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Assessment of hoki (*Macruronus novaezelandiae*) in 2018

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CONTENTS

EXECUTIVE SUMMARY

McKenzie, A. (2019). Assessment of hoki (*Macruronus novaezelandiae*) in 2018.

***New Zealand Fisheries Assessment Report 2019/22.* 67 p.**

An updated 2018 assessment is presented for hoki, which was based on the 2017 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 January 2018 research trawl survey on the Chatham Rise, and a winter 2017 acoustic survey in Cook Strait. New proportions-at-age data came from the Chatham Rise research trawl survey, commercial spawning fisheries for the west and east stocks, and the non-spawning commercial fishery for the east stock.

In the base model run, 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 64 (44–86) %B_0 and the eastern stock 54 (39–77) %B_0, where the values in brackets are 95% credible 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 above average from 2014–2016 (although very uncertain).

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 46–85 (95% CI range 29–112% B_0) for the western stock and 45–60 (95% CI range 30–87% B_0) for the eastern stock.

Five-year projections were carried out for the base model. In these projections, future recruitments were selected at random from those estimated for 2007–2016, and future catch assumed to equal the current TACC of 150 000 t with 62 000 t for the east stock and 88 000 t for the west stock. Under these projections the eastern and western biomasses are likely to increase 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).

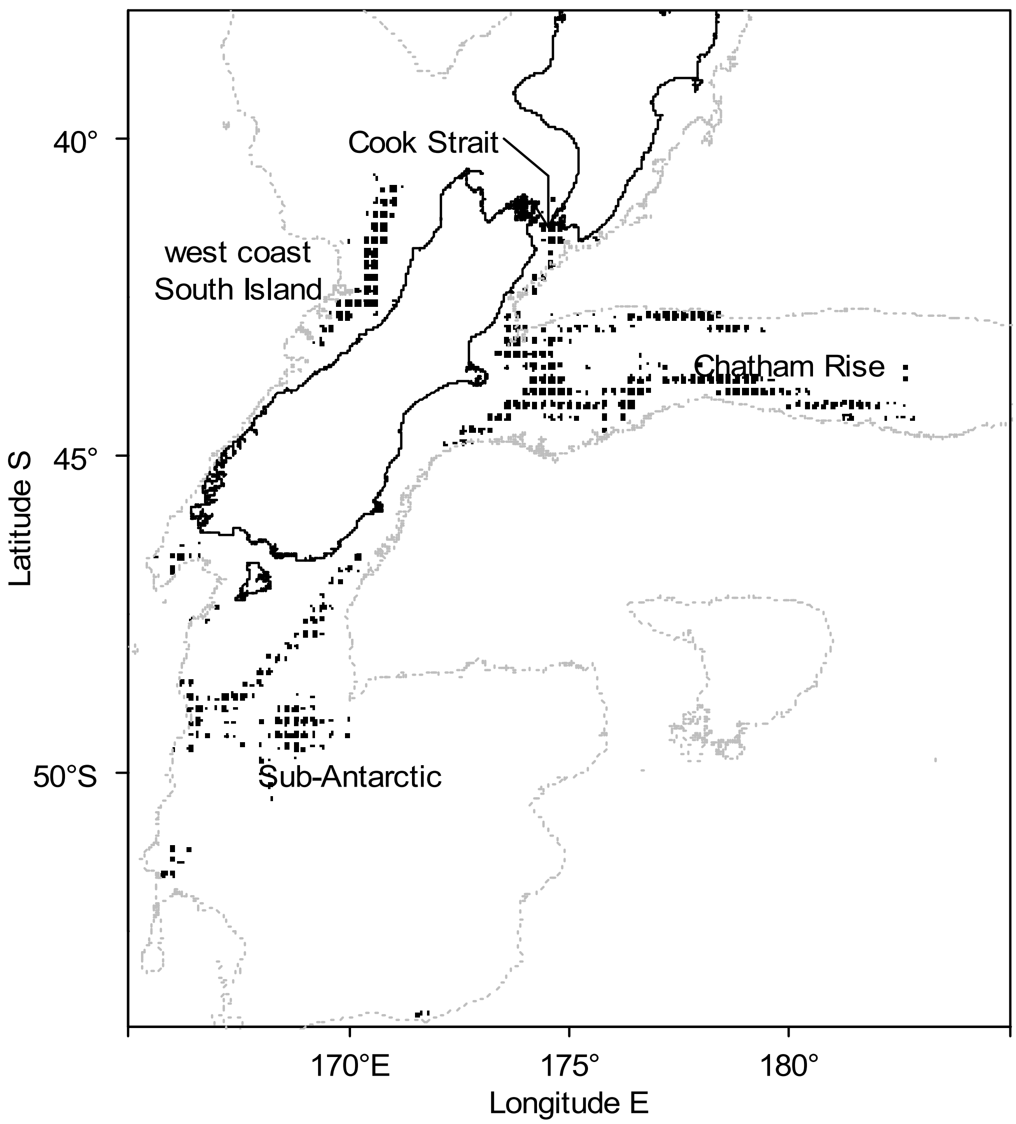

Figure 1: Southern New Zealand showing the main hoki fishing grounds, the 1000 m contour (broken grey line), and the position of all 2016–17 tows from TCEPRs (Trawl Catch and Effort Processing Returns) in which at least 10 t of hoki was caught (dots). Positions are rounded to the nearest 0.2 degrees and jittered.

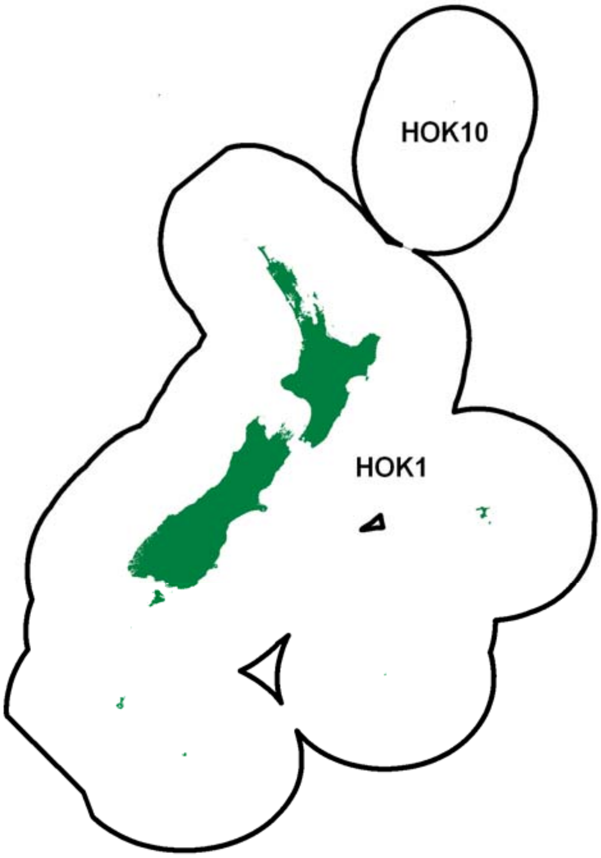

Figure 2: The Quota Management Areas for hoki.

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 2018 assessment of HOK 1, which is the seventeenth assessment to use NIWA's general-purpose stock-assessment model CASAL (Bull et al. 2012). Since the last assessment in 2017 (McKenzie 2018) there has been a winter 2017 acoustic survey in Cook Strait (O'Driscoll & Escobar-Flores 2018), and a trawl survey on the Chatham Rise in January 2018 (O'Driscoll 2018).

The work reported here addresses objective 2 of the Ministry for Primary Industries project HOK201703: *To update the stock assessment of hoki including estimates of biomass, risk and yields.*

2. MODEL ASSUMPTIONS AND INPUTS FOR 2018

This section provides a summary of all model assumptions and inputs for the 2018 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 2018 assessment the base case model and structure is the same as the previous assessment, as are the sensitivity runs.

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 that 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 much more time consuming to produce. For this reason only MPD runs were used for the initial exploratory analyses (Section 3). Final model runs were full Bayesian MCMC, and provide the results for the formal stock assessment (Section 4).

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.

Several 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.

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

As in the previous assessment, the catches used in the model (Table 3) were calculated by apportioning the official total catch for each year amongst the six model fisheries using the method described in Table 4.

In 2017 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. The total catch taken was 141 600 t, with 80 300 t from the western stock and 61 200 t from the eastern stock.

For the current year (2018) the TACC and catch split remains unchanged from 2017. It is estimated that the total catch for 2018 will equal the TACC of 150 000 t with catches: Ensp (41 000 t), Esp (21 000 t), Wnsp (18 000 t), Wsp (70 000 t) (Graham Patchell, pers. comm.). In the model the non-spawning fishery is split into two parts (Table 4) and it is assumed that the 2018 split proportions for this are the same as in 2017.

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	31 500	12 600	5 300	7 900	17 100	67 200	141 600
2018	29 300	11 700	7 200	10 800	21 000	70 000	150 000

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

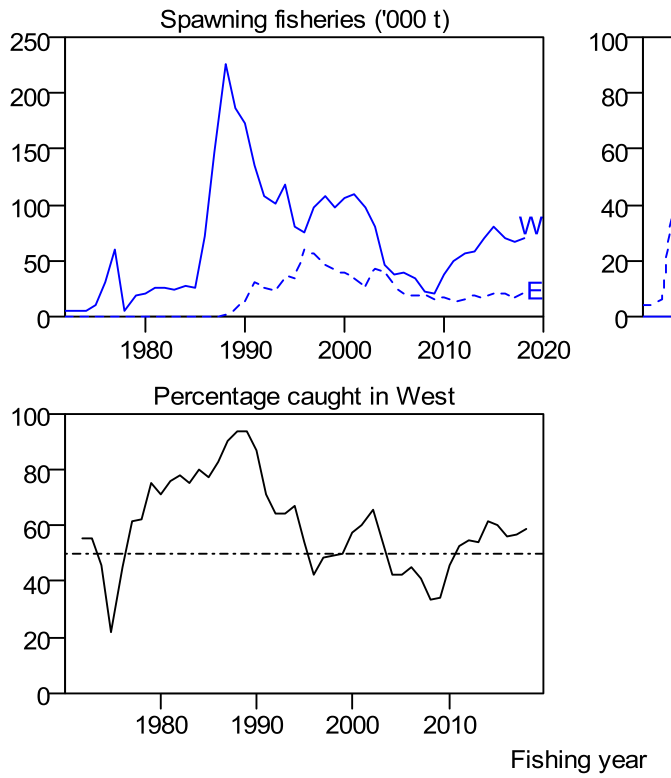

Figure 3: Annual catches by fishery for the spawning (top left panel) and non-spawning (top right panel) fisheries, and annual percentage of catch caught in western fisheries (Wsp, Wnsp1, Wnsp2) (bottom panel).

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 1.7). When the domed selectivities were used it was also necessary to combine sexes in the model and make the selectivities age-based (Francis 2005).

The home migration ogive, Whome, applied only to the W juveniles in CR and was the same in every year. At age 8, all W fish remaining in CR were forced to migrate to SA.

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

Runs	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
1.7	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 (304) was used for all years for which there was catch but no Wspage data (i.e., before 1988 and in 2018).

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	2017	Mean
298	300	301	300	301	297	304

2.3 Other structural assumptions

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

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

where YCS_y is the year-class strength for fish spawned in year y, SR is a Beverton-Holt stock-recruit relationship with assumed steepness 0.75 (Francis 2009, p. 23), and SSB_y is the mid-season spawning stock biomass in year y. Note there is no spawning ogive in the model, instead there are spawning areas (WC and CS), with the mid-season biomass in these defining spawning stock biomass.

Forty two YCSs were estimated for each stock, for 1975 to 2016, inclusive. YCSs for the initial years (1970 to 1974) were fixed at 1. The E and W YCSs for 2016 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 winter 2017 acoustic survey in Cook Strait, and a January 2018 trawl survey on the Chatham Rise.

The new at-age data are from the commercial spawning fisheries (Wspage, Espage), non-spawning commercial fishery for the east stock (Enspage), and the Chatham Rise trawl survey (CRsumage).

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 most model runs process errors for CRsumbio and SAsumbio are estimated within the model). Values of observation error for CSacous and WCacous were slightly revised for the 2018 assessment (but total CVs were used in the assessment model runs).

	CRsumbio	SAsumbio	SAautbio	CSacous	WCacous
1988	–	–	–	–	266 (0.12,0.60)
1989	–	–	–	–	165 (0.15,0.38)
1990	–	–	–	–	169 (0.06,0.40)
1991	–	–	–	88 (0.12,0.41)	227 (0.10,0.73)
1992	120 (0.08,0.21)	80 (0.07,0.21)	68 (0.08,0.22)	–	229 (0.17,0.49)
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 (0.14,0.91)	–
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 (0.09,0.36)	–
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 (0.12,0.35)	–
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 (0.31,0.34)	–
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 (0.11,0.39)	–
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 (0.18,0.35)
2014	102 (0.10,0.22)	–	–	–	–
2015	–	31 (0.13,0.24)	–	204 (0.18,0.33)	–
2016	113 (0.14,0.24)	–	–	–	–
2017	–	38 (0.17,0.26)	**–**	**102 (0.17,0.36)**	–
2018	**122 (0.16,0.26)**	**–**	**–**	**–**	**–**

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–**2017**	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–**2017**	otoliths
CR	EnspOLF	Catch at age	1992, 94, 96, 98	OLF
	Enspage	Catch at age	1999–**2017**	otoliths
	CRsumage	Trawl survey	1992–2014, 2016, **2018**	otoliths

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

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

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

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

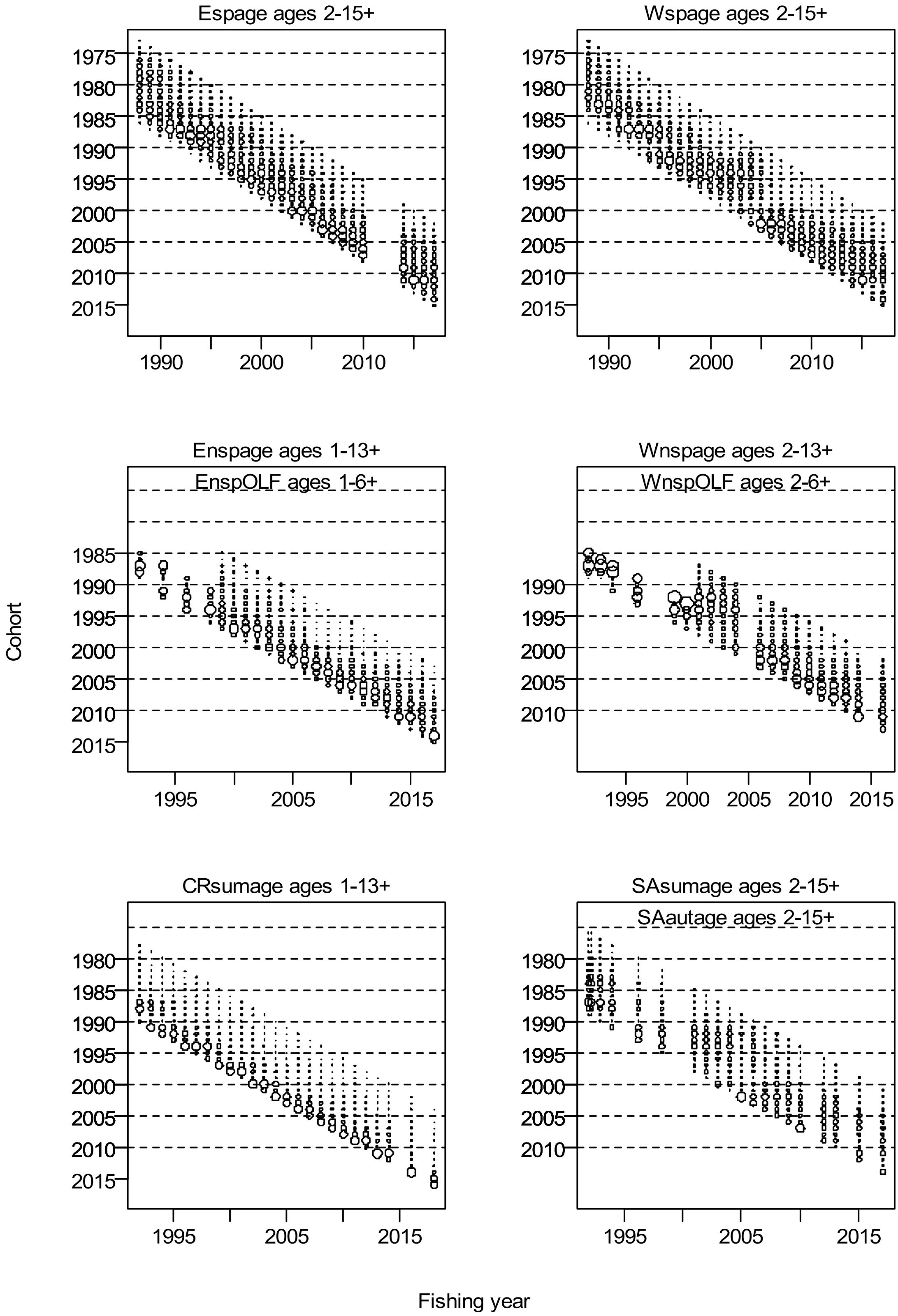

Figure 4: Proportions-at-age data, plotted by cohort and fishing year, with both sexes combined. The area of each circle is proportional to the associated proportion at age. Circle positions for the SAautage data in 1992 have been offset horizontally to allow them to be plotted on the same panel as the SAsumage data. Data new to the assessment are shown in Table 9.

2.5 Error assumptions

In the 2011 assessment the error distributions assumed for the proportions-at-age data were robust lognormal, to which process errors estimated within the model were added. In Francis (2011) the weighting of data in stock assessments was explored and one of the conclusions drawn was that proportions-at-age data are often over-weighted in assessments. Based on this, and explorations of reweighting for the 2011 assessment proportions-at-age data, it was decided by the Hoki Working Group to reweight the proportions-at-age data for the 2012 assessment using a multinomial error distribution (McKenzie 2013). This means that the weight assigned to each proportion-at-age datum is controlled by an effective sample size, these being calculated in MPD runs, then fixed for the full Bayesian runs. For the current assessment this same reweighting procedure was followed.

The error distributions assumed were lognormal for all other data. This means that the weight assigned to each datum was controlled by an error CV. For the biomass indices, two alternative sets of CVs were available (see Table 8). The total CVs represent the best estimates of the uncertainty associated with these data, although for the Chatham Rise and Sub-Antarctic trawl surveys it was decided for the current assessment to estimate this uncertainly within the model.

The total CVs for the acoustic indices were calculated using a simulation procedure intended to include all sources of uncertainty (O'Driscoll 2002), and the observation-error CVs were calculated in a similar way but including only the uncertainty associated with between-transect (and within-stratum) variation in total backscatter.

For the trawl indices, the total CVs were calculated as the sum of an observation-error CV (using the standard formulae for stratified random surveys, e.g., Livingston & Stevens (2002)) and a process-error CV. Note that CVs add as squares: $CV_{total}^2 = CV_{process}^2 + CV_{observation}^2$. The process error was set at 0.20 for some initial runs (Francis et al. 2001) , and estimated for the final base model run.

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 2015), 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 2015).

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 (often this penalty is dropped for Bayesian runs, but in any case it has little impact on the results) (Section 2.3). The third use of penalty functions was to link the spawning migration ogives for the two stocks (according to the constraints in Table 6).

2.7 No natal fidelity model structure

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

There have been a number of attempts to implement an adult fidelity model in CASAL, the first being for the 2006 assessment. However, these CASAL models have been problematic due to difficulties defining the eastern and western spawning stock biomasses and the uncertainty in these from Bayesian runs (section 7.3 in Francis 2006, section 3.3 in Francis 2007, sections 3.2 and 3.3 in Francis 2008, section 2.7 in Francis 2009, McKenzie 2009, McKenzie 2012). However, the problems appear to have been resolved, and in this section we give more detail as to how the no natal fidelity model is implemented in CASAL. Note 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. INITIAL MPD RUN 1.1: UPDATE OF BASE CASE FROM 2017 ASSESSMENT

For the 2017 hoki stock assessment final model MCMC runs there was a single base run, and six sensitivity runs (Table 13). The base run had age-varying natural mortality, a single catchability for the Sub-Antarctic trawl survey, assumed natal fidelity, and the process error for the Chatham Rise and Sub-Antarctic trawl surveys were estimated We update this base run for the 2018 assessment with new data, running at first an MPD fit, calling this model run 1.1. Later we update all runs in Table 13 as MCMC model runs (Section 4).

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.

Table 13: 2017 hoki stock assessment. Distinguishing characteristics for all MCMC final model runs, including all sensitivity runs to the base run 1.1.

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.

Using the updated 2018 model run 1.1, the biomass trajectory is compared to the analogous model run from last year's assessment (Table 14, Figure 5). For the updated assessment model the eastern and western virgin biomasses are very similar to the previous assessment. Biomass in 2017 (%B_0) is lower for the E stock and higher for the W stock, which is in part related to the new eastern stock biomass indices (Figure 6).

For the updated assessment and both stocks there are differences in the 2014 and 2015 year class strength estimates compared to the previous assessment (Figure 7).

For the updated model run 1.1 the process error for the Chatham Rise and Sub-Antarctic trawl survey were estimated to be 0.14 and 0.39 respectively (compared to 0.15 and 0.38 respectively for the previous assessment).

Other graphs show selectivities, migration ogives, and fitted age-varying natural mortality, and compare the updated and previous assessment (Figures 8–10). These are very similar with the only notable difference being the eastern and western spawning selectivities (Espsl, Wspsl) which were estimated as flat for the previous assessment, but not for the updated model run (see Figure 8). This difference in the spawning selectivities between assessments is related to the shift parameter for the western spawning selectivity (a_shift) which was estimated to be -0.098 for the updated model and zero for the previous assessment (see McKenzie (2018) for more detail on this).

Fits to the biomass indices are shown in Figure 11, and to the proportions-at-age in Appendix 4.

Table 14: Comparison of old and new biomass estimates for the stocks E and W. The label 2017.1 refers to the base run 1.1 from the 2017 assessment described by McKenzie (2018), while run 1.1 is the updated version of this for the 2018 assessment.

	B_0('000 t)		B_{2017}(%B_0)		B_{2018}(%B_0)	
Run	E	W	E	W	E	W
2017.1	449	869	63	48	–	–
1.1	433	876	53	54	52	55

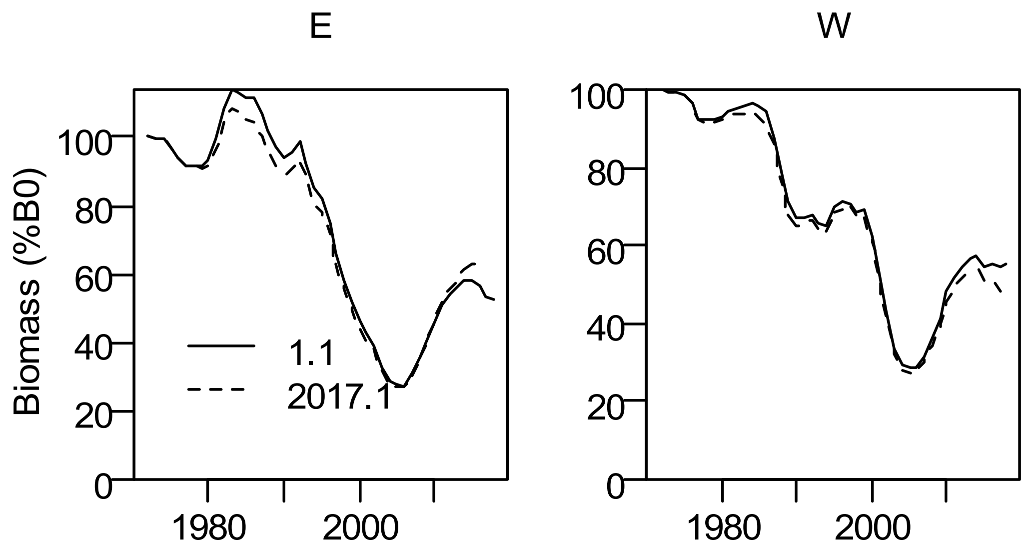

Figure 5: Comparison of biomass trajectories from different runs: E stock (left column), W stock (middle column), and E + W stocks combined (right column). The graphs compare run 1.1 from 2018 (solid lines) with the corresponding run from 2017 (broken lines). The label 2017.1 denotes run 1.1 from the 2017 assessment.

