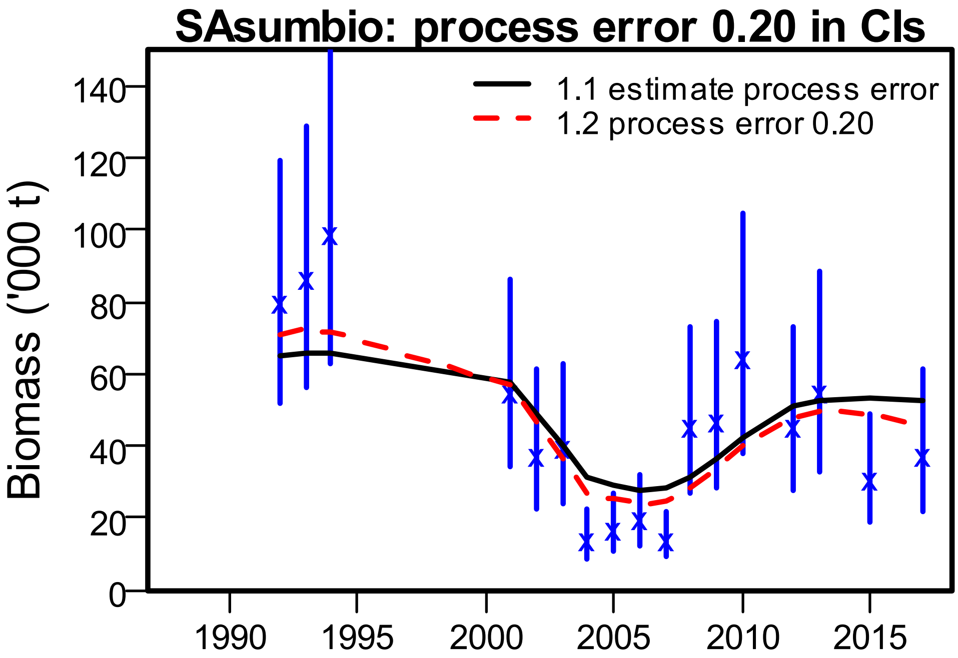

Figure 28: Fits to SAsumbio for 2017 runs 1.1 and 1.2, showing observed ('x', with vertical lines showing 95% confidence intervals including 0.20 process error) and expected values (lines). Plotted years are as in the model (so the last survey is plotted at 2017).

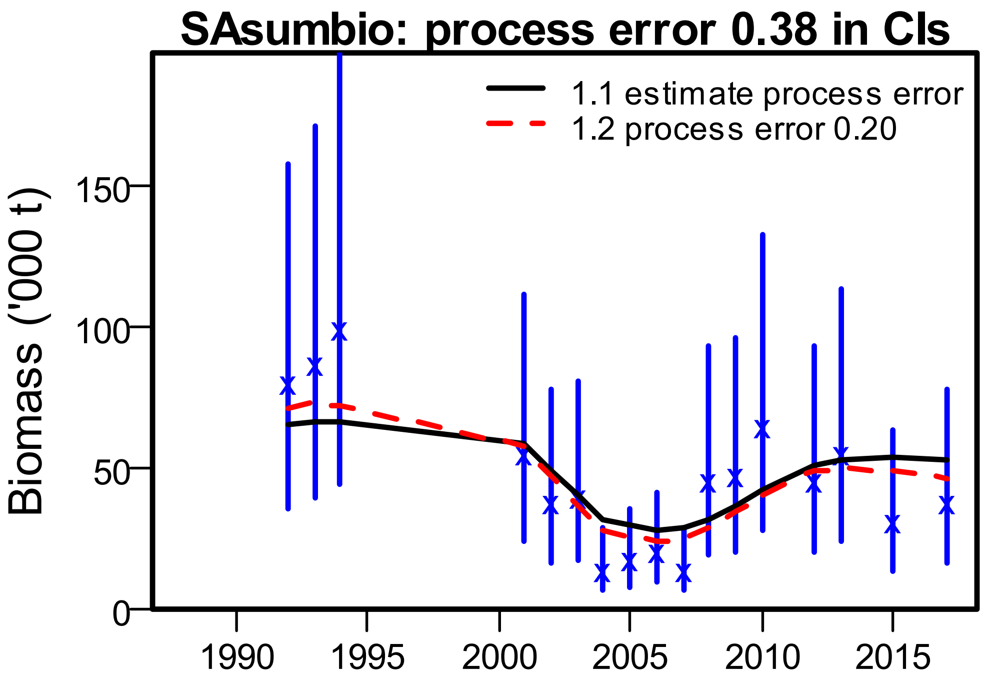

Figure 29: Fits to SAsumbio for 2017 runs 1.1 and 1.2, showing observed ('x', with vertical lines showing 95% confidence intervals including estimated process error) and expected values (lines). Plotted years are as in the model (so the last survey is plotted at 2017).

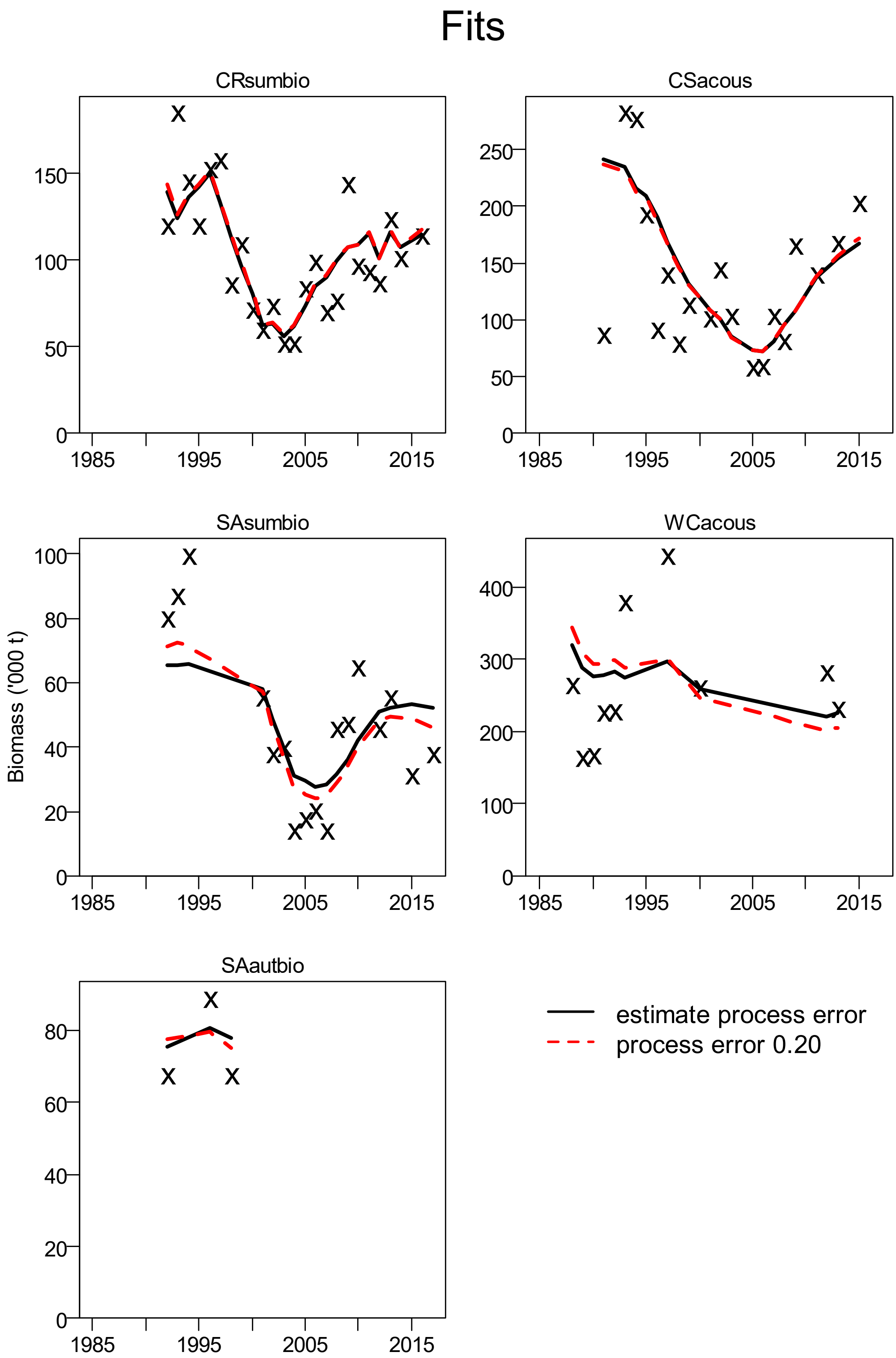

Figure 30: Fits to biomass indices for 2017 assessment run 1.1 (estimate process error) and 1.2 (process error 0.20). Shown are observed ('x') and expected values (lines).

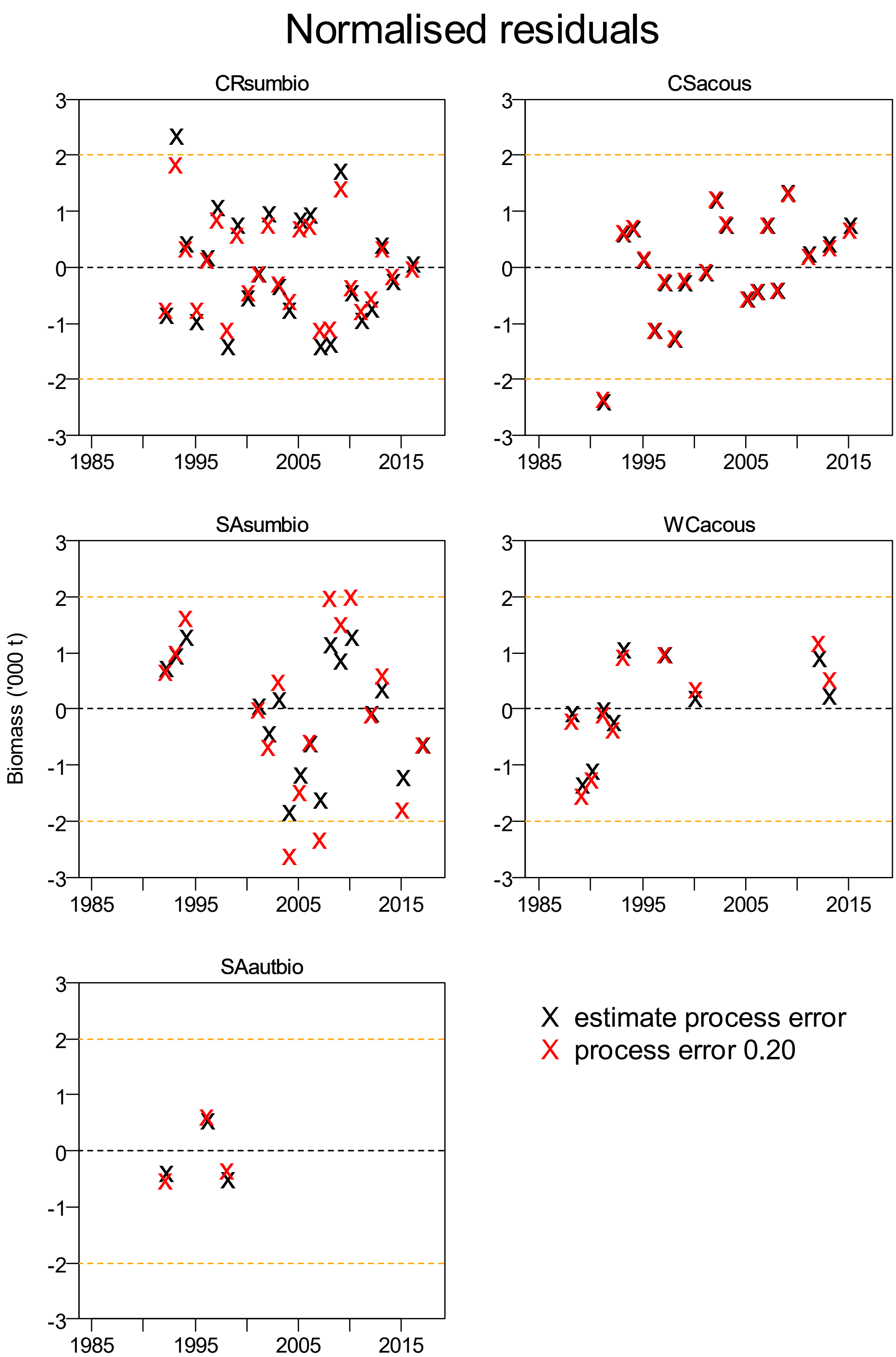

Figure 31: Normalised residuals for fits to biomass indices for 2017 assessment run 1.1 (estimate process error) and 1.2 (process error 0.20).

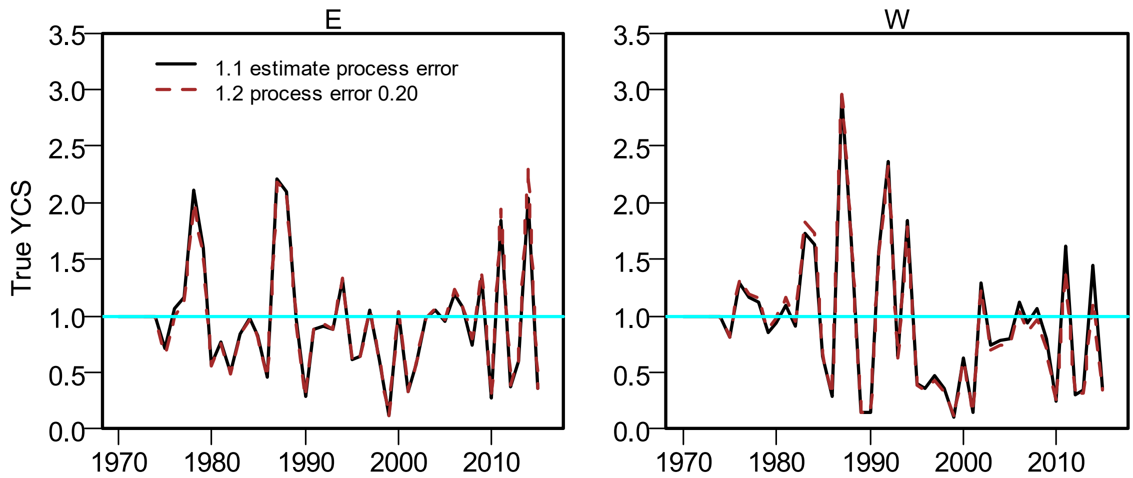

Figure 32: True YCS estimates for 2017 runs 1.1 and 1.2.

Table 20: Comparing true YCS for 2017 runs 1.1 and 1.2.

Stock	**Run**	**2010**	**2011**	**2012**	**2013**	**2014**	**2015**
East	1.1	0.27	1.84	0.38	0.60	2.04	0.36
	1.2	0.28	1.94	0.38	0.61	2.31	0.36
West	1.1	0.24	1.61	0.31	0.34	1.45	0.35
	1.2	0.23	1.40	0.28	0.32	1.13	0.34

5.6 Lowess estimates of process error

In this section process error estimate are made outside the constraints of the model, by considering smoothed lowess fits to the Chatham Rise and Sub-Antarctic trawl surveys.

The basic idea is to fit a smoothed lowess curve where the smoothness is of the “appropriate” amount, and infer from this the process error. For the lowess curves a smoothing of zero gives a lowess curve that goes through each point, while the maximum smoothness is one.

For a given amount of smoothing there is an associated total CV, from which the observation error CV can be “subtracted” (using the usual square root formulation), giving an estimated process error for each point. Taking the mean of these gives a mean process error associated with each value of smoothness.

Low smoothing can give a curve with high rates of change between years, which may be unrealistic. Setting a constraint on the maximum rate of change between years puts a lower bound on the amount of smoothing (and hence the process error). It is ambiguous what the maximum rate of change could be for the surveys, but estimates are obtained from the 2016 assessment SSB biomass trajectories for east and west stocks (median MCMC): for the east stock a maximum change of 16% increase in 2008, and for the west stock a maximum change of 21% decline in 2003.

Results for the lowess fits are shown in Figures 33–36.

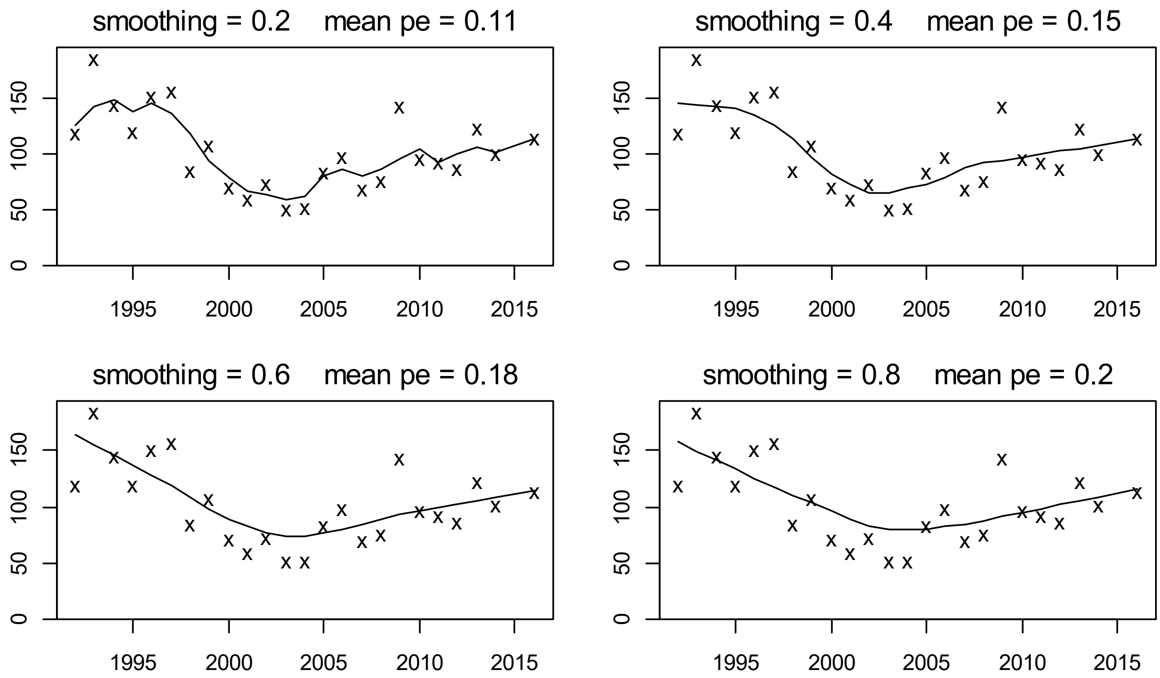

Figure 33: Fitted lowess curves to the Chatham Rise trawl survey.

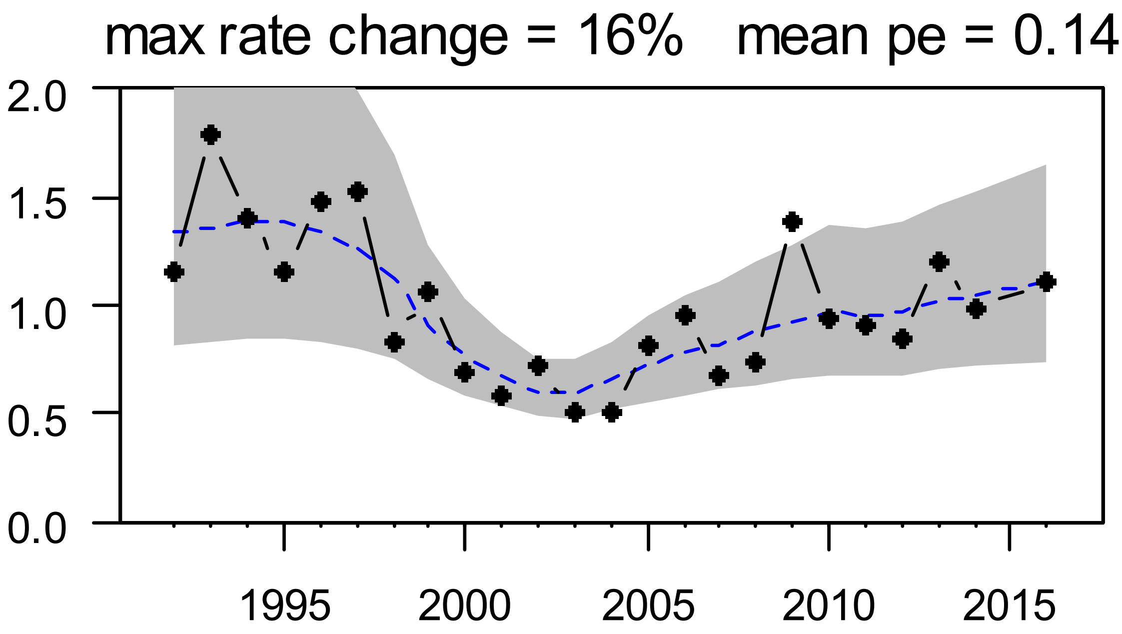

Figure 34: Constrained fitted lowess curve for the Chatham Rise trawl survey, with minimum amount of smoothing consistent with a maximum annual rate of change of 16%.

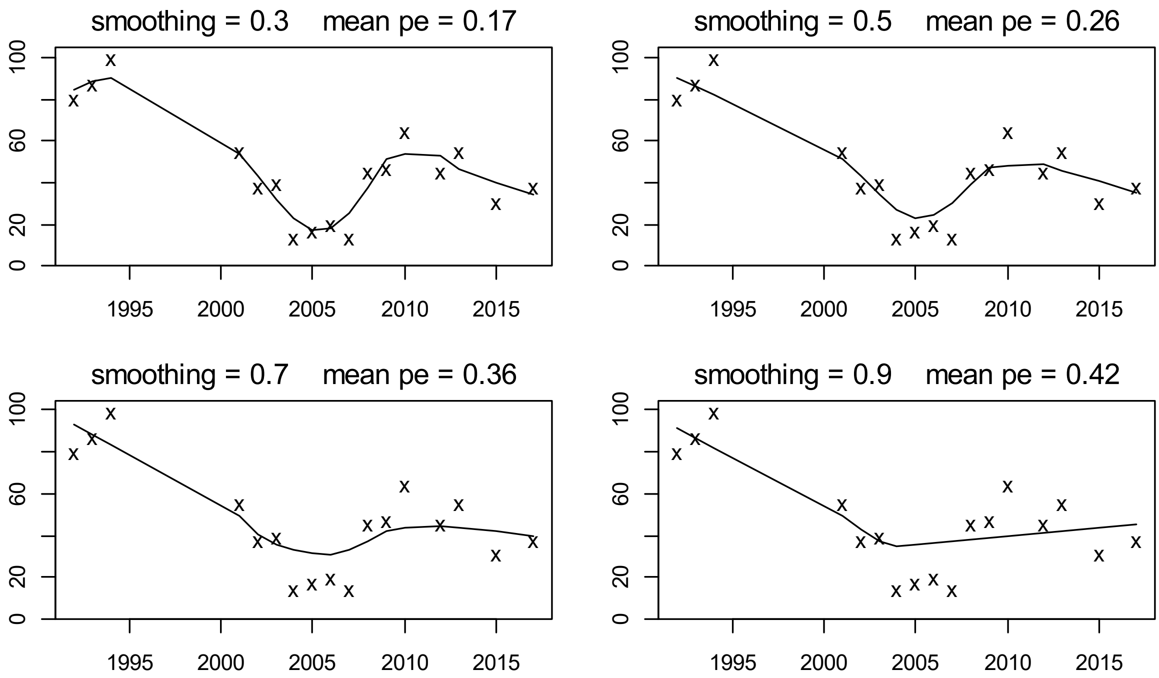

Figure 35: Fitted lowess curve for the Sub-Antarctic trawl survey.

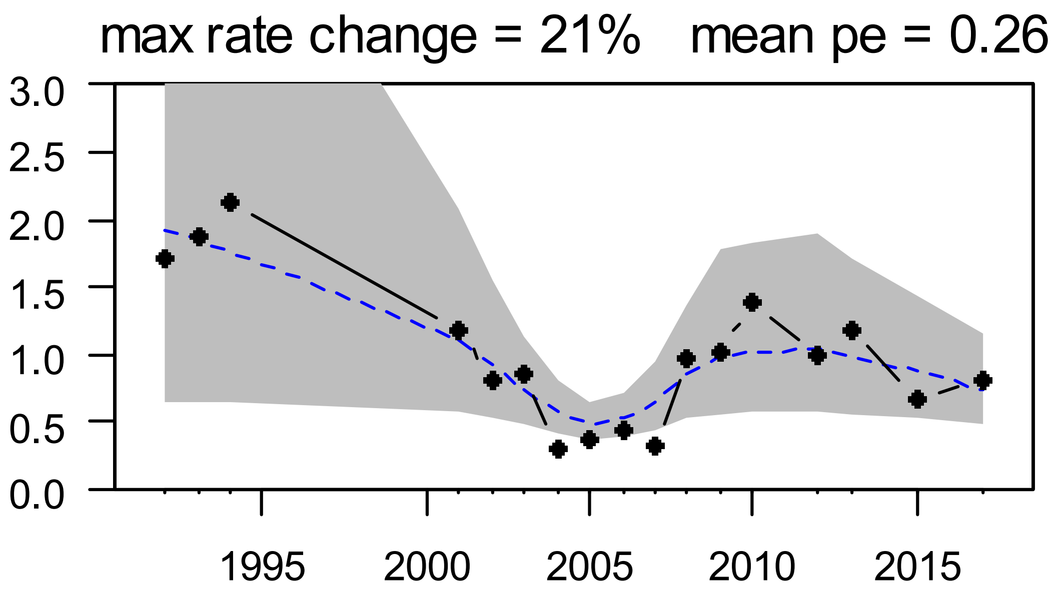

Figure 36: Constrained fitted lowess curve for the Sub-Antarctic trawl survey, with minimum amount of smoothing consistent with a maximum annual rate of change of 21%.

5.7 Impact of western acoustic survey on western stock biomass trajectory

With WCacous in the model and its associated catchability prior, the current biomass for the western stock is estimated to be 48%B_0; without WCacous current biomass is 39%B_0 (see Table 16, Figures 37–39).

A posterior profile with the process errors set at the estimated values from run 1.1 indicates that WCacous fits slightly better with a higher western stock virgin biomass, whereas SAsumbio fits better with a lower western stock biomass (Figure 40). However, much of the difference in biomass estimates with and without WCacous is driven by the WCacous catchability prior, which is more consistent with a higher western virgin biomass (Figure 41).

The biomass signal from WCacous is flatter relative to the rest of the model data (in particular the Sub-Antarctic trawl survey). Without WCacous in the model the biomass trajectory is steeper, with a better fit to the Sub-Antarctic trawl survey (Figure 42). With an estimated process error of 0.38 for the Sub-Antarctic trawl survey, the total CVs for half of the years for WCacous are comparable or less (see Table 8). The 2012 and 2013 WCacous indices have a particular impact with CVs of 0.34 and 0.35 respectively and a large temporal separation from the other WCacous indices (Figure 43).

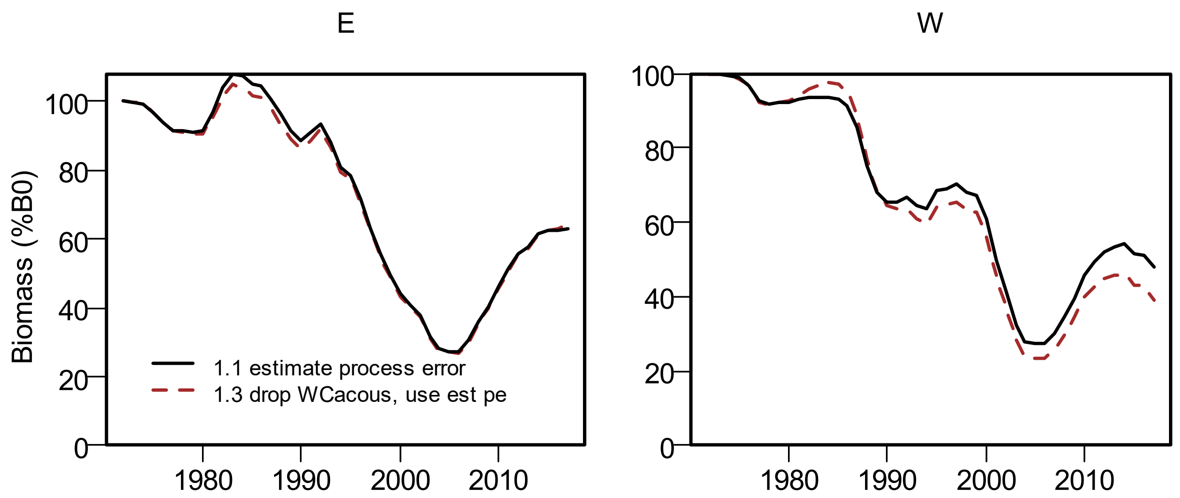

Figure 37: Comparison of biomass trajectories for runs 1.1 and 1.3: E stock (left column), W stock (right column).