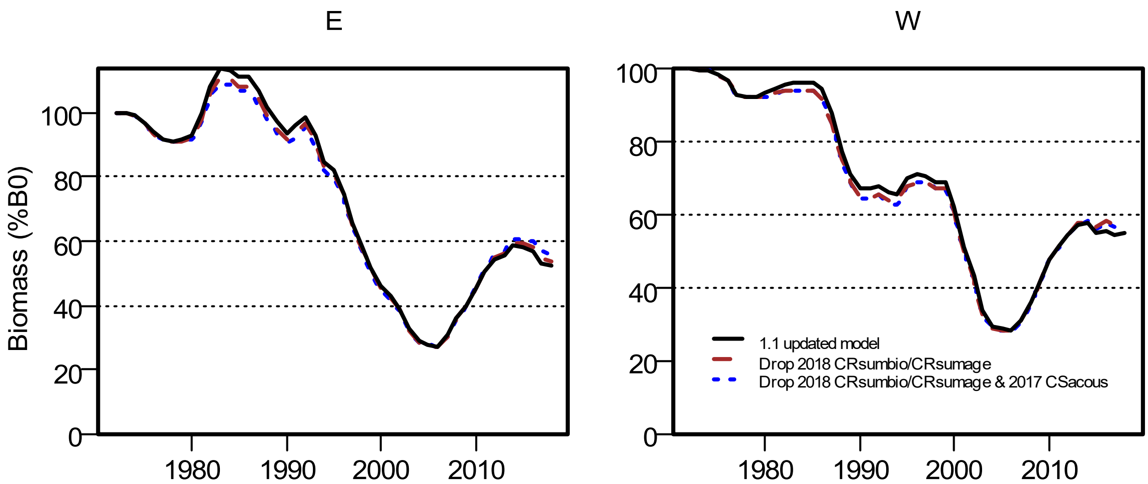

Figure 6: Biomass trajectories for different model runs, comparing the updated model run 1.1. with one in which the 2018 CRsumbio and 2018 CRsumage data are dropped, and another in which the 2017 CSacous index is dropped as well.

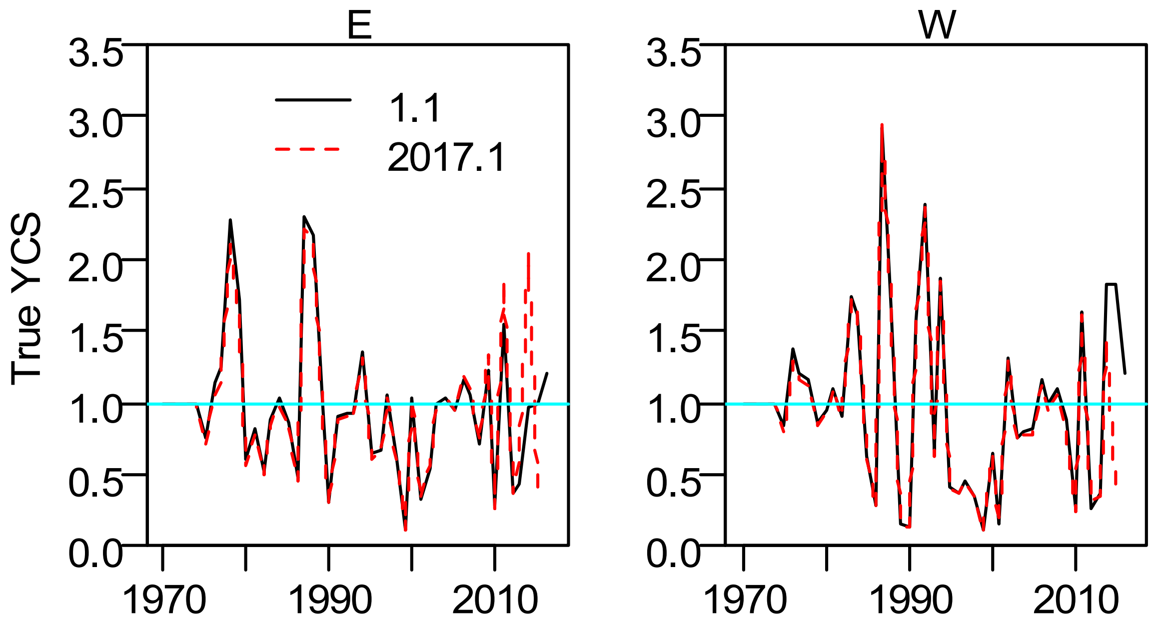

Figure 7: True YCS estimates for new run 1.1 from 2018 (solid lines) and the analogous run from last year's assessment. The label 2017.1 denotes run 1.1 from the 2017 assessment.

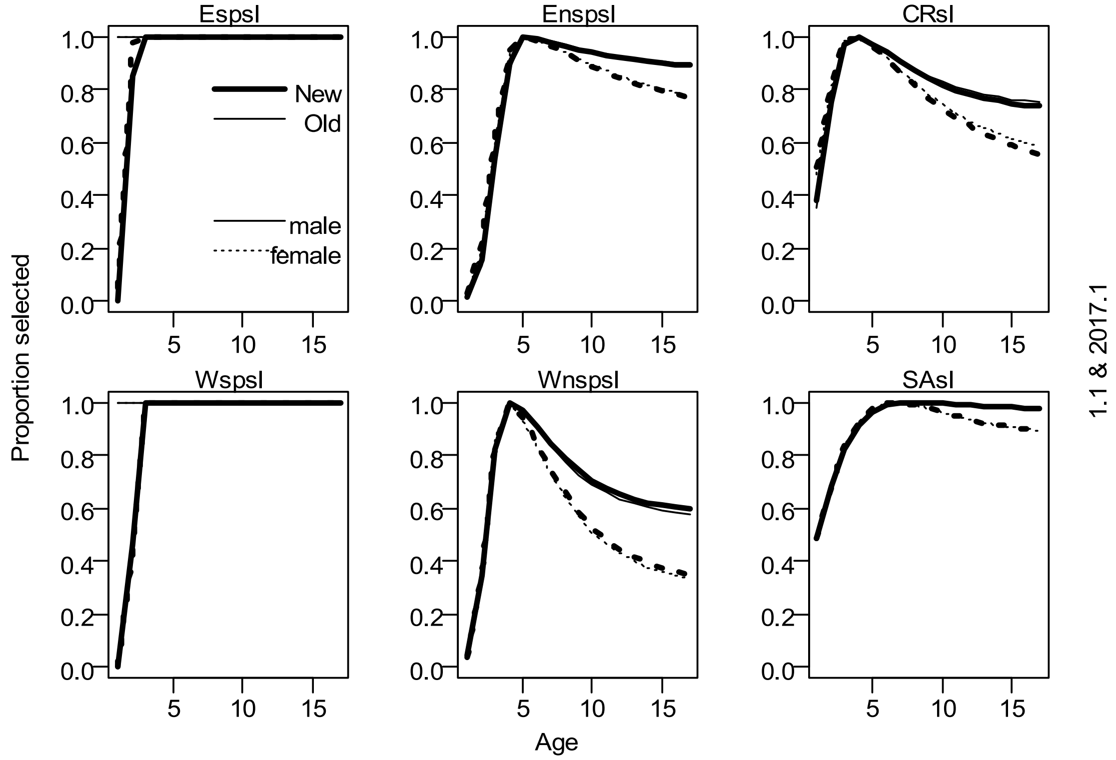

Figure 8: Estimated selectivity curves for the new model run 1.1 from the new 2018 (heavy lines) and the analogous model run from the previous assessment (light lines). Males are shown with a solid line, females with a dotted line. The label 2017.1 denotes run 1.1 for the 2017 assessment.

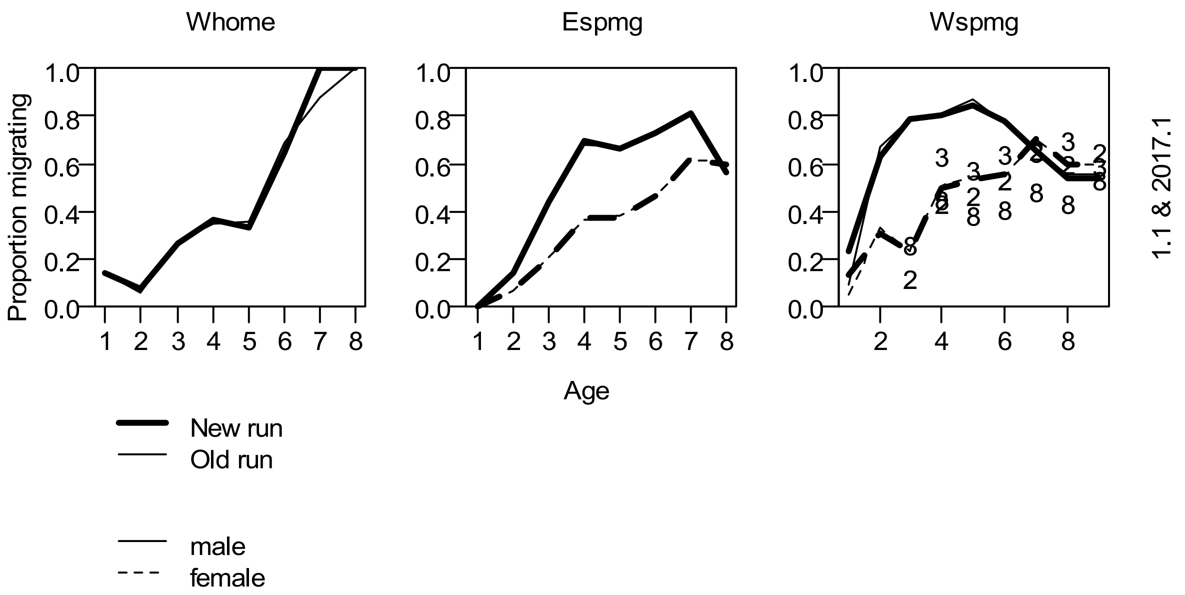

Figure 9: Estimated migration ogives for new run 1.1 from 2018 (heavy lines) and the analogous model run from the previous assessment (light lines). Each row of plots compares ogives from the new run (heavy lines) with that from the previous assessment (light lines). Where ogives differ by sex, female 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 2017.1 denotes run 1.1 from the 2017 assessment.

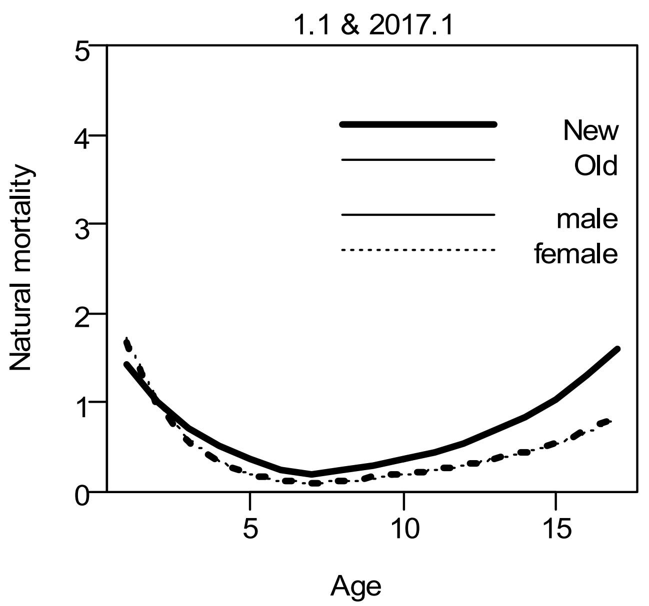

Figure 10: Comparison between age-dependent natural mortality estimated in the new run 1.1 from 2017 (heavy lines) and the analogous model run from the previous assessment (light lines). The label 2017.1 denotes run 1.1 from the 2017 assessment.

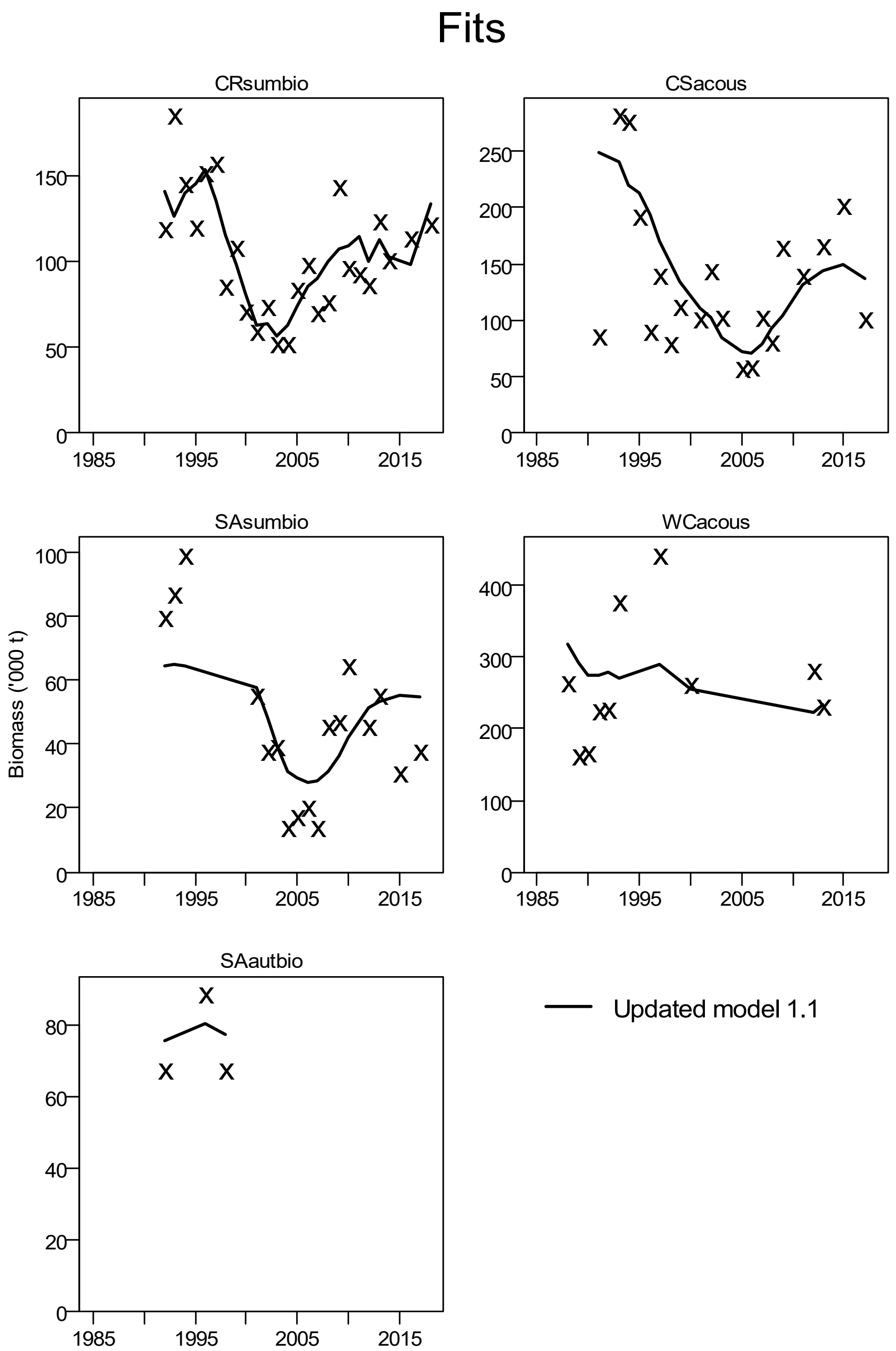

Figure 11: Fits to the biomass indices for updated model run 1.1. for the 2018 assessment. Shown are observed ('x') and expected values (lines).

4. FINAL MODEL ASSESSMENT RESULTS (MCMC)

4.1 Introduction

The final MCMC model runs for the 2017 assessment were updated for the 2018 assessment (see Table 13, Table 15). 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.

In the model "pe 0.20" (run 1.2) 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 (1.3–1.5) 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 1.6), or a domed spawning selectivity is used instead of an age-dependent natural mortality (run 1.7).

Run 1.1 was preferred over the run with the process error set at 0.20 for the trawl surveys (1.2) 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 0.39 for run 1.1, compared to 0.20 for run 1.2, means that the estimate of western stock biomass is more uncertain.

Table 15: Runs taken through to MCMC for the 2018 assessment.

Run	Short name	Model description
1.1	initial	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	pe 0.20	as 1.1 but process error fixed at 0.20
1.3	drop SAsumbio	as 1.1 but drop SAsumbio
1.4	drop WCacous	as 1.1 but drop WCacous
1.5	drop WCacous pe 0.20	as 1.1 but drop WCacous with process error fixed at 0.20
1.6	no natal fidelity	as 1.1 but natal fidelity is not assumed.
1.7	M constant	as 1.1 but with M fixed 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. Estimated MPD trawl survey process errors for the runs are shown in Table 16. They range from 0.14–0.15 (CRsumbio) and 0.33–0.48 (SAsumbio).

Where the model description is "pe 0.20" this refers to the process error for the CRsumbio and SAsumbio trawl surveys. In run 1.3 where SAsumbio (Sub-Antarctic trawl survey biomass indices) is dropped the corresponding at-age data (SAsumage) is retained.

Table 16: Chatham Rise and Sub-Antarctic process error for each run. For runs 1.2 and 1.5 the process errors are set at 0.20 ("pe 0.20").

Run	Short name	CR process error	SA process error
1.1	base	0.14	0.39
1.2	pe 0.20	0.20	0.20
1.3	drop SAsumbio	0.15	-
1.4	drop WCacous	0.14	0.34
1.5	drop WCacous pe 0.20	0.20	0.20
1.6	no natal fidelity	0.15	0.48
1.7	M constant	0.14	0.43

4.2 MCMC setup

The MCMC chains were generated in the same way as in the 2017 assessment (McKenzie 2018). 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. For the no natal fidelity run longer chains with length 14 million were used to improve diagnostics.

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 (2016 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 12–15. They suggest that convergence was adequate to estimate key quantities and their uncertainty. To form the final single chain for each run, the first 1/8 of each chain was discarded (i.e. the first 500 000 samples from the chain of length 4 million were discarded), the three chains concatenated, and the resulting chain thinned by systematic sub-sampling to produce a posterior sample of length 2000.

4.3 Comparison to base run from previous assessment

Estimates of the western 2017 biomass are similar between run 1.1 and the analogous model run from the previous assessment, but less for the eastern stock (Figure 16).

Comparing the current stock assessment to the previous one, then across model runs current stock status is estimated to be lower for the eastern stock by 6–8%, and higher for the western stock by about the same amount (Table 17).

The estimated selectivities, migration ogives, and natural mortality estimates (Figures 17–19), are similar to those from the 2017 assessment (Appendix 5). The main difference for the MPD run is that the western and eastern spawning selectivities are steeper, and the proportion of ages six and seven fish that migrate from the Chatham Rise to the Sub-Antarctic is higher (Whome ogive). Where these selectivities differ they are now more like those estimated for the base run 1.7 from the 2016 assessment (Appendix 6).

Posteriors are within the bounds of the priors (Figure 20) and are very similar to those for the 2017 assessment (Appendix 5). The parameter a_shift that estimates annual changes in Wspsl has a median value of -0.14 (-0.028 in the 2017 assessment) and a posterior to the left of the prior (Figure 21).

4.4 Further results and other model runs

Estimates of YCSs for the 2015 and 2016 years are above average and very uncertain (Figure 22, Table 18). Normalised residuals for SAsumbio and CRsumbio are shown in Figures 23–24.

Dropping the Sub-Antarctic trawl survey biomass indices (SAsumbio) leads to a much higher estimate for the western current biomass compared to the base case (84%B_0 instead of 64%B_0) (Table 17, Figure 25). In contrast dropping the west coast acoustic survey (WCacous) gives a lower estimate of western current biomass (56%B_0 instead of 64%B_0).

With a process error of 0.20 for the trawl surveys the western current biomass is estimated to be lower (52%B_0 versus 64%B_0 for the base case), and similarly if the west coast acoustic survey is dropped (46%B_0 versus 56%B_0) (see Table 17).

For both the no natal fidelity and constant M runs (1.6, 1.7) western current biomass is estimated to be higher than for the base model run. The eastern current biomass, however, is estimated to be lower for the no natal fidelity run and higher for the constant M run (see Table 17).

Biomass trajectories are shown for runs 1.1–1.4 (Figures 26–27).

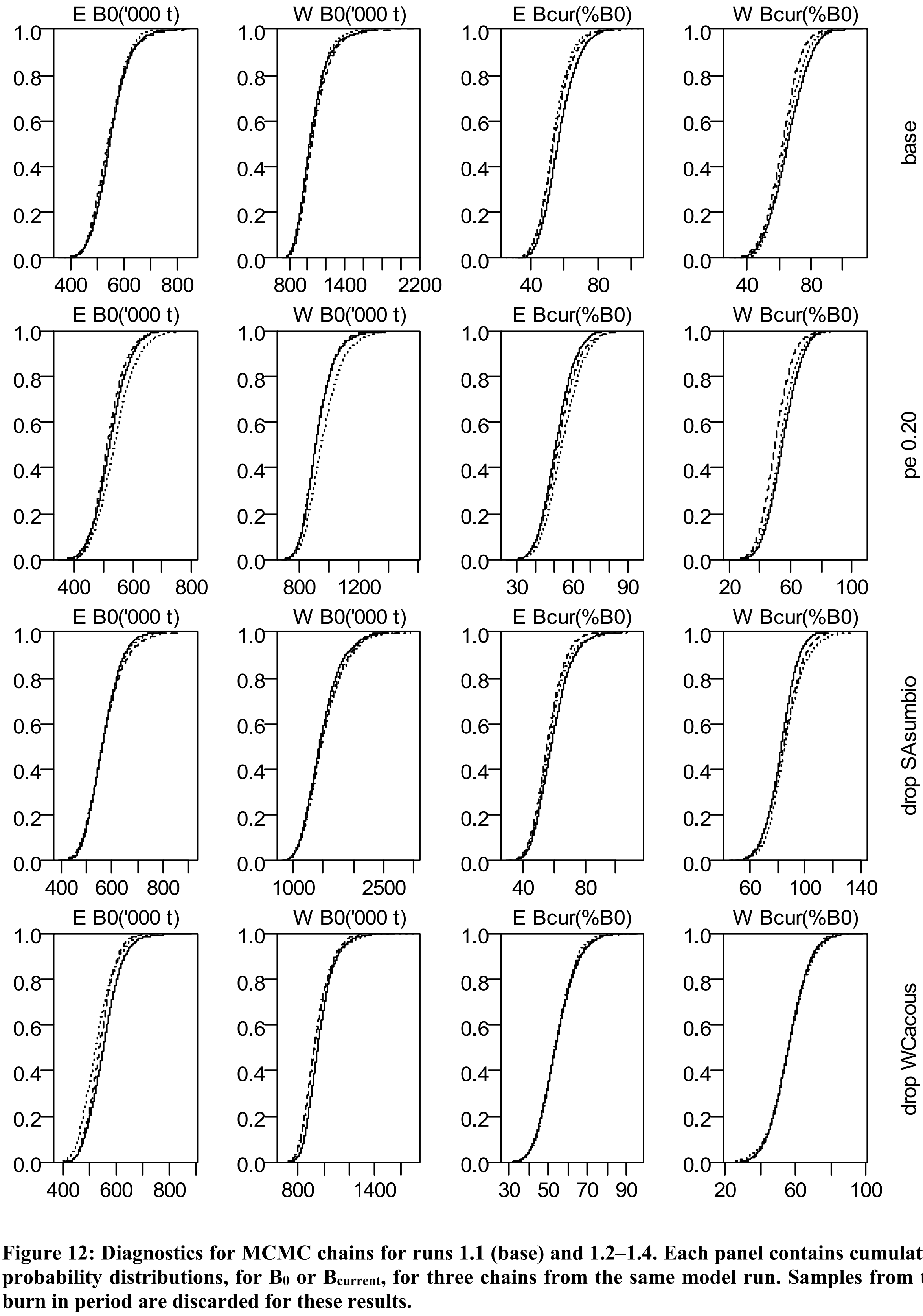

Figure 12: Diagnostics for MCMC chains for runs 1.1 (base) and 1.2–1.4. Each panel contains cumulative probability distributions, for B_0 or $B_{current}$, for three chains from the same model run. Samples from the burn in period are discarded for these results.

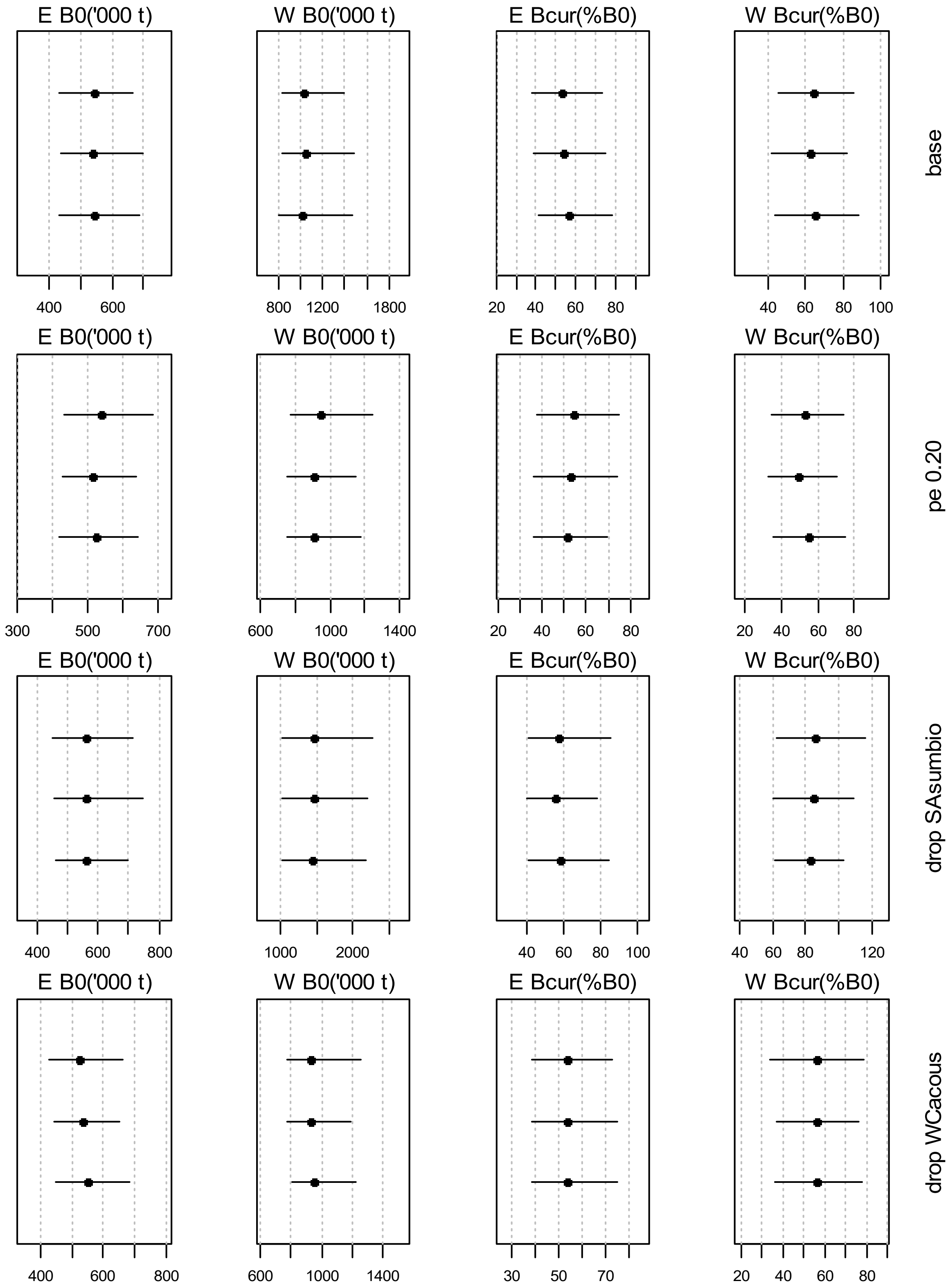

Figure 13: Further diagnostics for MCMC chains for runs 1.1 (base) and 1.2–1.4. Each panel contains the median (solid dot) and 95% credible interval, for B_0 or $B_{current}$, for three chains from the same model run.

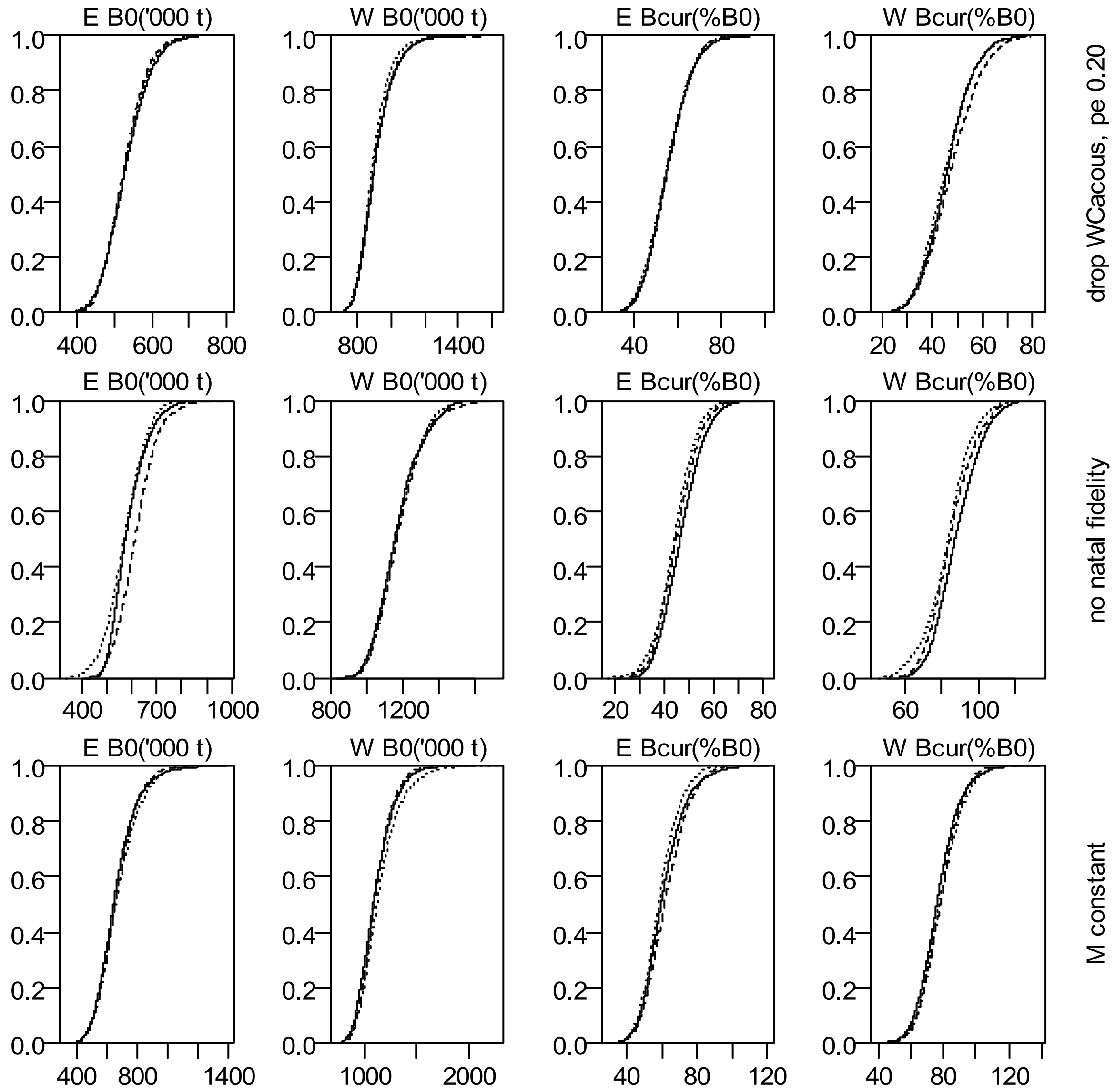

Figure 14: Diagnostics for MCMC chains for runs 1.5–1.7. Each panel contains cumulative probability distributions, for B_0 or $B_{current}$, for three chains from the same model run. Samples from the burn in period are discarded for these results.

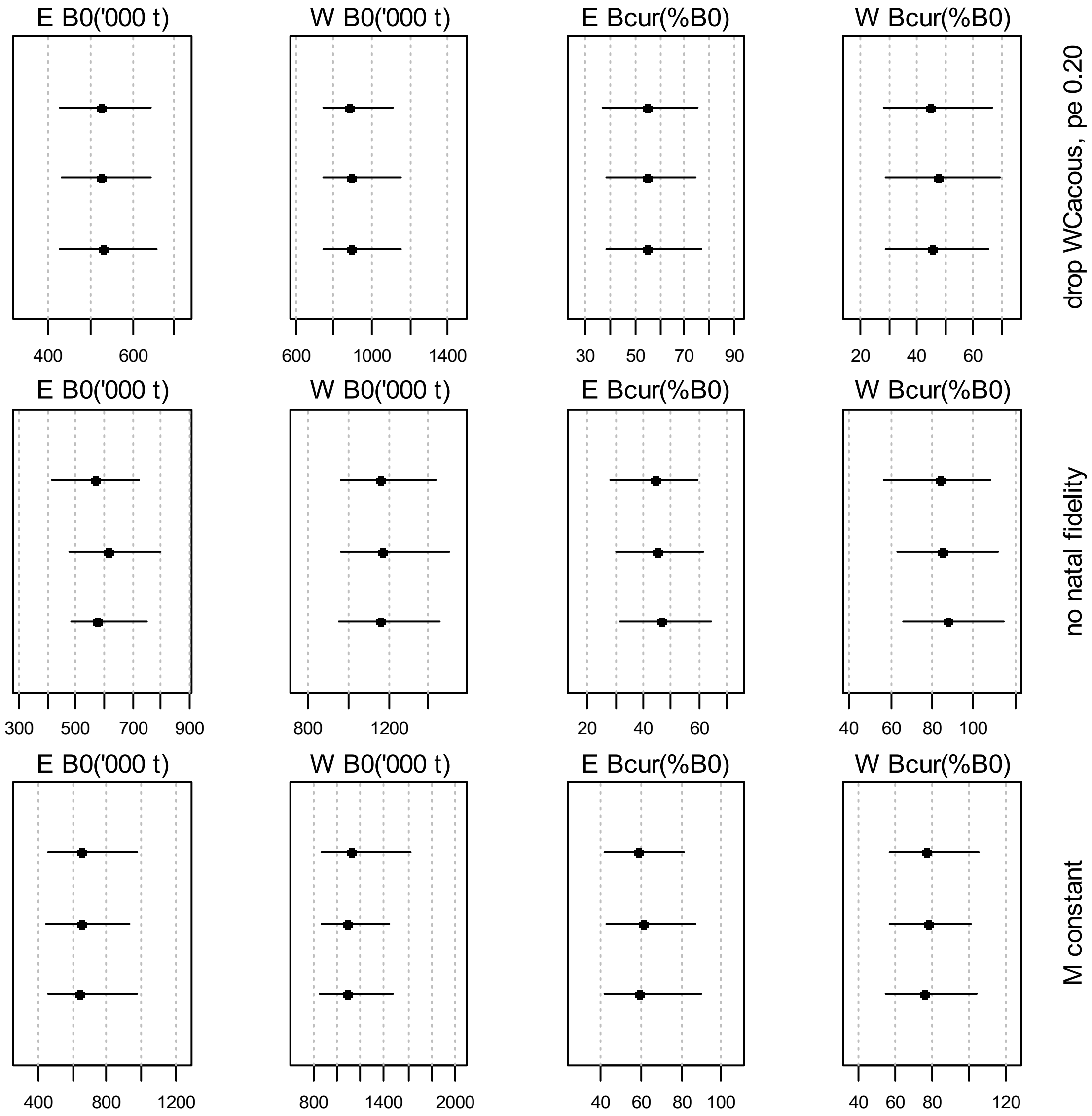

Figure 15: Further diagnostics for MCMC chains for runs 1.5–1.7. Each panel contains the median (solid dot) and 95% credible interval, for B_0 or $B_{current}$, for three chains from the same model run.

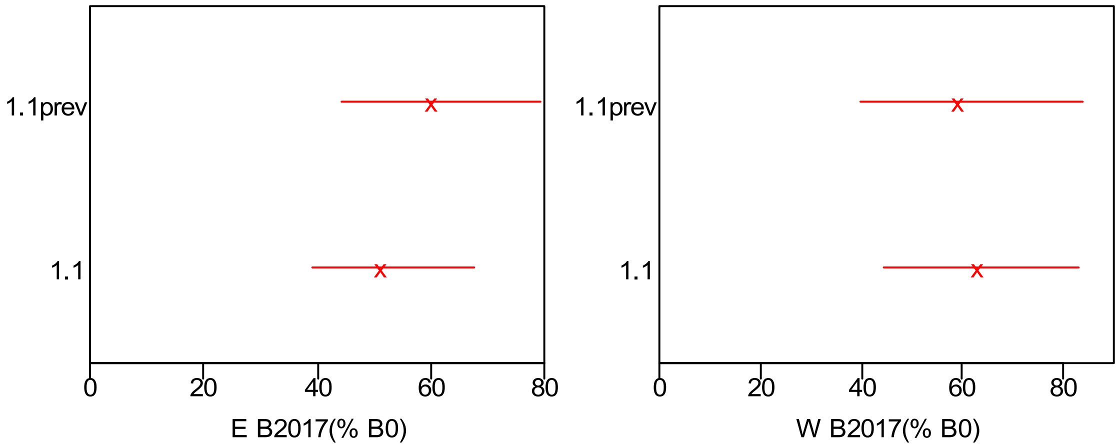

Figure 16: Comparison of 2018 base run 1.1 (single q) with the comparable run from 2017 (1.1prev): estimates of stock status in 2017 (B_{2017} as $\%B_0$), with 95% credible intervals shown as horizontal lines.

Table 17: Estimates of spawning biomass (medians of marginal posterior, with 95% credible intervals in parentheses). $B_{current}$ is the biomass in mid-season 2018.

	B_0('000 t)		$B_{current}$('000 t)		$B_{current}$($\%B_0$)	
Run	E	W	E	W	E	W
base	543(438,682)	1036(822,1448)	293(193,458)	659(378,1187)	54(39,77)	64(44,86)
pe 0.20	525(425,661)	922(764,1192)	277(173,441)	483(276,829)	53(37,73)	52(34,73)
drop SAsumbio	563(456,729)	1449(1010,2228)	320(205,530)	1234(683,2170)	57(40,83)	84(61,110)
drop WCacous	540(438,671)	941(781,1211)	288(188,440)	527(291,883)	53(38,73)	56(35,78)
drop WCacous pe 0.20	524(429,652)	889(747,1157)	289(178,443)	408(225,704)	55(37,75)	46(29,67)
no natal fidelity	585(454,761)	1162(963,1462)	265(151,405)	993(636,1505)	45(30,63)	85(61,112)
M constant	651(454,973)	1100(859,1542)	388(227,684)	843(527,1363)	60(41,87)	76(56,101)

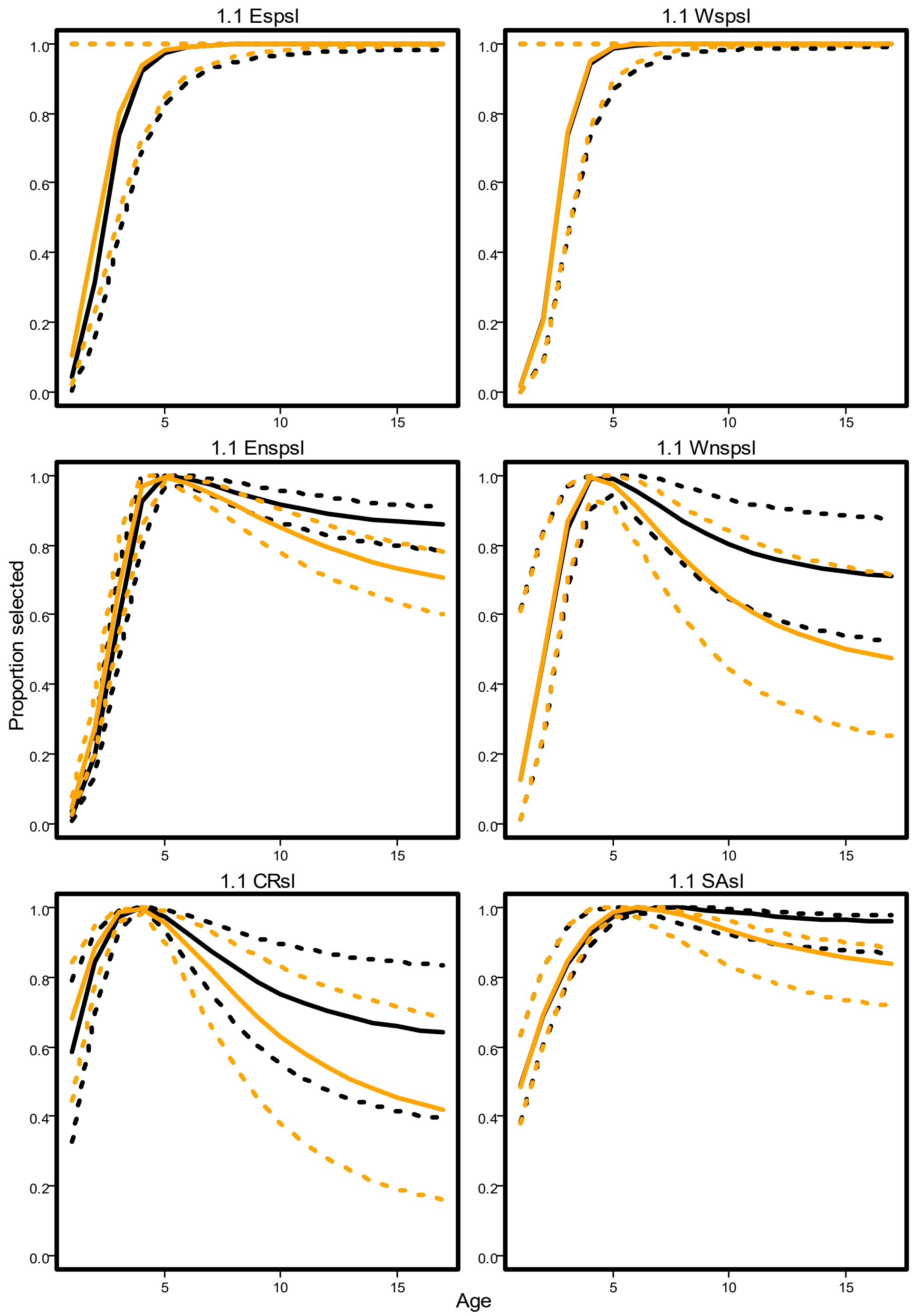

Figure 17: Posterior estimates of selectivity ogives for each for the MCMC run 1.1. Solid lines are medians; broken lines show 95% credible intervals. Where ogives differ by sex they are plotted as black for males and orange for females. Where they differ by stock or time step the plotted curves are for one selected combination (E step 2 for Enspsl and CRsl, W step 2 for Wnspsl and SAsl).

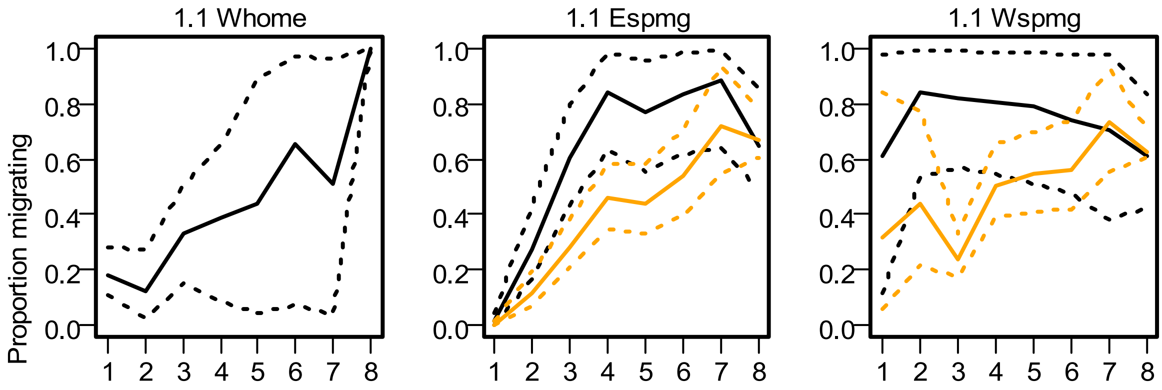

Figure 18: Estimated migration ogives estimated. Solid lines are medians, broken lines show 95% credible intervals. Where ogives differ by sex they are plotted as black for males and orange for females. The x-axis shows age (years).

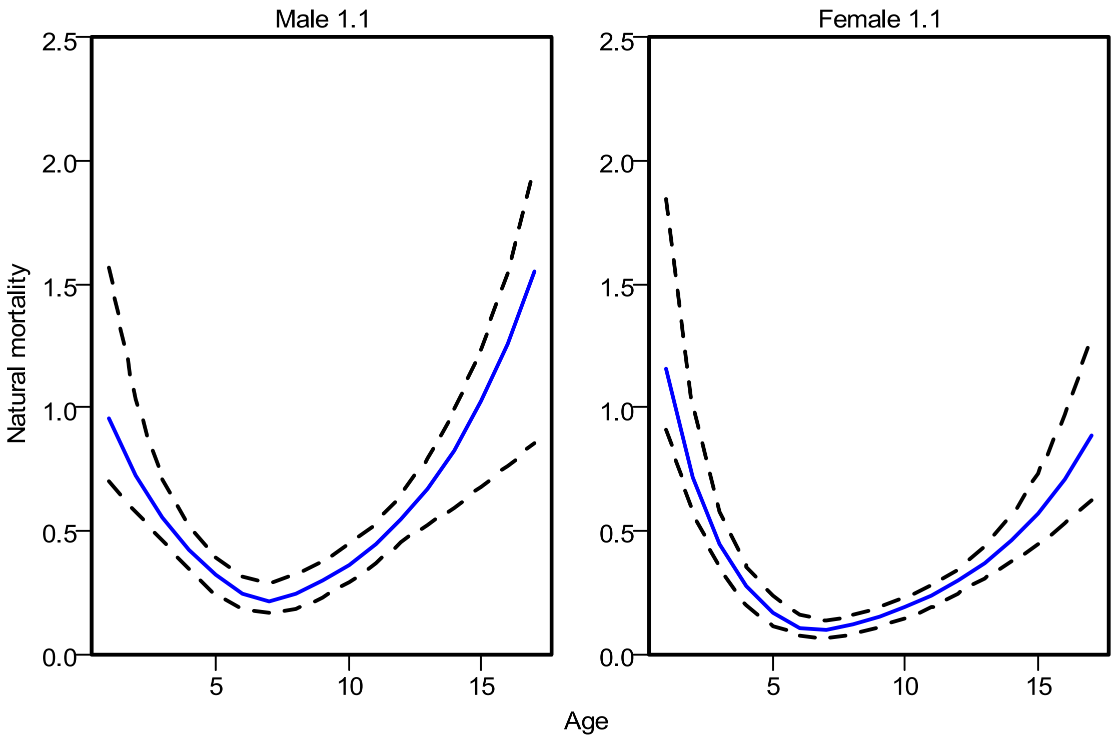

Figure 19: Assessment estimates of age-dependent natural mortality ogives for the MCMC runs showing median estimates (solid blue lines) and 95% credible intervals (broken lines) for each sex.