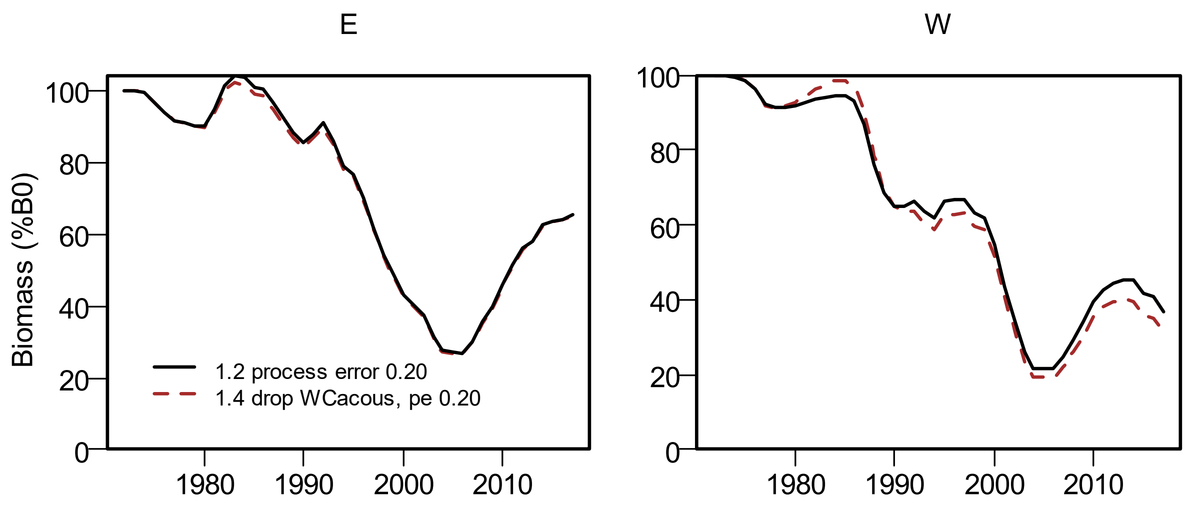

Figure 38: Comparison of biomass trajectories for runs 1.2 and 1.4: E stock (left column), W stock (right column).

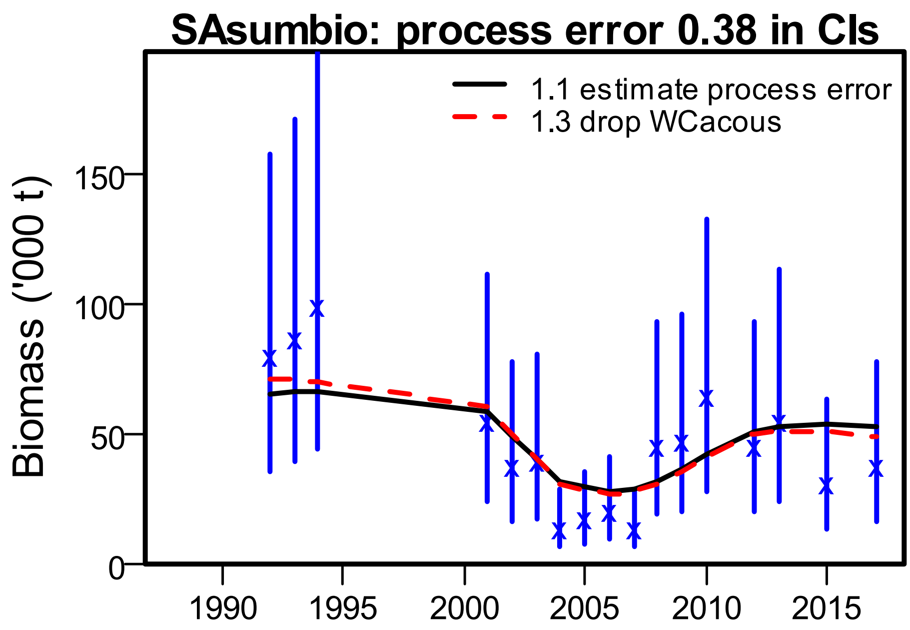

Figure 39: Fits to SAsumbio for 2017 runs 1.1 and 1.3, showing observed ('x', with vertical lines showing 95% confidence intervals including estimated process error) and expected values (lines). Plotted years are as in the model (so the last survey is plotted at 2017).

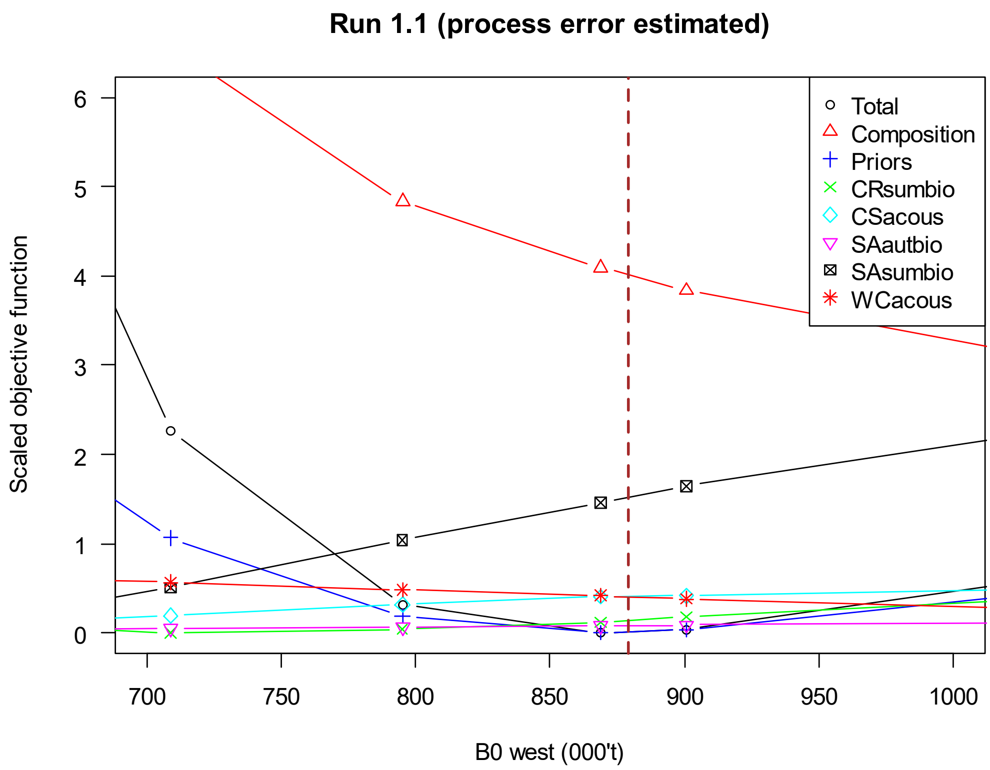

Figure 40: Likelihood profile for run 1.1, but with the process error fixed at their estimated values for the run (0.15 for CRsumbio and 0.38 for SAsumbio). Likelihood components are scaled so that they are zero at their minimum value. Note that in the assessment the western virgin biomass is a derived quantity from the estimated parameters: total virgin biomass, proportion of total virgin biomass in the eastern stock.

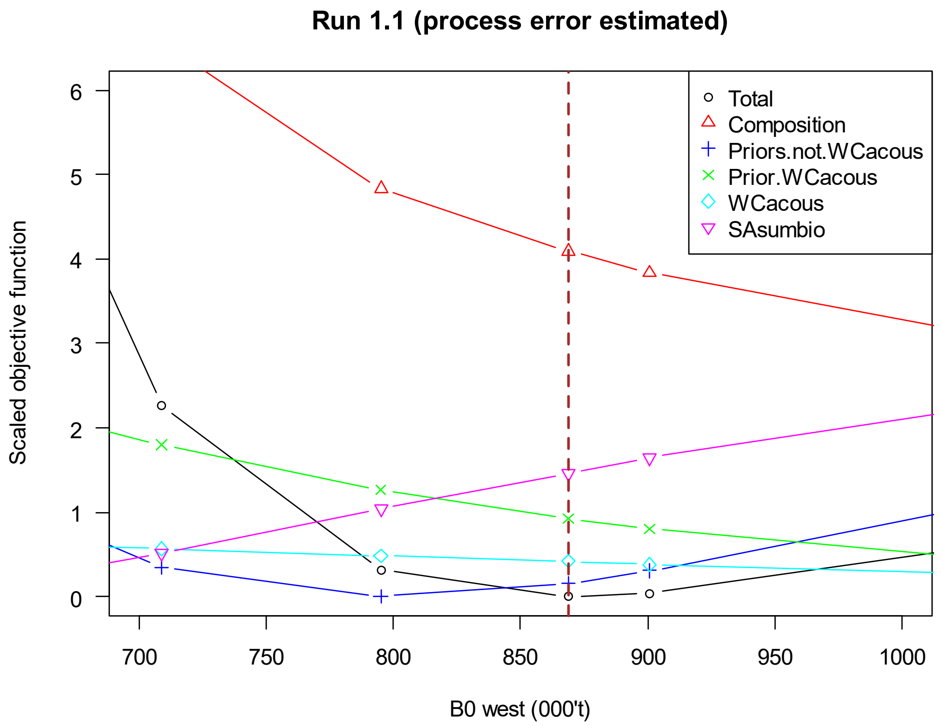

Figure 41: As in Figure 40 but showing selected components, and separating out the prior for WCacous from the rest of the priors.

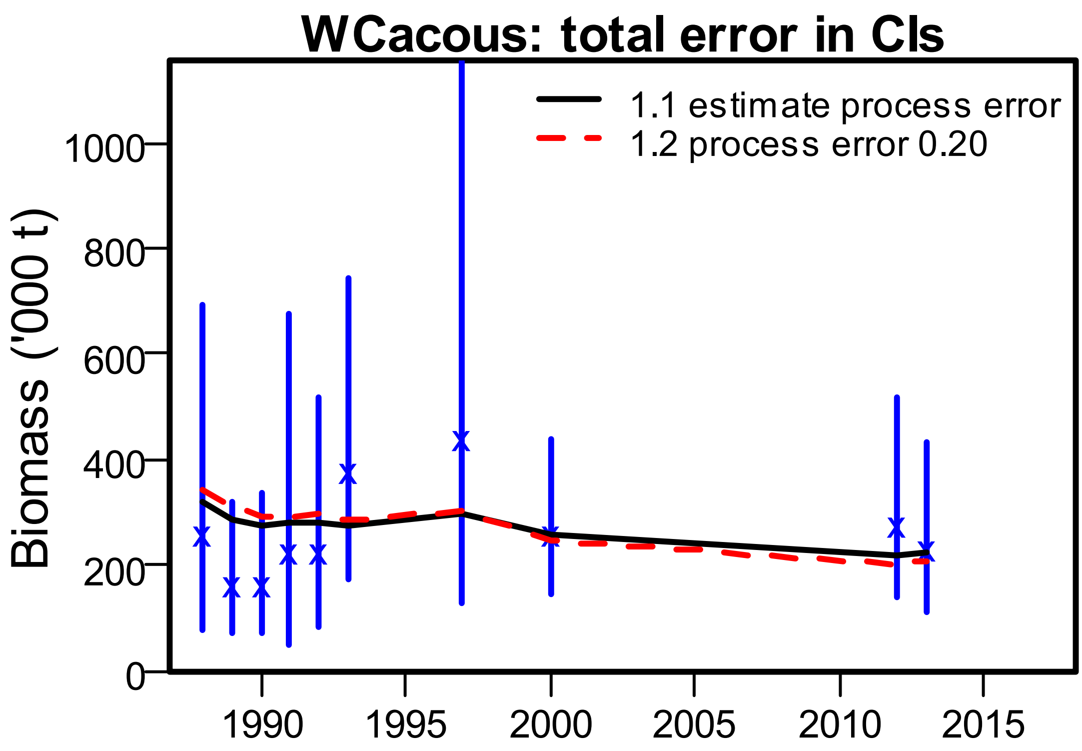

Figure 42: Fits to WCacous for 2017 runs 1.1 and 1.2 showing observed ('x', with vertical lines showing 95% confidence intervals based on the total error) and expected values (lines).

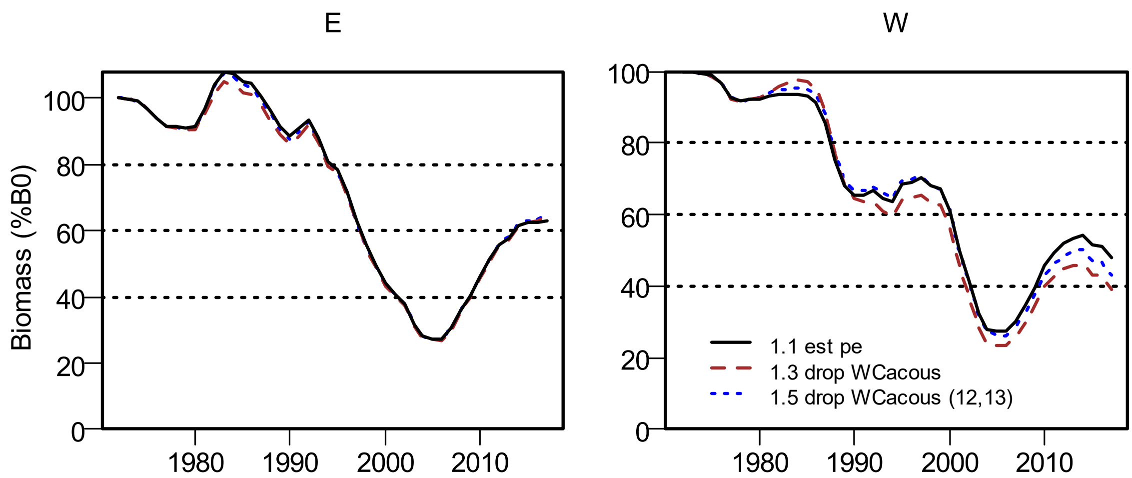

Figure 43: Comparison of biomass trajectories for runs 1.1, 1.3, and 1.5: E stock (left column) and W stock (right column). The process error for the Chatham Rise and Sub-Antarctic trawl surveys is the same as estimated in run 1.1. In run 1.5 the 2012 and 2013 biomass indices for WCacous are dropped, but the rest retained.

6. FINAL MODEL ASSESSMENT RESULTS

6.1 Introduction

Based on the initial model runs, it was decided by the Deepwater Working Group to take seven runs through to MCMC (Table 21). The base run 1.1 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. All runs were chosen by the Deepwater Working Group as final model runs, except for the run where WCacous is dropped and the process error set to 0.20 for the SAsumbio trawl survey (run 1.18).

In the model “pe 0.20” (run 1.15) the process error is set at 0.20 for both the Sub-Antarctic and Chatham Rise trawl surveys, giving more weight to the Sub-Antarctic trawl survey compared to the base run. The following three runs (1.16–1.18) test the sensitivity of the model to the two western stock biomass indices (SAsumbio, WCacous). In the last two model runs natal fidelity is not assumed but adult fidelity is (run 1.19), or a domed spawning selectivity is used instead of an age-dependent natural mortality (run 1.20).

Run 1.1 was preferred over the run with the process error set at 0.20 for the trawl surveys (1.15) 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 of 0.38 for run 1.1, compared to 0.20 for run 1.15, means that the estimate of western stock biomass is more uncertain.

Table 21: Runs taken through to MCMC.

Run	Short name	Model description
1.1	initial or base	natal fidelity *M* is age-dependent single q for Sub-Antarctic trawl series process error of CRsumbio and SAsumbio estimated in MPD run
1.15	pe 0.20	as 1.1 but process error fixed at 0.20
1.16	drop SAsumbio	as 1.1 but drop SAsumbio
1.17	drop WCacous	as 1.1 but drop WCacous
1.18	drop WCacous pe 0.20	as 1.1 but drop WCacous with process error fixed at 0.20
1.19	no natal fidelity	as 1.1 but natal fidelity is not assumed.
1.20	M constant	as 1.1 but with M constant and a one sex model.

For each run reweighting is done for the effective sample size of the at-age data, and the process errors for CRsumbio and SAsumbio estimated during the iterative reweighting process (except of course where they are fixed). This is done in an MPD run, and the estimates of effective sample sizes and process error are held fixed for the MCMC run.

Note that the model run numbers from 1.15 onwards are new compared to previous MPD runs, as the effective sample sizes and process errors are re-estimated. Three of the runs are new compared to the initial MPD runs: drop SAsumbio (1.16), no natal fidelity (1.19), and M constant (1.20).

Where the model description is "pe 0.20" this refers to the process error for the CRsumbio and SAsumbio trawl surveys. In run 1.16 where SAsumbio (Sub-Antarctic trawl survey biomass indices) is dropped the corresponding at-age data (SAsumage) is retained.

Estimated MPD trawl survey process errors for the runs are shown in Table 22. They range from 0.14–0.15 (CRsumbio) and 0.33–0.38 (SAsumbio).

Table 22: Chatham Rise and Sub-Antarctic process error for each run. For run 1.15 and 1.18 the process errors are set at 0.20 ("pe 0.20").

Run	Short name	CR process error	SA process error
1.1	base	0.15	0.38
1.15	pe 0.20	0.20	0.20
1.16	drop SAsumbio	0.15	-
1.17	drop WCacous	0.14	0.33
1.18	drop WCacous pe 0.20	0.20	0.20
1.19	no natal fidelity	0.15	0.48
1.20	M constant	0.15	0.43

6.2 MCMC setup

The MCMC chains were generated in the same way as the 2016 assessment (McKenzie 2017). For each model run three MCMC chains of length 4 million samples were created, with adaptive step size allowed during the first 100 000 samples. Each chain had a different starting point, which was generated by stepping randomly away from the MPD.

Following the practice of the previous assessment, catchability parameters are estimated as free parameters, all migration and selectivity migration are free in the MCMC (whether they run into bounds or not), and there is an equality constraint for the last estimated east and west year class strengths (2015 for this assessment).

Diagnostic plots comparing the three chains for each run, after removing the first 1/8 of each chain ("burn-in") are shown in Figures 44–47. They suggest that convergence was problematic in some aspects although they were adequate to estimate key quantities and their uncertainly (the "no natal fidelity" run 1.18 looks particularly problematic – for improvements see Section 6.5). To form the final single chain for each run, the first 1/8 of each chain was discarded (i.e. the first 500 000 samples from the chain of length 4 million were discarded), the three chains concatenated, and the resulting chain thinned by systematic sub-sampling to produce a posterior sample of length 2000.

6.3 Results for base and pe 0.20 runs

Estimate of 2016 biomass are similar between run 1.1 and the analogous model run 1.7 from the previous assessment (Figure 48).

When the process errors are set at 0.20 (instead of estimated) eastern stock current biomass is little changed, while for the western stock it decreases from 59%B_0 to 47%B_0 with less uncertainty (Table 23, Figure 49). The estimate of the last two year class strengths (2014, 2015) is very uncertain for both east and west stocks (Figures 50–51).

The estimated selectivities are similar for the 2017 models 1.1 and 1.5, as are the migration ogives and natural mortality estimates (Figures 52–54), and are similar to those for the 2016 assessment (Appendix 5). Where they do differ was noted previously for the MPD runs (see Section 4.2): the western and eastern spawning selectivities are flatter, and the proportion of ages six and seven fish that migrate from the Chatham Rise to the Sub-Antarctic is lower (Whome ogive).

Posteriors are within the bounds of the priors (Figure 55) and are very similar to those for the 2016 assessment (Appendix 5). The parameter a_shift that estimates annual changes in Wspsl has a median value of -0.028 and a posterior similar to the prior (Figure 56).

Residuals for SAsumbio and CRsumbio are shown in Figures 57–60. Run 1.1 was preferred as the base case over the run with the process errors set at 0.20 (run 1.15) by the Deepwater Working Group because the residual patterns for the fits to SAsumbio and CRsumbio were better.

6.4 Results for other model runs

Dropping the Sub-Antarctic trawl survey biomass indices (SAsumbio) leads to a much higher estimate for the western current biomass compared to the base (79%B_0 instead of 59%B_0) (Figure 61).

In contrast the west acoustic survey (WCacous) and its prior have a flatter biomass trend signal compared to SAsumbio, and dropping WCacous leads to a lower estimate for the western current biomass (47%B_0 instead of 59%B_0) (see Figure 61). Alternatively, comparing runs where the process errors are fixed at 0.20, western current biomass is estimated to be 41%B_0 instead of 47%B_0 when WCacous is dropped (Figure 62).

For both the no natal fidelity and constant M runs (1.19, 1.20) western current biomass is estimated to be higher than for the base model run (Figure 63). The eastern current biomass, however, is estimated to be lower for the no natal fidelity run and higher for the constant M run (see Figure 63).

Biomass trajectories are shown for runs 1.1, and 1.15–1.17 (Figures 64–65).

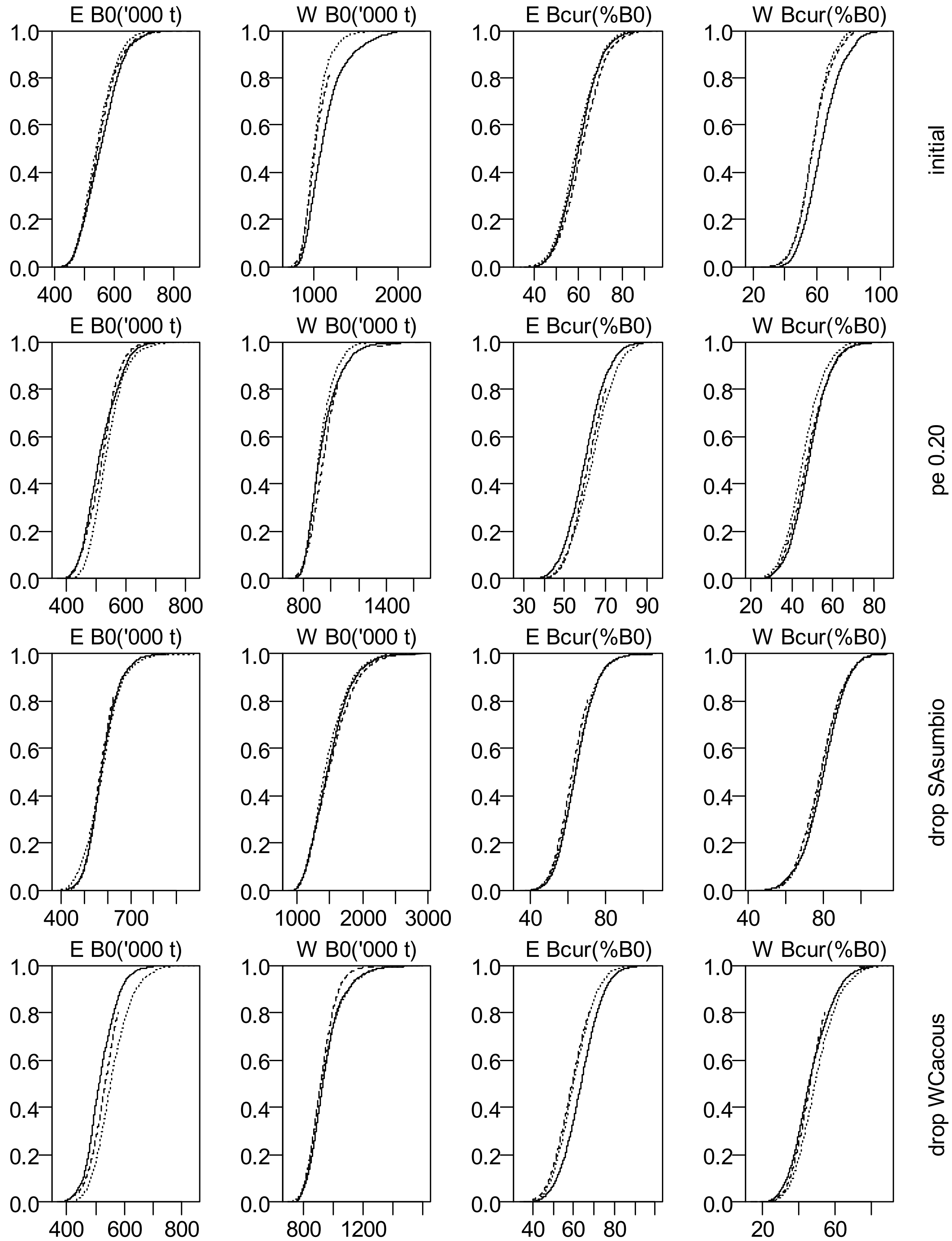

Figure 44: Diagnostics for MCMC chains for runs 1.1 (base) and 1.15–1.17. Each panel contains cumulative probability distributions, for B_0 or $B_{current}$, for three chains from the same model run. Samples from the burn in period are discarded for these results.

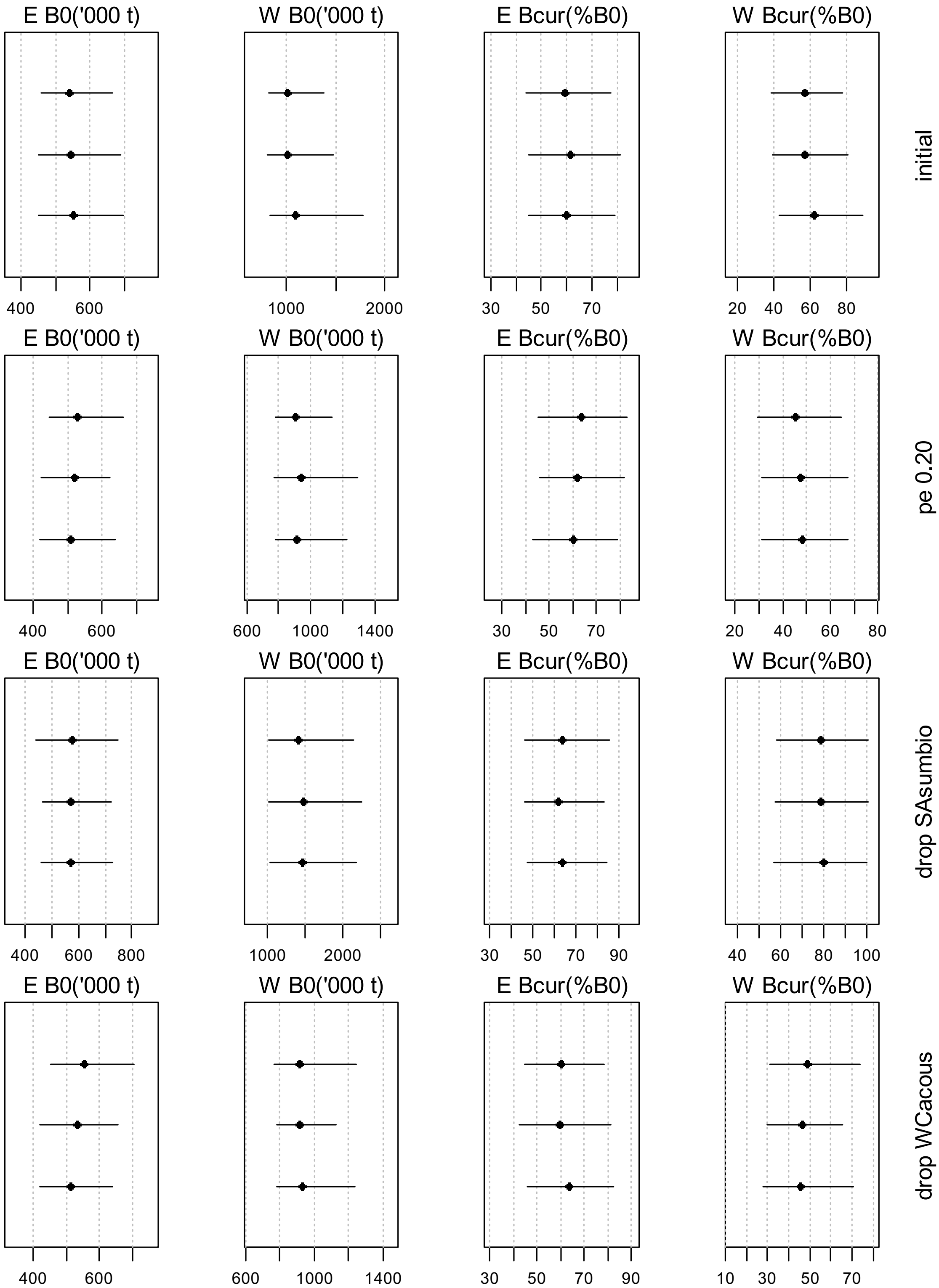

Figure 45: Further diagnostics for MCMC chains for runs 1.1 (base) and 1.15–1.17. Each panel contains the median (solid dot) and 95% confidence interval, for B_0 or $B_{current}$, for three chains from the same model run.