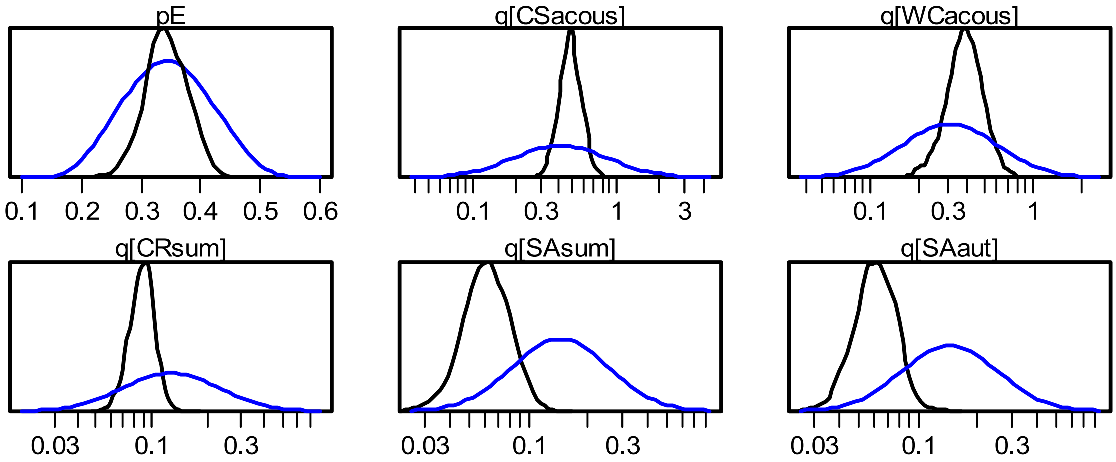

Figure 20: Base case 1.1. Assessment prior (blue lines) and estimated posterior (black lines) distributions for the following parameters: pE (proportion of B_0 in E stock), and survey catchabilities (acoustic and trawl).

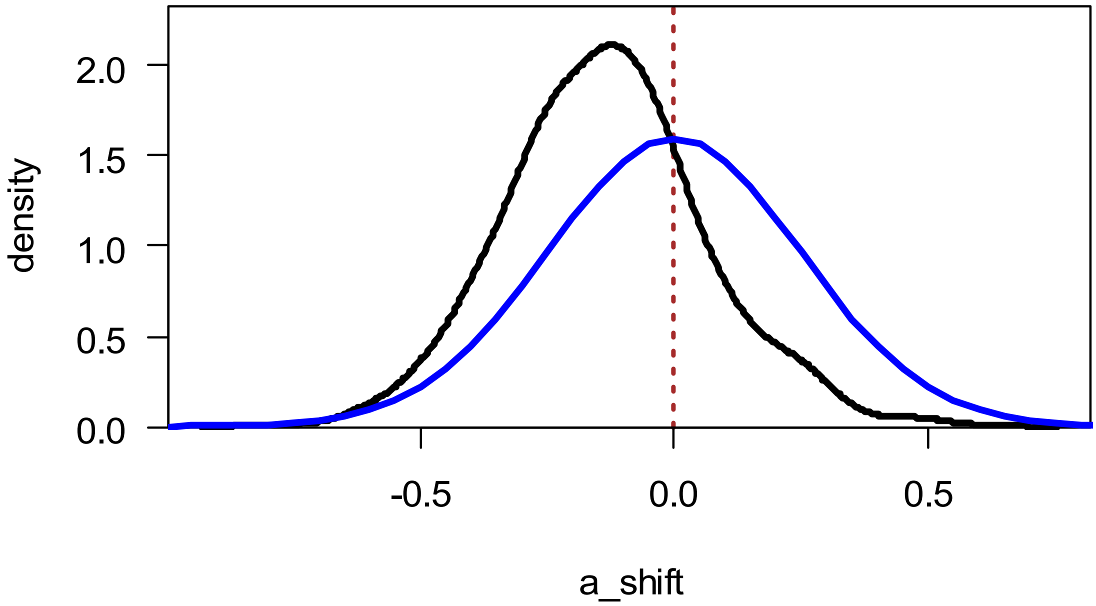

Figure 21: Assessment prior (blue line) and estimated posterior (black line) distributions for the a_shift parameter which estimates annual shifts in the western spawning selectivity.

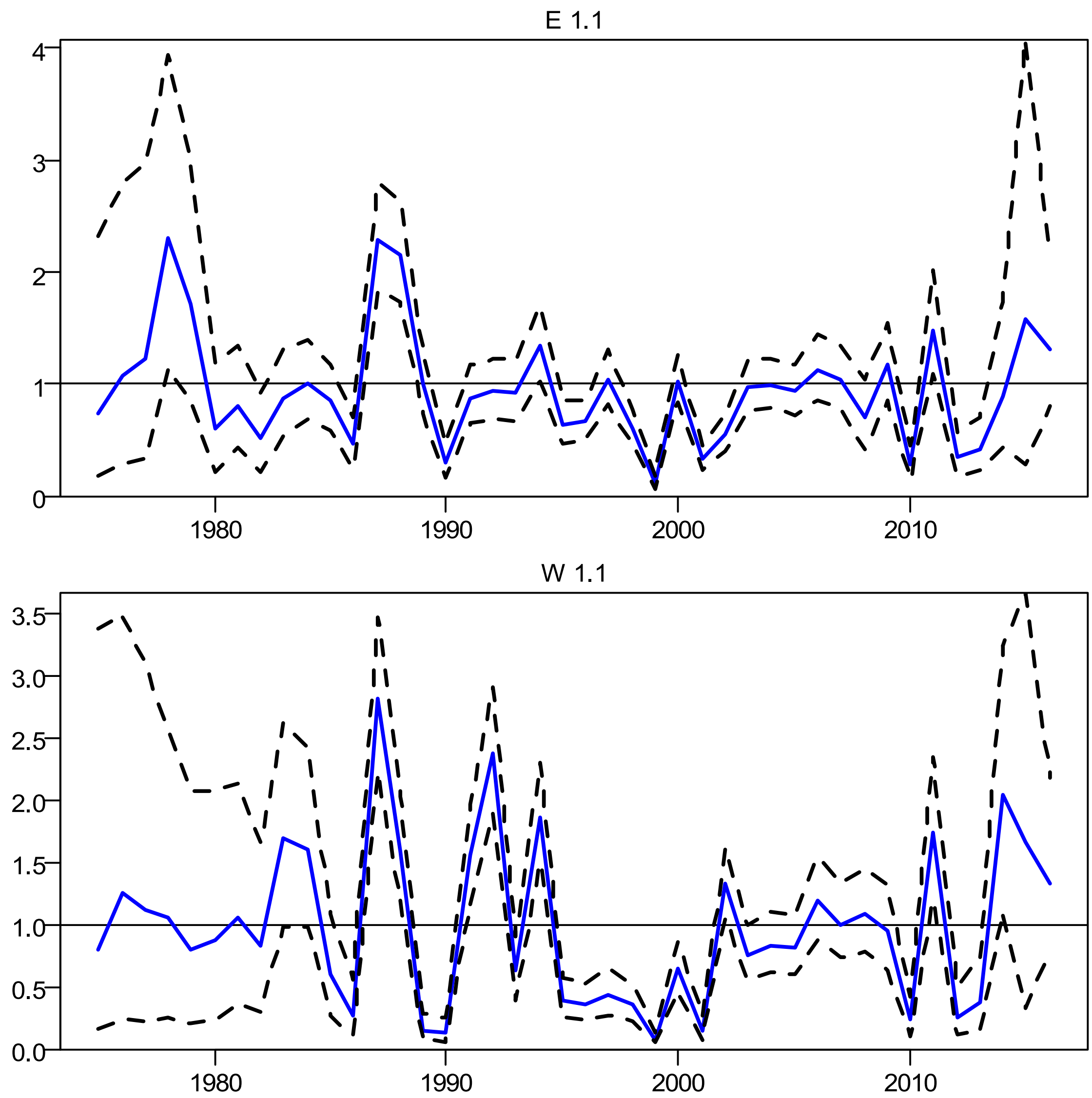

Figure 22: Estimated true year-class strengths (YCSs) from run 1.1 showing medians (solid lines) and 95% credible intervals (broken lines) by run for E (top panel), W (bottom panel).

Table 18: Median value for true YCSs for the base model 1.1.

Fishing year	2012	2013	2014	2015	2016
E stock	0.35	0.42	0.89	1.57	1.32
W stock	0.26	0.38	2.05	1.67	1.33

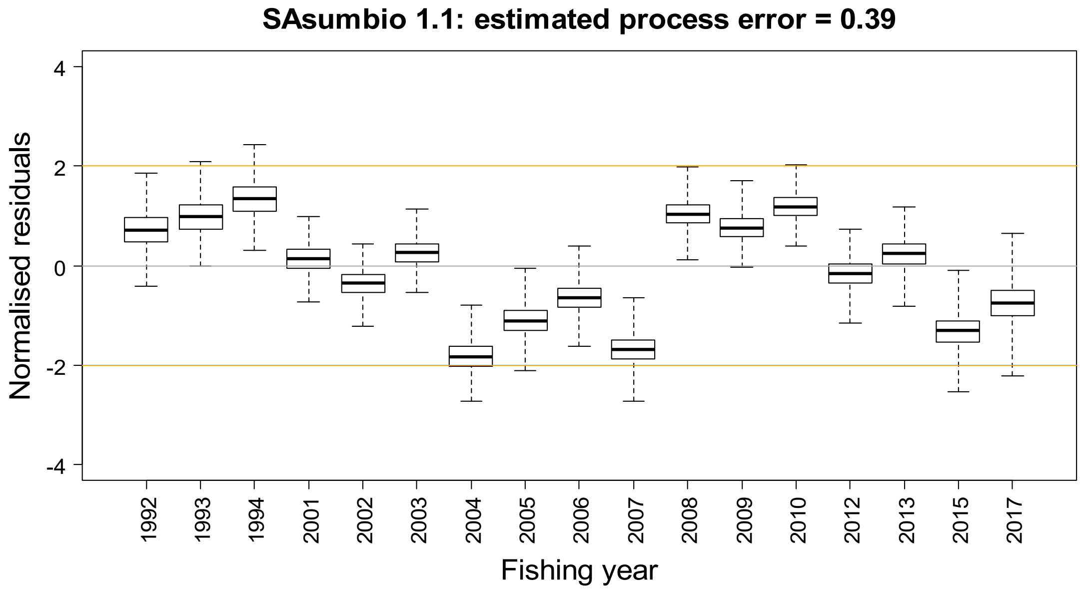

Figure 23: MCMC normalised residuals for model 1.1 and the fit to the Sub-Antarctic trawl survey.

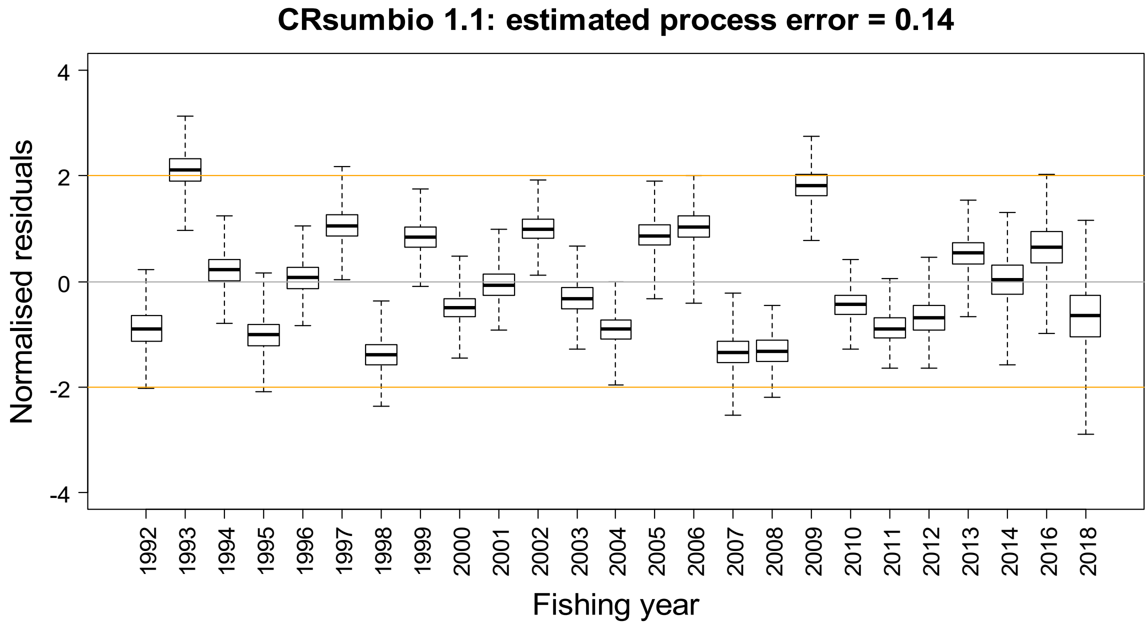

Figure 24: MCMC normalised residuals for model 1.1 and the fit to the Chatham Rise trawl survey.

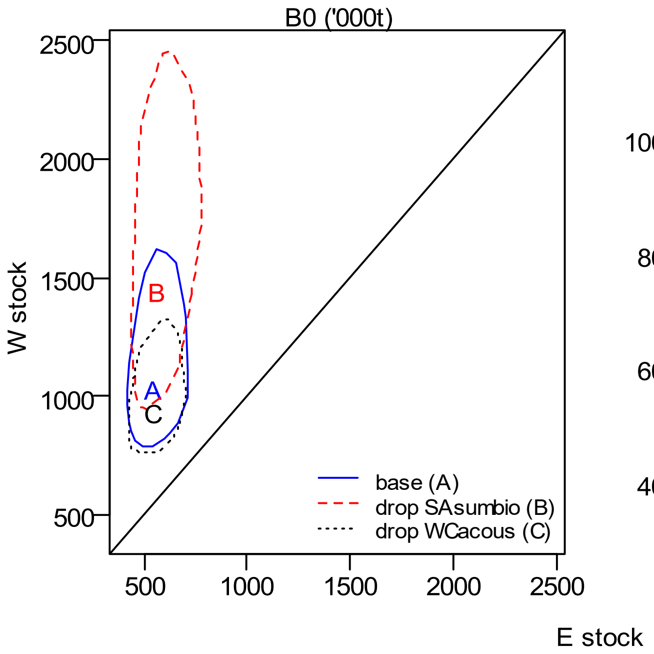

Figure 25: Estimates and approximate 95% credible intervals for virgin (B_0) and current ($B_{current}$ as $\%B_0$) biomass by stock for the three runs 1.1 (A), 1.3 (B), and 1.4 (C). In each panel the points 'A' and 'B' indicate best estimates (median of the posterior distribution) for these two runs, and the polygons (with solid, broken and dotted lines, respectively) enclose approximate 95% credible intervals. Diagonal lines indicate equality (y = x).

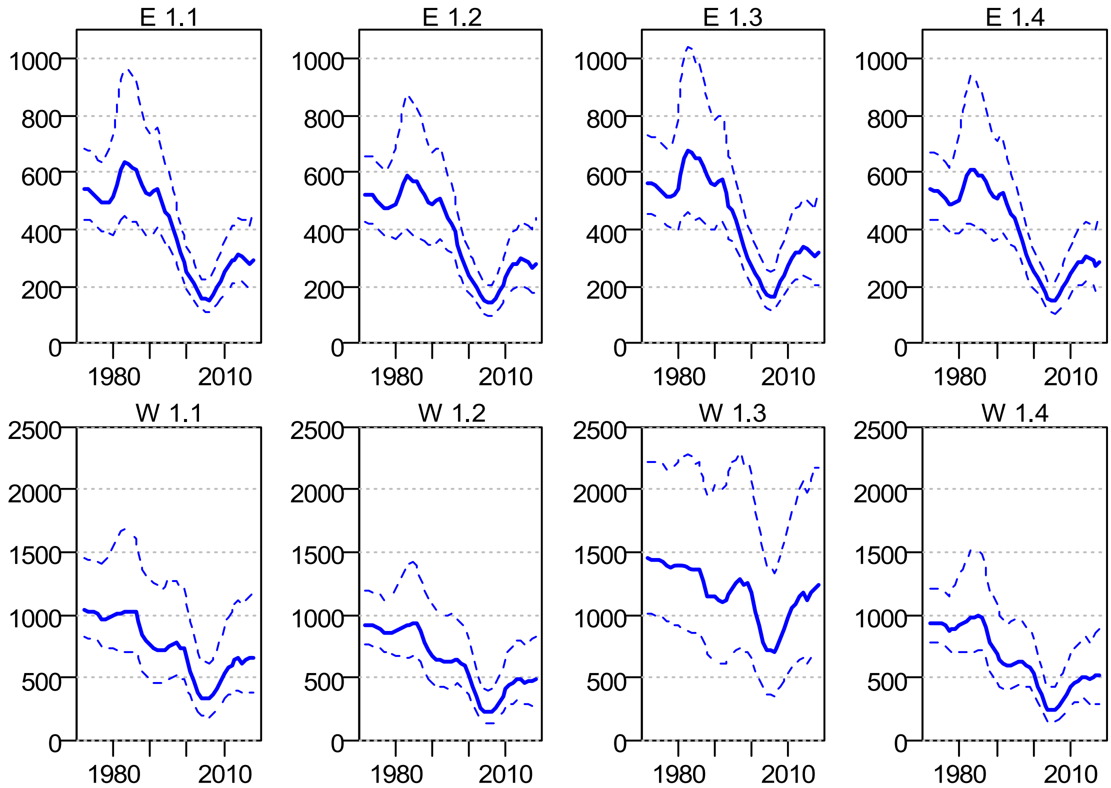

Figure 26: Estimated spawning-biomass trajectories from the MCMC runs, showing medians (solid lines) and 95% credible intervals (broken lines) by run for E (upper panels) and W (lower panels).

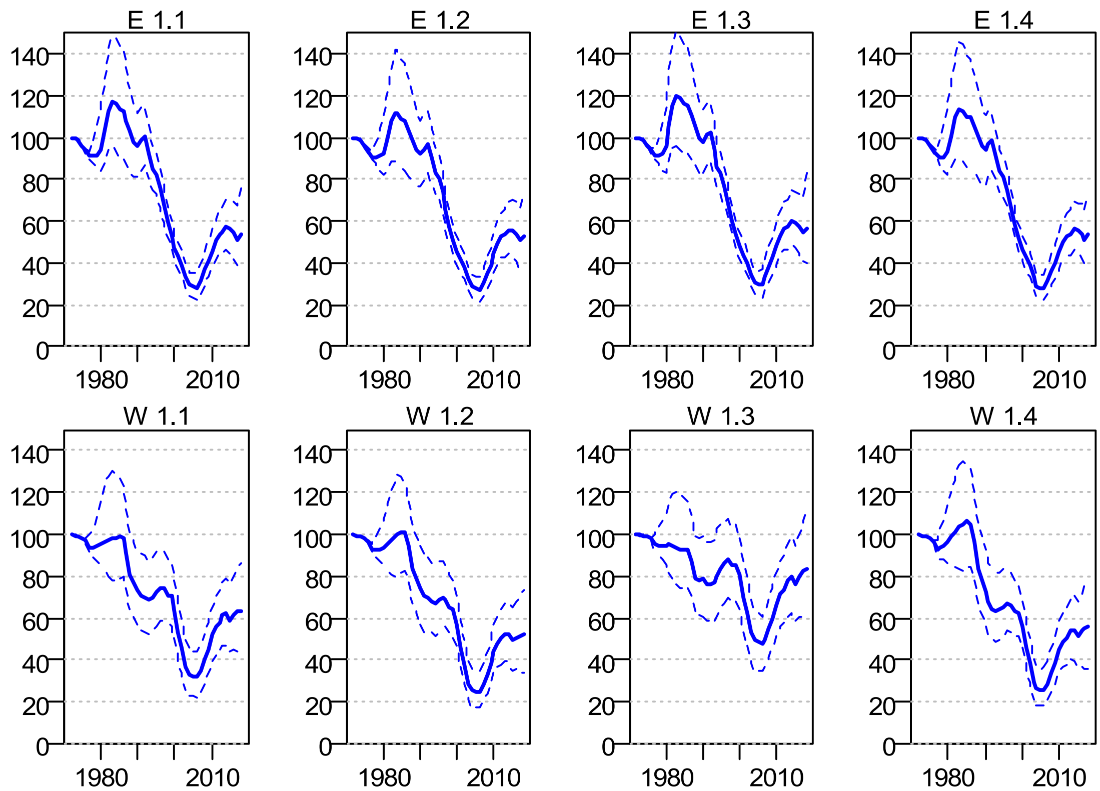

Figure 27: As in Figure 26, but plotted as %B_0.

5. PROJECTIONS

Five-year projections were carried out for the base model (1.1) and the model with the west coast South Island acoustic biomass series dropped (1.4), with future recruitments selected at random from those estimated for 2007–2016. Total catch was assumed to equal the current TACC of 150 000 t with 62 000 t catch for the east stock and 88 000 t for the west stock. The projections indicate that the E and W biomass are likely to increase over the next five years (Figure 28).

The probabilities of the current (2018) 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 19. 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.

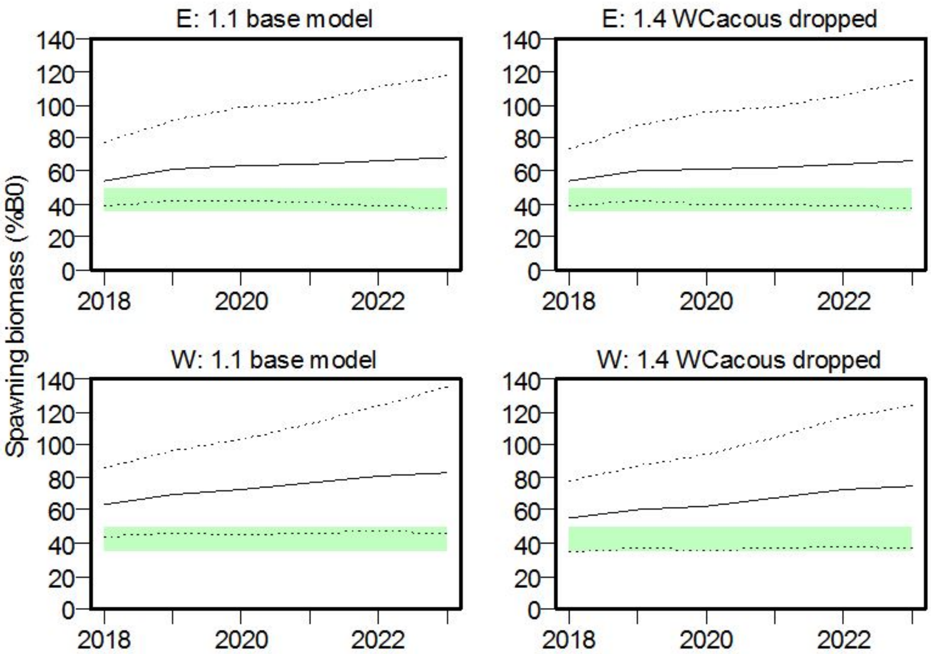

Figure 28: Projected spawning biomass (as %B_0): median (solid lines) and 95% credible intervals (broken lines) for the base case (1.1) and a sensitivity run with the west coast South Island acoustic biomass series dropped (1.4). The shaded green region represents the target management range of 35–50% B_0.

Table 19: Probabilities (to two decimal places) associated with projections for east and west stock SSB ($\%B_0$) for the base case (1.1) for 2018 through to 2023, and a sensitivity run with the west coast South Island acoustic biomass series dropped (1.4).

	2018	2019	2020	2021	2022	2023
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	0.01	0.01
P (SSB<50%B_0)	0.32	0.14	0.14	0.13	0.14	0.14
EAST 1.4						
P (SSB<10%B_0)	0	0	0	0	0	0
P (SSB<20%B_0)	0	0	0	0	0	0
P (SSB<35%B_0)	0	0	0	0	0.01	0.01
P (SSB<50%B_0)	0.34	0.17	0.17	0.16	0.16	0.16
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	0	0	0	0	0
P (SSB<50%B_0)	0.10	0.06	0.06	0.04	0.04	0.05
WEST 1.4						
P (SSB<10%B_0)	0	0	0	0	0	0
P (SSB<20%B_0)	0	0	0	0	0	0
P (SSB<35%B_0)	0.02	0.02	0.02	0.02	0.02	0.02
P (SSB<50%B_0)	0.29	0.19	0.17	0.13	0.10	0.11

6. FISHING PRESSURE

The fishing pressure for a given stock and model run was calculated as an annual exploitation rate, $U_y = \max_{as}\left(\sum_f C_{asfy}/N_{asy}\right)$, where the subscripts *a*, *s*, *f*, and *y* index age, sex, fishery, and year, respectively, *C* is the catch in numbers, and *N* is the number of fish in the population immediately before the first fishery of the year.

This measure is deemed to be more useful than the spawning fisheries exploitation rates that have been presented in previous assessments, because it does not ignore the effect of the non-spawning fisheries, and thus represents the total fishing pressure on each stock. An alternative measure is the fishing pressure (*F*), which is virtually identical to *U*, except for the scale on which it is measured. However, as *F* may be less easily interpretable by non-scientists, *U* is preferred as a measure of fishing pressure.

For a given stock and run, the reference fishing pressures, $U_{35\%}$ and $U_{50\%}$, are defined as the levels of *U* that would cause the spawning biomass for that stock to tend to 35% B_0 or 50% B_0, respectively, assuming deterministic recruitment and individual fishery exploitation rates that are multiples of those in the current year. These reference pressures were calculated by simulating fishing using a harvest strategy in which the exploitation rate for fishery *f* was $mU_{f,\mathrm{current}}$, where $U_{f,\mathrm{current}}$ is the estimated exploitation rate for that fishery in the current year, and *m* is some multiplier (the same for all fisheries). For each of a series of values of *m*, simulations were carried out with this harvest strategy and deterministic recruitment, with each simulation continuing until the population reached equilibrium. For a given stock, $U_{x\%}$ was set equal to $m_{x\%}U_{\mathrm{current}}$, where the multiplier, $m_{x\%}$ (calculated by interpolation) was that which caused the equilibrium biomass of that stock to be *x*% B_0.

Fishing intensity and B_{MSY} were calculated 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 intensities on both stocks were estimated to be at or near all-time highs in about 2003 and are now substantially lower (Figure 29).

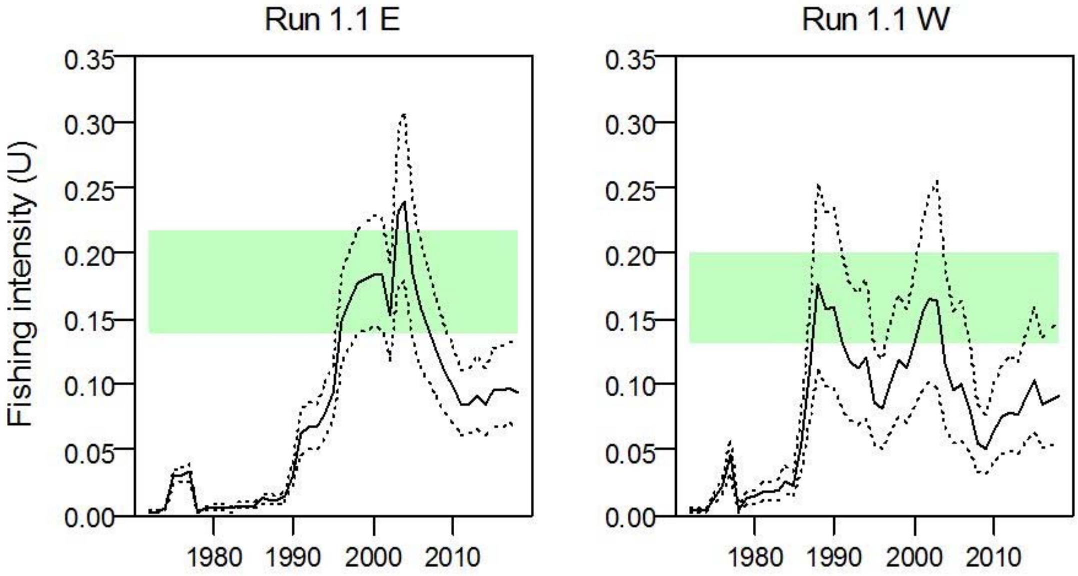

Figure 29: Fishing intensity, U (from MCMCs), plotted by stock. Shown are medians (solid black line) with 95% credible intervals (dotted lines). Also shown shaded in green is the management range where the upper bound is the reference level $U_{35\%Bo}$ and the lower bound $U_{50\%Bo}$ which are the fishing intensities that would cause the spawning biomass to tend to 35% B_0 and 50% B_0, respectively.

7. CALCULATION OF B_{MSY}

B_{MSY} was calculated for each stock, assuming a harvest strategy in which the exploitation rate for fishery f was $mU_{f,2018}$, where $U_{f,2018}$ is the estimated 2018 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 with 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 26.9% (95% CI 25.3–28.2) for the E stock and 27.0% (95% CI 25.8–28.0) 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.

8. DISCUSSION

The eastern and western stocks are estimated to have been increasing since about 2006. Current biomass is estimated to be 44–86% B_0 for the western stock and 39–77% 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 in 2015–2016 (though very uncertain for the last two years). 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. This uncertainty may be considered 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.

9. ACKNOWLEDGMENTS

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10. REFERENCES

Bull, B.; Francis, R.I.C.C.; Dunn, A.; McKenzie, A.; Gilbert, D.J.; Smith, M.H.; Bian, R.; Fu, D. (2012). CASAL (C++ algorithmic stock assessment laboratory): CASAL user manual v2.30-2012/03/21. *NIWA Technical Report 135.* 279 p.

Cordue, P.L. (2001). MIAEL estimation of biomass and fishery indicators for the 2001 assessment of hoki stocks. *New Zealand Fisheries Assessment Report 2001/65.* 59 p.

Cordue, P.L. (2006). Report on the 13 November 2006 M-prior HWG sub-group meeting. Unpublished report to the Hoki Working Group, dated 17 November 2006. WG-HOK-2007/11. (Unpublished report held by Fisheries New Zealand, Wellington.)

Francis, R.I.C.C. (2003). Analyses supporting the 2002 stock assessment of hoki. *New Zealand Fisheries Assessment Report 2003/5.* 34 p.

Francis, R.I.C.C. (2004). Assessment of hoki (*Macruronus novaezelandiae*) in 2003. *New Zealand Fisheries Assessment Report 2004/15.* 95 p.

Francis, R.I.C.C. (2005). Assessment of hoki (*Macruronus novaezelandiae*) in 2004. *New Zealand Fisheries Assessment Report 2005/35.* 97 p.

Francis, R.I.C.C. (2006). Assessment of hoki (*Macruronus novaezelandiae*) in 2005. *New Zealand Fisheries Assessment Report 2006/3*. 96 p.

Francis, R.I.C.C. (2007). Assessment of hoki (*Macruronus novaezelandiae*) in 2006. *New Zealand Fisheries Assessment Report 2007/15*. 99 p.

Francis, R.I.C.C. (2008). Assessment of hoki (*Macruronus novaezelandiae*) in 2007. *New Zealand Fisheries Assessment Report 2008/4*. 109 p.

Francis, R.I.C.C. (2009). Assessment of hoki (*Macruronus novaezelandiae*) in 2008. *New Zealand Fisheries Assessment Report 2009/7*. 80 p.

Francis, R.I.C.C. (2011). Data weighting in statistical fisheries stock assessment models. *Canadian Journal of Fisheries and Aquatic Sciences 68*: 1124–1138.

Francis, R.I.C.C.; Haist, V.; Bull, B. (2003). Assessment of hoki (*Macruronus novaezelandiae*) in 2002 using a new model. *New Zealand Fisheries Assessment Report 2003/6*. 69 p.

Francis, R.I.C.C.; Hurst, R.J.; Renwick, J.A. (2001). An evaluation of catchability assumptions in New Zealand stock assessments. *New Zealand Fisheries Assessment Report 2001/1*. 37 p.

Hicks, A.C.; Cordue, P.L.; Bull, B. (2002). Estimating proportions-at-age and sex in the commercial catch of hoki (*Macruronus novaezelandiae*) using length frequency data. *New Zealand Fisheries Assessment Report 2002/43*. 51 p.

Horn, P.L. (2011). Natal fidelity: a literature review in relation to the management of the New Zealand hoki (*Macruronus novaezelandiae*) stocks. *New Zealand Fisheries Assessment Report 2011/34.* 18 p.

Horn, P.L.; Sullivan, K.J. (1996). Validated aging methodology using otoliths, and growth parameters for hoki (*Macruronus novaezelandiae*) in New Zealand waters. *New Zealand Journal of Marine and Freshwater Research 30(2)*: 161–174.

Livingston, M.E.; Stevens, D.W. (2002). Review of trawl survey data inputs to hoki stock assessment 2002. *New Zealand Fisheries Assessment Report 2002/48*. 69 p.

McKenzie, A. (2009). Preliminary assessment results for hoki in 2009. WG-HOK-2009/10. (Unpublished report held by Fisheries New Zealand, Wellington.)

McKenzie, A. (2011). Assessment of hoki (*Macruronus novaezelandiae*) in 2010. *New Zealand Fisheries Assessment Report 2011/06*. 44 p.

McKenzie, A. (2012). Further exploratory analyses of no natal fidelity runs. WG-HOK-2012/11. (Unpublished report held by Fisheries New Zealand, Wellington.)

McKenzie, A. (2013). Assessment of hoki (*Macruronus novaezelandiae*) in 2012. *New Zealand Fisheries Assessment Report 2013/27*. 65 p.

McKenzie, A. (2015). Assessment of hoki (*Macruronus novaezelandiae*) in 2013. *New Zealand Fisheries Assessment Report 2015/08*. 73 p.

McKenzie, A. (2018). Assessment of hoki (*Macruronus novaezelandiae*) in 2017. *New Zealand Fisheries Assessment Report 2018/40*. 105 p.

Ministry of Fisheries (2010). Report from the Fisheries Assessment Plenary, May 2010: stock assessments and yield estimates. 1086 p. Ministry of Fisheries, Wellington, New Zealand.

Ministry for Primary Industries (2016). Fisheries Assessment Plenary, May 2016: stock assessments and stock status. Compiled by the Fisheries Science Group, Ministry for Primary Industries, Wellington, New Zealand. 1556 p.

O'Driscoll, R.L. (2002). Review of acoustic data inputs for the 2002 hoki stock assessment. *New Zealand Fisheries Assessment Report 2002/36*. 66 p.

O'Driscoll, R.L.; Hurst, R.J.; Livingston, M.E.; Cordue, P.L.; Starr, P. (2002). Report of hoki working group technical meeting 8 March 2002. WG-HOK-2002/27. (Unpublished report held by Fisheries New Zealand, Wellington.)

O’Driscoll, R.L.; Escobar-Flores, P. (2018). Acoustic survey of spawning hoki in Cook Strait during winter 2017. New Zealand Fisheries Assessment Report 2018/12. 43 p.

O’Driscoll, R.L.; Ladroit, Y.; Dunford, A.J.; MacGibbon, D.J. (2016). Acoustic survey of spawning hoki in Cook Strait during winter 2015 and update of acoustic q priors for hoki assessment modelling. *New Zealand Fisheries Assessment Report 2016/44*. 55 p.

O’Driscoll (2018). Multi-species trawl survey on the Chatham Rise to estimate abundance of middle depth and deep water fish species. Draft New Zealand Fisheries Assessment Report held by Fisheries New Zealand

Smith, M.H. (2003). Fitting a prior for the proportion of B_0 in the eastern stock. WG-HOK-2003/22. 2 p. (Unpublished report held by Fisheries New Zealand, Wellington.)

Smith, M.H. (2004). Fitting priors for natural mortality and proportion of virgin hoki biomass in eastern stock. WG-HOK-2004/14. 7 p. (Unpublished report held by Fisheries New Zealand, Wellington.)

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, for the base case, may be obtained from the Science Officer at Fisheries New Zealand (science.officer@mpi.govt.nz).

Appendix 2: Changes in stock-assessment model assumptions

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

Year	Changes
2003	Changed timing of spawning migrations from the middle to the end of the non-spawning fisheries (and after the autumn SA surveys)
	Earliest estimated YCS changed to 1977 from 1980
	Assumed Beverton-Holt stock-recruit relationship
	Disallowed annual variation in selectivities for Wnsp fishery
	Allowed for ageing error (expected to reduce bias in estimates of YCSs)
	Process errors for at-age data sets estimated within the model
	Non-uniform prior on pE
	Max. age of otolith-based at-age data increased from 10 (plus group) to 12 (no plus group)
	First use of otolith-based at-age data for non-spawning fisheries (Enspage & Wnspage)
	Forced equality of recent W and E YCSs extended from 2 y to 3 y
	Improvements in methods of converting ogives from size-based to age-based and implementing annual variation in selectivities
2004	First use of age-dependent natural mortality and domed spawning selectivities to cope with lack of old fish
	Maximum age in partition increased from 13 y to 17 y
	New parameterisation for YCSs
	Earliest estimated YCS changed to 1975 from 1977
	Change in priors for CSacous catchability and pE
	Max. age of otolith-based at-age data increased from 12 (no plus group) to 13/15 (plus group)
2005	For runs with domed spawning selectivities, spawning selectivities (rather than migrations) constrained to be equal
	Some at-age data revised
2006	Annual variation in Wsp selectivity restricted to years with significant data and constrained by non-uniform prior on controlling parameter
	Forced equality of recent W and E YCSs reduced from 3 y to 1 y
	Added smoothing penalty for age-dependent natural mortality
	First model run without the assumption of natal fidelity
2007	New parameterisation (double-exponential) and prior for age-dependent natural mortality
2008	Models runs without natal fidelity dropped
	Stock recruitment steepness reduced from 0.90 to 0.75
	1998 proportions spawning data re-analysed
2009	Median catch day re-calculated using a new first year
	1992 and 1993 proportions spawning data re-analysed
2010	Allow two catchabilities for the Sub-Antarctic trawl survey in sensitivity model runs
2011	Reduce to one base model (age-varying natural mortality) from two base models (for the other base model there were domed shaped fishing selectivities in the spawning fishery)
2012	Re-weight the proportions-at-age data (the procedure giving them a substantial down-weighting)
	Re-introduce a sensitivity model run without natal fidelity
2013	Of the three final model runs, two have a time-varying catchability for the Sub-Antarctic trawl survey biomass series
2014	Use the Haist year class strength parameterisation (instead of the Francis parameterisation)
2015	Three changes in MCMC procedure:
	(i) estimate catchabilities as free parameters instead of analytical,
	(ii) leave as free those migration and selectivity parameters that hit bounds in MPDs
	(instead of fixing them to the bounds), and
	(iii) increase chain length from two million to four million.
2016	Process error estimated for Chatham Rise and Sub-Antarctic trawl surveys
	Equality constraint in MCMC for last year class strength (2014 for 2016 assessment)
2017	Same model structure as previous year for the base case
2018	Same model structure as previous year for the base case

Appendix 3: Reweighting the 2018 assessment at-age data

The same procedure as in McKenzie (2018) was used to reweight the at-age data for the updated model run 1.1. Summary results from the reweighting are shown in the tables and figures below. Final mean N values are very similar to those for the analogous model run 1.1 for the 2017 assessment (Table 21). The west stock is more sensitive than the east stock to the weightings given to the data (Figure 10).

Table 20: Model run 1.1. Iterative reweighting for multinomial sample sizes using method TA1.8 . Shown are the mean values of N for the at age data sets in the model.

Stage	Espage	Wspage	EnspOLF	Enspage	WnspOLF	Wnspage	CRsumage	SAsumage	SAautage
Initial	664	907	89	337	80	195	1351	572	829
2	56	33	12	39	104	17	90	13	24
3	66	24	12	33	61	15	65	15	17
4	77	21	14	31	59	16	59	17	15
5	82	20	14	30	58	16	55	18	14
Final	84	19	14	29	58	16	54	18	14
Initial/Final	8	48	6	12	1	12	25	32	59

Table 21: Comparing final mean values of N for at age data sets in the model: 1.1 from the 2017 assessment (denoted 2017.1) and the updated version 1.1 for the 2018 assessment.

Model	Espage	Wspage	EnspOLF	Enspage	WnspOLF	Wnspage	CRsumage	SAsumage	SAautage
2017.1	84	19	12	38	57	16	63	18	14
1.1	84	19	14	29	58	16	54	18	14

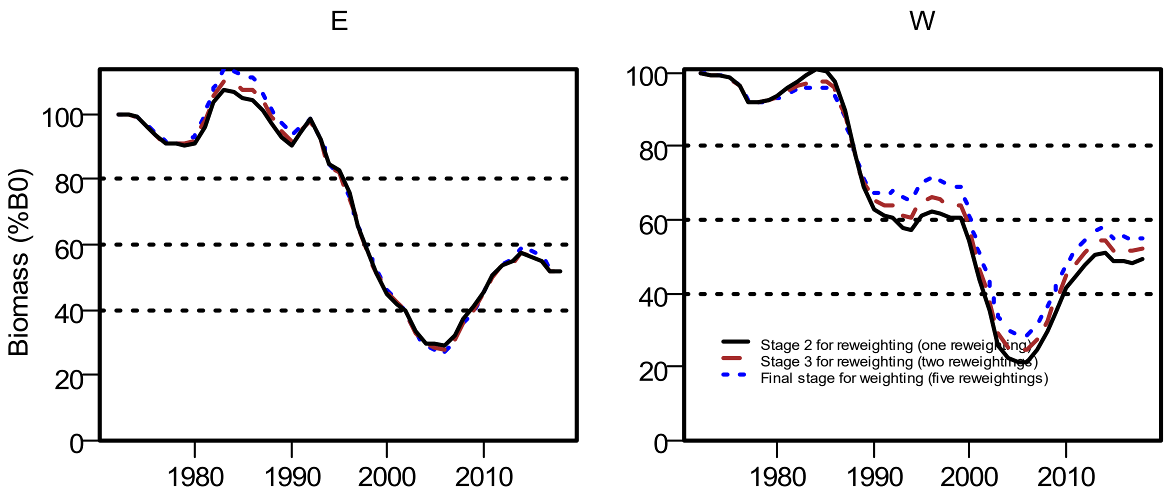

Figure 30: Updated model 1.1. biomass trajectories for different weightings of the data (see Table 21). At stages 2, 3, and final the Sub-Antarctic trawl survey process error is 0.35, 0.37, and 0.39 respectively.

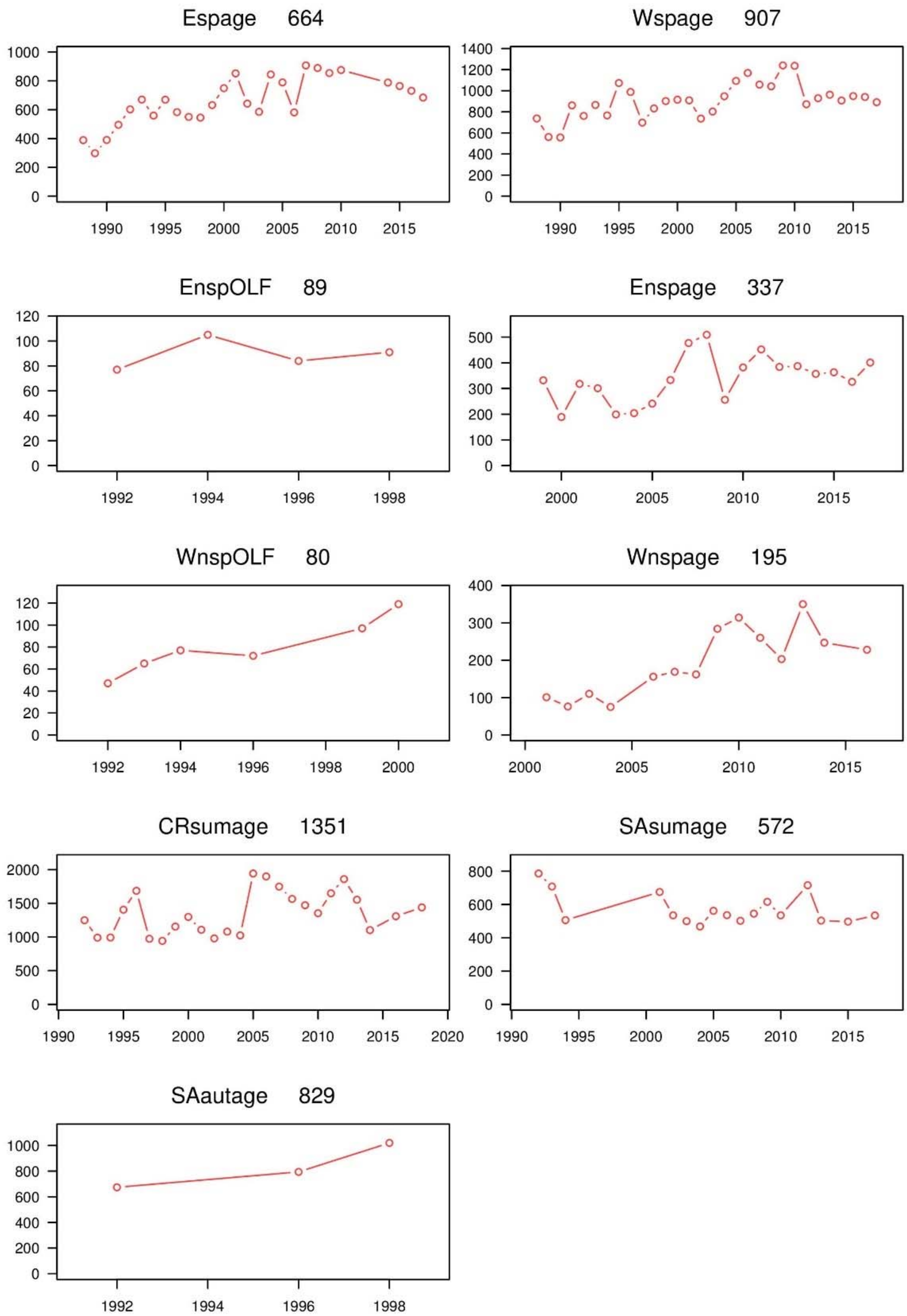

Figure 31: Model 1.1. Equivalent multinomial N values for the observational error. The number above each panel is the mean value over the fishing years.