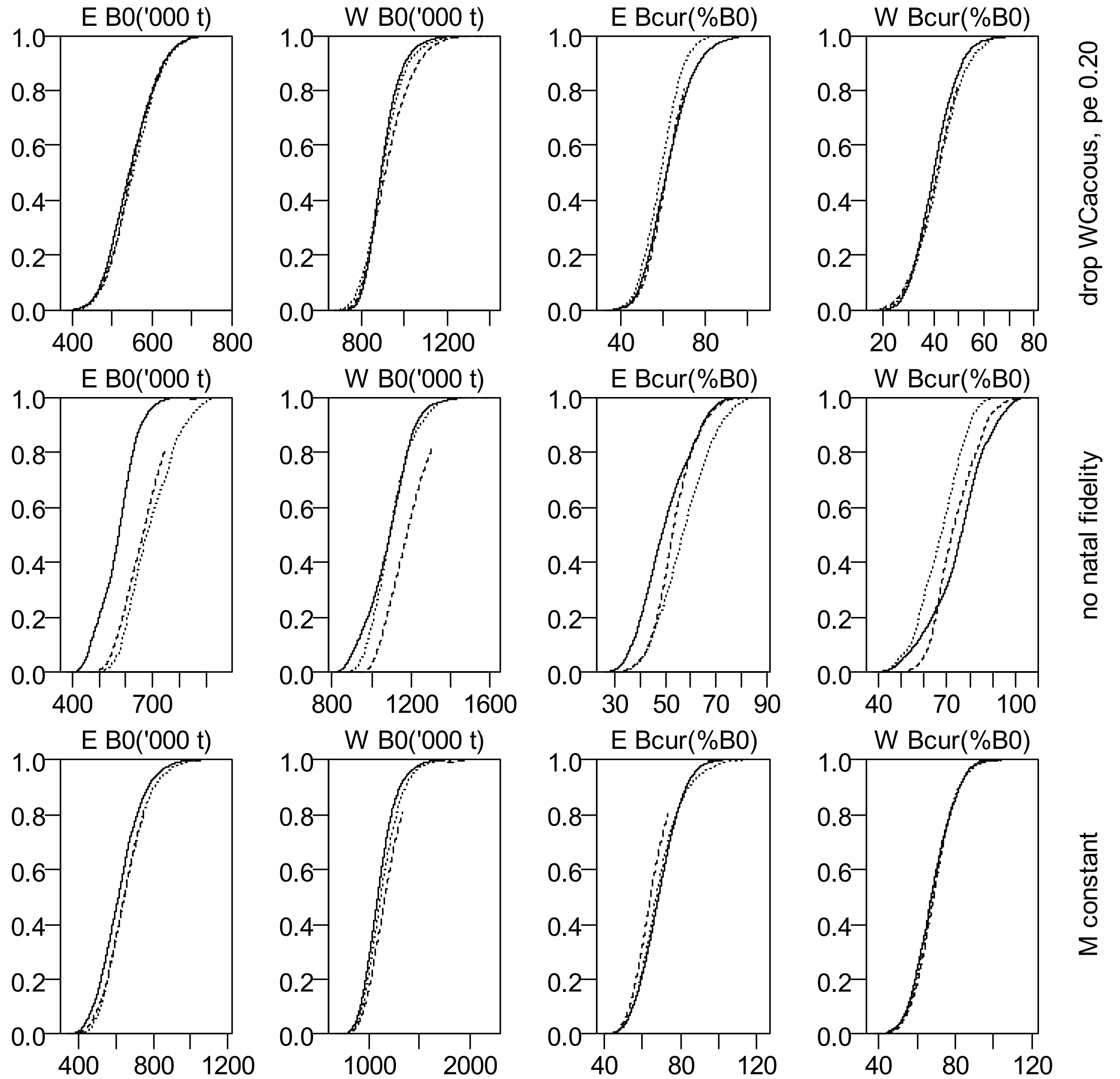

Figure 46: Diagnostics for MCMC chains for runs 1.18–1.20. Each panel contains cumulative probability distributions, for B_0 or $B_{current}$, for three chains from the same model run. Samples from the burn in period are discarded for these results.

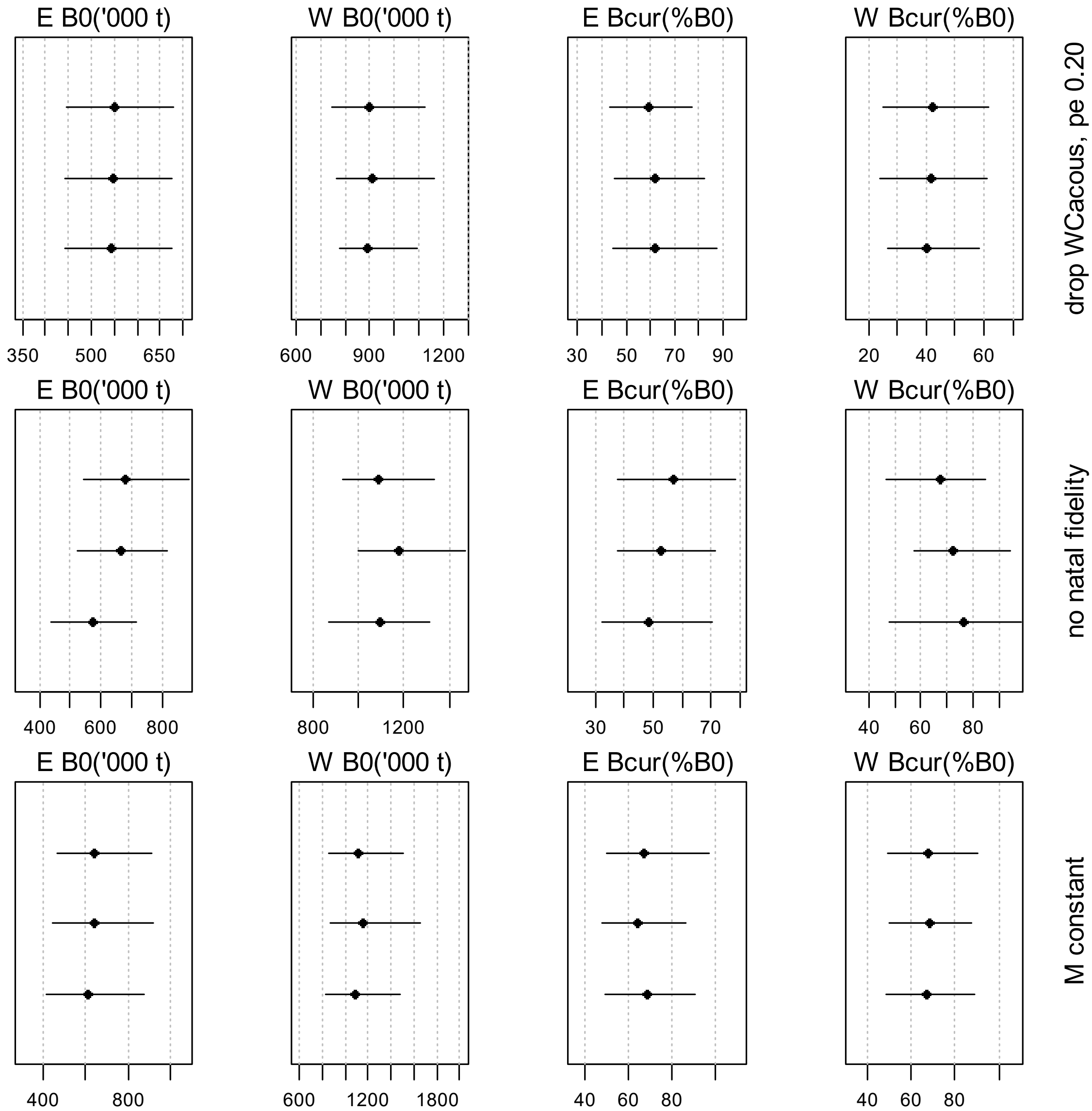

Figure 47: Further diagnostics for MCMC chains for runs 1.18–1.20. Each panel contains the median (solid dot) and 95% confidence interval, for B_0 or $B_{current}$, for three chains from the same model run.

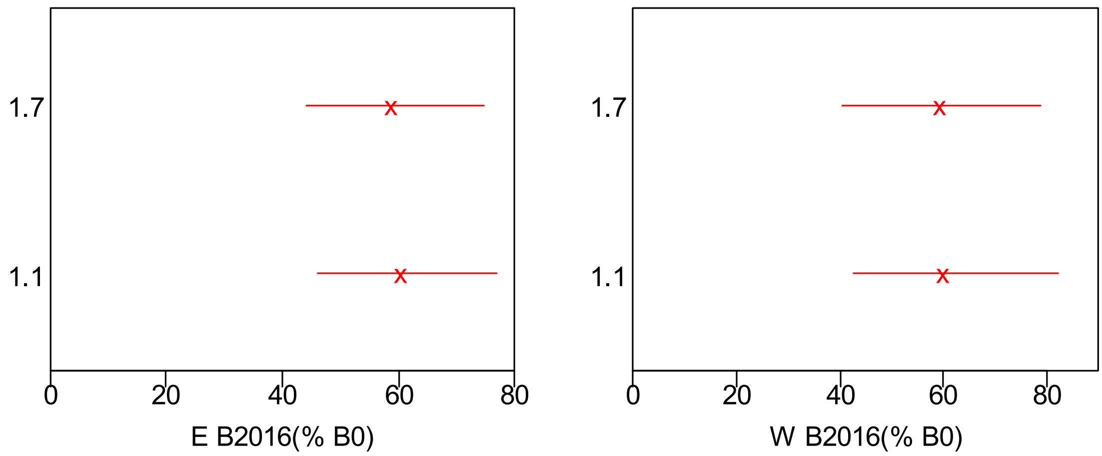

Figure 48: Comparison of 2017 continuity run 1.1 (single q) with the comparable run from 2016 (1.7): estimates of stock status in 2016 (B_{2016} as $\%B_0$), with 95% confidence intervals shown as horizontal lines.

Table 23: Estimates of spawning biomass (medians of marginal posterior, with 95% confidence intervals in parentheses). $B_{current}$ is the biomass in mid-season 2017.

	B_0('000 t)		$B_{current}$('000 t)		$B_{current}$($\%B_0$)	
Run	E	W	E	W	E	W
initial	547(455,684)	1031(824,1594)	328(223,492)	611(338,1263)	60(44,79)	59(40,84)
pe 0.20	522(428,643)	923(782,1223)	322(205,479)	431(249,783)	62(44,81)	47(31,66)
drop SAsumbio	573(453,735)	1453(1037,2220)	360(232,562)	1140(638,2042)	63(46,84)	79(58,100)
drop WCacous	535(429,674)	922(778,1216)	323(212,483)	434(239,792)	60(44,81)	47(29,70)
drop WCacous pe 0.20	551(445,677)	898(764,1132)	336(220,492)	367(201,639)	61(44,82)	41(25,61)
no natal fidelity	632(456,845)	1116(901,1398)	341(171,551)	808(457,1237)	53(35,74)	72(48,95)
M constant	634(438,909)	1116(858,1580)	418(253,694)	767(456,1226)	66(48,92)	68(49,90)

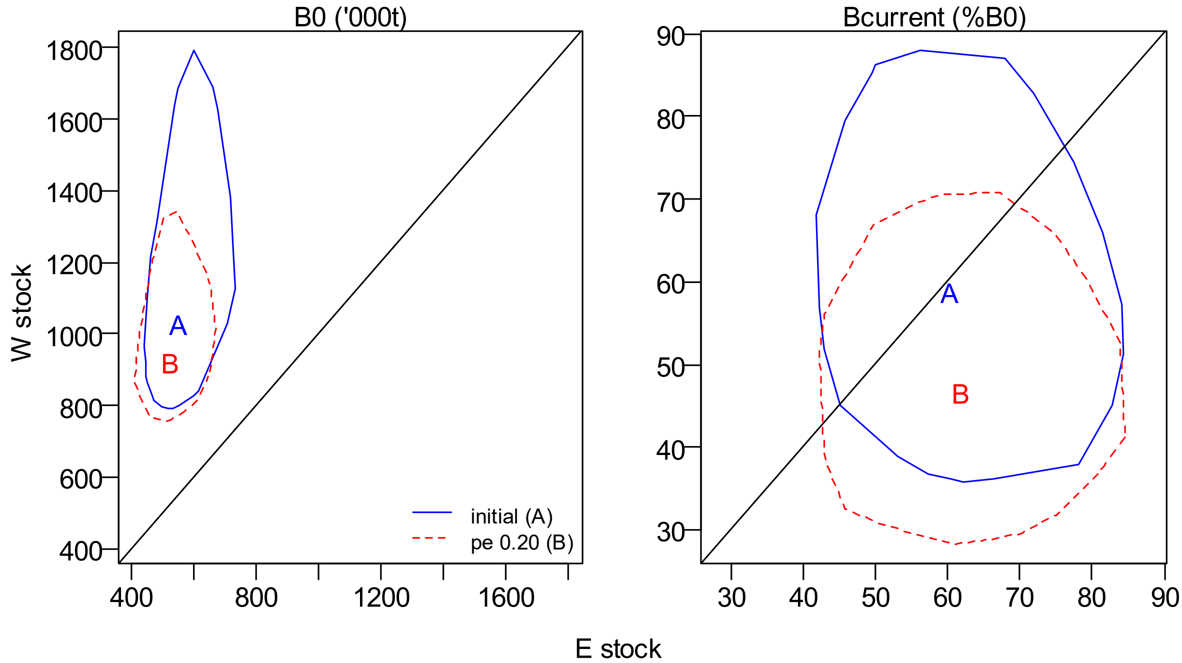

Figure 49: Estimates and approximate 95% confidence intervals for virgin (B_0) and current ($B_{current}$ as %B_0) biomass by stock for the two runs 1.1 (A) and 1.15 (B). In each panel the points 'A' and 'B' indicate best estimates (median of the posterior distribution) for these two runs, and the polygons (with solid, broken and dotted lines, respectively) enclose approximate 95% confidence intervals. Diagonal lines indicate equality (y = x).

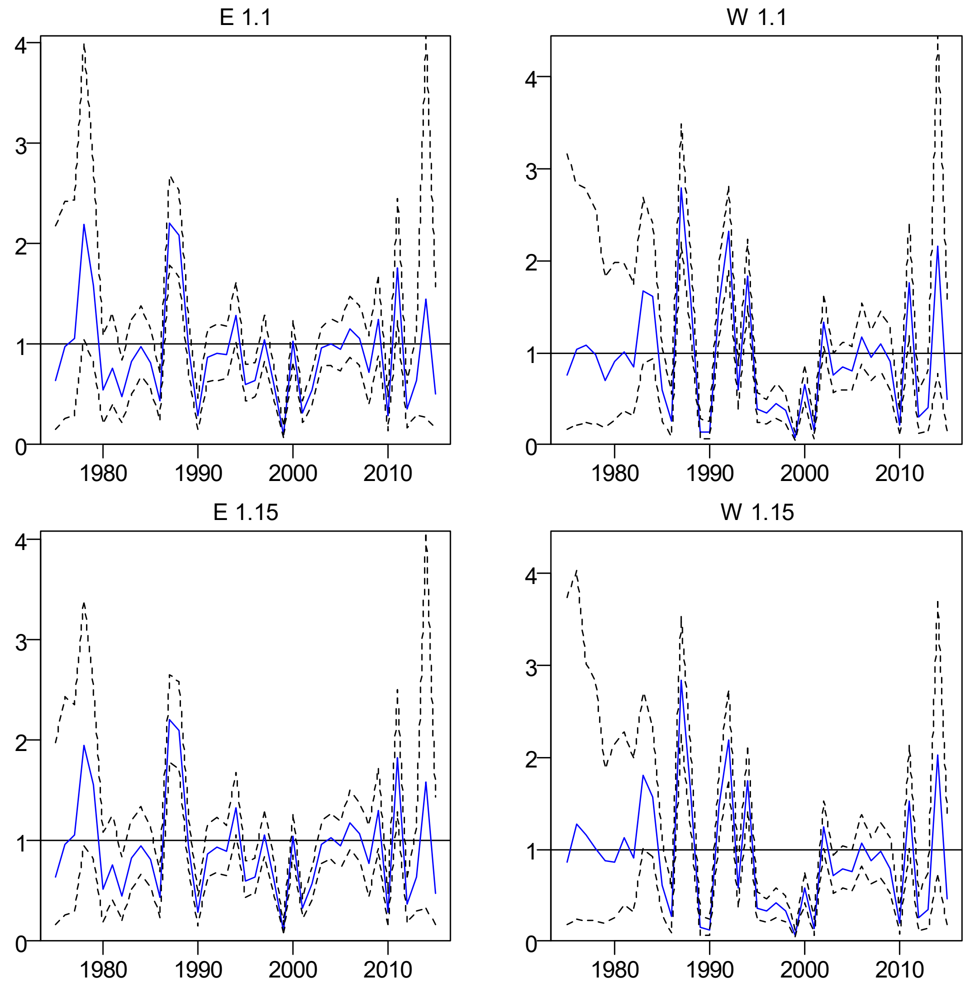

Figure 50: Estimated year-class strengths (YCSs) from the runs 1.1 and 1.15 showing medians (solid lines) and 95% confidence intervals (broken lines) by run for E (left panels), W (right panels).

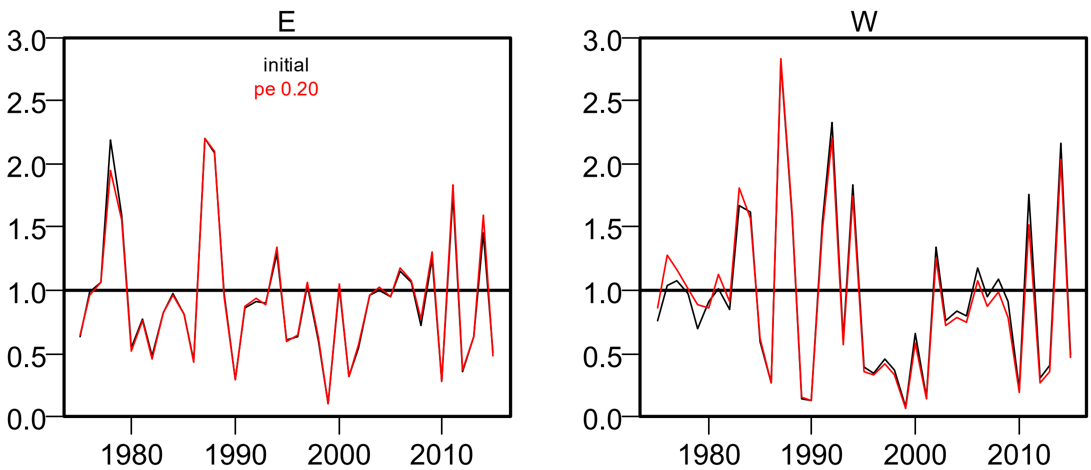

Figure 51: As in Figure 50 but showing just the medians.

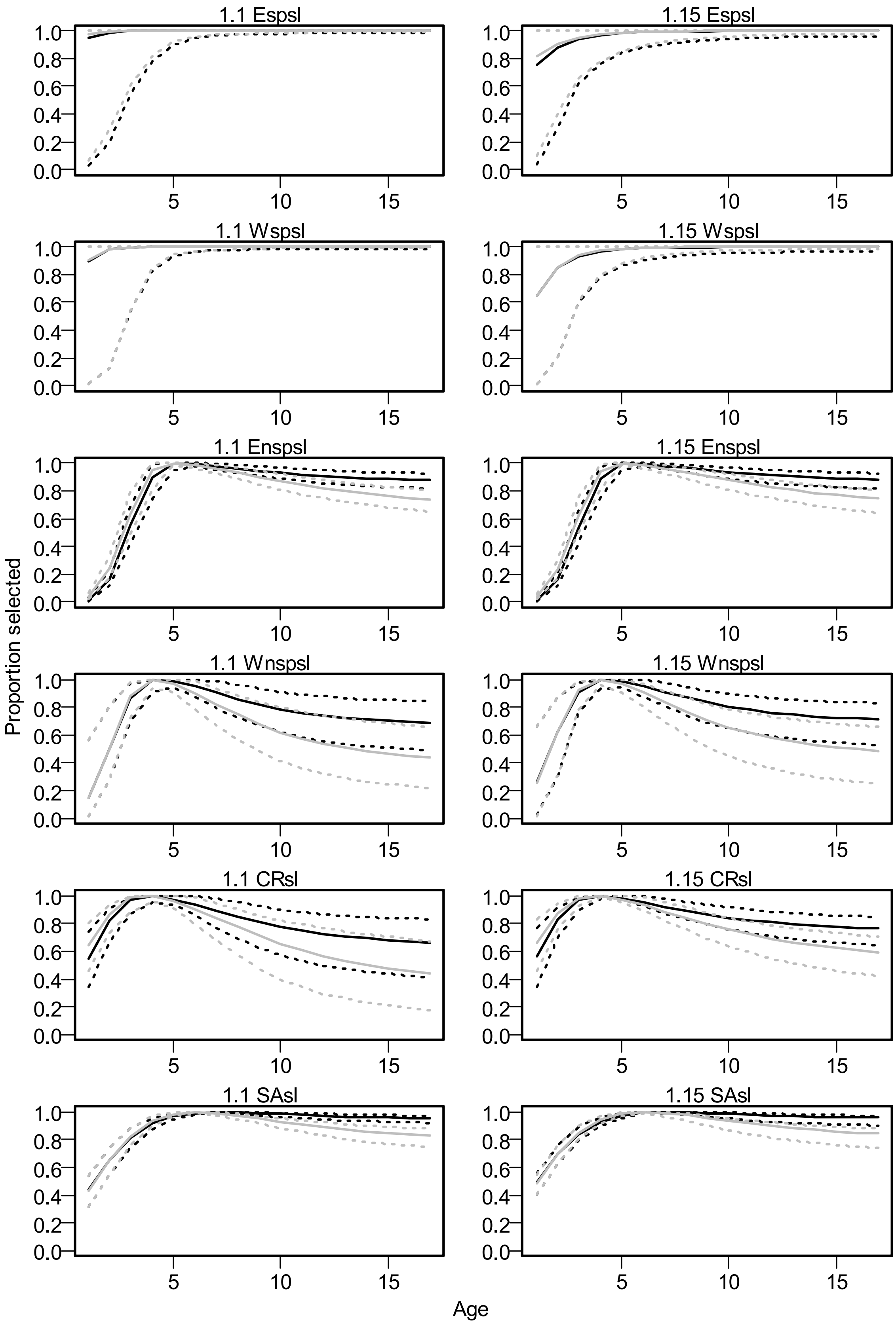

Figure 52: Posterior estimates of selectivity ogives for each for the two MCMC runs 1.1 and 1.15. Solid lines are medians; broken lines show 95% confidence intervals. Where ogives differ by sex they are plotted as black for males and grey for females. Where they differ by stock or time step the plotted curves are for one selected combination (E step 2 for Enspsl and CRsl, W step 2 for Wnspsl and SAsl).

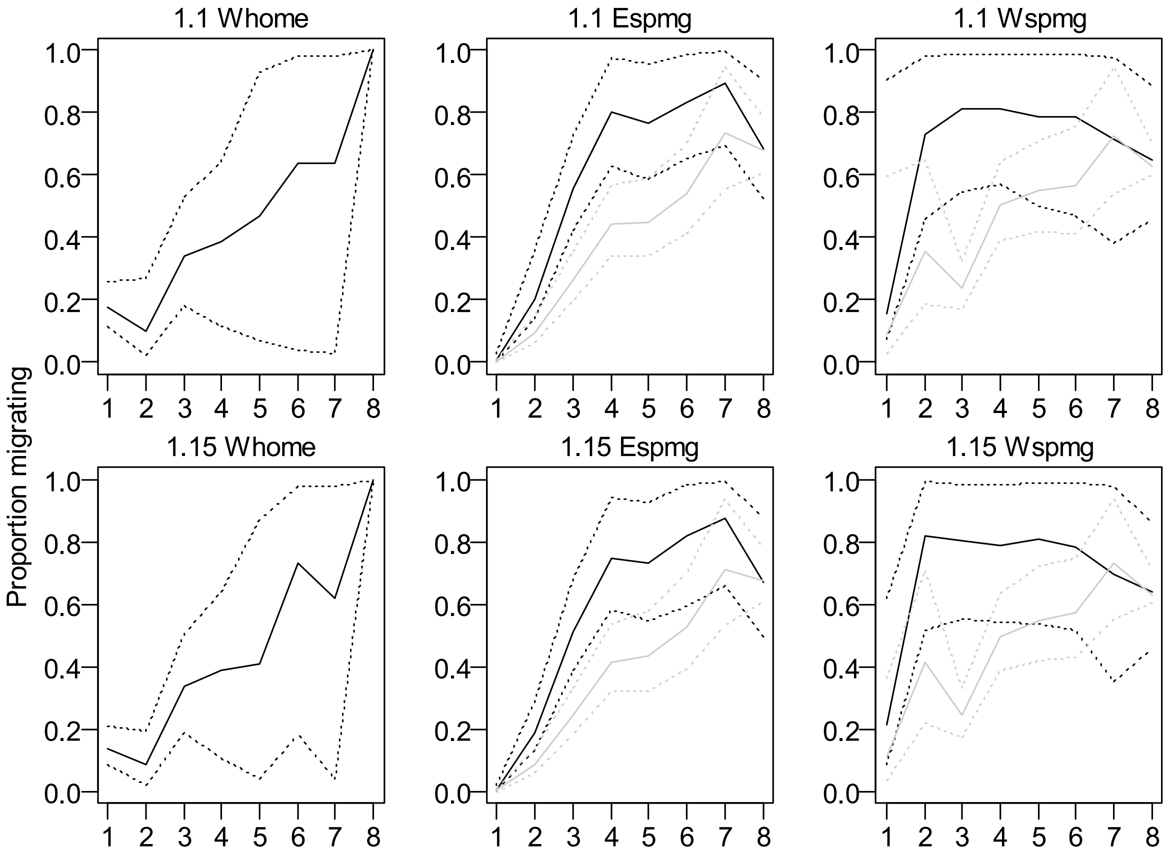

Figure 53: Estimated migration ogives estimated. Solid lines are medians, broken lines show 95% confidence intervals. Where ogives differ by sex they are plotted as black for males and grey for females. The x-axis shows age (years).

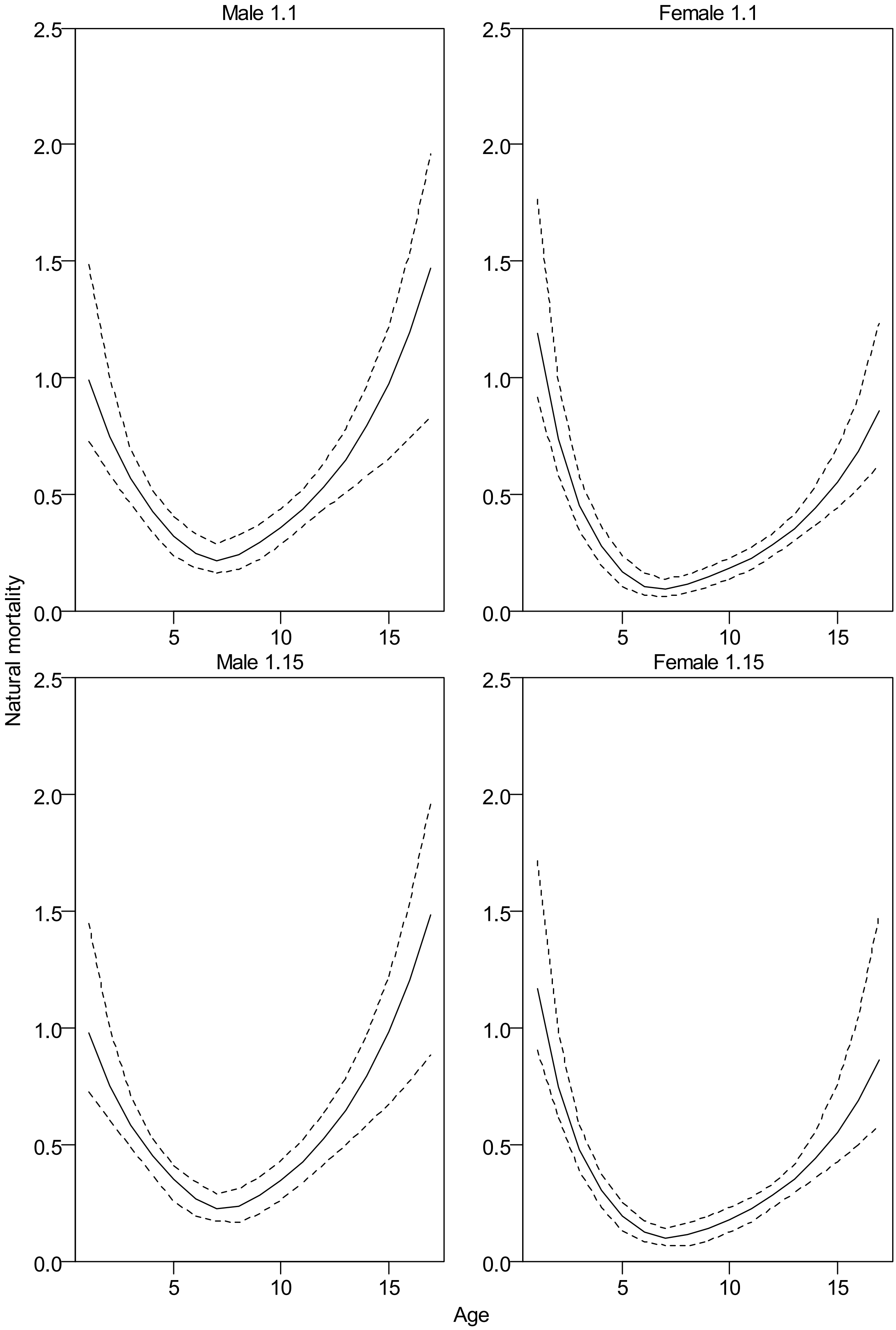

Figure 54: Assessment estimates of age-dependent natural mortality ogives for the MCMC runs showing median estimates (solid lines) and 95% confidence intervals (broken lines) for each sex.