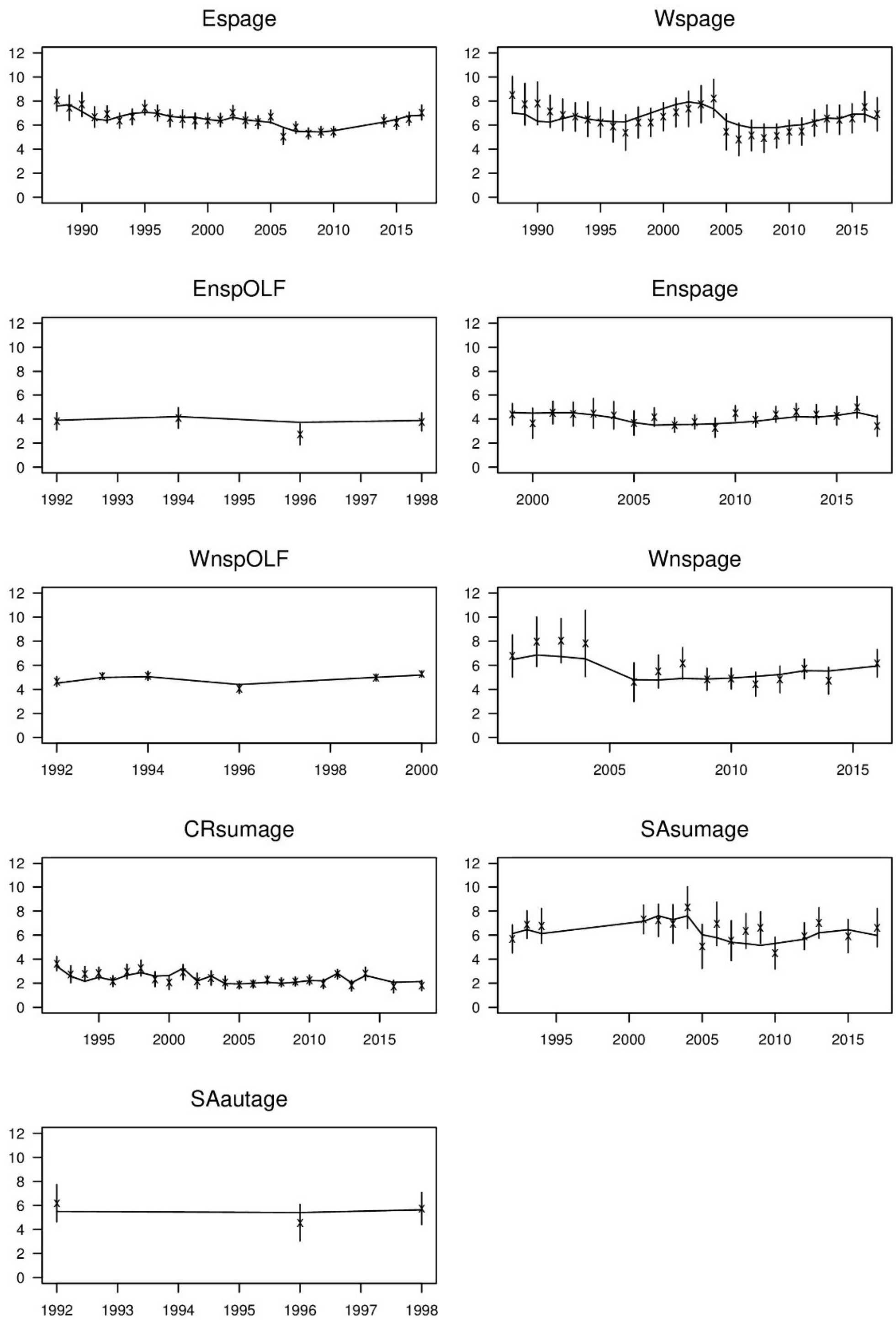

Figure 32: Model 1.1. Observed ('x', with 95% c.i.s. as vertical lines) and expected (lines) for the at-age data sets in updated run 1.1 after reweighting.

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

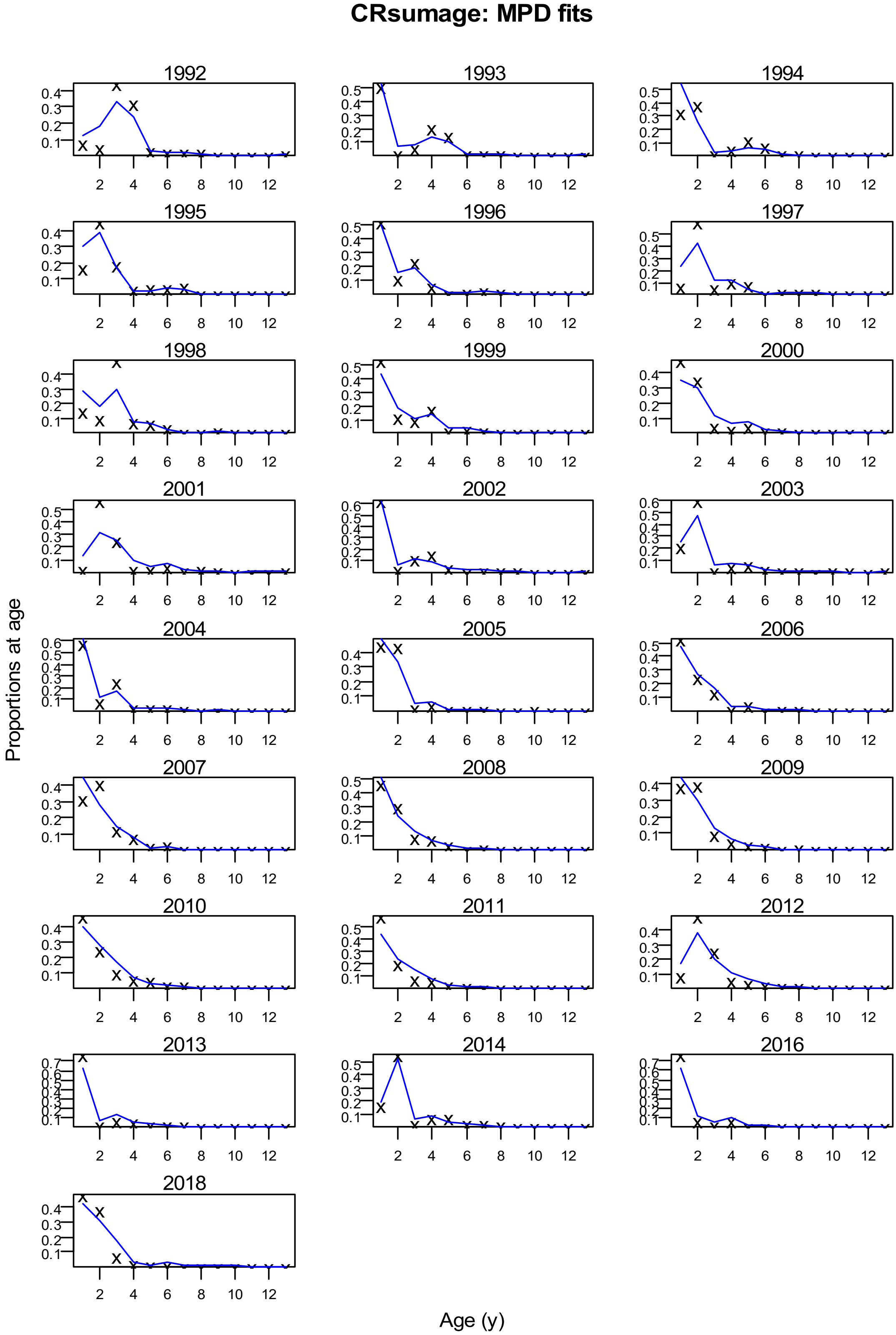

Figure 33: MPD fits to CRsumage. Observed ('×') and expected (lines) for run 1.1. Male and female observed and expected proportions are summed for an age group.

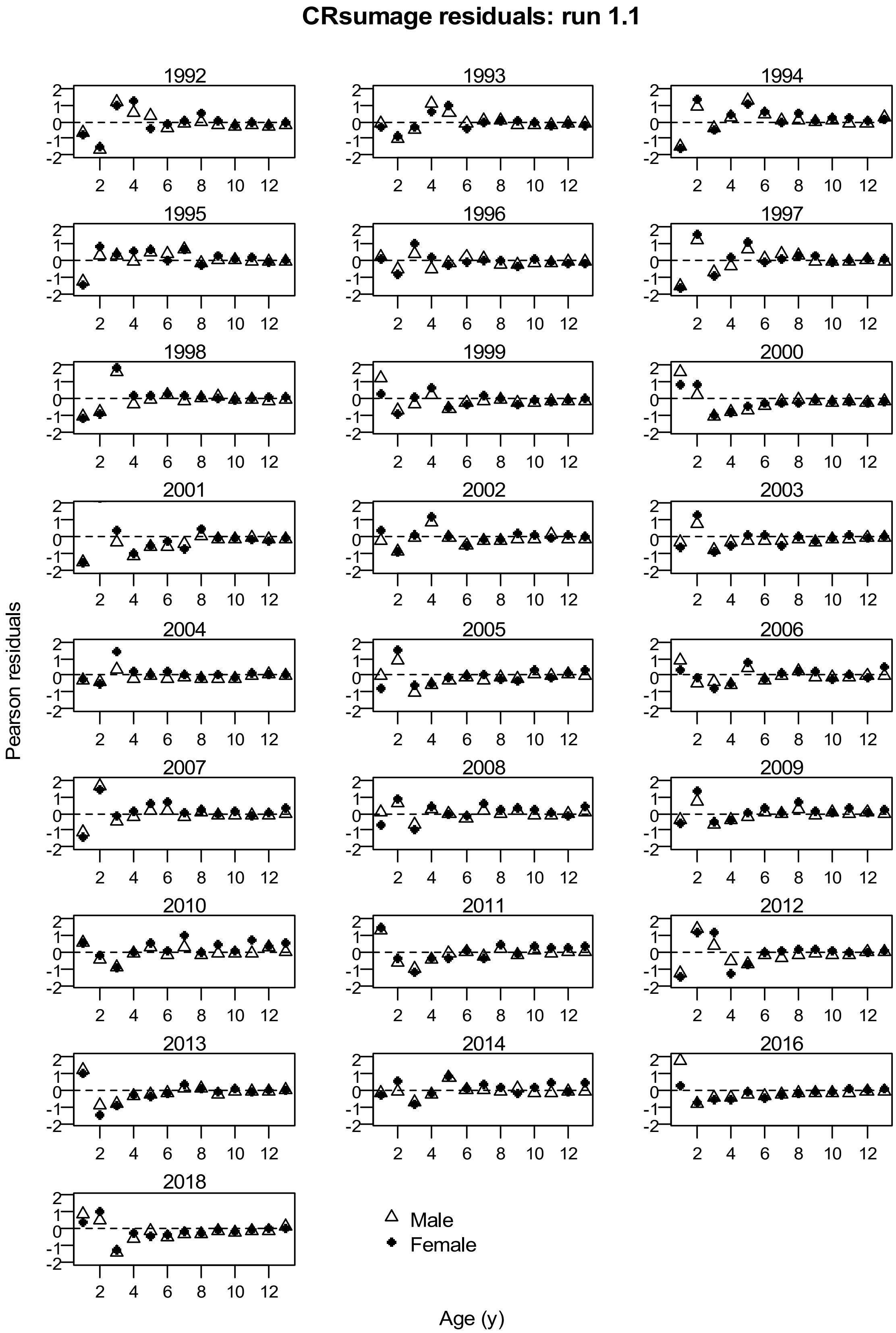

Figure 34: MPD Pearson residuals for the fit to CRsumage (run 1.1 with estimated process error).

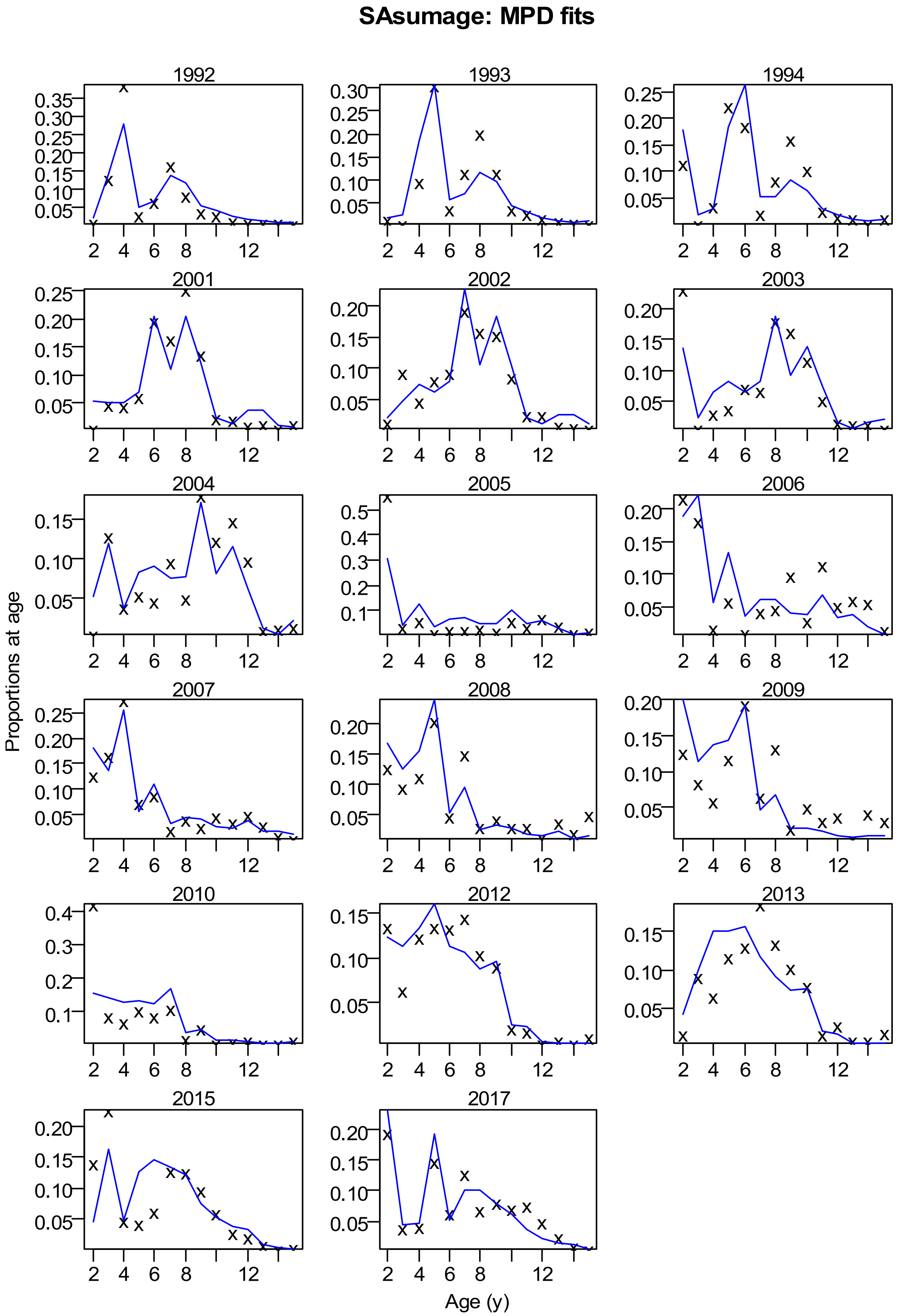

Figure 35: MPD fits to the SAsumage data. Observed ('×') and expected (lines) for runs 1.1. Male and female observed and expected proportions are summed for an age group.

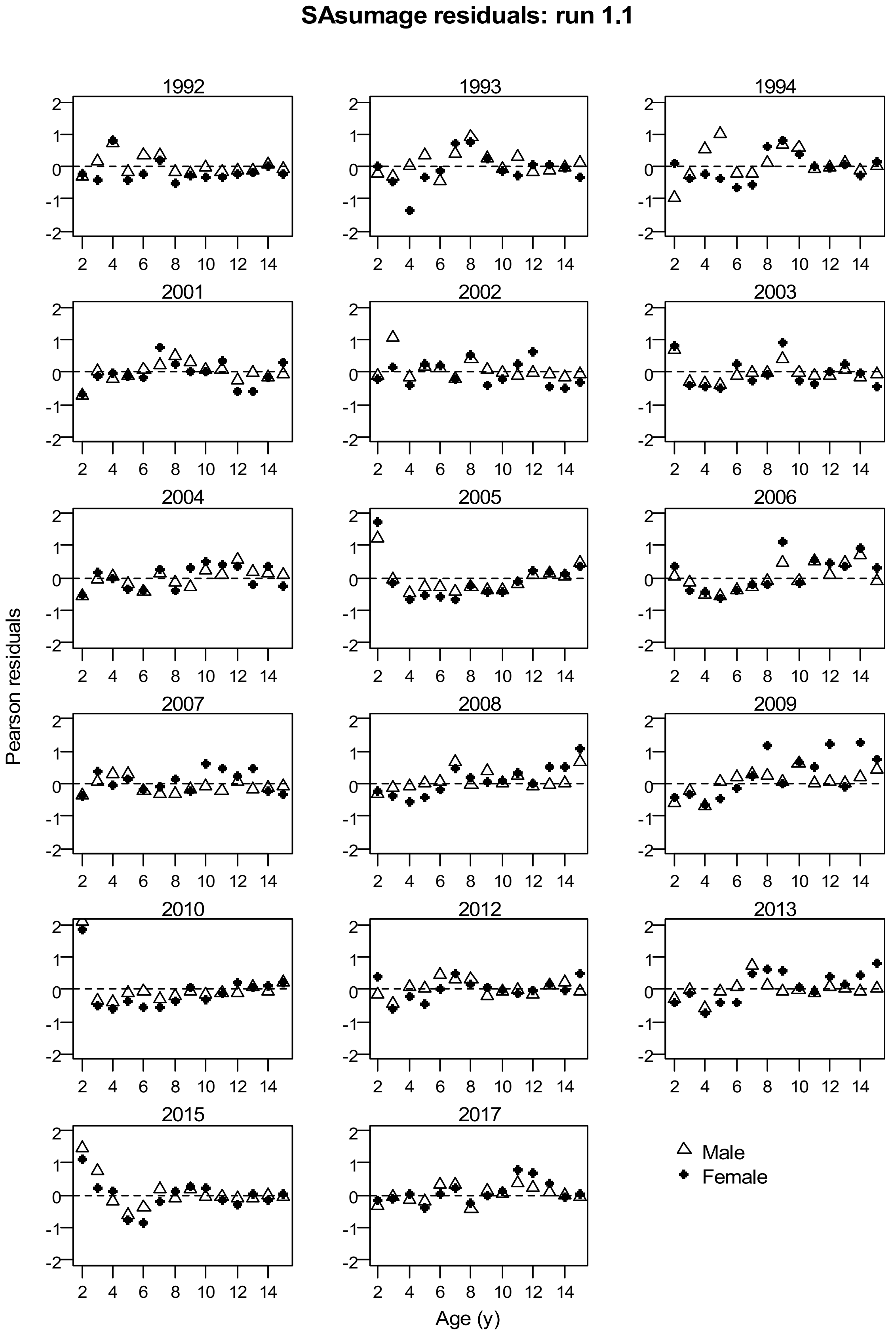

Figure 36: MPD Pearson residuals for the fit to SAsumage (run 1.1 estimate process error).

Espage: MPD fits

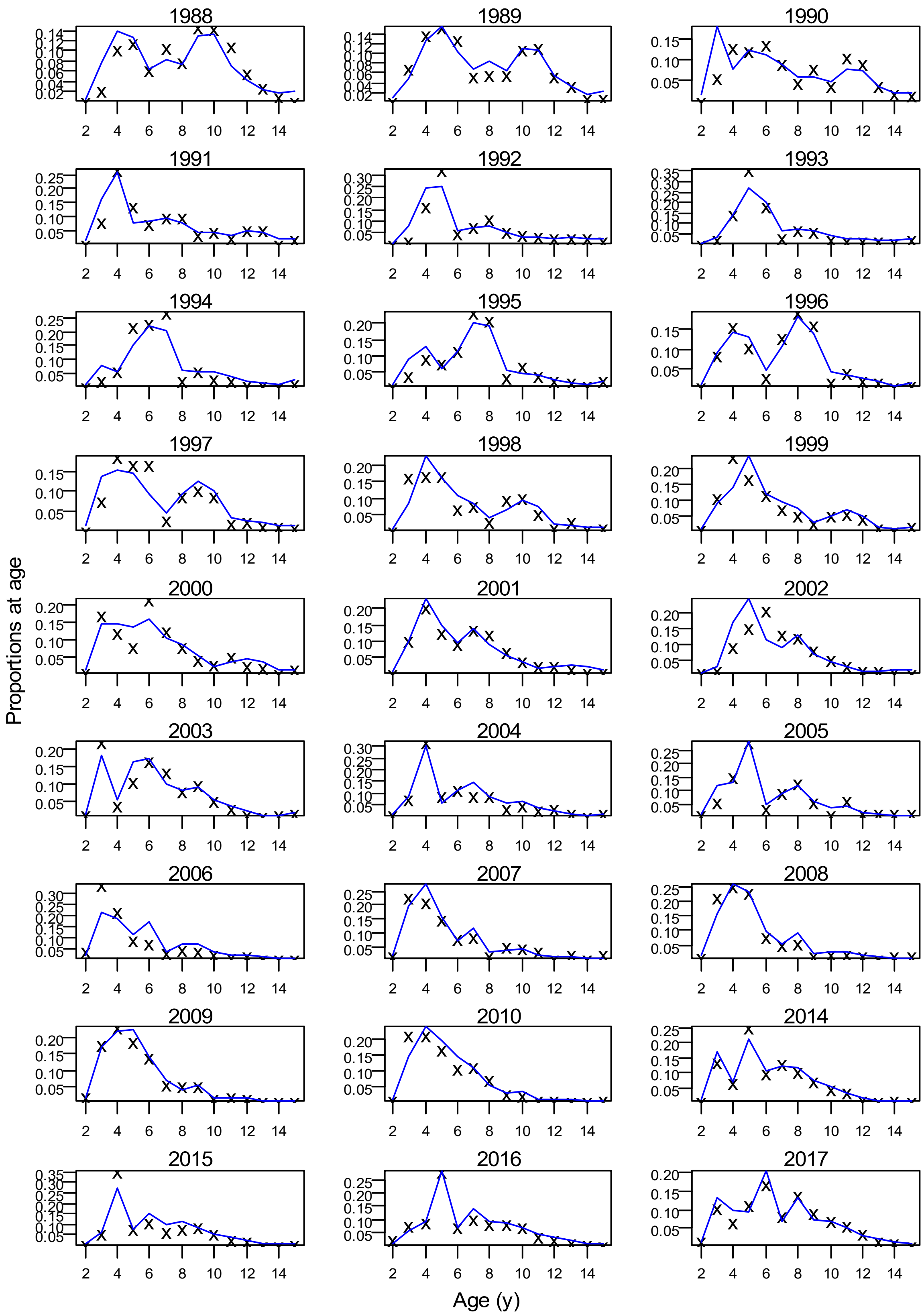

Figure 37: MPD fits to the Espage data. Observed ('×') and expected (lines) for run 1.1. Male and female observed and expected proportions are summed for an age group.

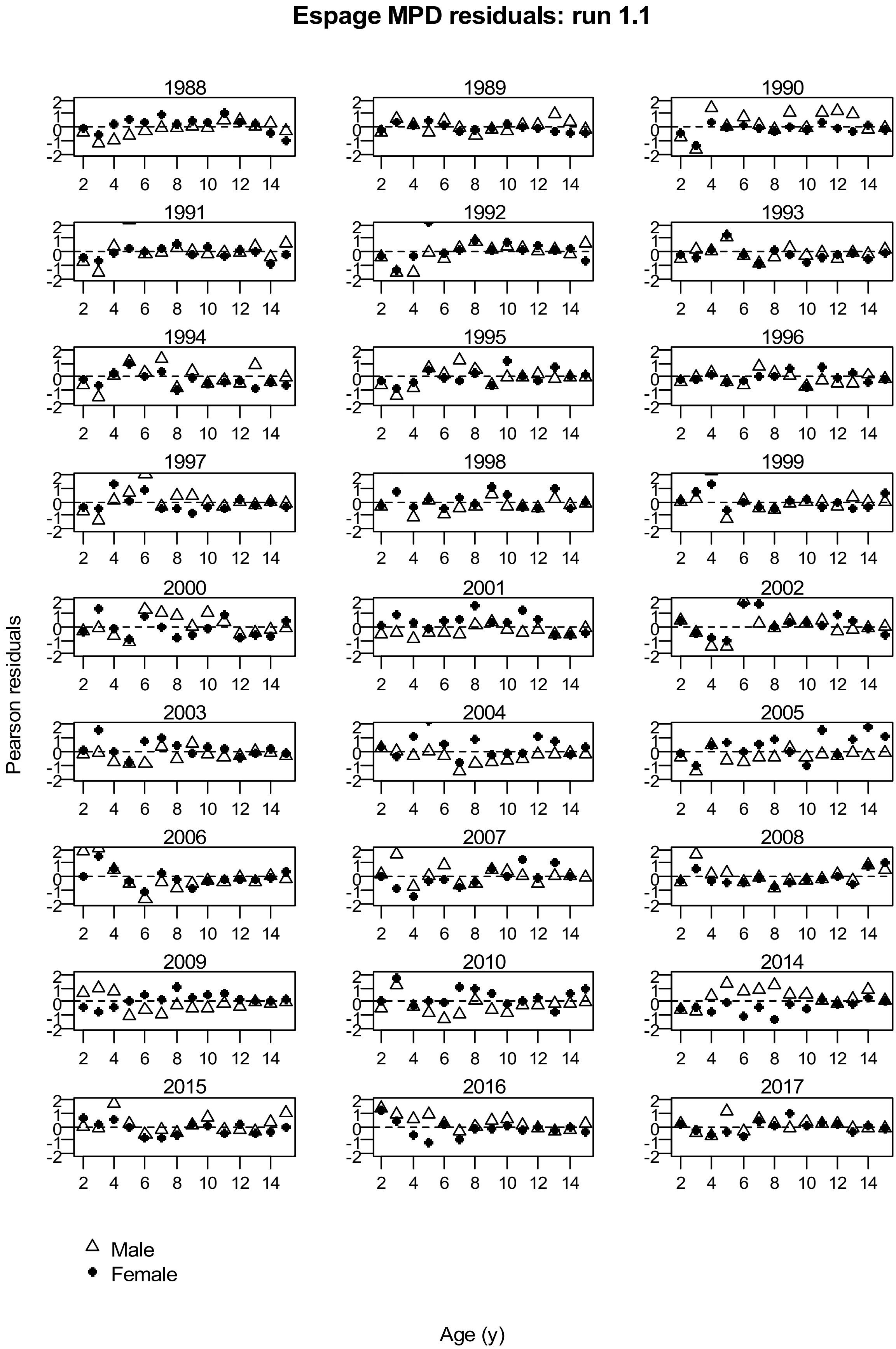

Figure 38: MPD Pearson residuals for the fits to Espage data in run 1.1 (estimate process error).

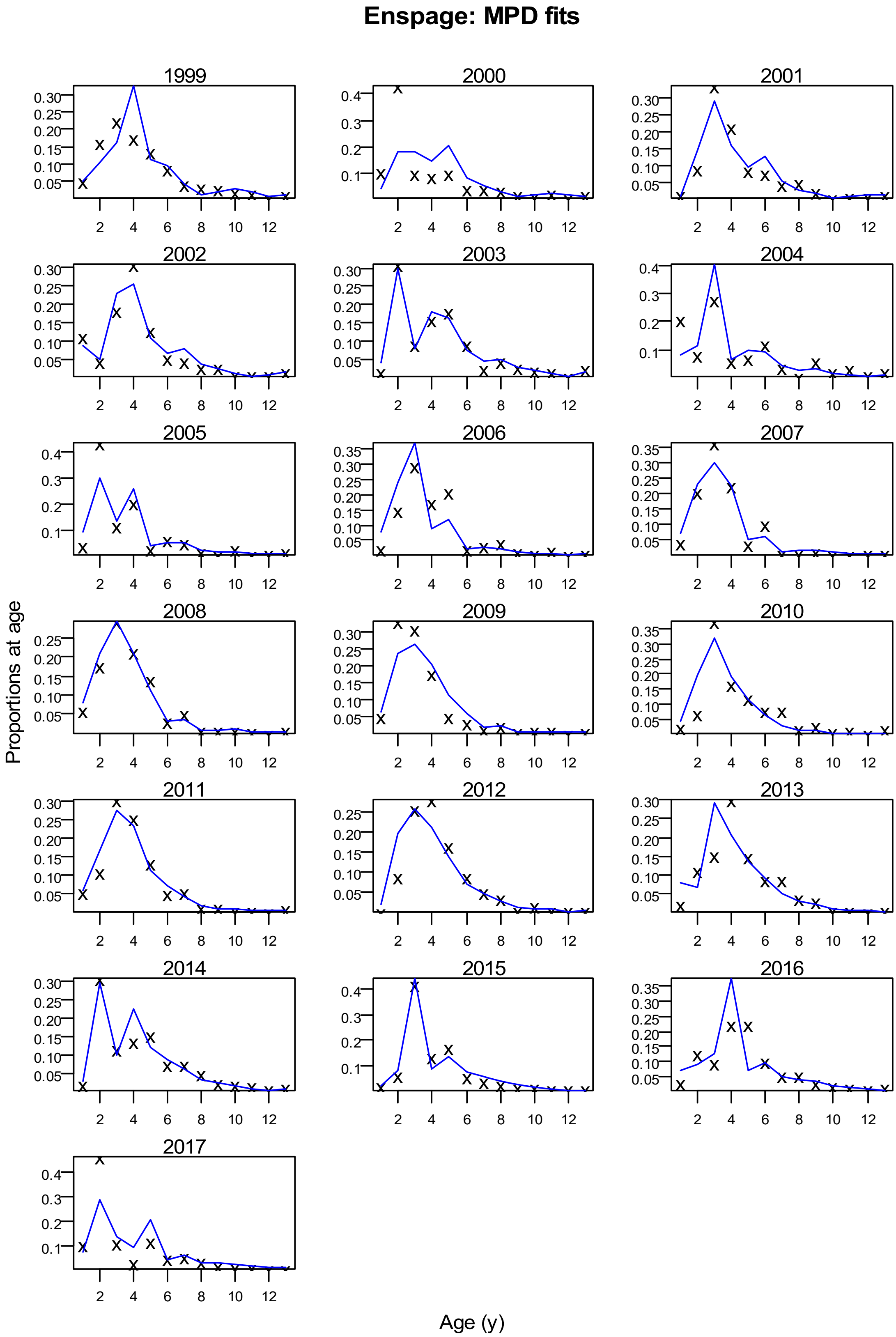

Figure 39: MPD fits to the Enspage data. Observed ('×') and expected (lines) for run 1.1. Male and female observed and expected proportions are summed for an age group.

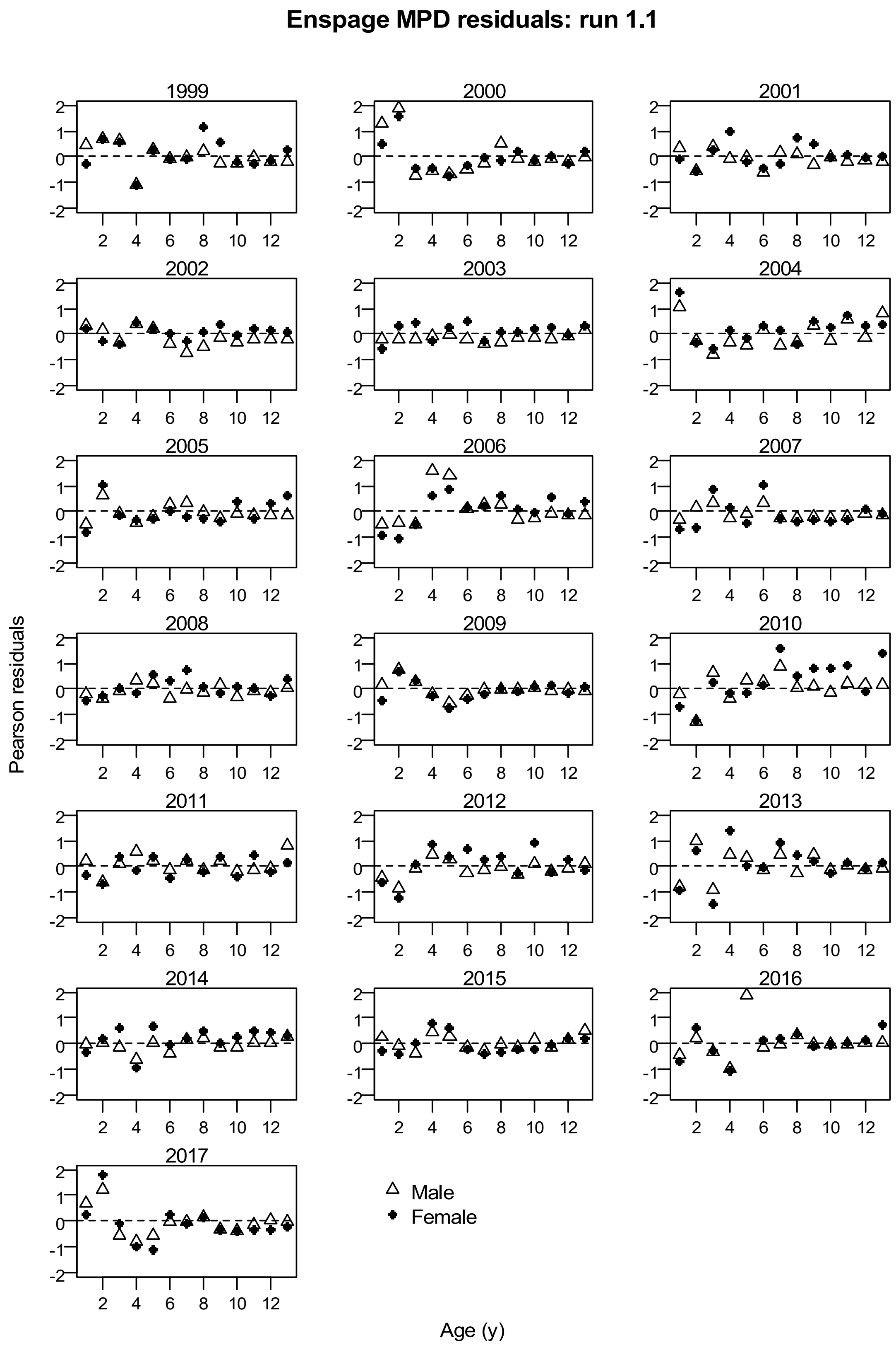

Figure 40: MPD Pearson residuals for the fits to Enspage data in run 1.1 (estimate process error).

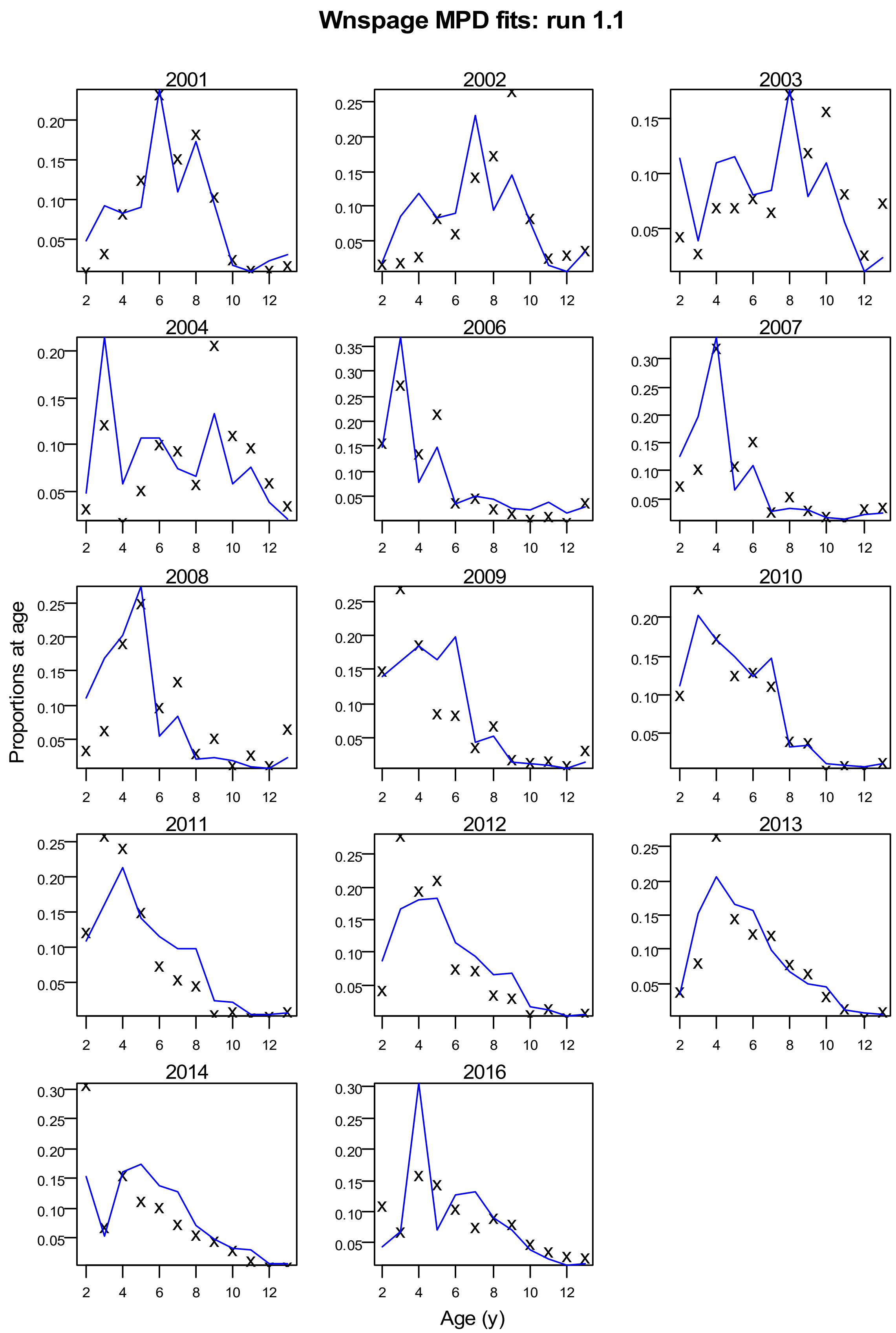

Figure 41: MPD fits to the Wnspage data. Observed ('×') and expected (lines) for run 1.1. Male and female observed and expected proportions are summed for an age group.

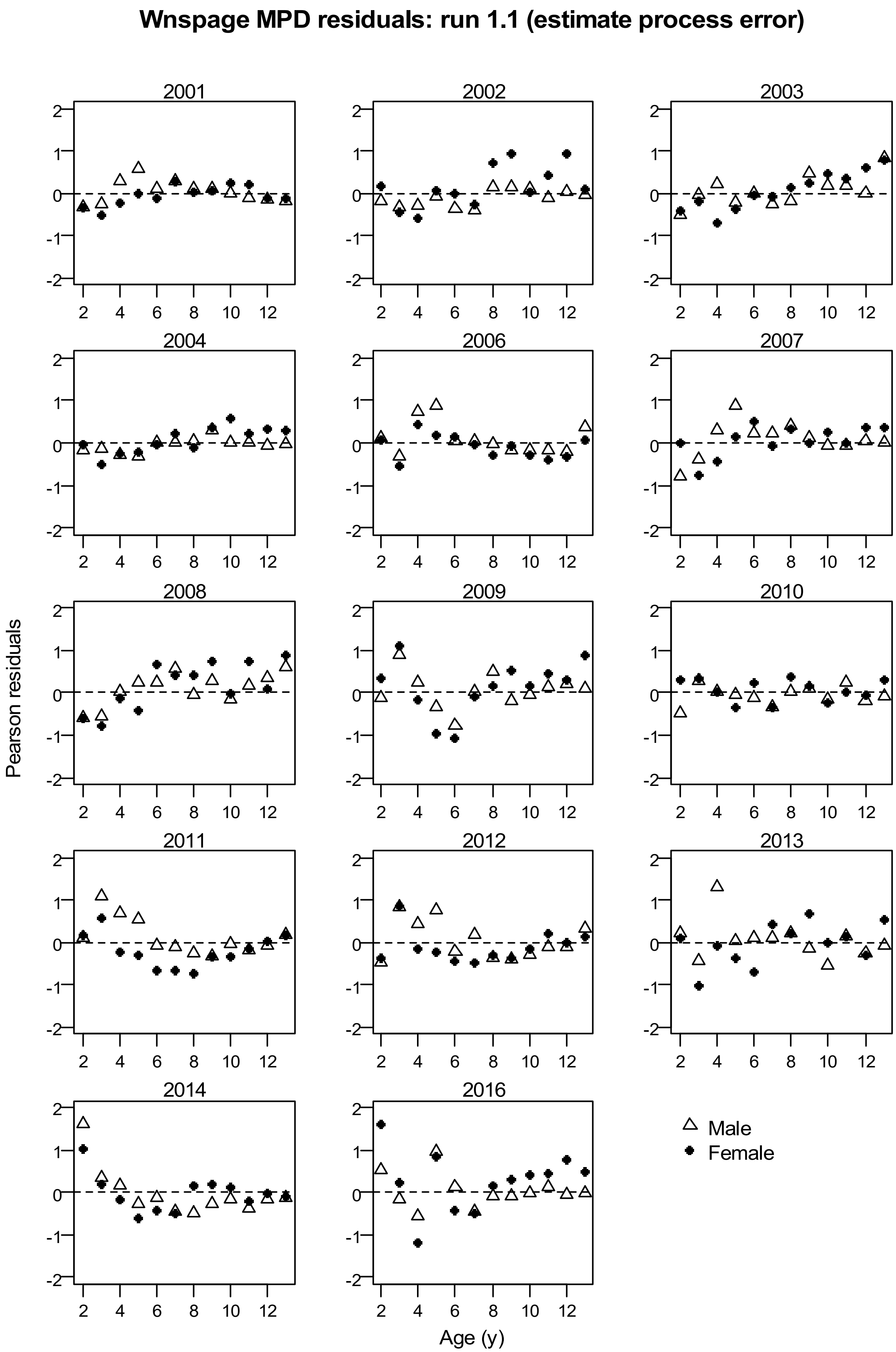

Figure 42: MPD Pearson residuals for the fits to Wnspage data in run 1.1 (estimate process error).

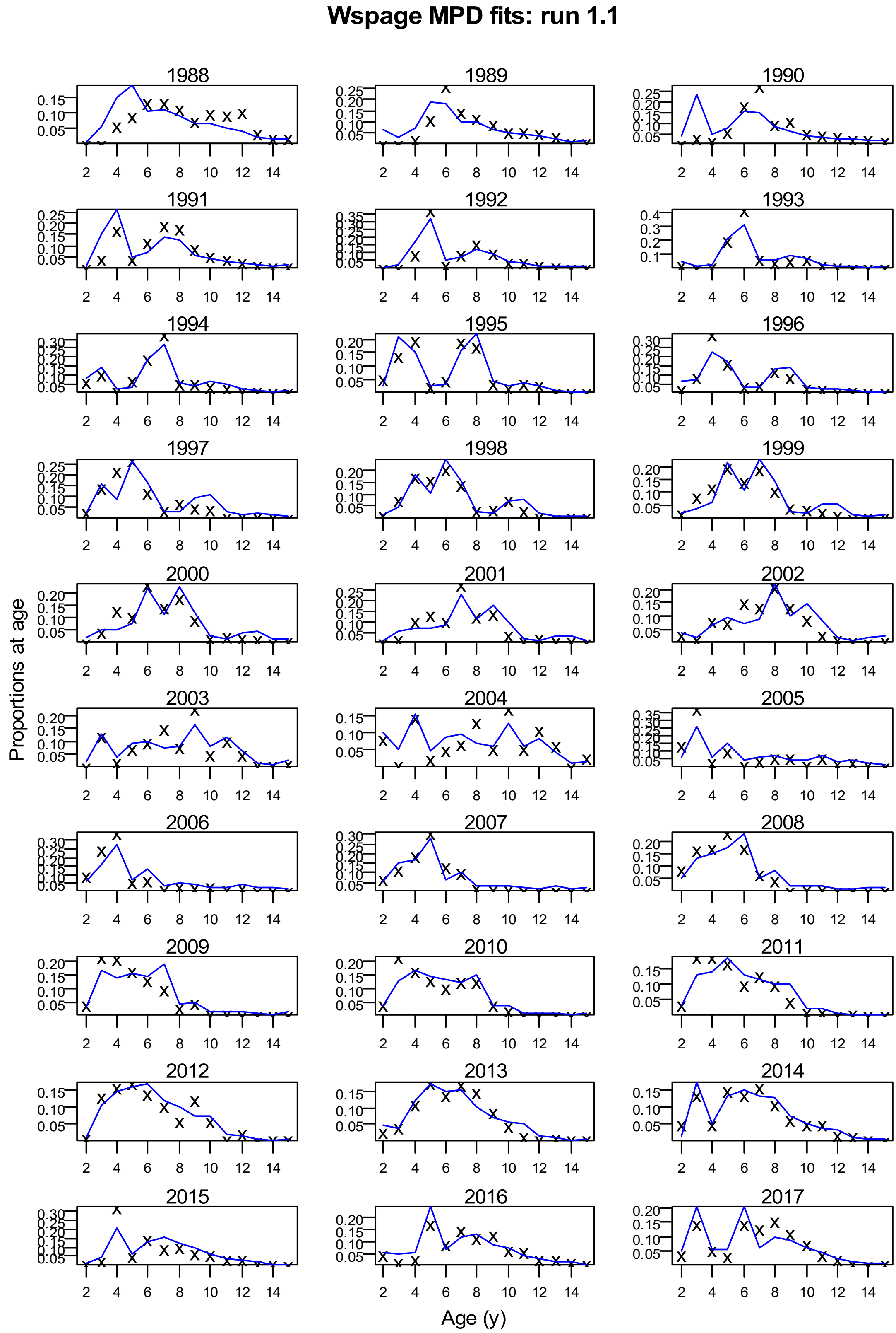

Figure 43: MPD fits to the Wspage data. Observed ('×') and expected (lines) for run 1.1. Male and female observed and expected proportions are summed for an age group.