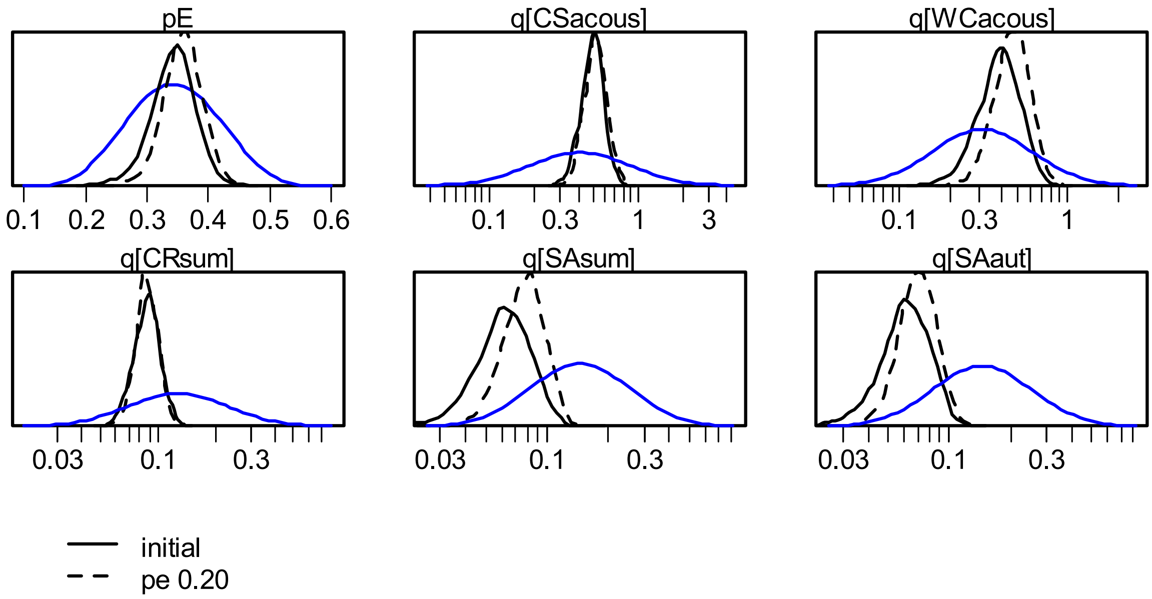

Figure 55: Assessment prior (blue lines) and estimated posterior (black lines) distributions for the following parameters: pE (proportion of B_0 in E stock), and survey catchabilities (acoustic and trawl).

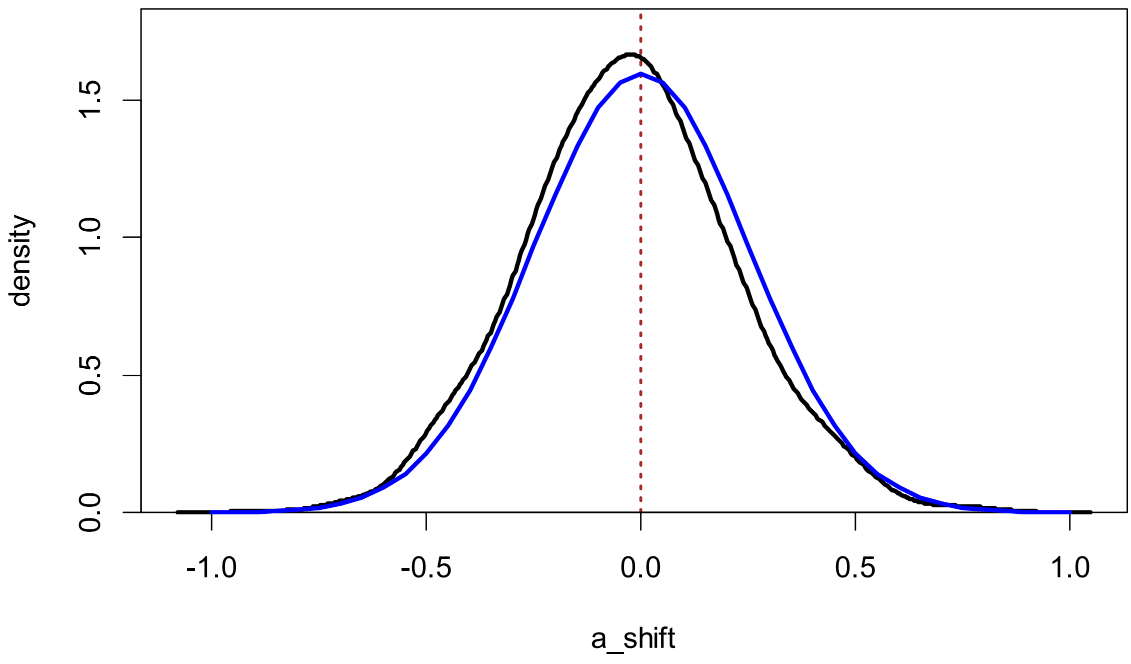

Figure 56: Assessment prior (blue line) and estimated posterior (black line) distributions for the a_shift parameter that estimates annual shifts in the western spawning selectivity.

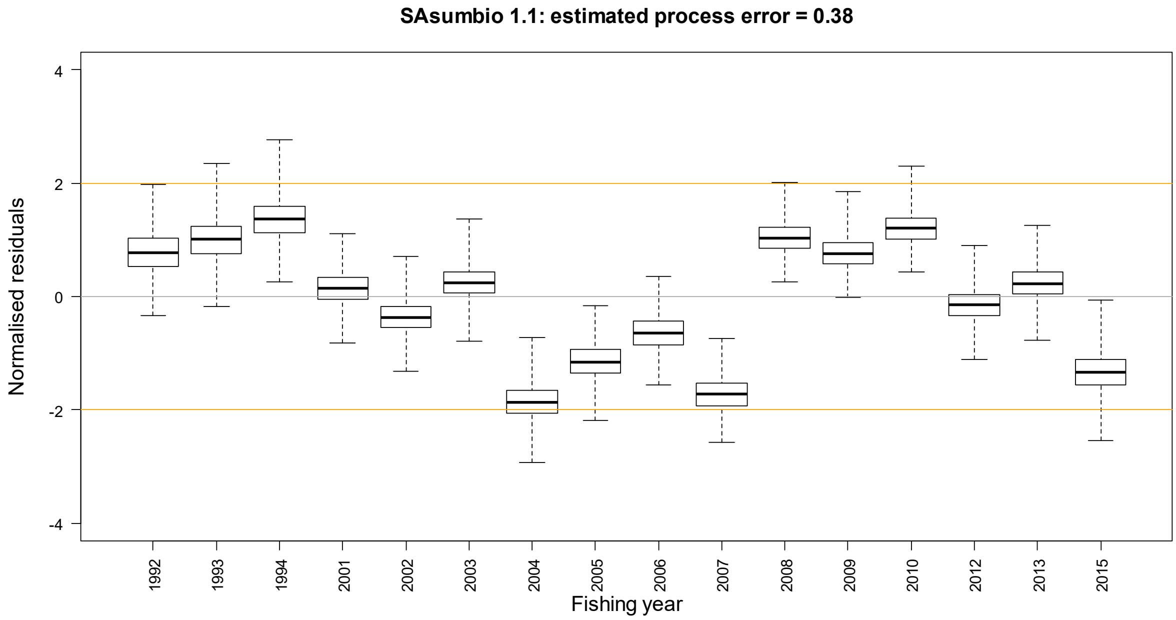

Figure 57: MCMC normalised residuals for model 1.1 and the fit to the Sub-Antarctic trawl survey.

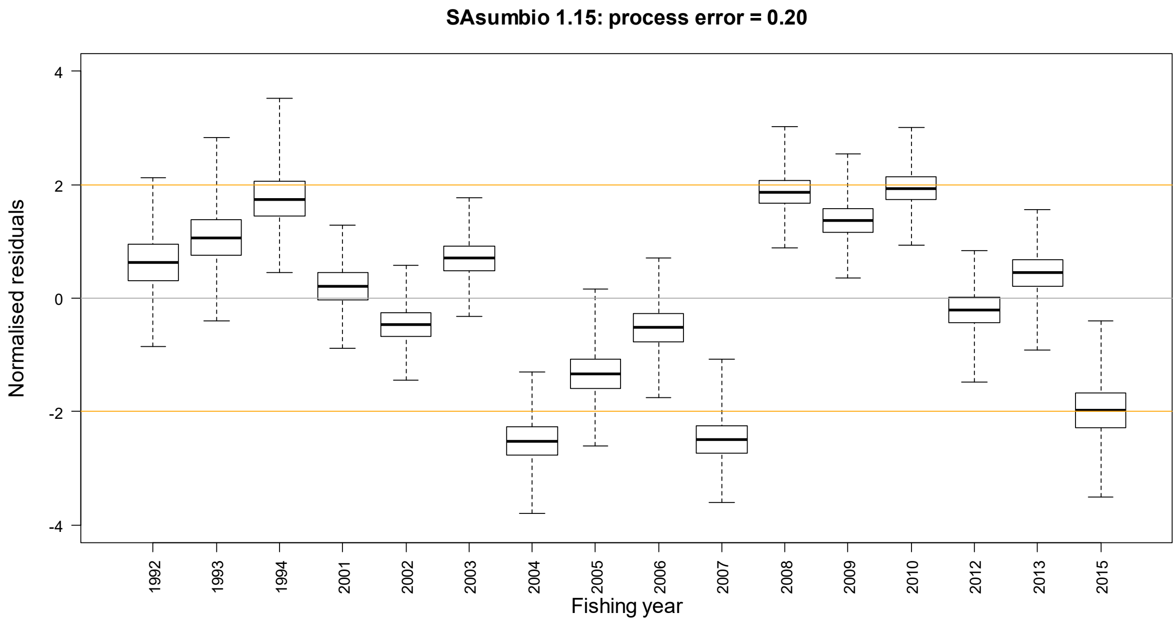

Figure 58: MCMC normalised residuals for model 1.15 and the fit to the Sub-Antarctic trawl survey.

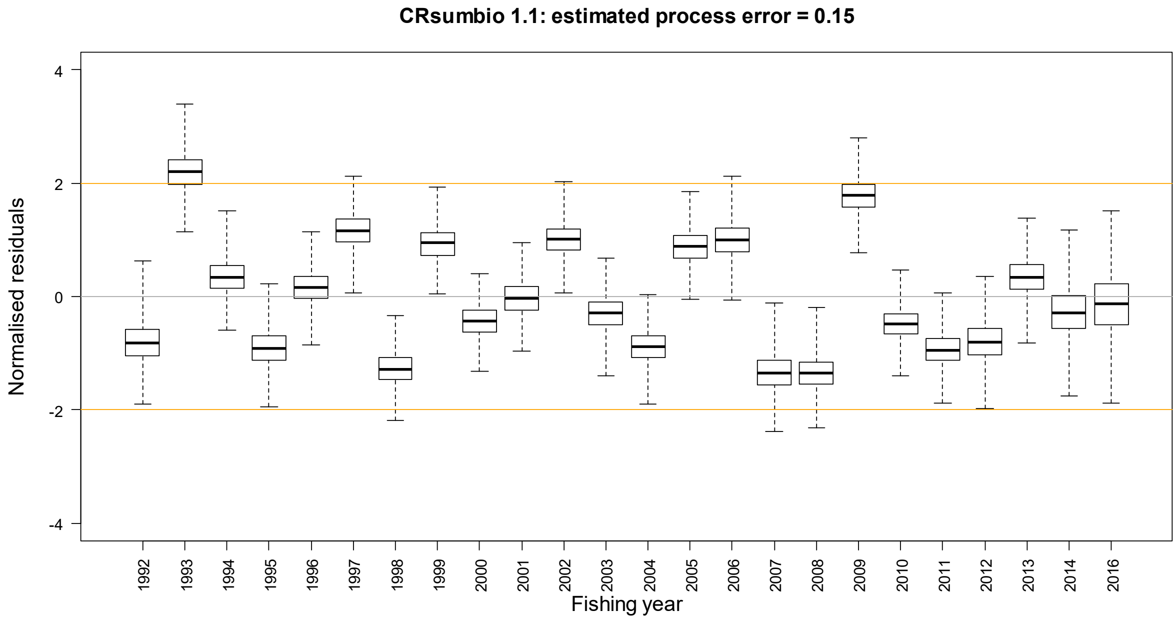

Figure 59: MCMC normalised residuals for model 1.1 and the fit to the Chatham Rise trawl survey.

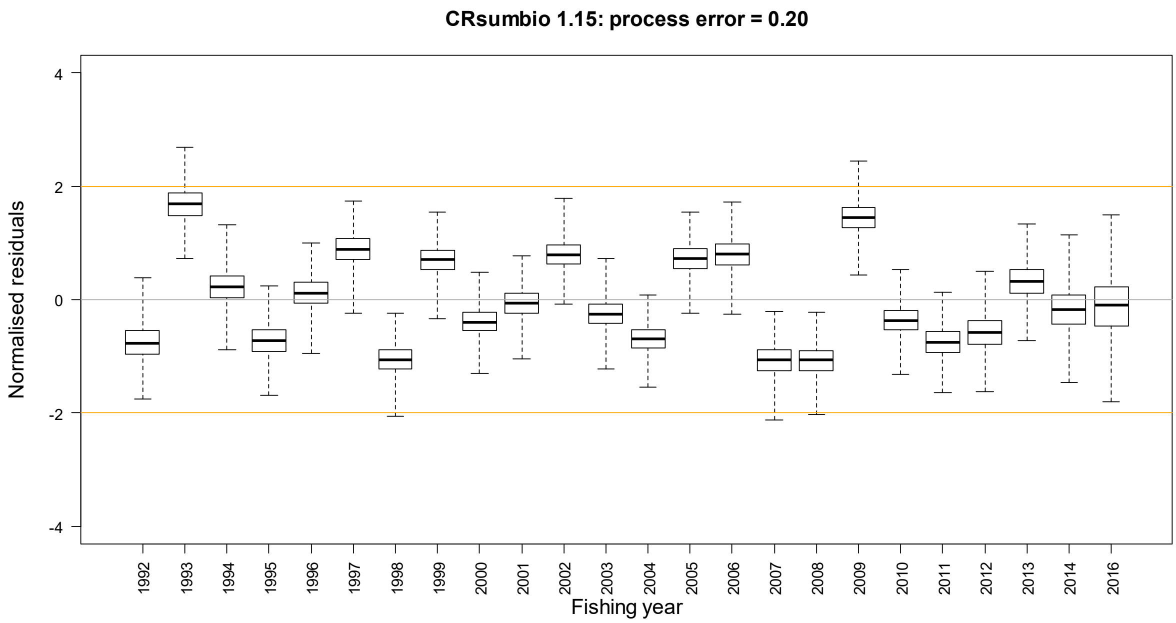

Figure 60: MCMC normalised residuals for model 1.15 and the fit to the Chatham Rise trawl survey.

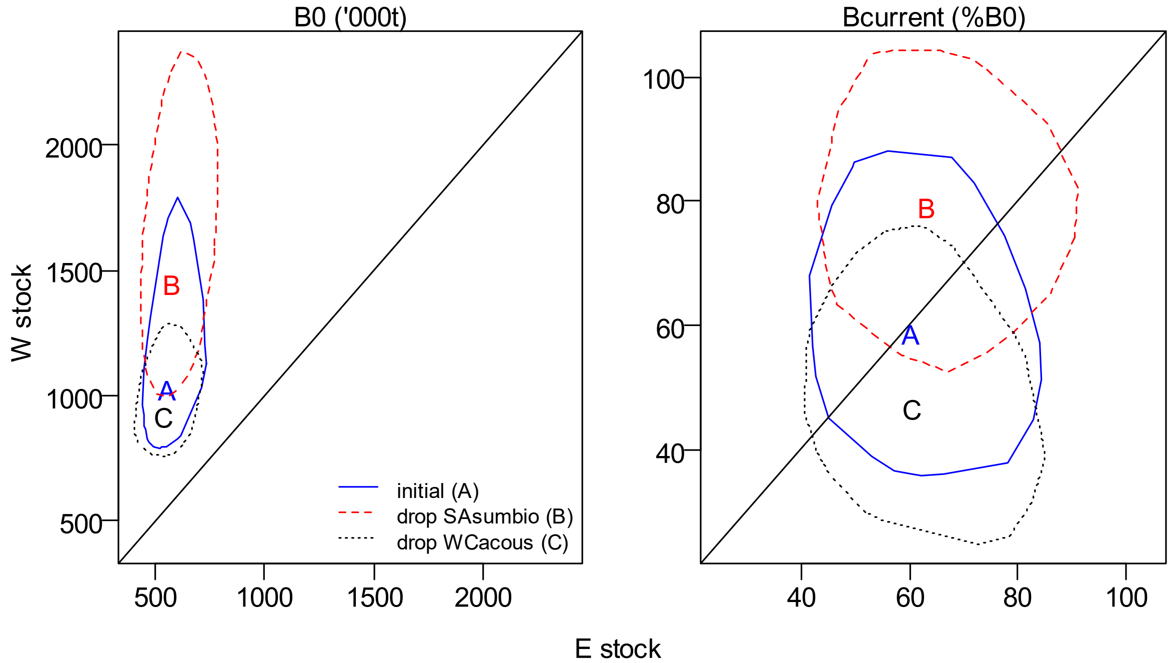

Figure 61: As in Figure 49 but for the three runs: 1.1 (A), 1.16 (B), and 1.17 (C).

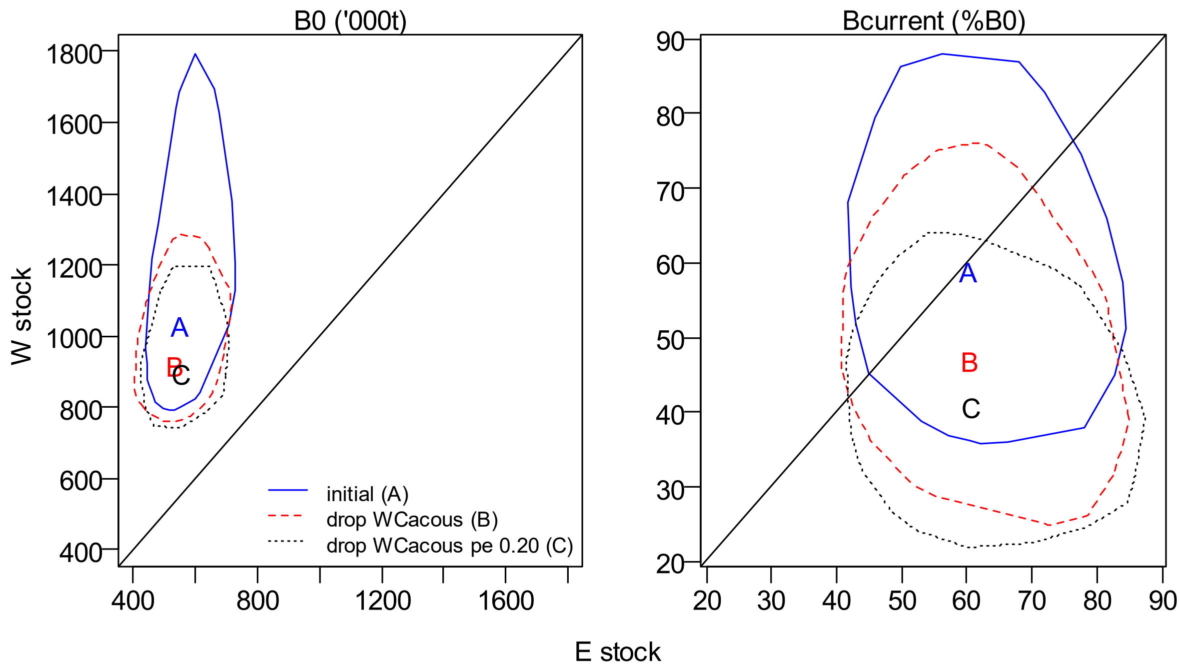

Figure 62: As in Figure 49 for the three runs: 1.1 (A), 1.17 (B), and 1.18 (C).

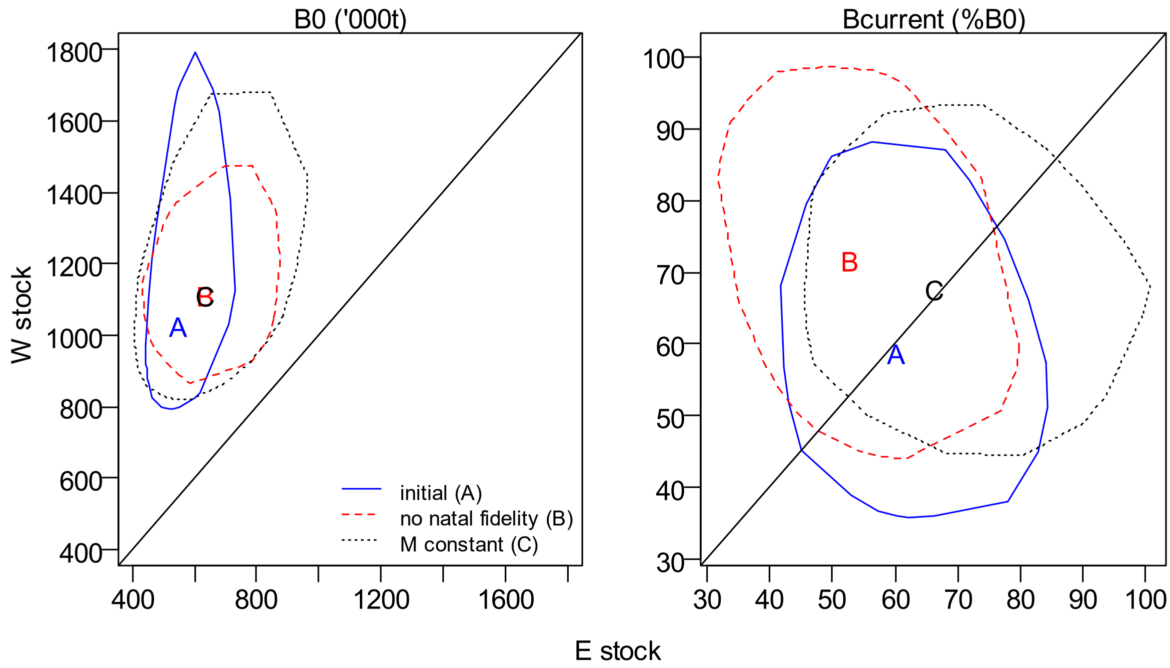

Figure 63: As in Figure 49 but for the three runs: 1.1 (A), 1.19 (B), and 1.20 (C).

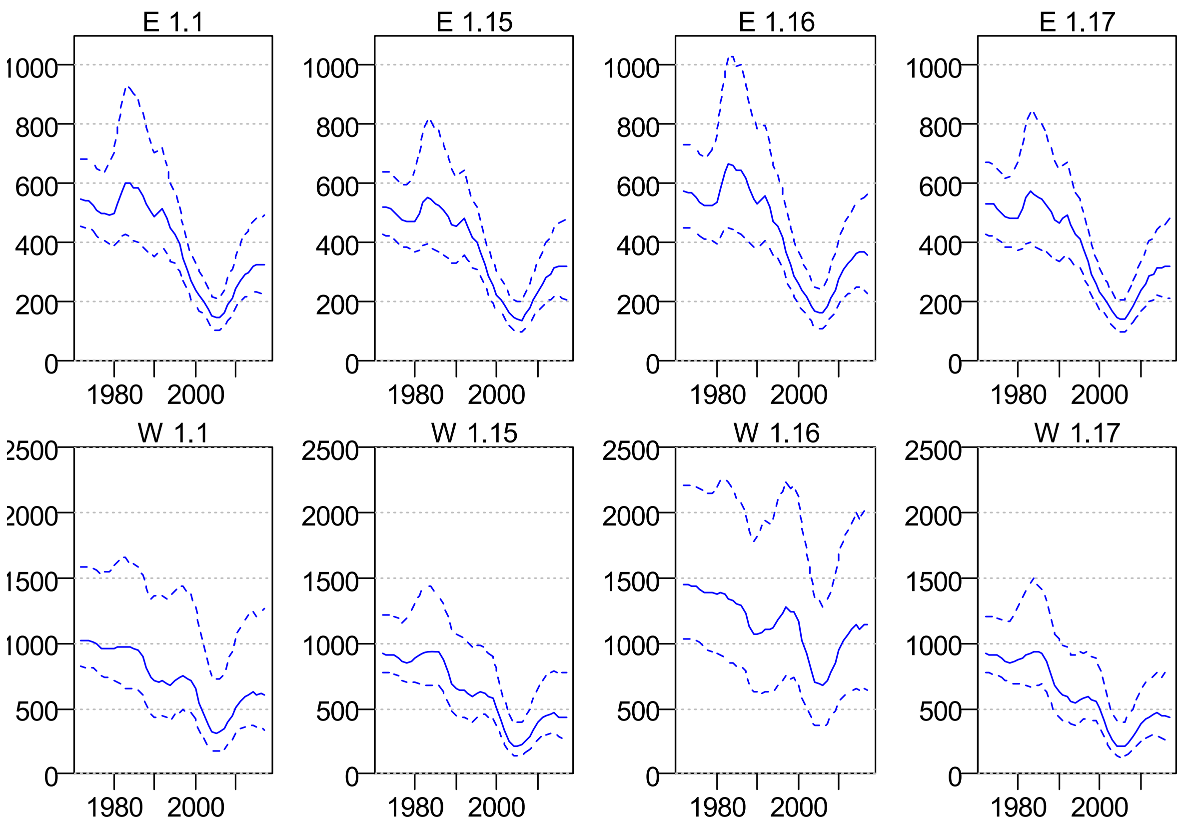

Figure 64: Estimated spawning-biomass trajectories from the MCMC runs, showing medians (solid lines) and 95% confidence intervals (broken lines) by run for E (upper panels) and W (lower panels).

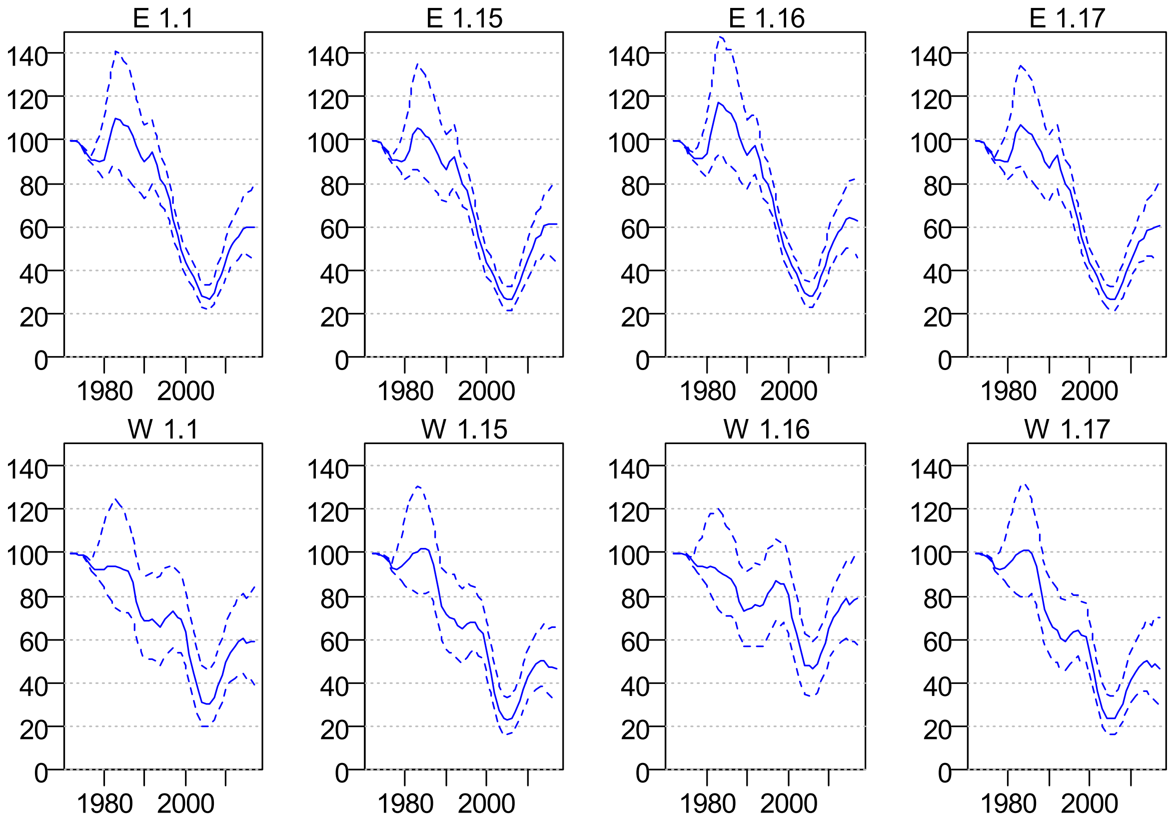

Figure 65: As in Figure 64, but plotted as %B_0.

6.5 Longer chain for the no natal fidelity model run

The diagnostic plots for the no natal fidelity run are not good, showing significant differences between the chains, though for all three chains current biomass is estimated to be at the upper end of the target management range of 35–50% (see Figures 46–47). Using chains of length 22.5 million instead of 4 million gives better diagnostics, though with little changes in biomass estimates (Figure 66–68).

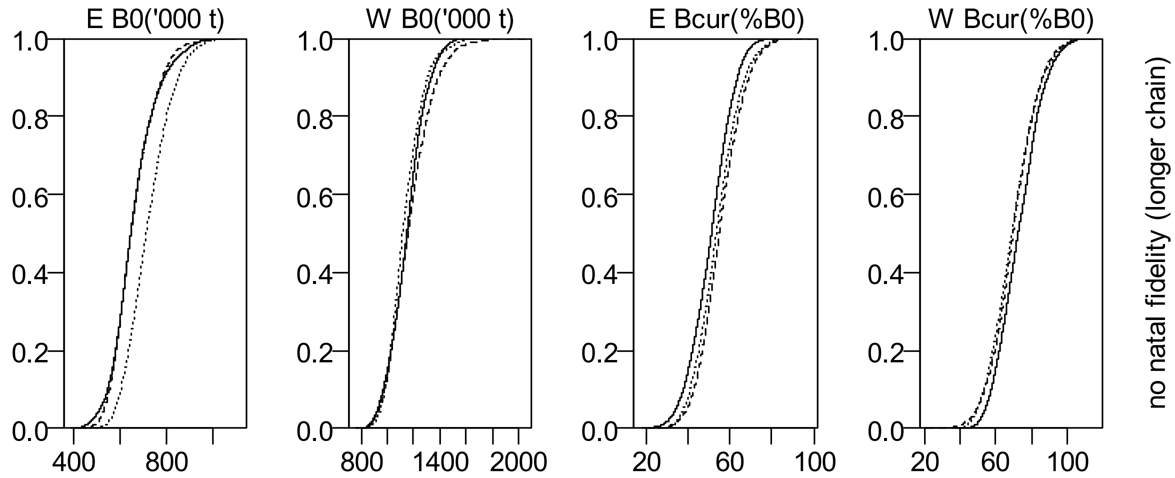

Figure 66: Diagnostics for longer MCMC chain for the no natal fidelity model run. Each panel contains cumulative probability distributions, for B_0 or $B_{current}$, for three chains from the same model run. Samples from the burn in period are discarded.

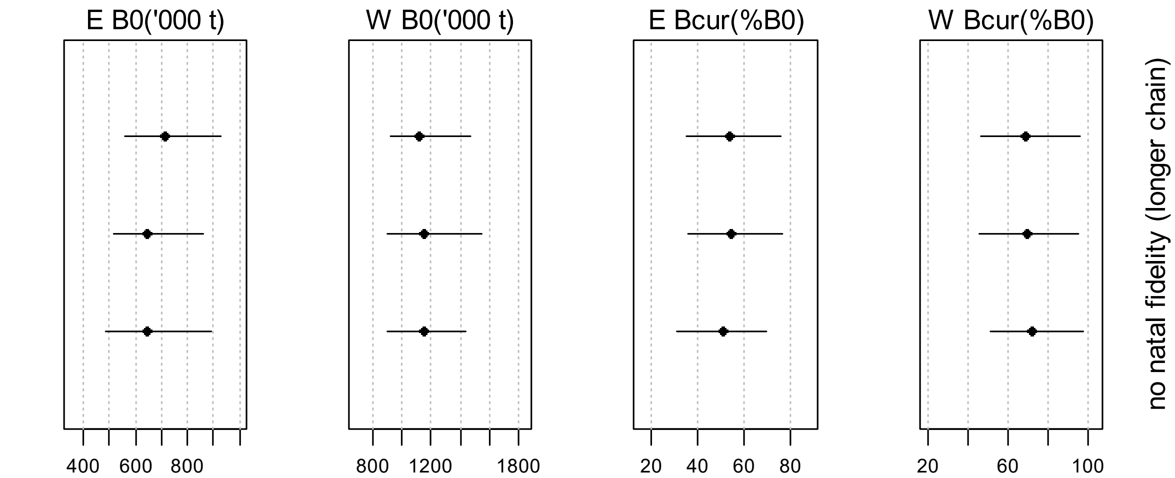

Figure 67: Further diagnostics for MCMC chain for the no natal fidelity model run with longer chains. Each panel contains the median (solid dot) and 95% confidence interval, for B_0 or $B_{current}$, for three chains from the same model run.

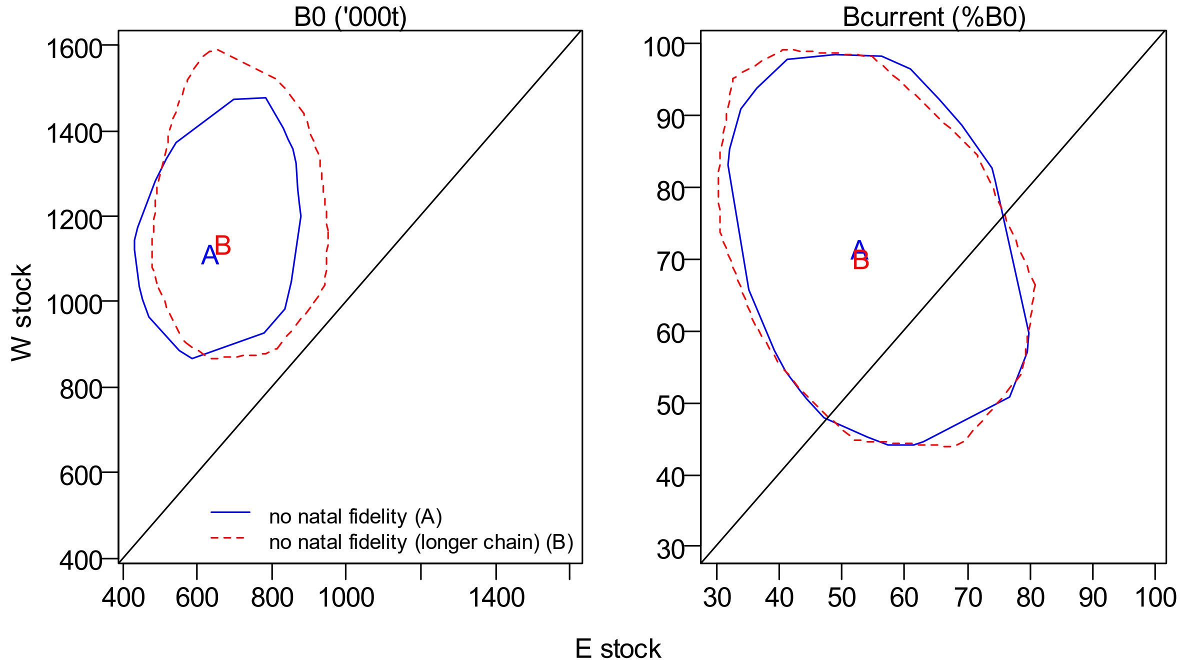

Figure 68: Estimates and approximate 95% confidence intervals for virgin (B_0) and current ($B_{current}$ as $\%B_0$) biomass by stock for the no natal fidelity model run, for a chain of length 4 million (A), and longer chain of length 22.5 million (B). In each panel the points 'A' and 'B' indicate best estimates (median of the posterior distribution) for these two runs, and the polygons (with solid, broken and dotted lines, respectively) enclose approximate 95% confidence intervals. Diagonal lines indicate equality (y = x).

7. PROJECTIONS

Five-year projections were carried out for the base model (1.1) and the most pessimistic model for the western stock (1.17), with future recruitments selected at random from those estimated for 2006–2015. Total catch was assumed to equal the current TACC of 150 000 t with 60 000 t catch for the east stock and 90 000 t for the west stock. The projections indicate that the E and W biomass are likely to increase slightly over the next five years (Figure 69).

The probabilities of the current (2017) 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 24. The probability of either stock being less than either the soft or the hard limit over the five year projection period is negligible. Both stocks are projected to be within or above the 35–50% B_0 target range at the end of the projection period.

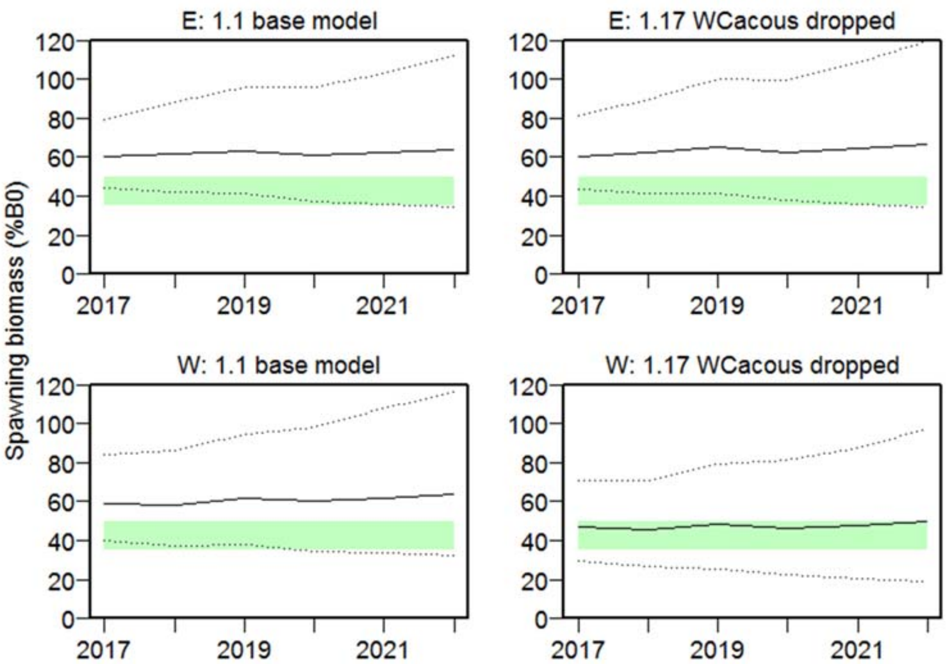

Figure 69: Projected spawning biomass (as %B_0): median (solid lines) and 95% confidence intervals (broken lines) for the base case (1.1) and a sensitivity run with the west coast South Island acoustic biomass series dropped (1.17). The shaded green region represents the target management range of 35–50% B_0.

Table 24: Probabilities (to two decimal places) associated with projections for east and west stock SSB ($\%B_0$) for the base case (1.1) for 2017 through to 2022, and a sensitivity run with the west coast South Island acoustic biomass series dropped (1.17).

	2017	2018	2019	2020	2021	2022
EAST 1.1						
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	0.01	0.02	0.03
P ($SSB<50\%B_0$)	0.11	0.14	0.14	0.20	0.20	0.20
EAST 1.17						
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	0.01	0.02	0.03
P ($SSB<50\%B_0$)	0.11	0.13	0.13	0.19	0.18	0.17
WEST 1.1						
P ($SSB<10\%B_0$)	0	0	0	0	0	0
P ($SSB<20\%B_0$)	0	0	0	0	0	0
P ($SSB<35\%B_0$)	0.01	0.01	0.02	0.03	0.03	0.04
P ($SSB<50\%B_0$)	0.18	0.23	0.17	0.24	0.23	0.21
WEST 1.17						
P ($SSB<10\%B_0$)	0	0	0	0	0	0
P ($SSB<20\%B_0$)	0	0	0.01	0.02	0.02	0.03
P ($SSB<35\%B_0$)	0.10	0.15	0.14	0.19	0.20	0.20
P ($SSB<50\%B_0$)	0.62	0.64	0.55	0.58	0.55	0.51

8. 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.

Calculations of fishing intensity and B_{MSY} were done for each sample from the MCMC, and results summarised as medians and credible intervals. The reference fishing intensities, $U_{35\%Bo}$ and $U_{50\%Bo}$ are summarised as medians.

Fishing intensity on both stocks was estimated to be at or near an all-time high in about 2003 and is now substantially lower (Figure 70).

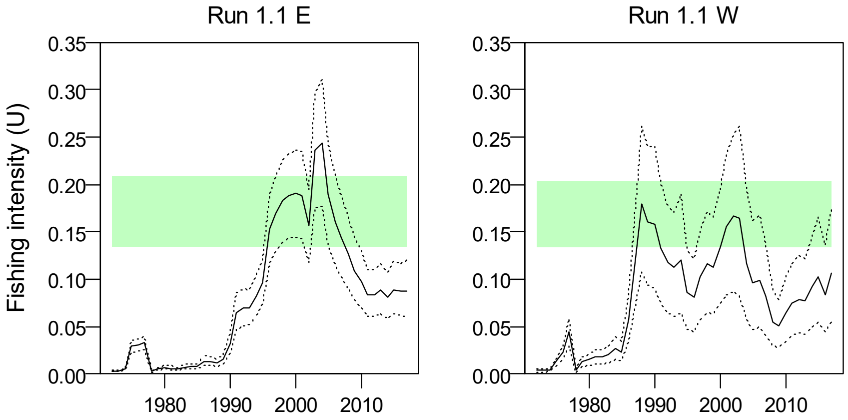

Figure 70: Fishing intensity, U (from MCMCs), plotted by stock. Shown are medians (solid black line) with 95% confidence intervals (dotted lines). Also shown shaded in green is the management range where the upper bound is the reference level $U_{35\%Bo}$ and the lower bound $U_{50\%Bo}$ which are the fishing intensities that would cause the spawning biomass to tend to 35% B_0 and 50% B_0, respectively.

9. CALCULATION OF B_{MSY}

B_{MSY} was calculated, for each stock, assuming a harvest strategy in which the exploitation rate for fishery *f* was $mU_{f,2017}$, where $U_{f,2017}$ is the estimated 2017 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*. Calculations of B_{MSY} were done for each sample from the MCMC, and results summarised as medians and credible intervals.

For the base run (1.1) estimates of deterministic B_{MSY} were 26.5% (95% CI 25.0–28.0) for the E stock and 26.9% (95% CI 25.6–28.0) 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 defined by the Harvest Strategy Standard.

10. DISCUSSION

The eastern and western stocks are estimated to have been increasing since about 2006. Current biomass is estimated to be 40–84% B_0 for the western stock and 44–79% 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 was well above average in 2011 and 2014, and below average in 2015. Projections indicate that with future catches equal to 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 variability, 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.

11. 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 NIWA Data Manager for fisheries data (David.Fisher@niwa.co.nz).

Appendix 2: Changes in stock-assessment model assumptions

Table 25: 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)
2017	Same model structure as previous year for the base case

Appendix 3: Reweighting the 2017 assessment at-age data

The same procedure as in McKenzie (2017) was used to reweight the at-age data for the model run 1.1. Summary results from the reweighting are shown in the table and figures below (Table 26, Figures 71–72). Final mean N values are very similar to those for the analogous model run 1.7 for the 2016 assessment (Table 27).

Table 26: 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	663	907	89	334	80	195	1347	572	829
2	66	33	13	38	103	16	93	14	24
3	72	24	12	39	61	14	72	15	16
4	79	21	12	38	58	15	66	17	15
5	82	20	12	38	57	15	64	18	14
Final	84	19	12	38	57	16	63	18	14
Initial/Final	8	48	7	9	1	12	21	32	59

Table 27: Comparing final mean values of N for at age data sets in the model: 1.7 from the 2016 assessment (denoted 2016.7) and 1.1 for the 2017 assessment.

Model	Espage	Wspage	EnspOLF	Enspage	WnspOLF	Wnspage	CRsumage	SAsumage	SAautage
2016.7	77	23	12	39	55	13	67	14	14
1.1	84	19	12	38	57	16	63	18	14

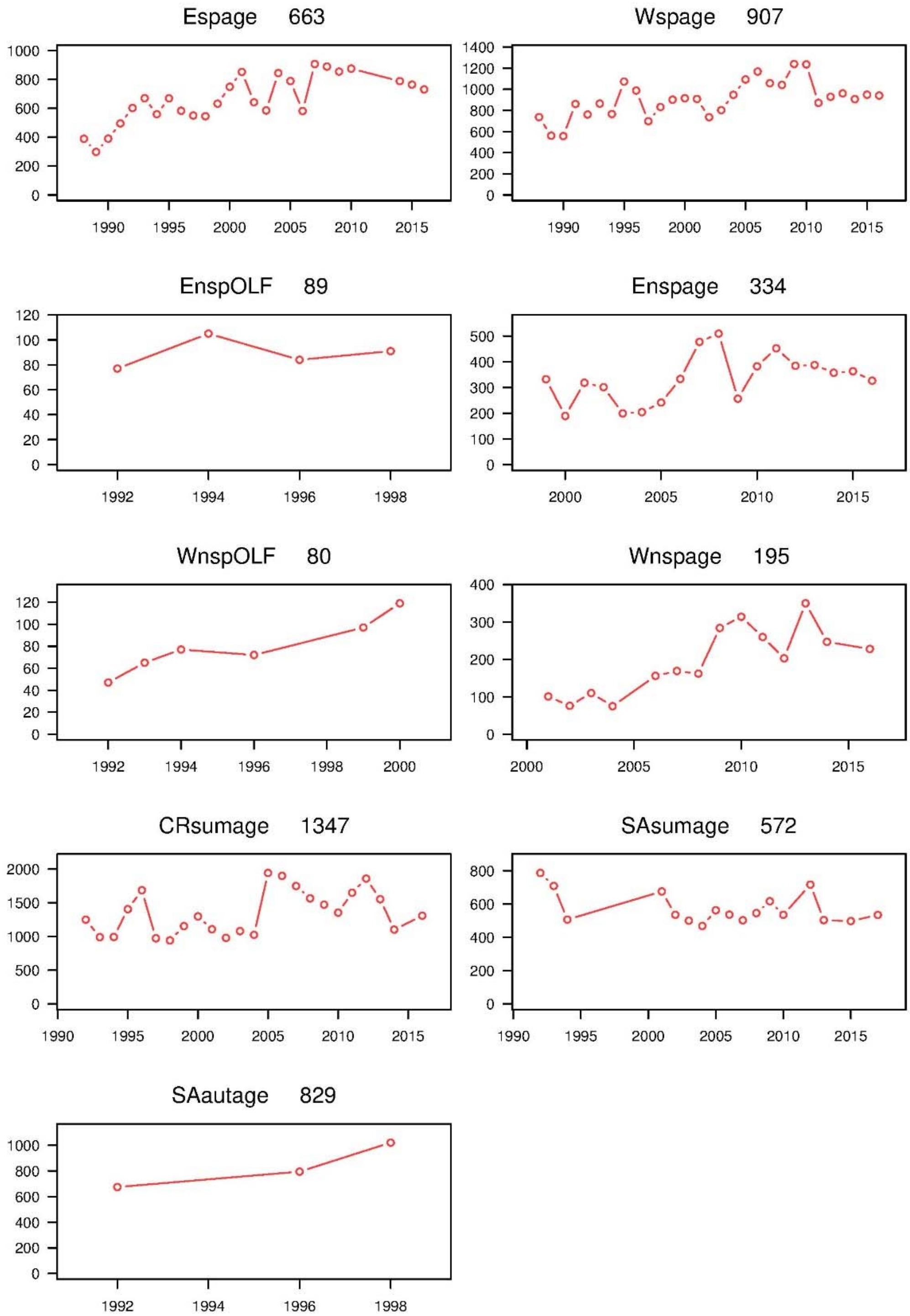

Figure 71: Model 1.1. Equivalent multinomial N values for the observational error. The number above each panel is the mean value over the fishing years.

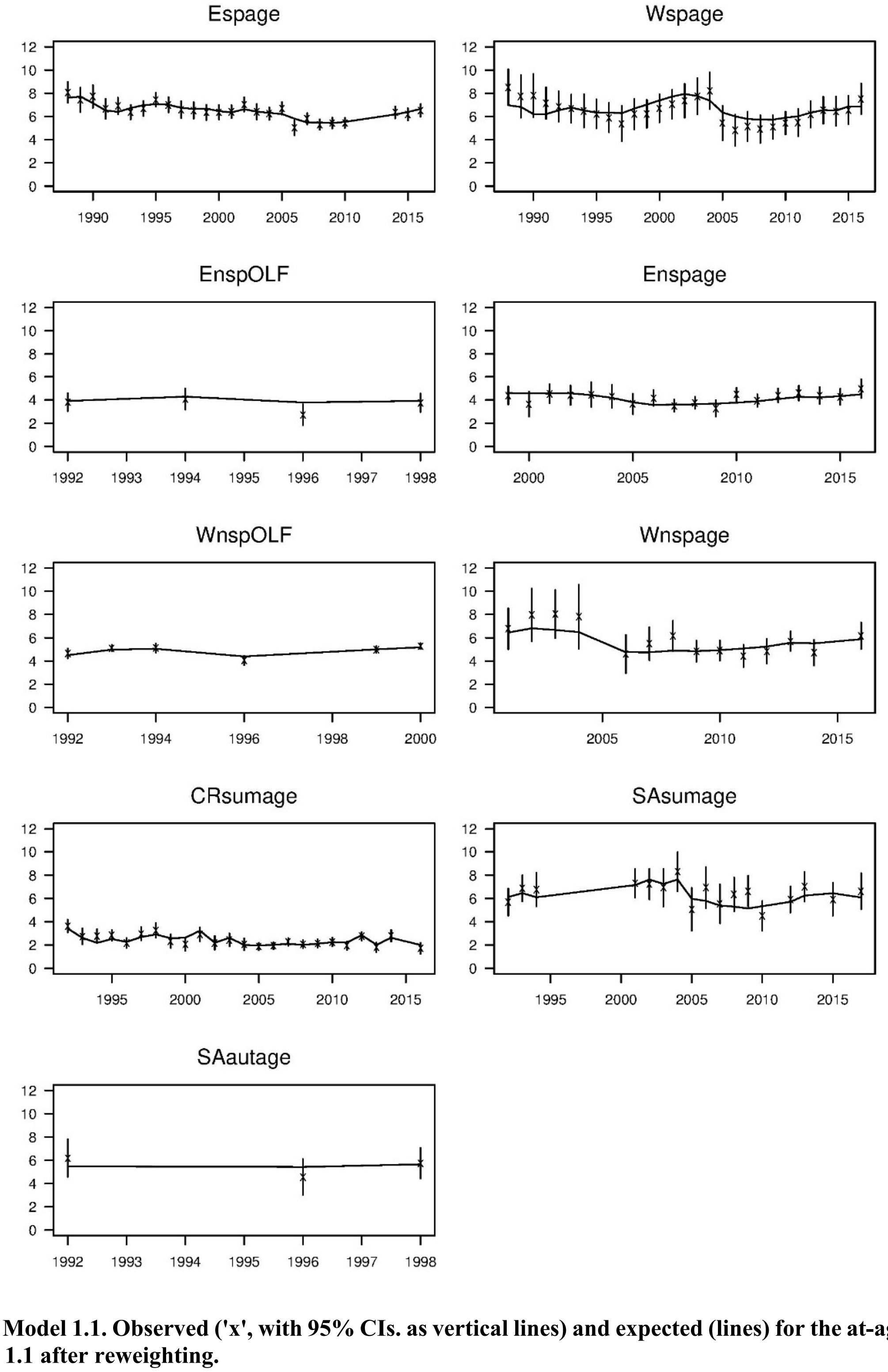

Figure 72: Model 1.1. Observed ('x', with 95% CIs. as vertical lines) and expected (lines) for the at-age data sets in run 1.1 after reweighting.

Appendix 4: MPD fits to proportions-at-age data for run 1.1. and 1.2

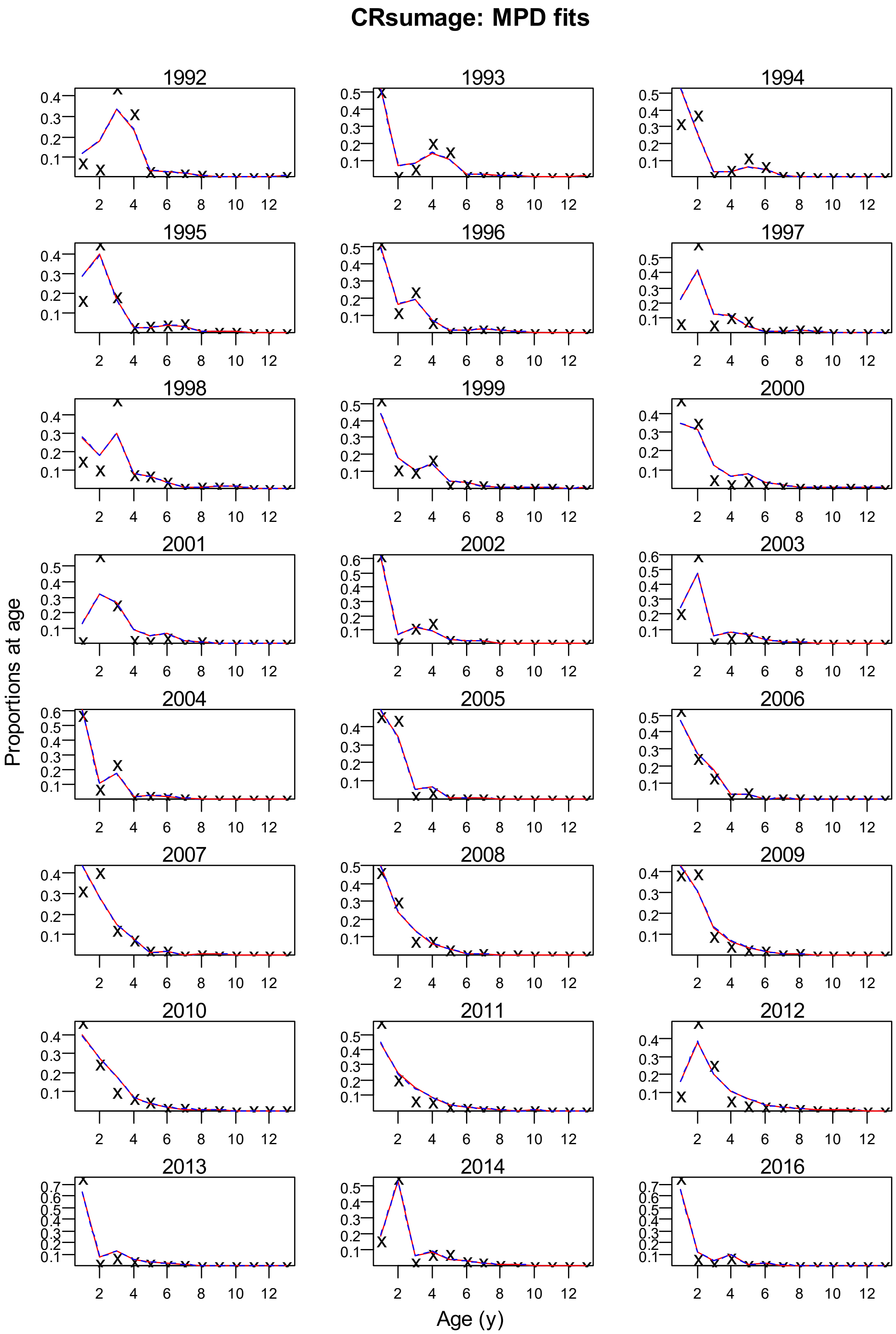

Figure 73: MPD fits to CRsumage. Observed ('×') and expected (lines) for runs 1.1 (red solid lines) and 1.2 (blue broken lines). Note that the expected value lines overlap substantially. Male and female observed and expected proportions are summed for an age group.

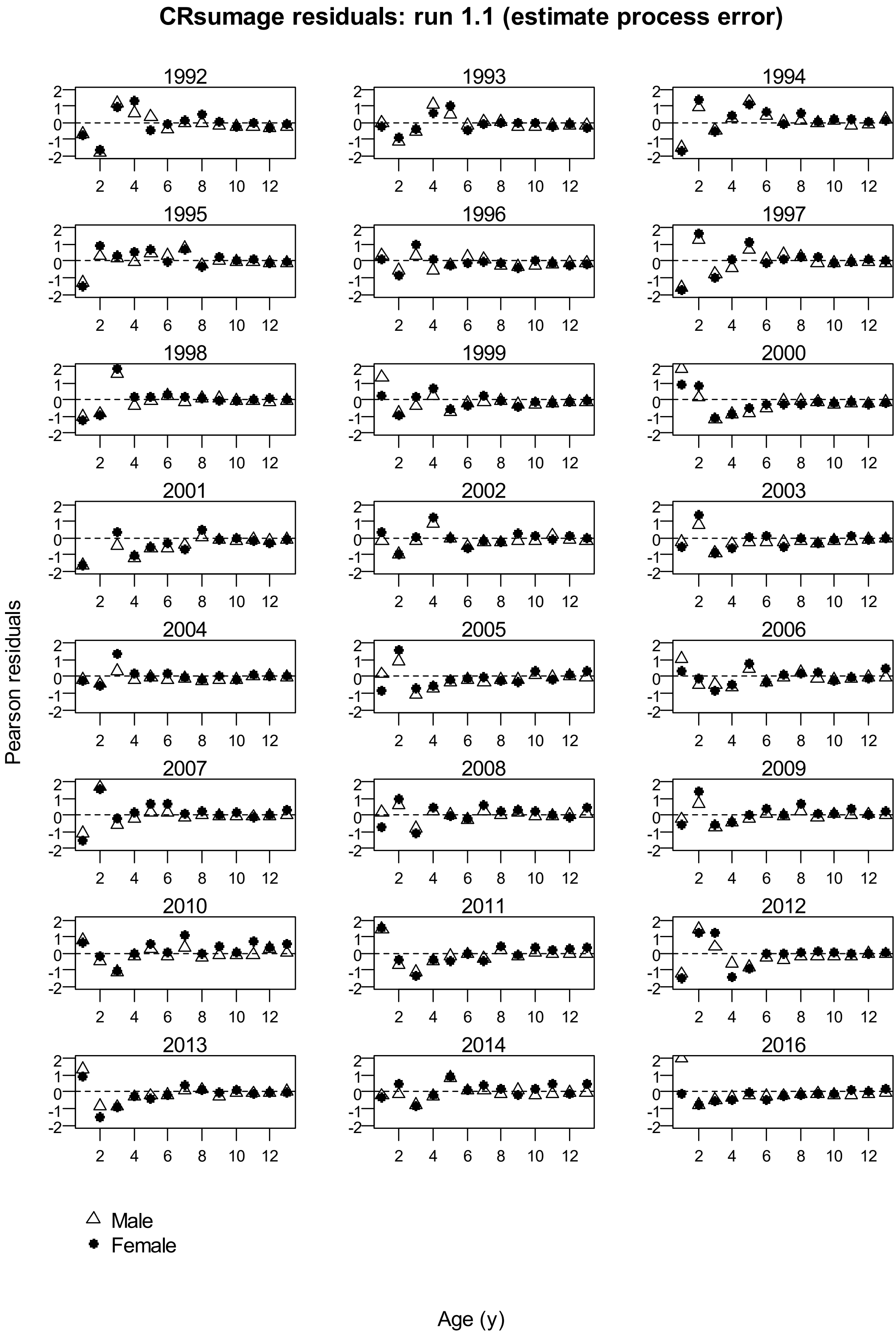

Figure 74: MPD Pearson residuals for the fit to CRsumage (run 1.1 with estimated process error).

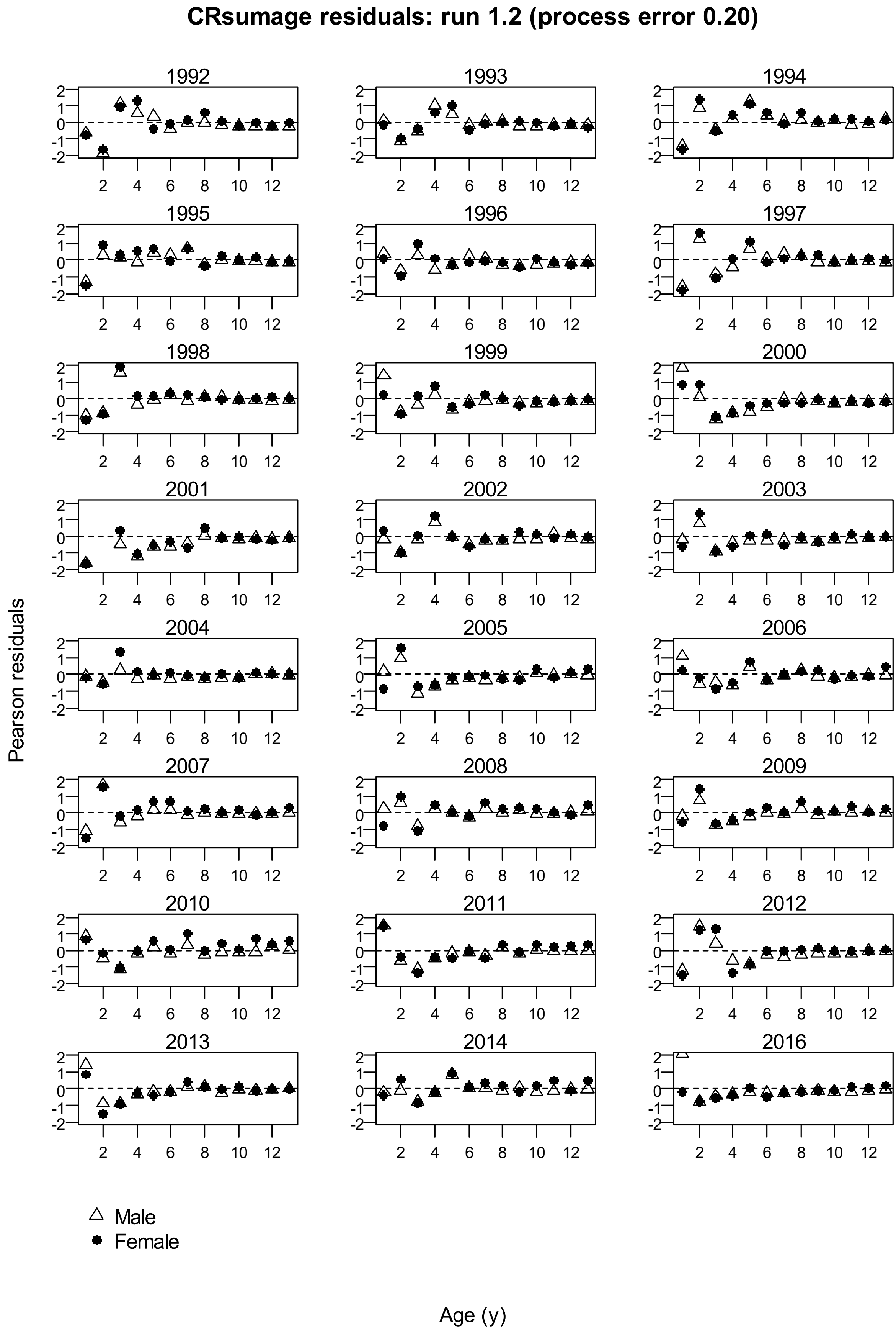

Figure 75: MPD Pearson residuals for the fit to CRsumage (run 1.2 with estimated process error).

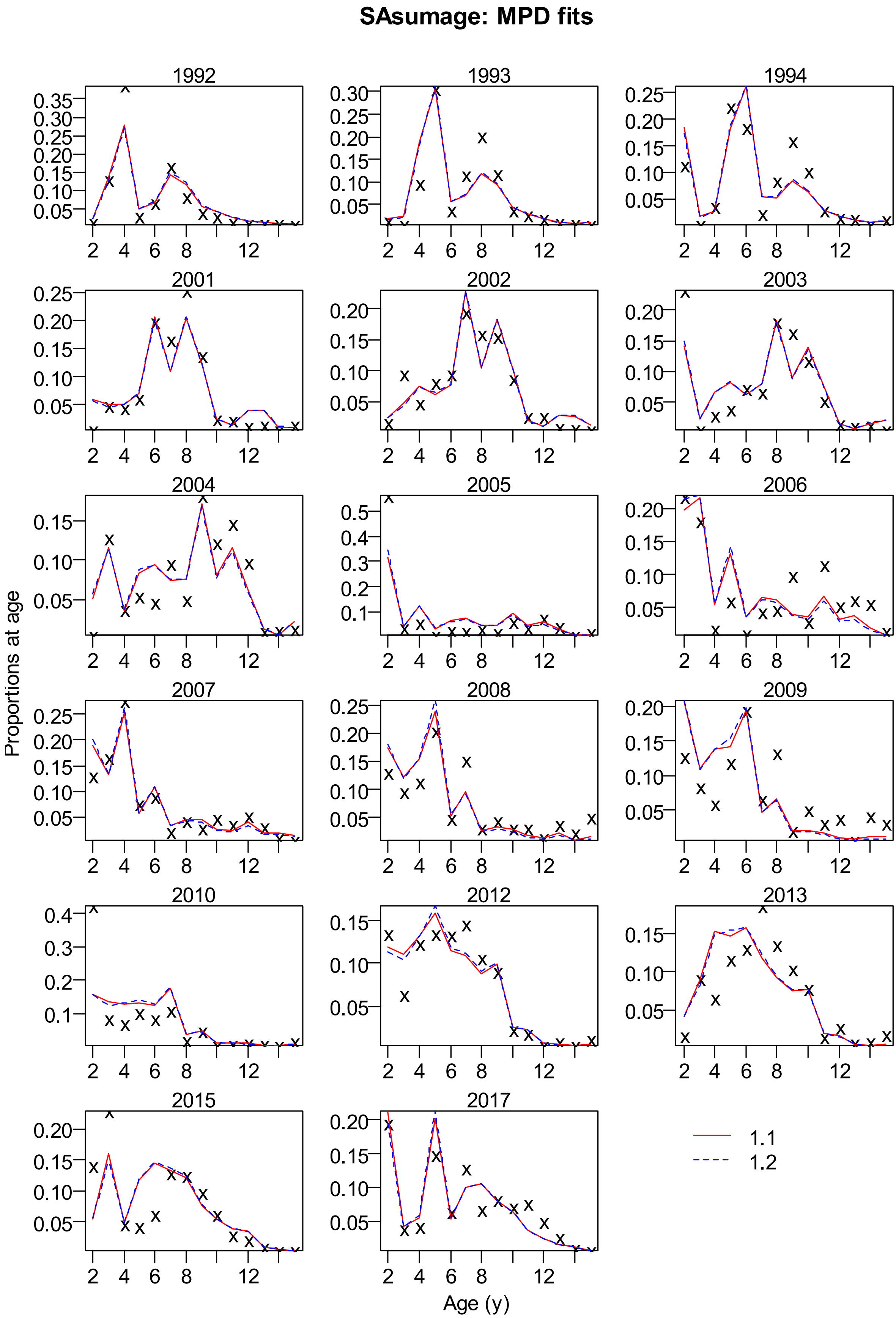

Figure 76: MPD fits to the SAsumage data. Observed ('×') and expected (lines) for runs 1.1 (red solid lines) and 1.2 (blue broken lines). Note that the expected value lines overlap substantially. Male and female observed and expected proportions are summed for an age group.

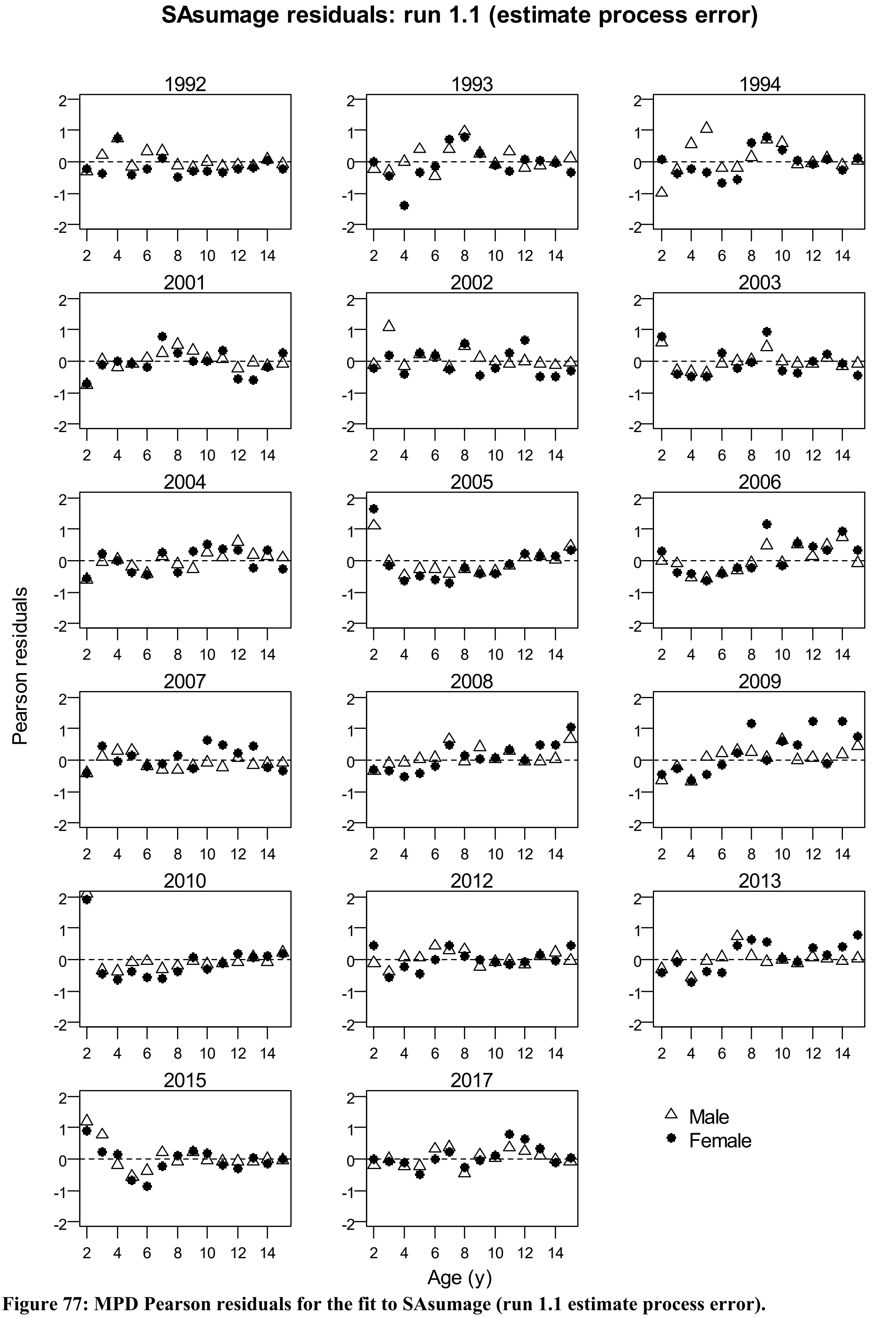

Figure 77: MPD Pearson residuals for the fit to SAsumage (run 1.1 estimate process error).

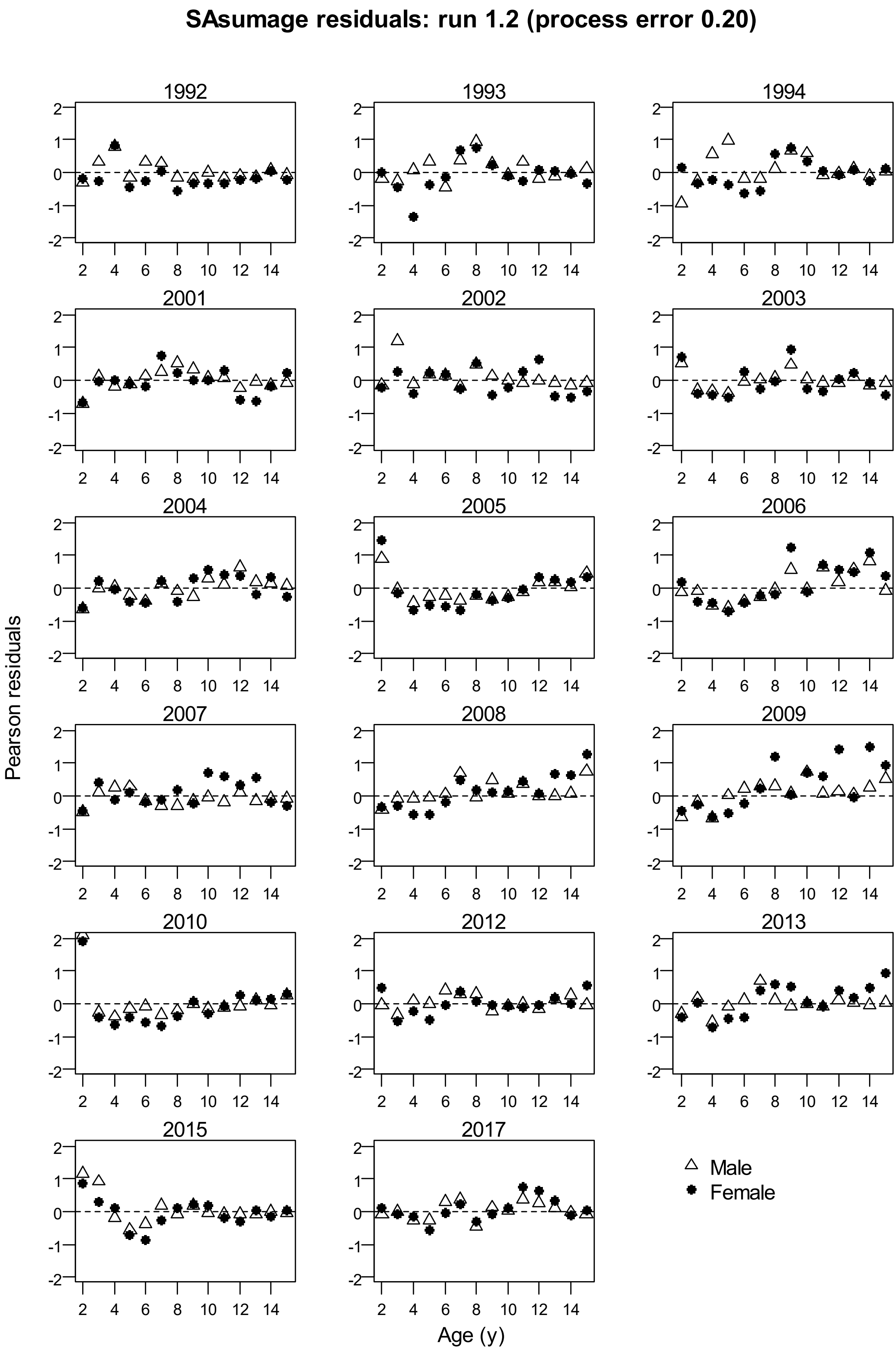

Figure 78: MPD Pearson residuals for the fit to SAsumage (process error 0.20).

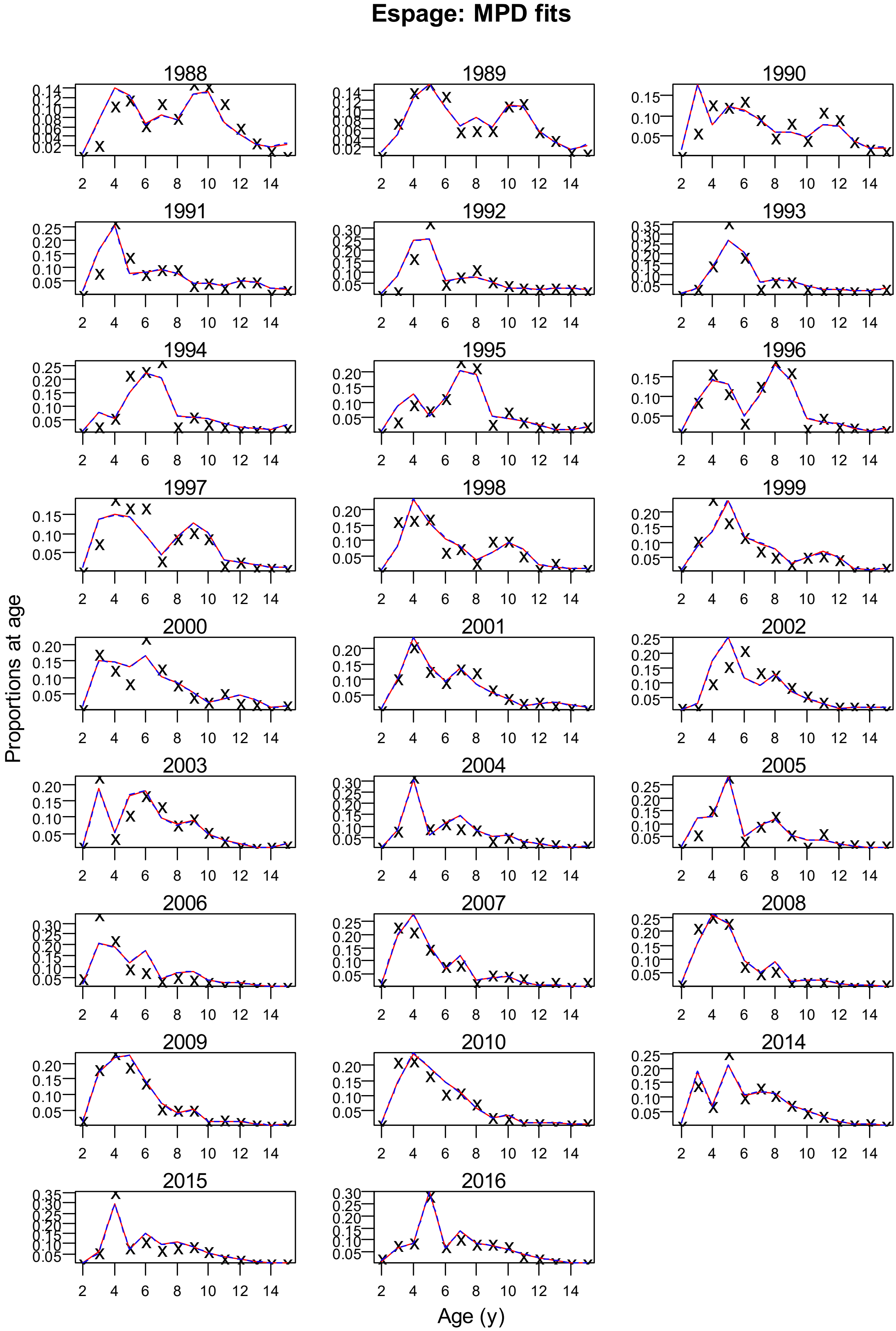

Figure 79: MPD fits to the Espage data. Observed ('×') and expected (lines) for runs 1.1 (red solid lines) and 1.2 (blue broken lines). Note that the expected value lines overlap substantially. Male and female observed and expected proportions are summed for an age group.

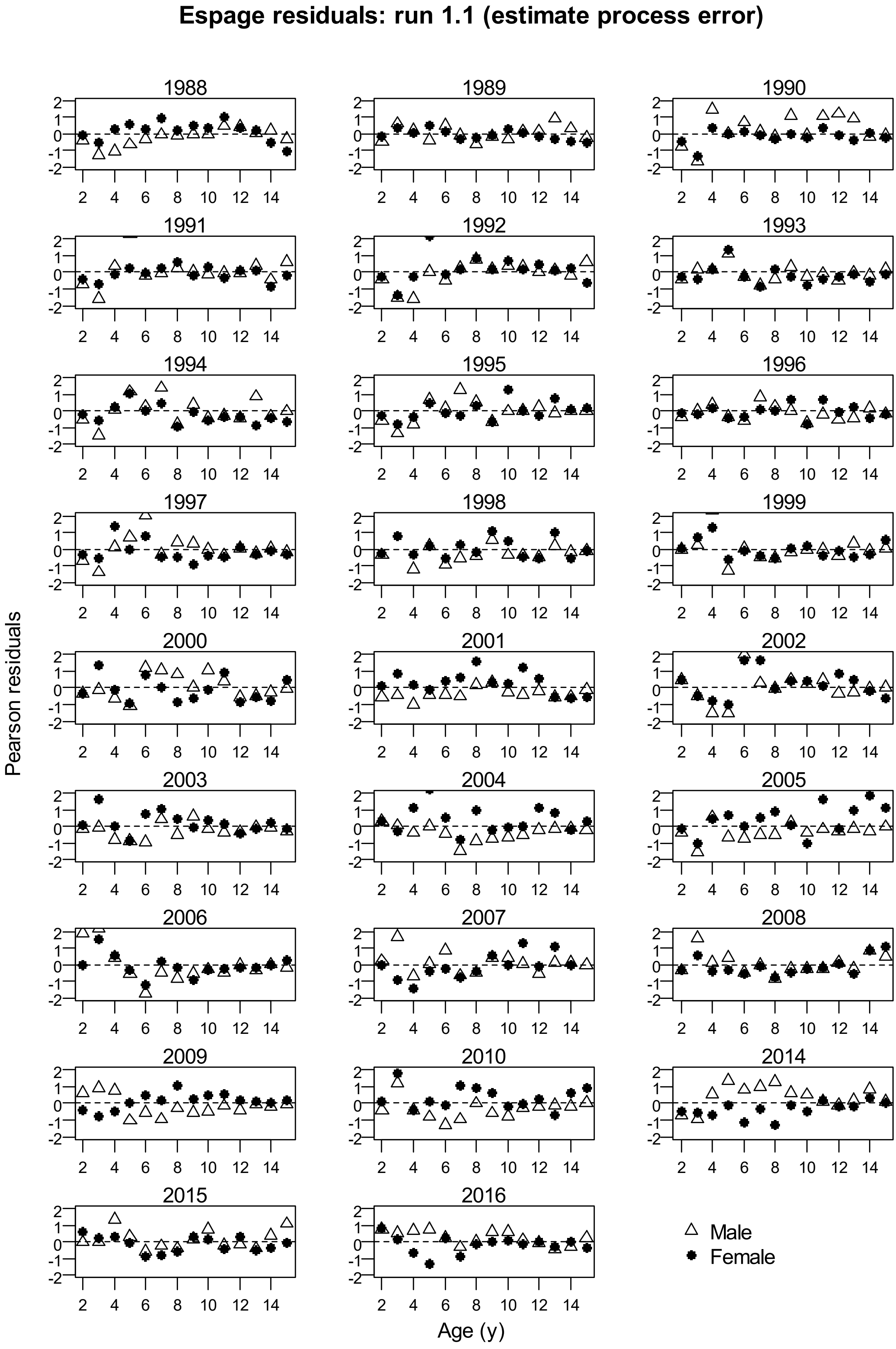

Figure 80: MPD Pearson residuals for the fits to Espage data in run 1.1 (estimate process error).

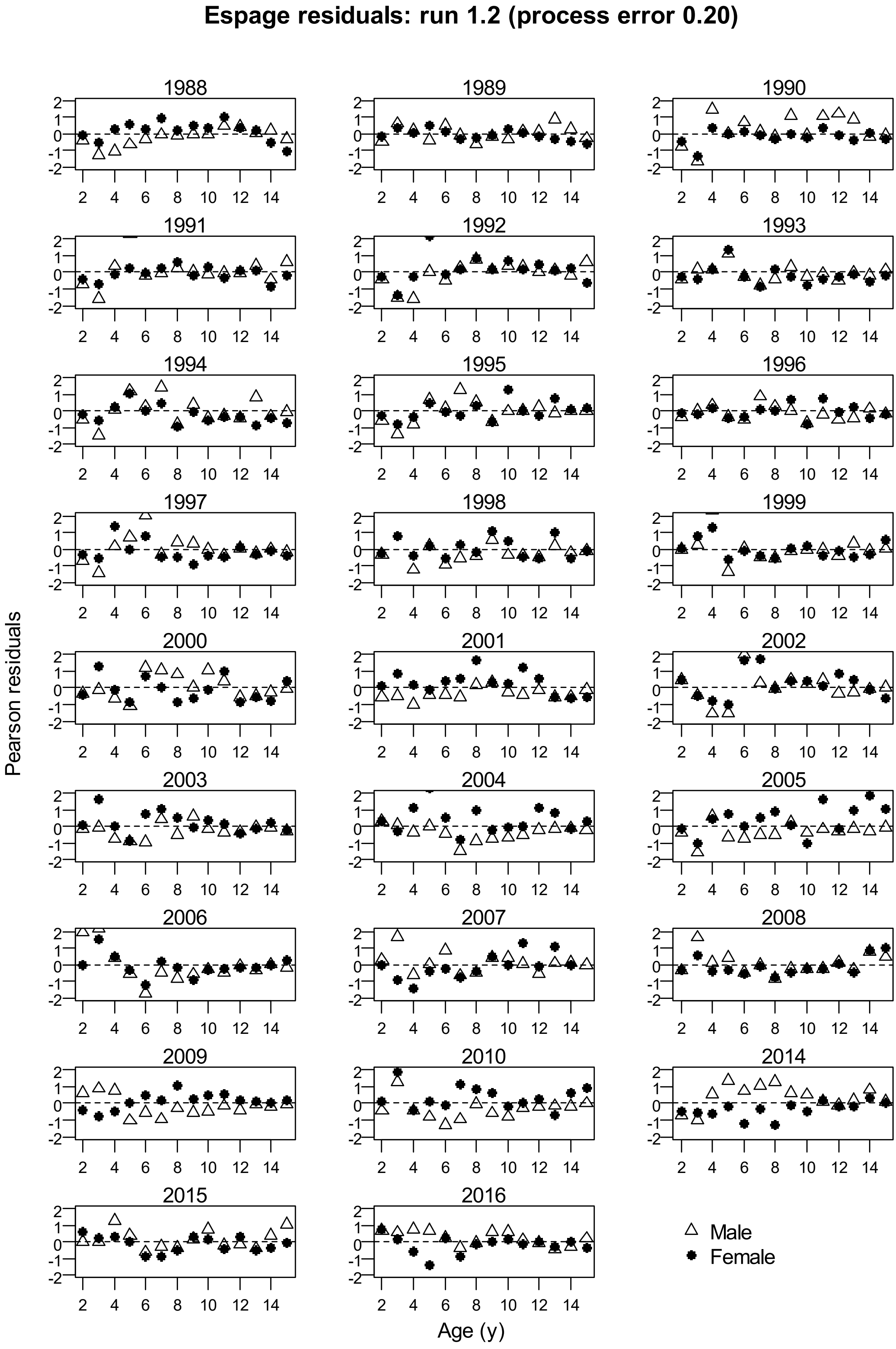

Figure 81: MPD Pearson residuals for the fits to Espage data in run 1.2 (process error 0.20).

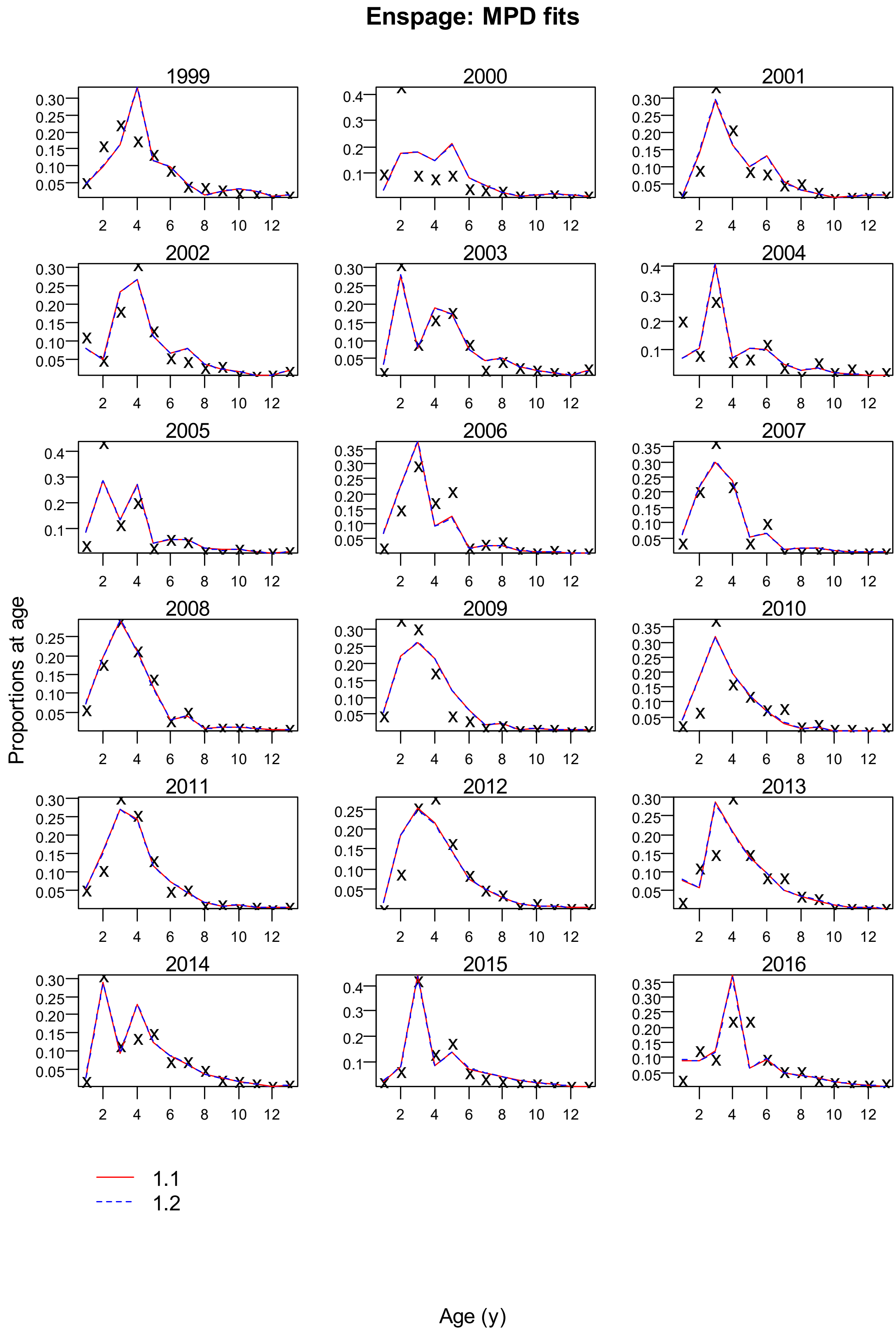

Figure 82: MPD fits to the Enspage data. Observed ('×') and expected (lines) for runs 1.1 (red solid lines) and 1.2 (blue broken lines). Note that the expected value lines overlap substantially. Male and female observed and expected proportions are summed for an age group.

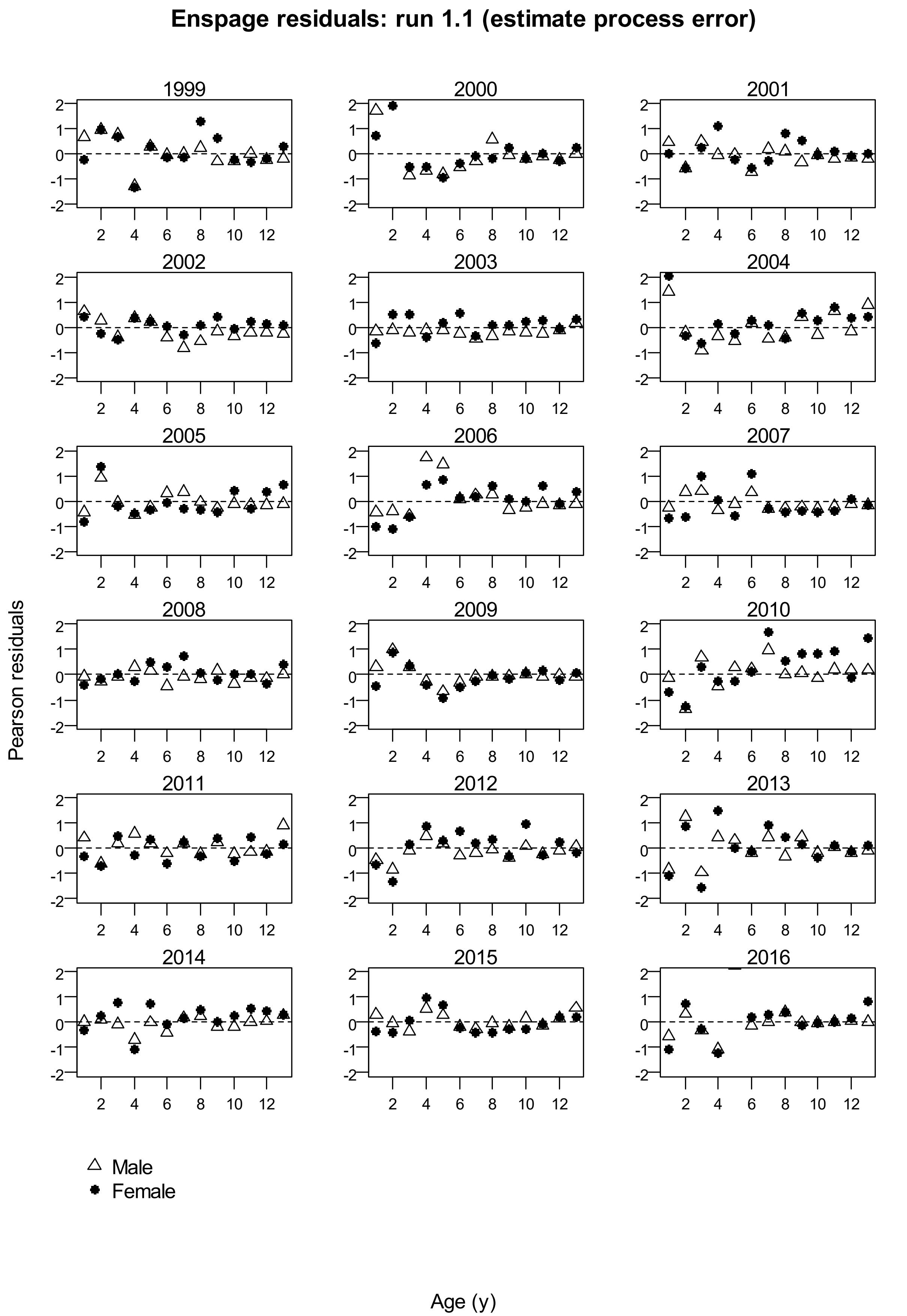

Figure 83: MPD Pearson residuals for the fits to Enspage data in run 1.1 (estimate process error).

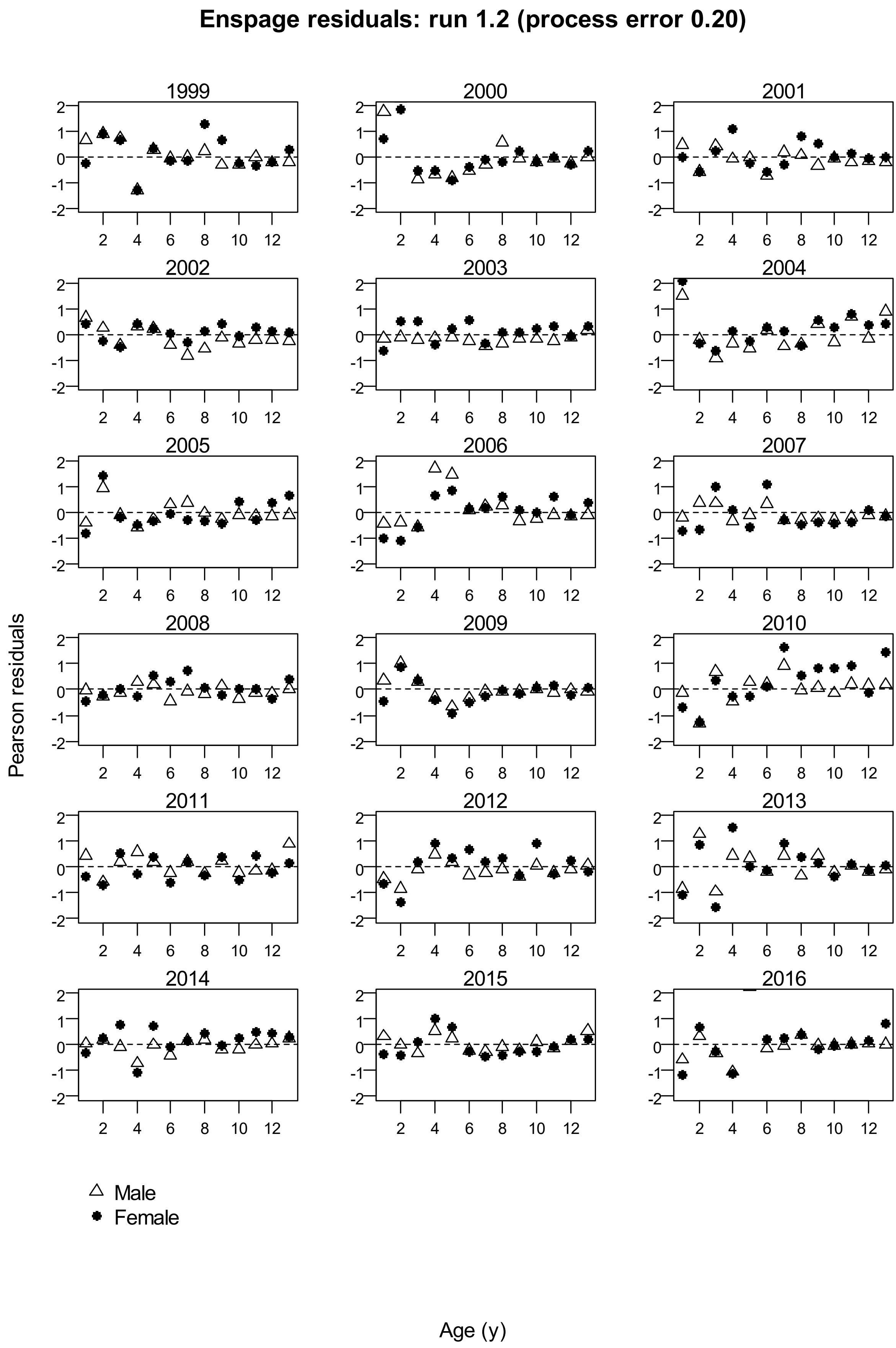

Figure 84: MPD Pearson residuals for the fits to Enspage data in run 1.2 (process error 0.20).

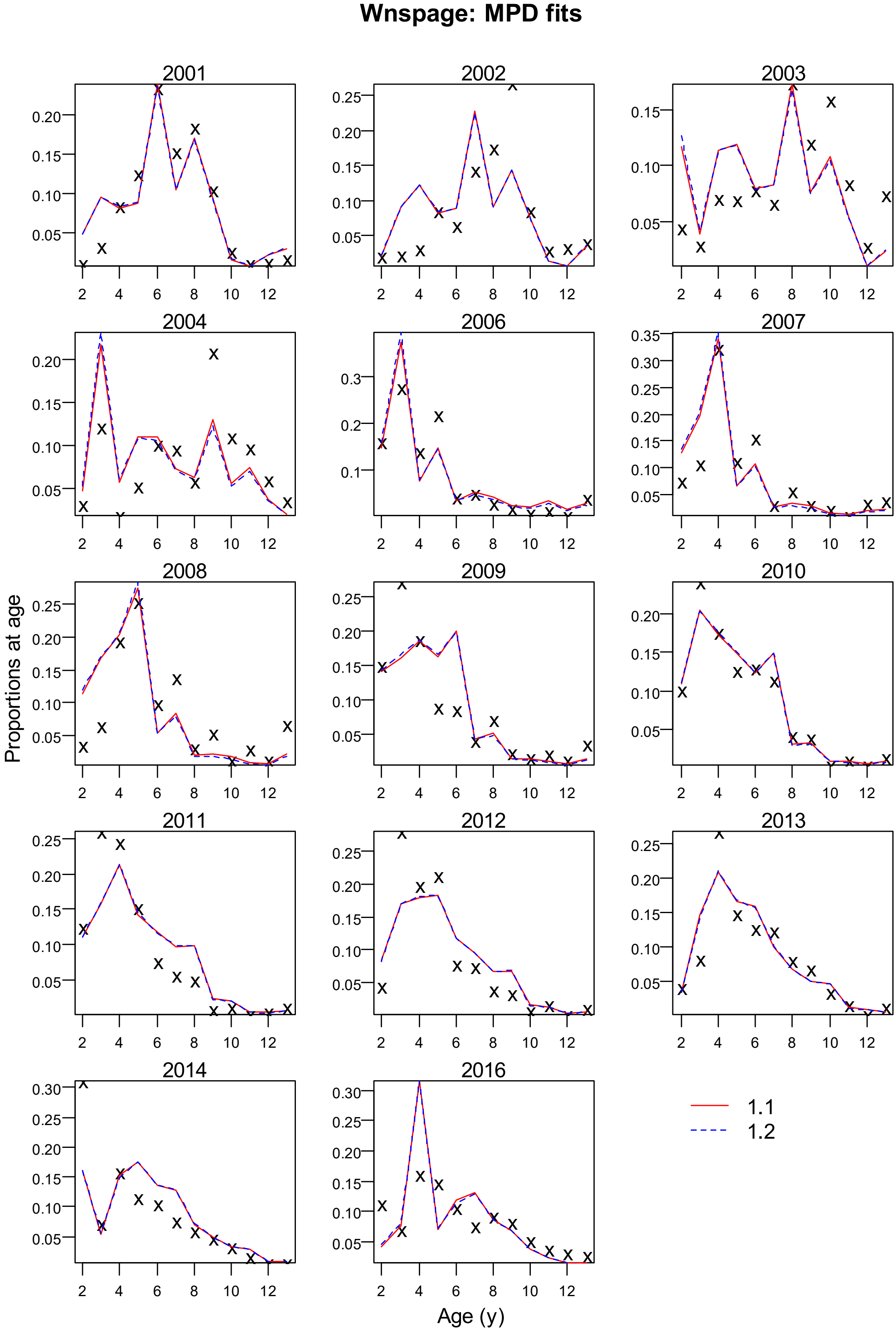

Figure 85: MPD fits to the Wnspage data. Observed ('×') and expected (lines) for runs 1.1 (red solid lines) and 1.2 (blue broken lines). Note that the expected value lines overlap substantially. Male and female observed and expected proportions are summed for an age group.

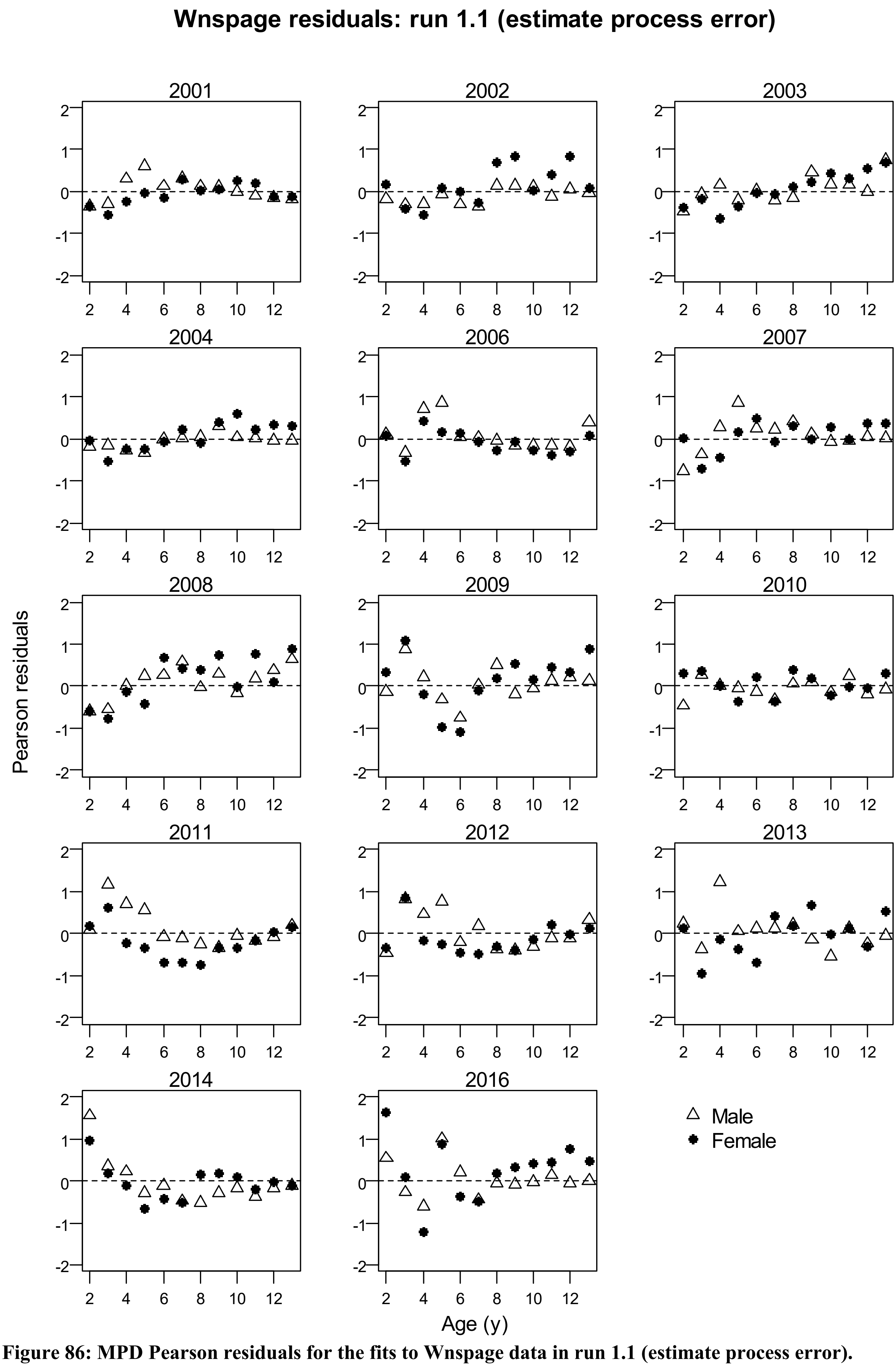

Figure 86: MPD Pearson residuals for the fits to Wnspage data in run 1.1 (estimate process error).

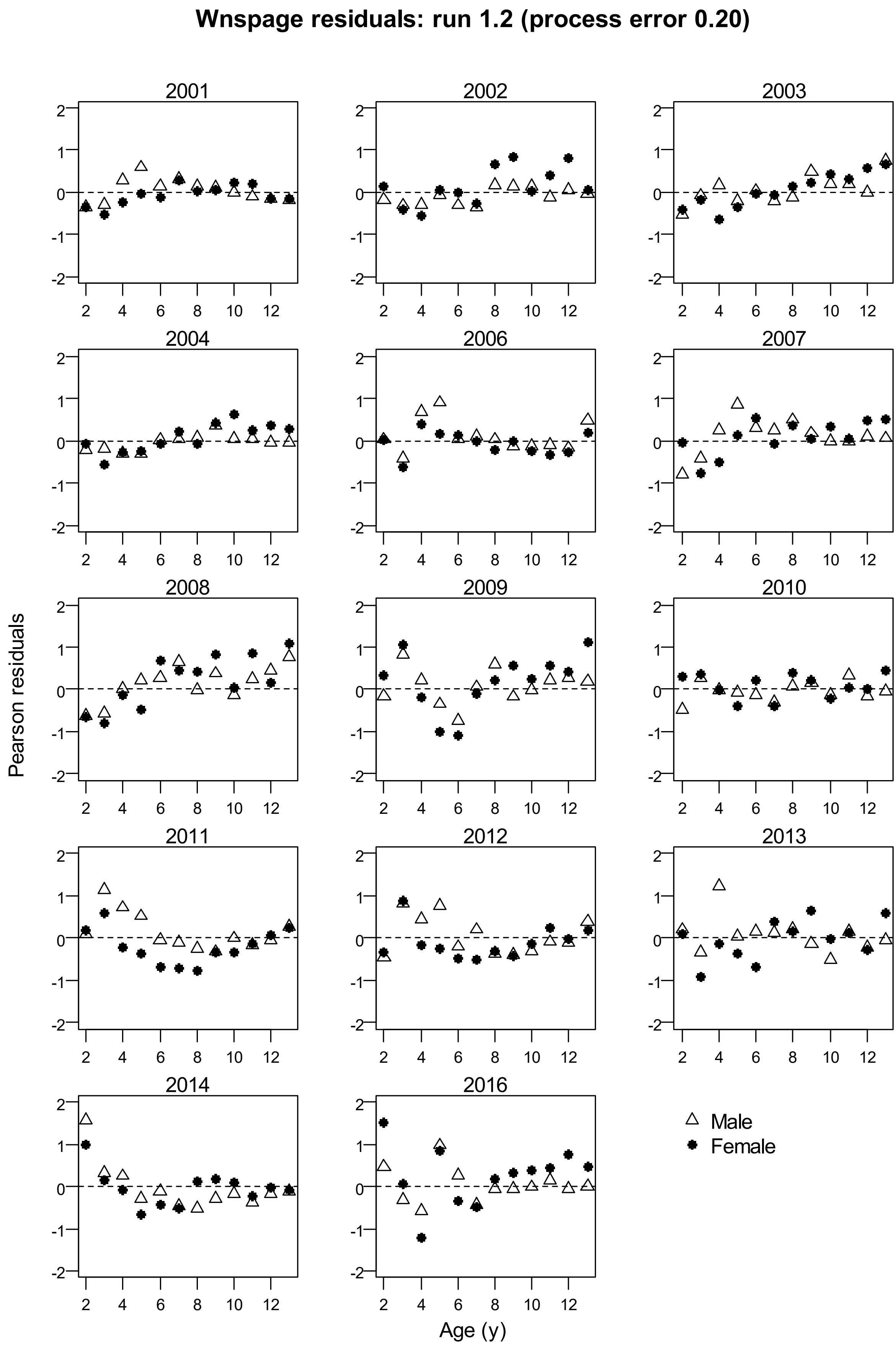

Figure 87: MPD Pearson residuals for the fits to Wnspage data in run 1.2 (process error 0.20).

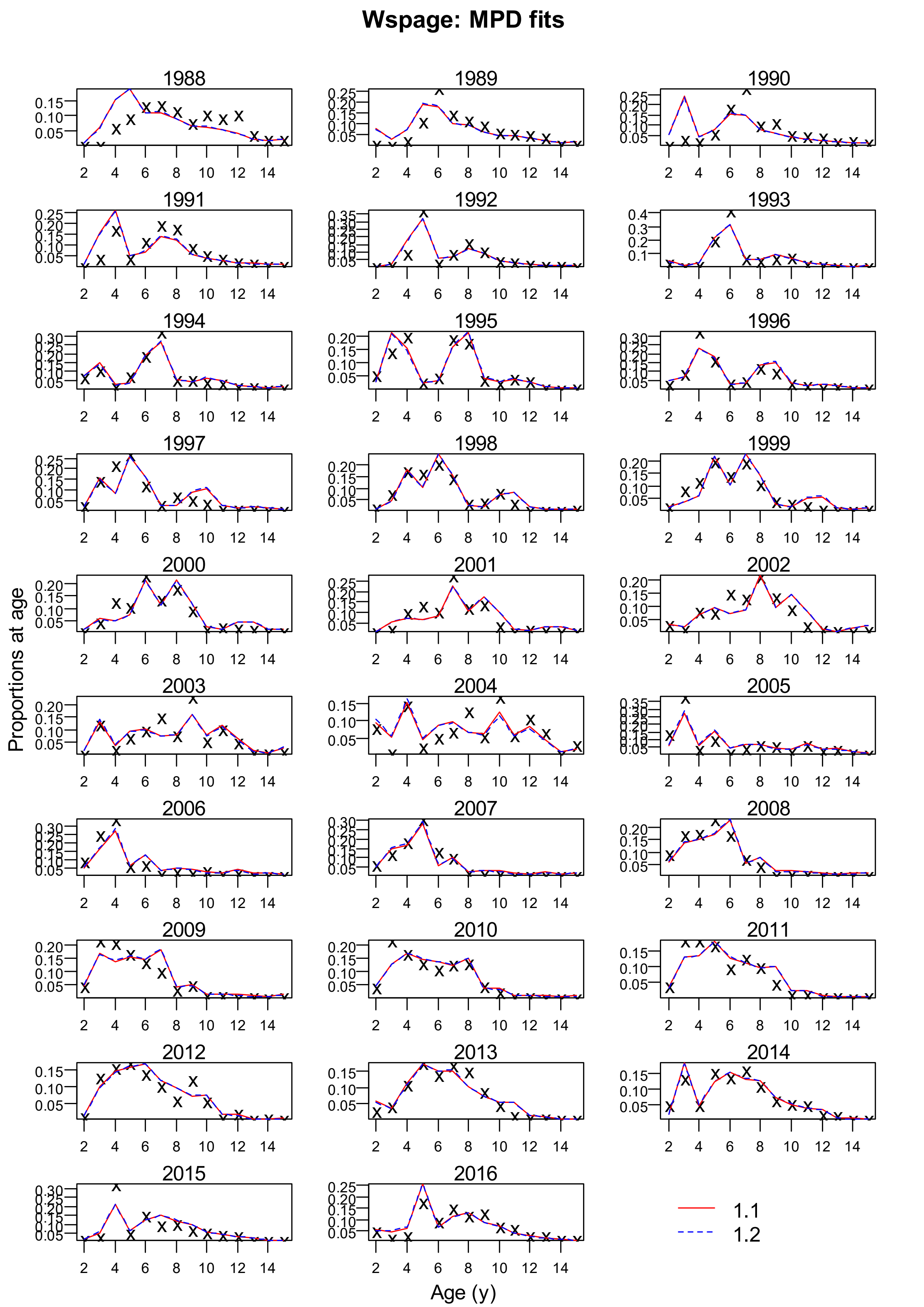

Figure 88: MPD fits to the Wspage data. Observed ('×') and expected (lines) for runs 1.1 (red solid lines) and 1.2 (blue broken lines). Note that the expected value lines overlap substantially. Male and female observed and expected proportions are summed for an age group.

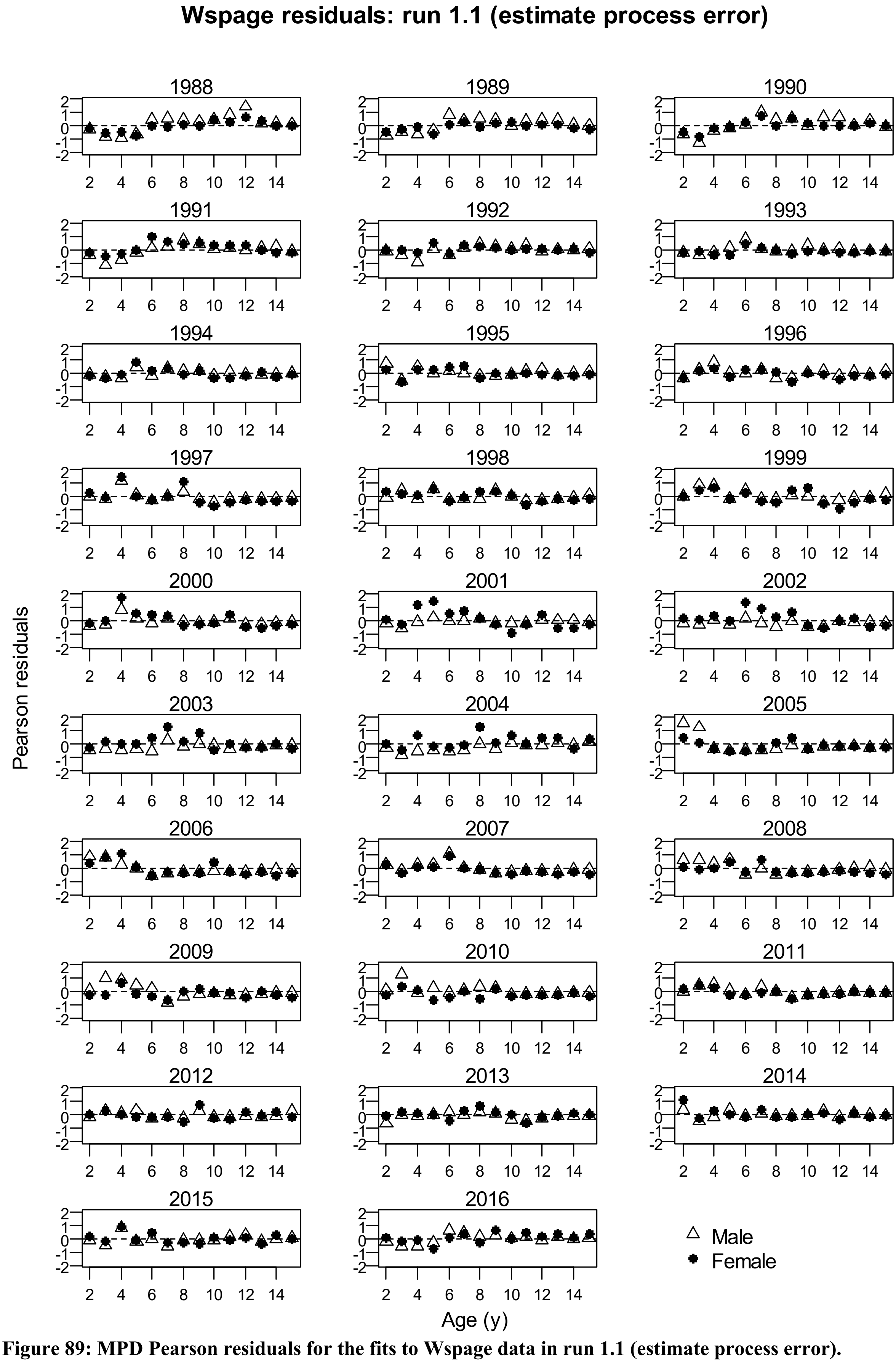

Figure 89: MPD Pearson residuals for the fits to Wspage data in run 1.1 (estimate process error).

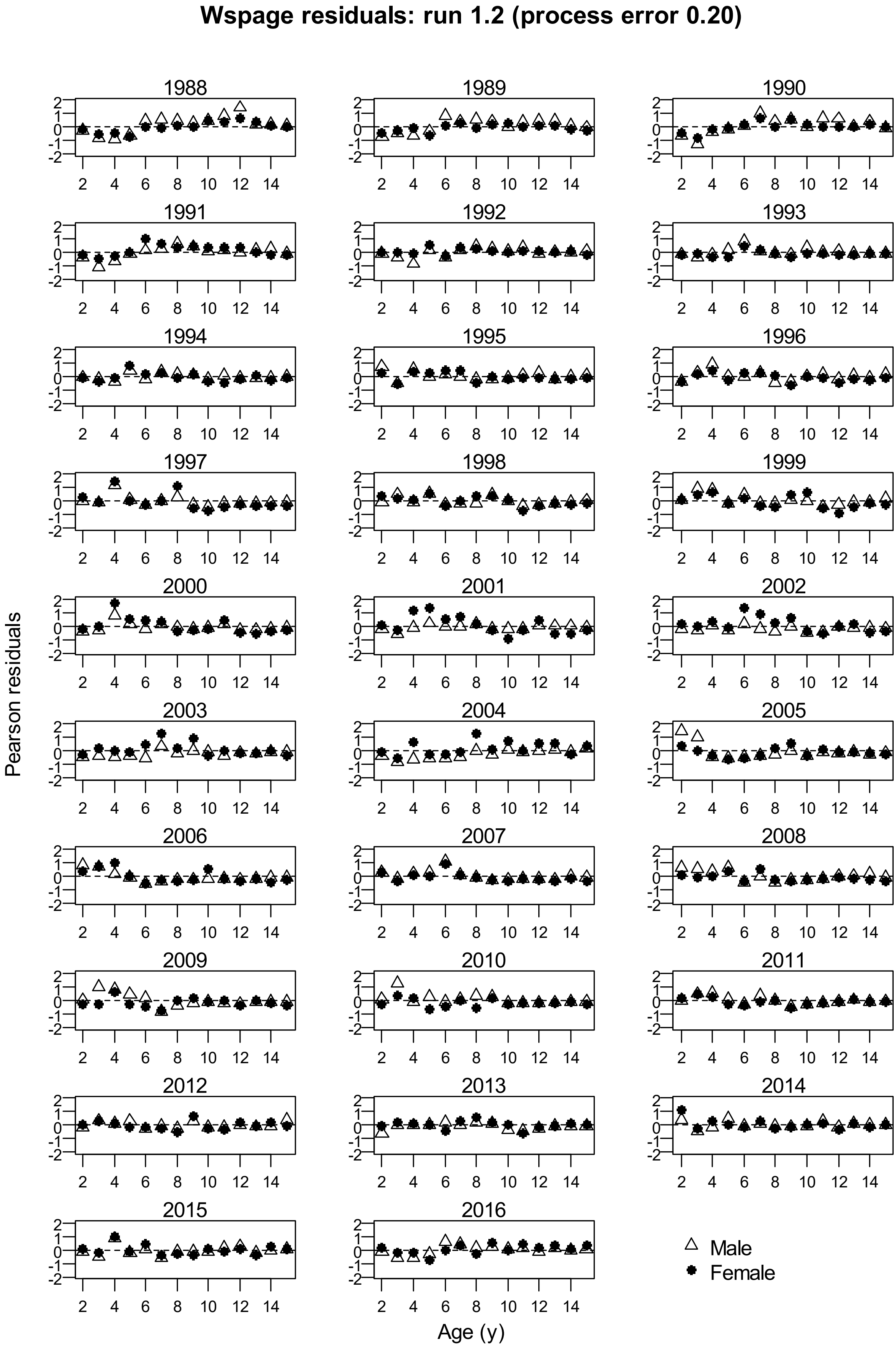

Figure 90: MPD Pearson residuals for the fits to Wspage data in run 1.2 (process error 0.20).

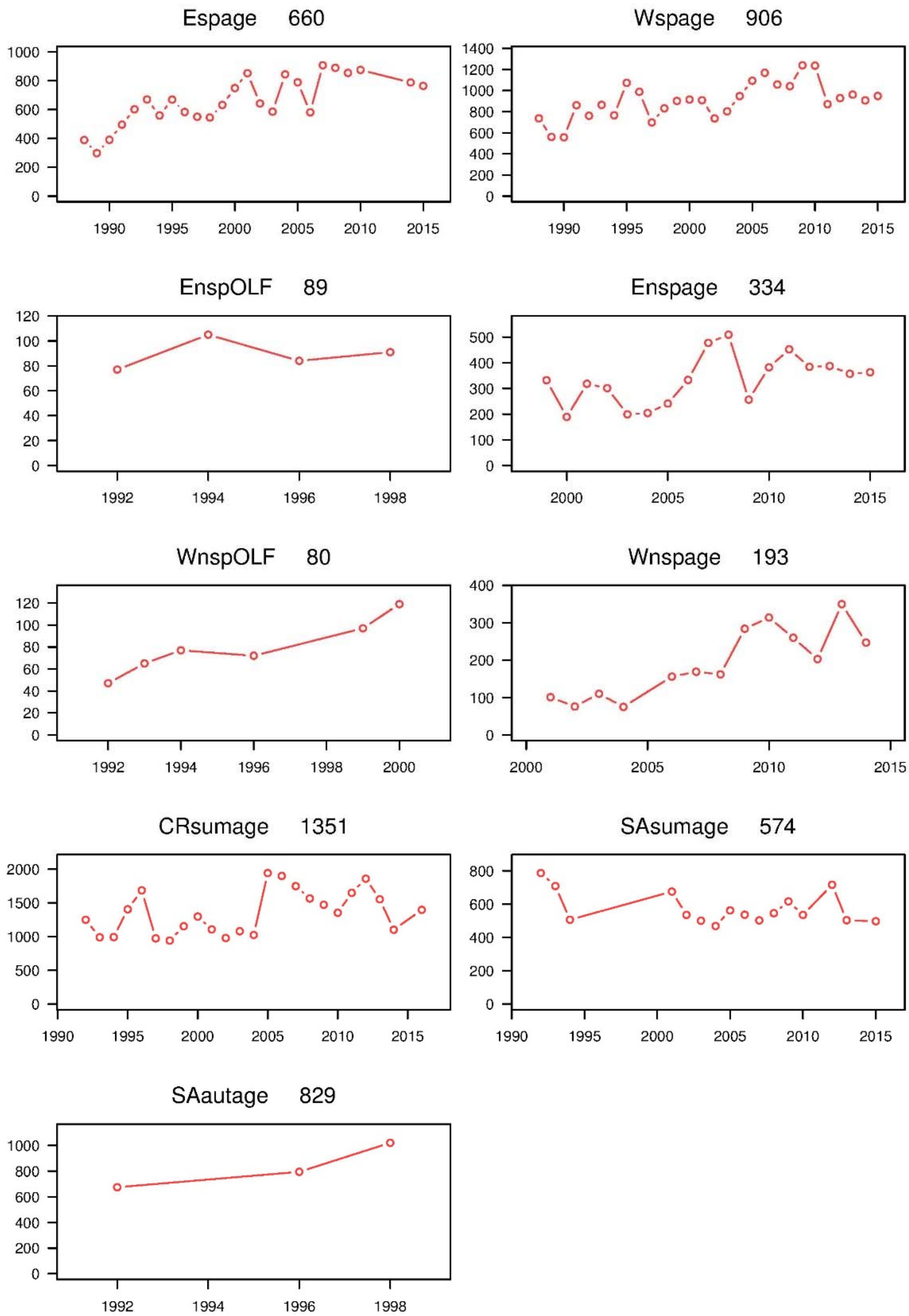

Figure 91: Model 1.1. Equivalent multinomial N values for the observational error. The number above each panel is the mean value over the fishing years.

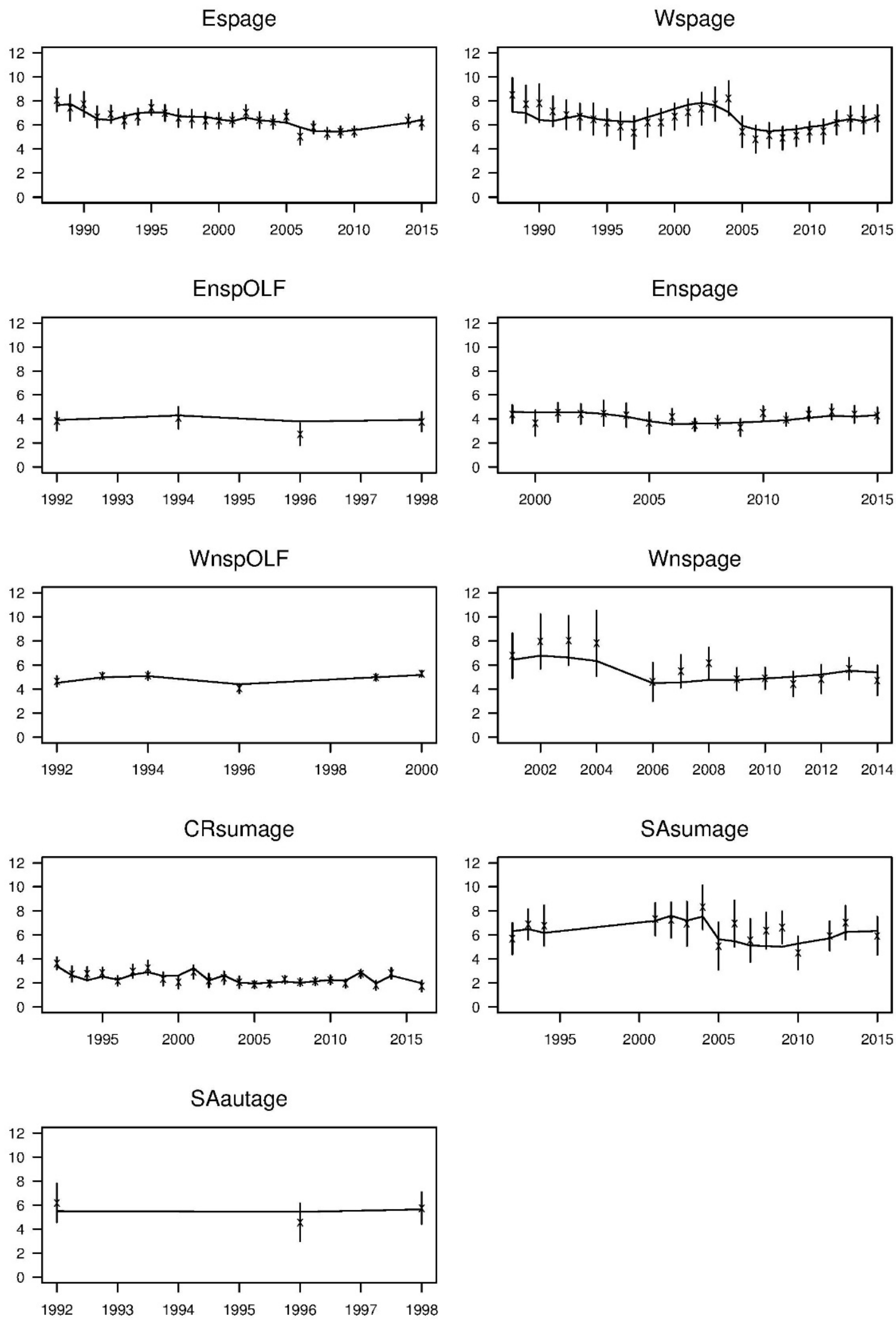

Figure 92: Model 1.1. Observed ('×', with 95% CIs as vertical lines) and expected (lines) for the at-age data sets in run 1.1 after reweighting.

Appendix 5: 2016 hoki assessment selectivities, migration ogives, natural mortality, and priors

These are from McKenzie (2016).

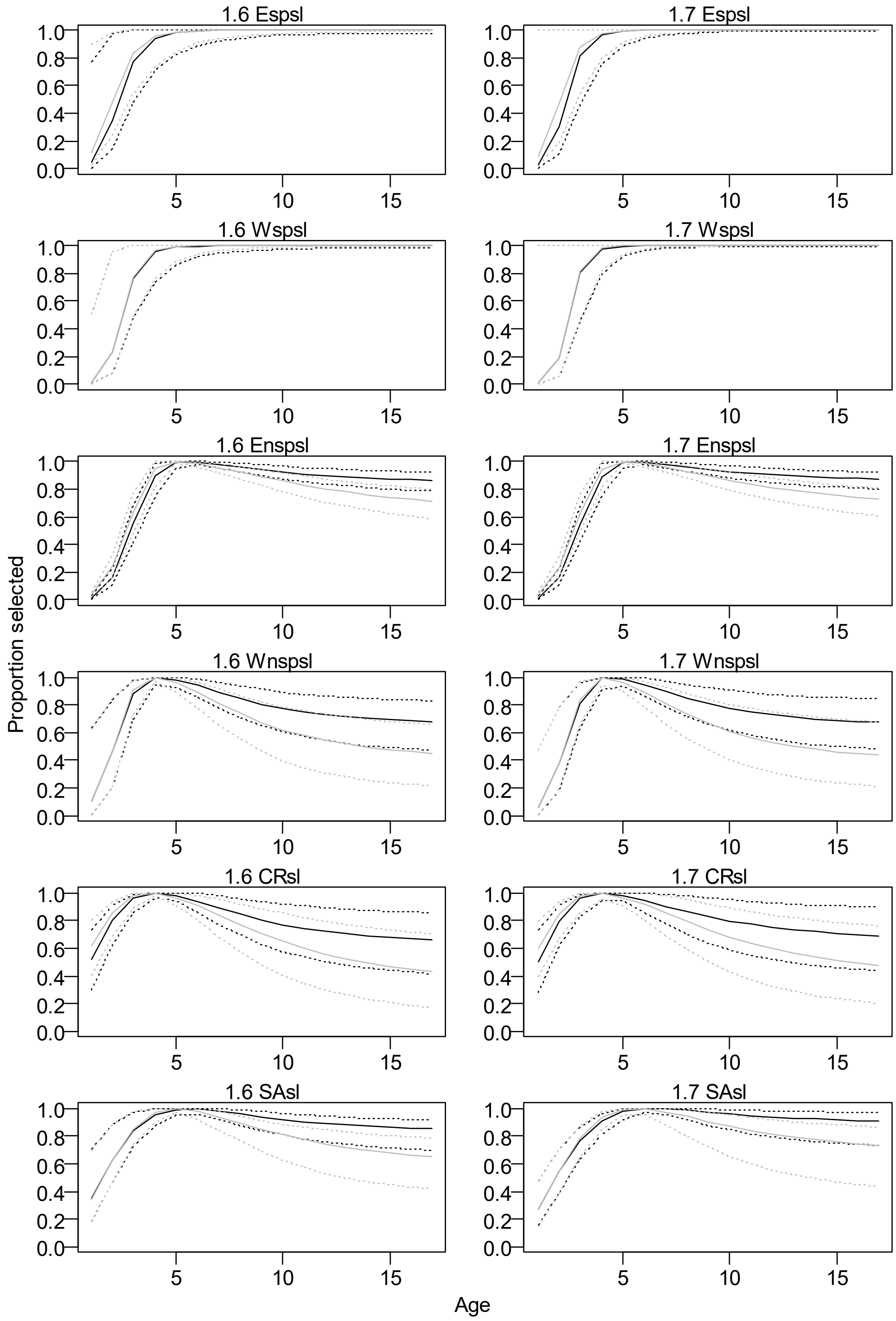

Figure 93: Posterior estimates of selectivity ogives for each of the two 2016 MCMC runs 1.6 and 1.7. Solid lines are medians; broken lines show 95% confidence intervals. Where ogives differ by sex they are plotted as black for males and grey for females. Where they differ by stock or time step the plotted curves are for one selected combination (E step 2 for Enspsl and CRsl, W step 2 for Wnspsl and SAsl).

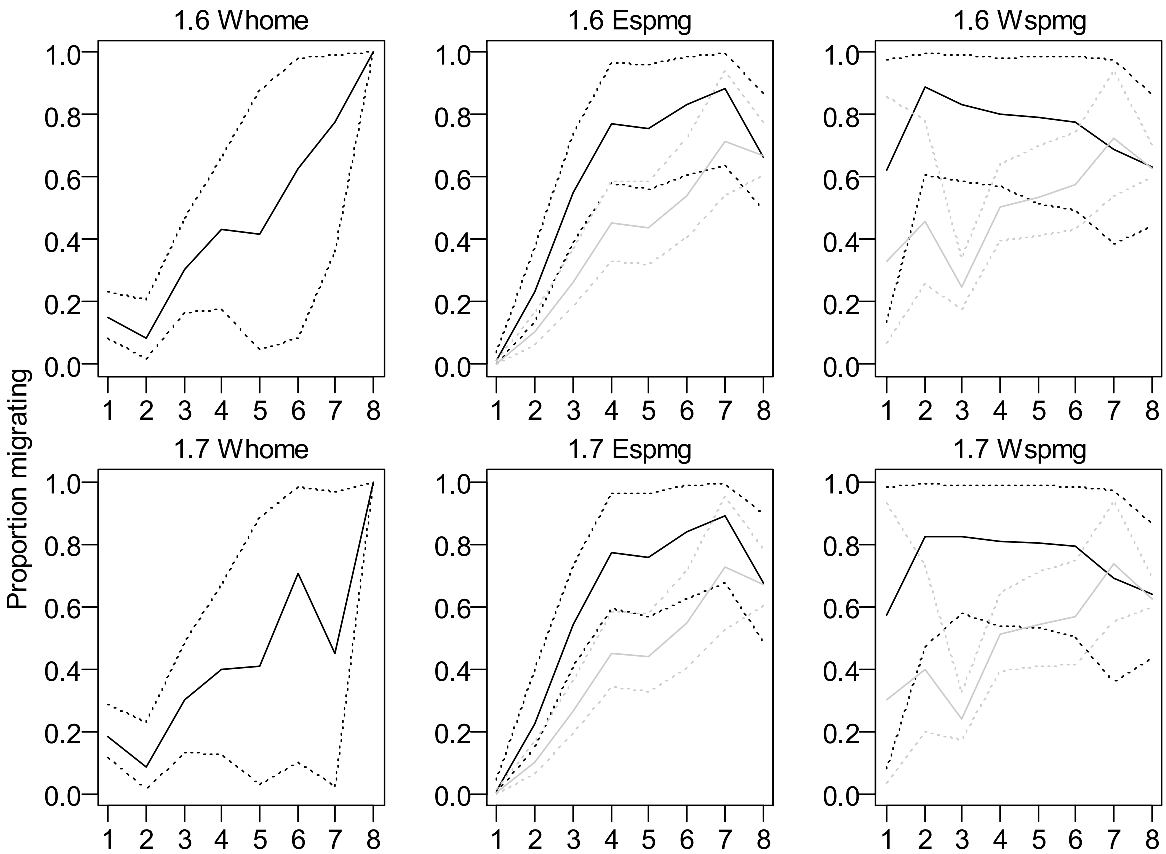

Figure 94: Estimated migration ogives. Solid lines are medians, broken lines show 95% confidence intervals. Where ogives differ by sex they are plotted as black for males and grey for females. Age is along the x-axis.

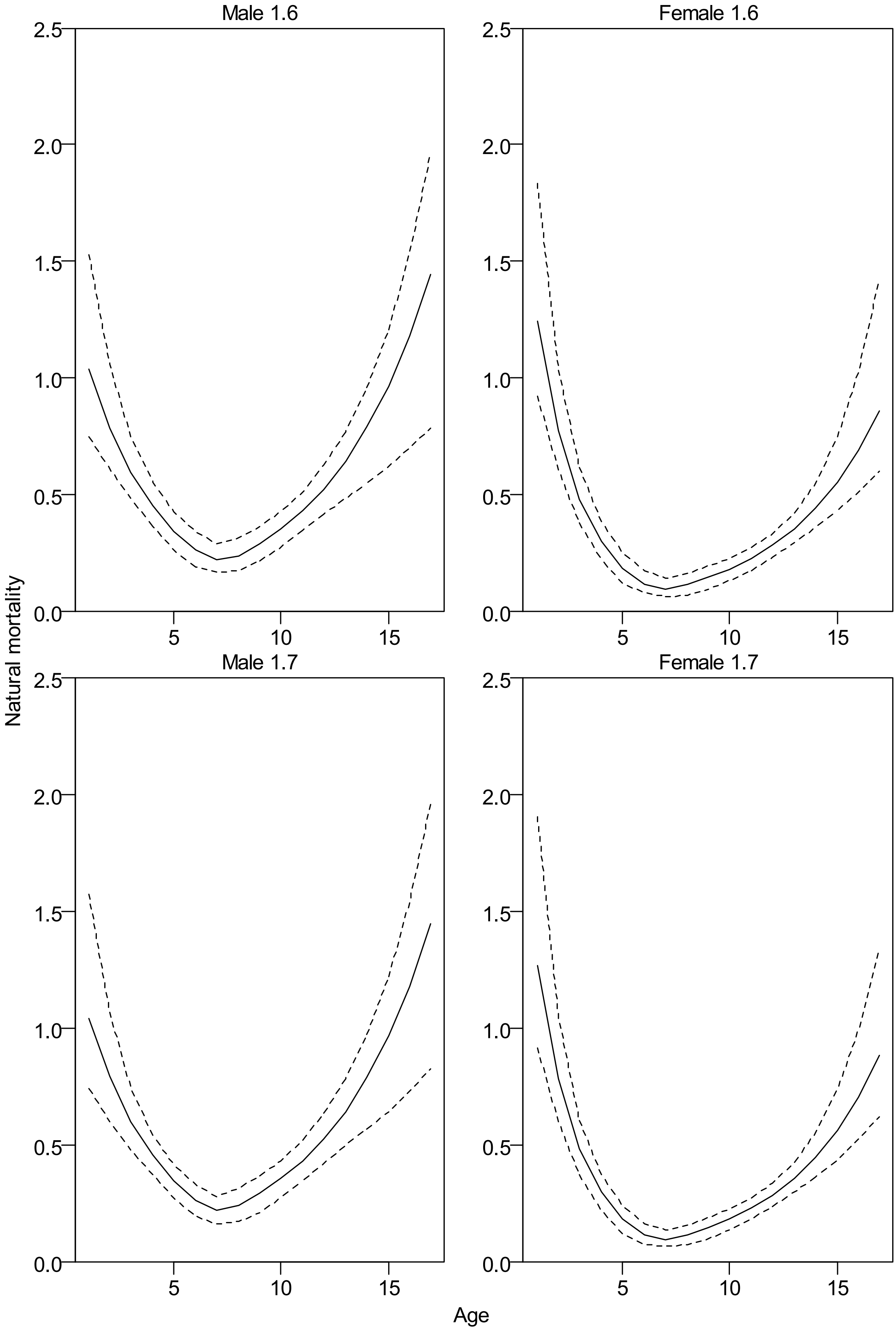

Figure 95: Assessment estimates of age-dependent natural mortality ogives for the MCMC runs showing median estimates (solid lines) and 95% confidence intervals (broken lines) for each sex.

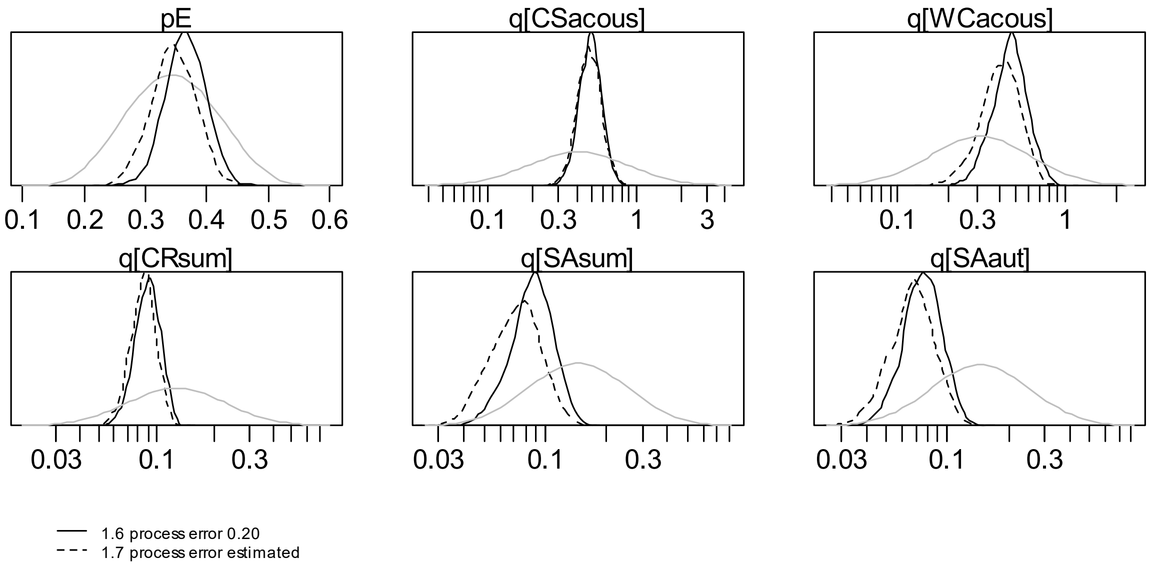

Figure 96: 2016 assessment prior (grey lines) and estimated posterior (black lines, solid for run 1.6, broken for run 1.7)) distributions for the following parameters: pE (proportion of B_0 in E stock), and survey catchabilities (acoustic and trawl). Note that the priors for CSacous and WCacous were changed for the 2016 assessment.