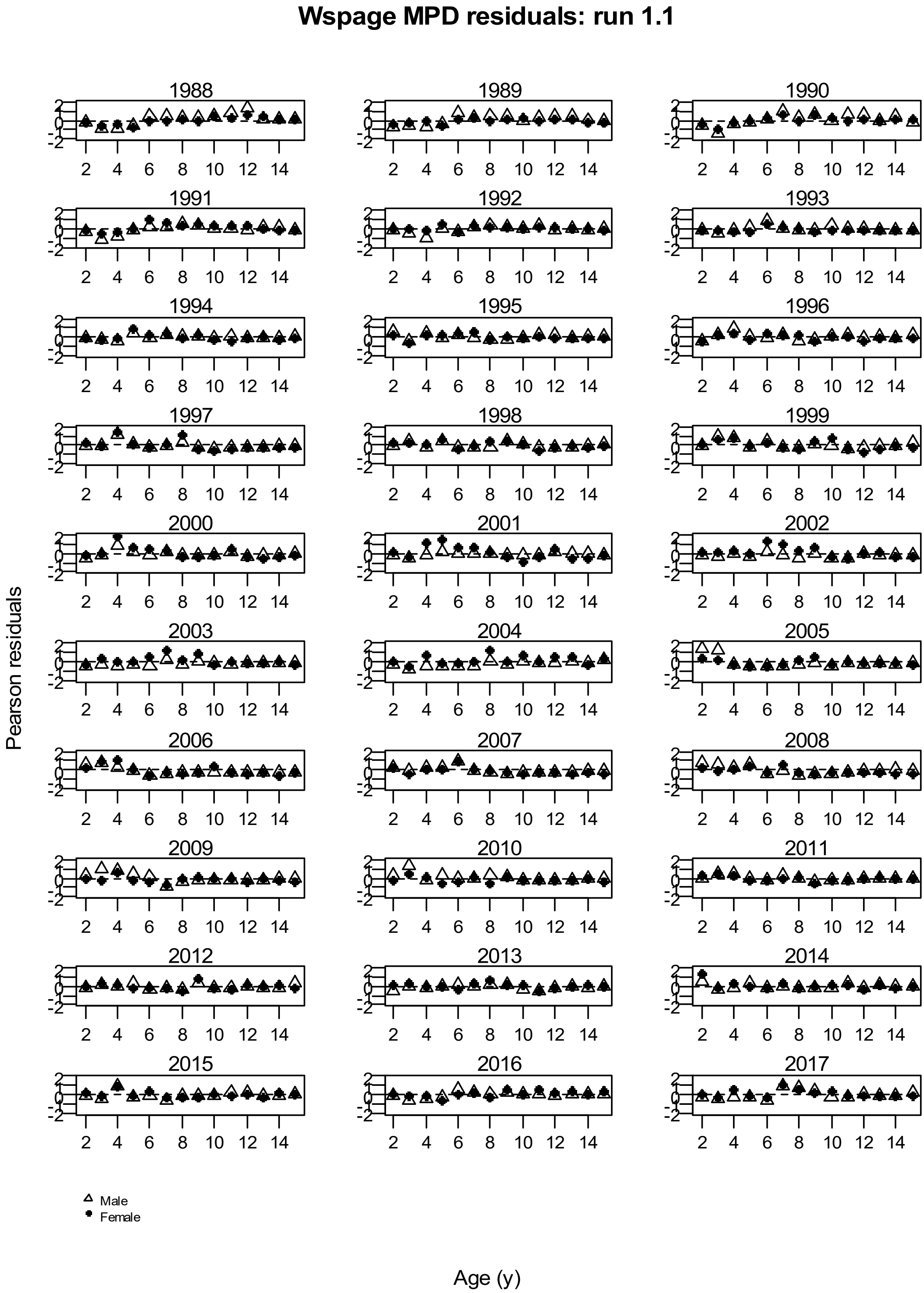

Figure 44: MPD Pearson residuals for the fits to Wspage data in run 1.1 (estimate process error).

Appendix 5: 2017 hoki assessment selectivities, migration ogives, natural mortality, and priors

Reproduced from McKenzie (2018).

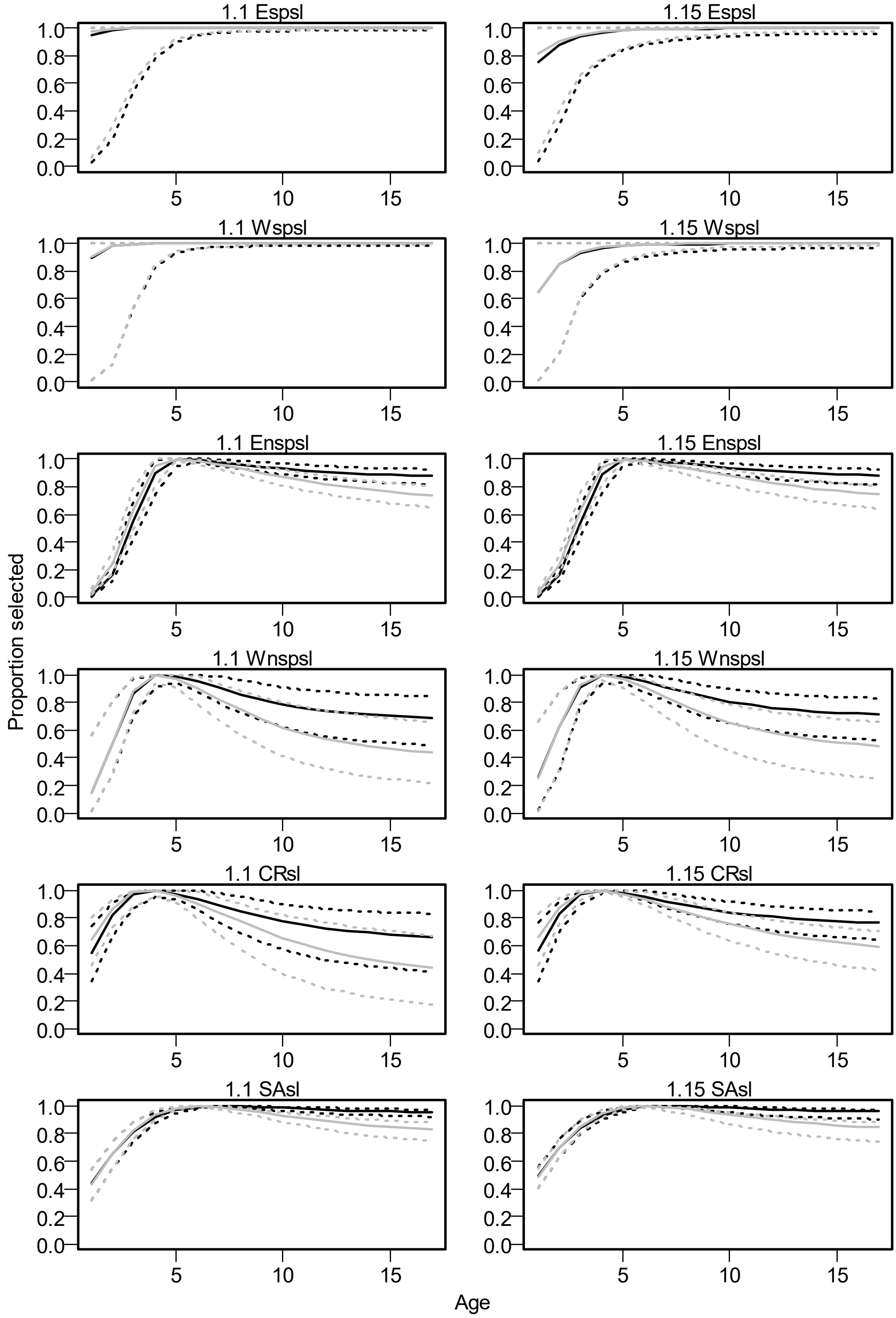

Figure 45: Posterior estimates of selectivity ogives for each for the two MCMC runs 1.1 and 1.15. Solid lines are medians; broken lines show 95% credible intervals. Where ogives differ by sex they are plotted as black for males and grey for females. Where they differ by stock or time step the plotted curves are for one selected combination (E step 2 for Enspsl and CRsl, W step 2 for Wnspsl and SAsl).

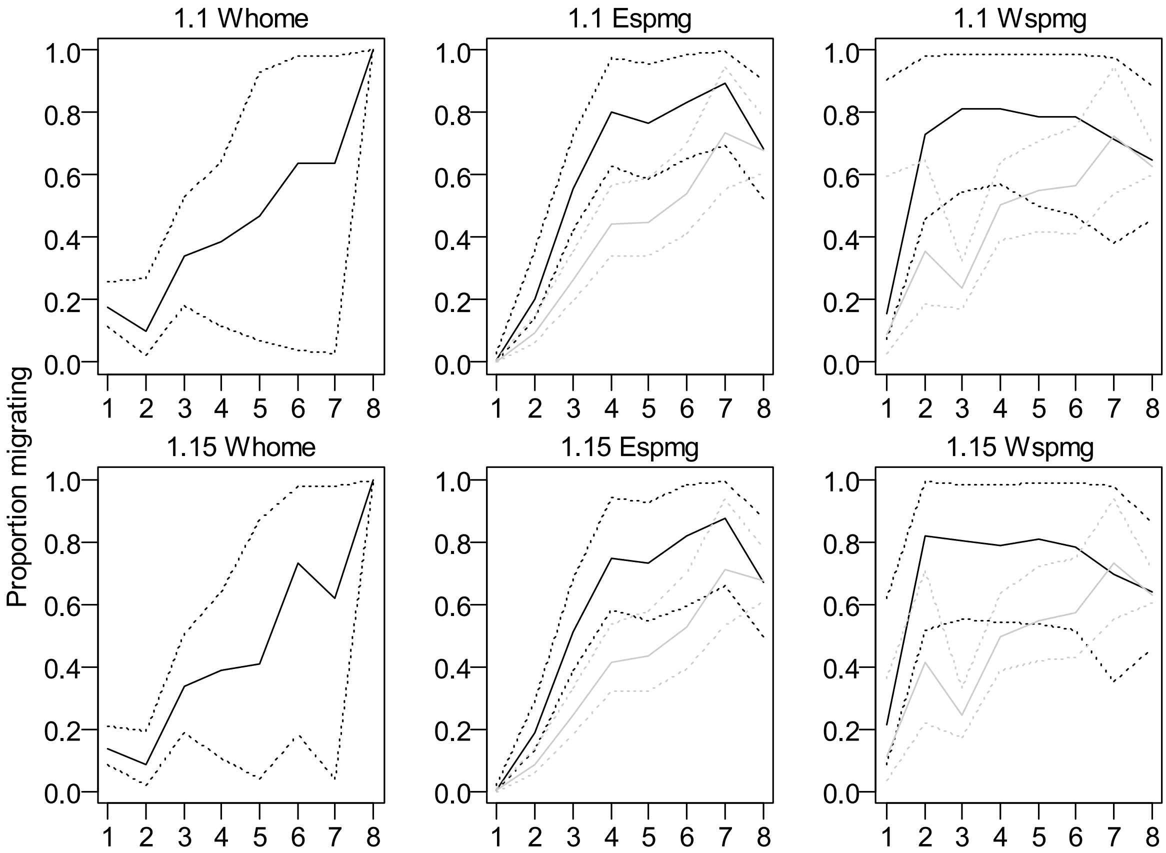

Figure 46: Estimated migration ogives estimated. Solid lines are medians, broken lines show 95% credible intervals. Where ogives differ by sex they are plotted as black for males and grey for females. The x-axis shows age (years).

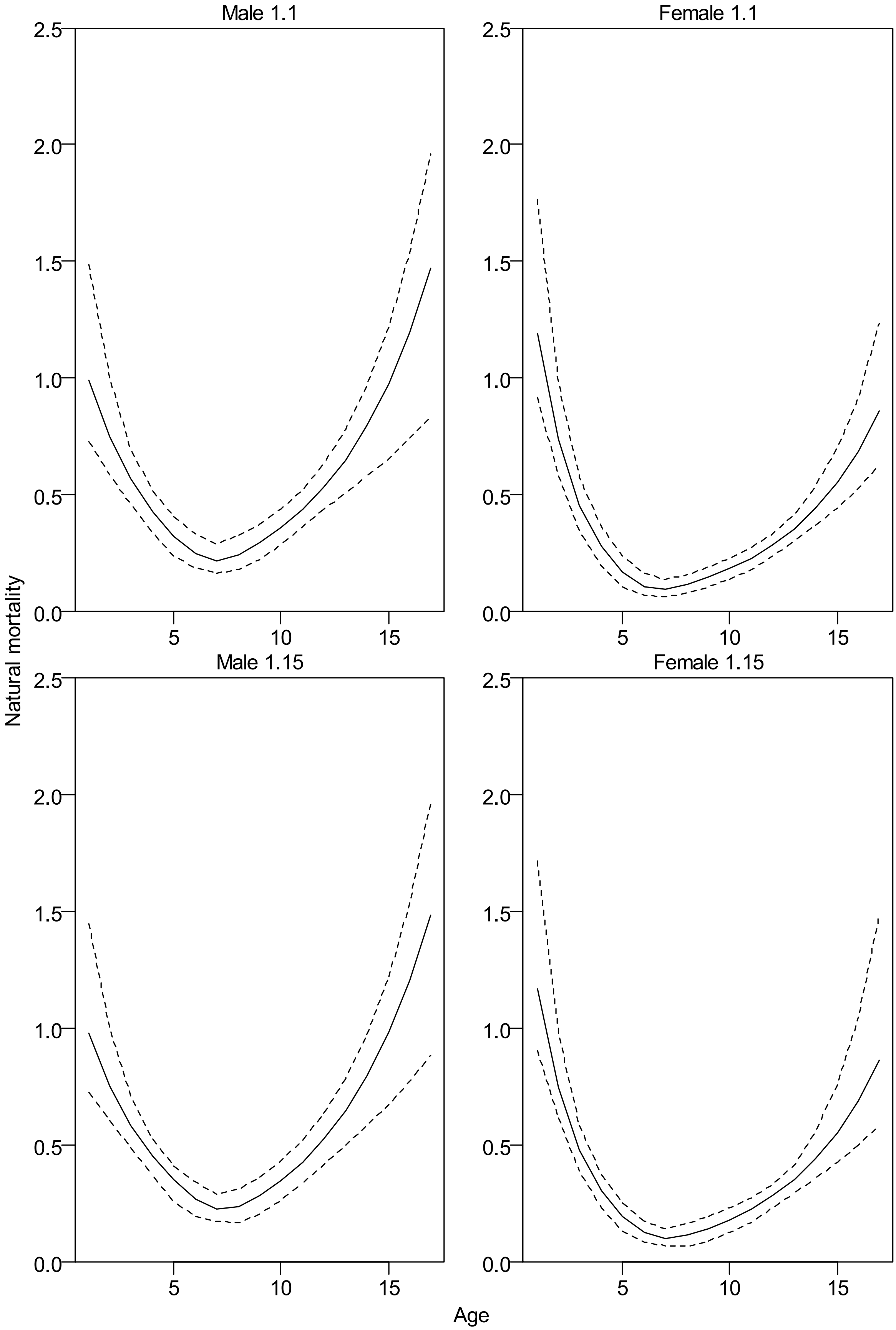

Figure 47: Assessment estimates of age-dependent natural mortality ogives for the MCMC runs showing median estimates (solid lines) and 95% credible intervals (broken lines) for each sex.

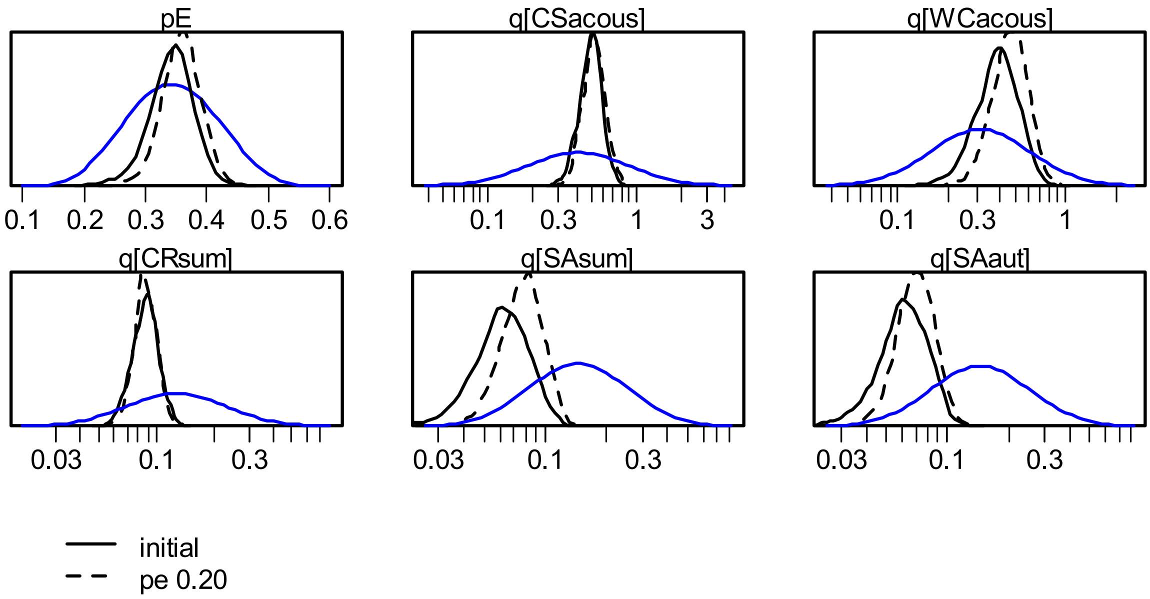

Figure 48: Assessment prior (blue lines) and estimated posterior (black lines) distributions for the following parameters: pE (proportion of B_0 in E stock), and survey catchabilities (acoustic and trawl).

Appendix 6: 2016 hoki assessment selectivities, migration ogives, natural mortality, and priors

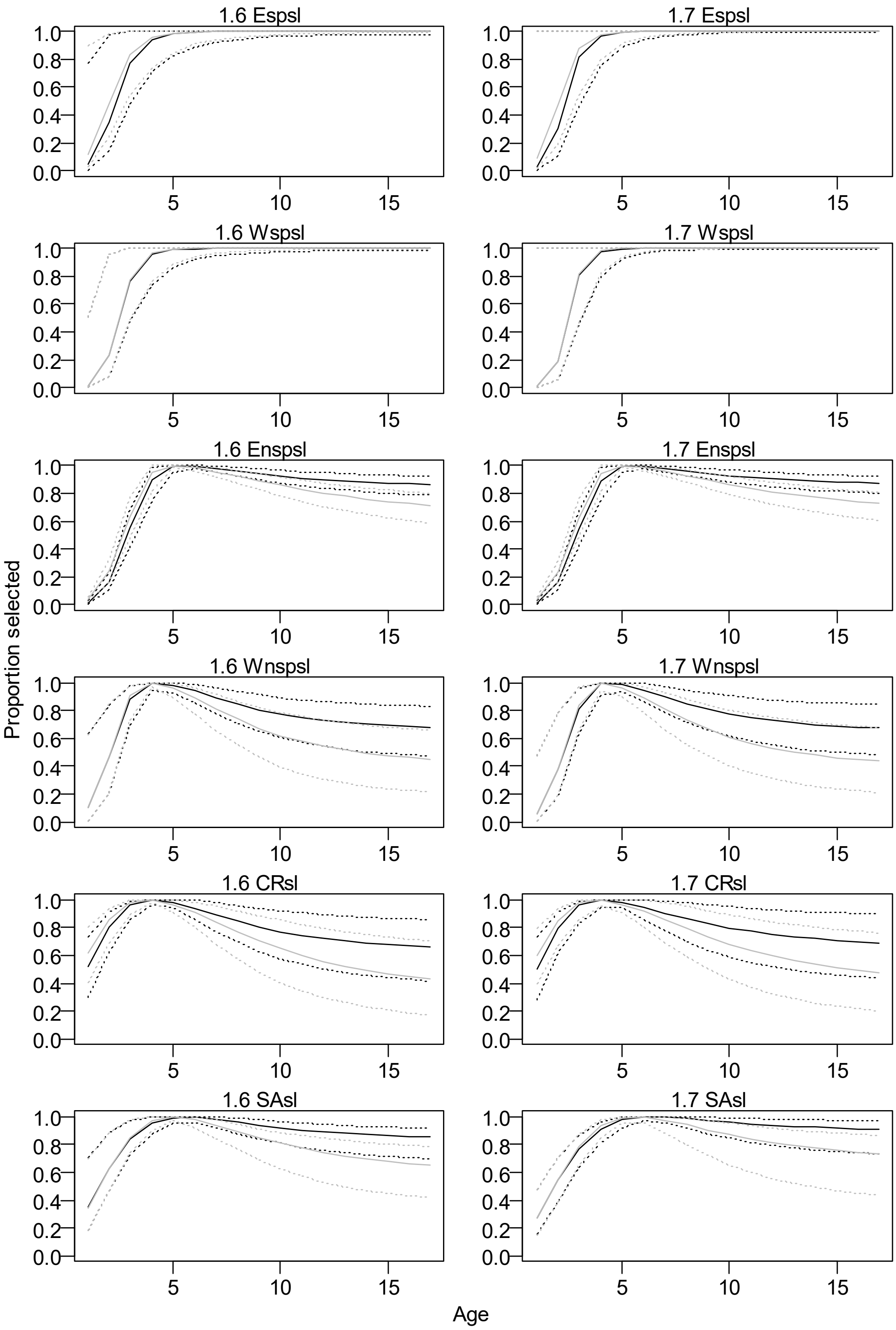

Figure 49: Posterior estimates of selectivity ogives for each for the two MCMC runs 1.6 and 1.7. Solid lines are medians; broken lines show 95% credible intervals. Where ogives differ by sex they are plotted as black for males and grey for females. Where they differ by stock or time step the plotted curves are for one selected combination (E step 2 for Enspsl and CRsl, W step 2 for Wnspsl and SAsl).

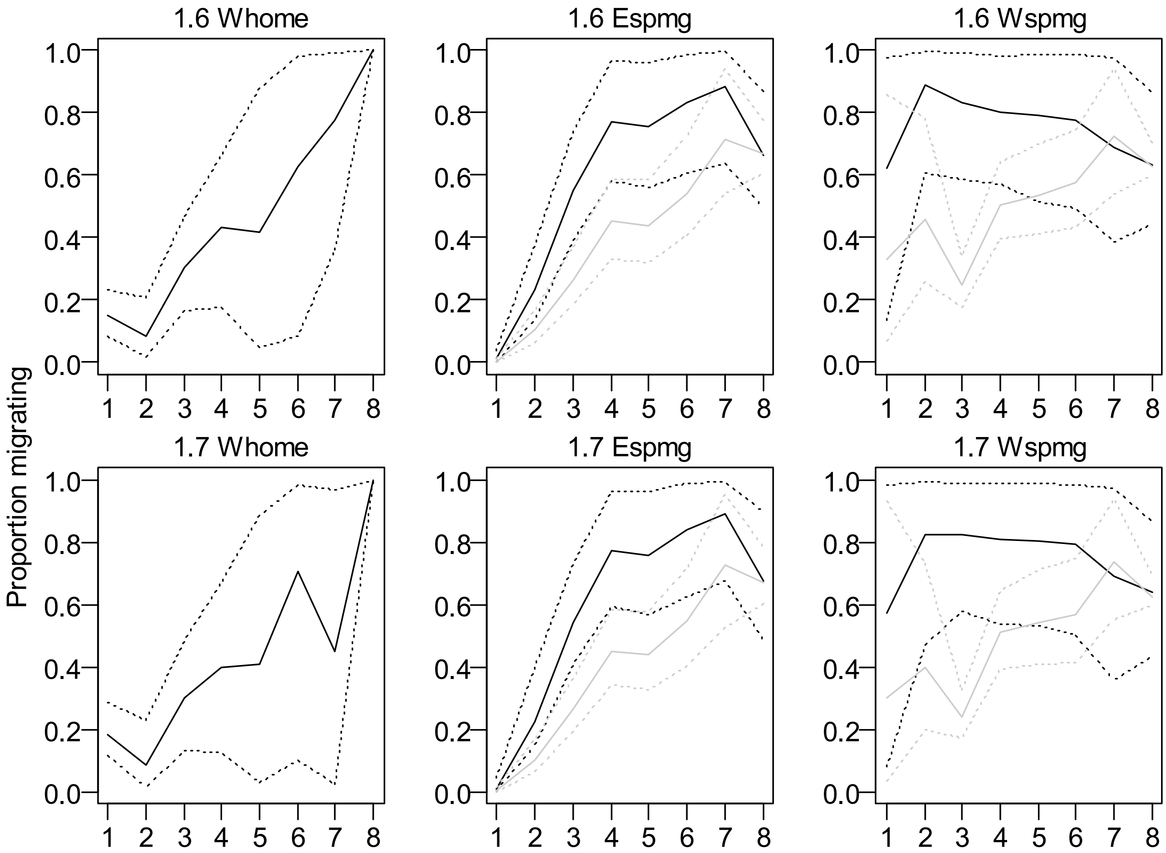

Figure 50: Estimated migration ogives. Solid lines are medians, broken lines show 95% credible intervals. Where ogives differ by sex they are plotted as black for males and grey for females. Age is along the x-axis.

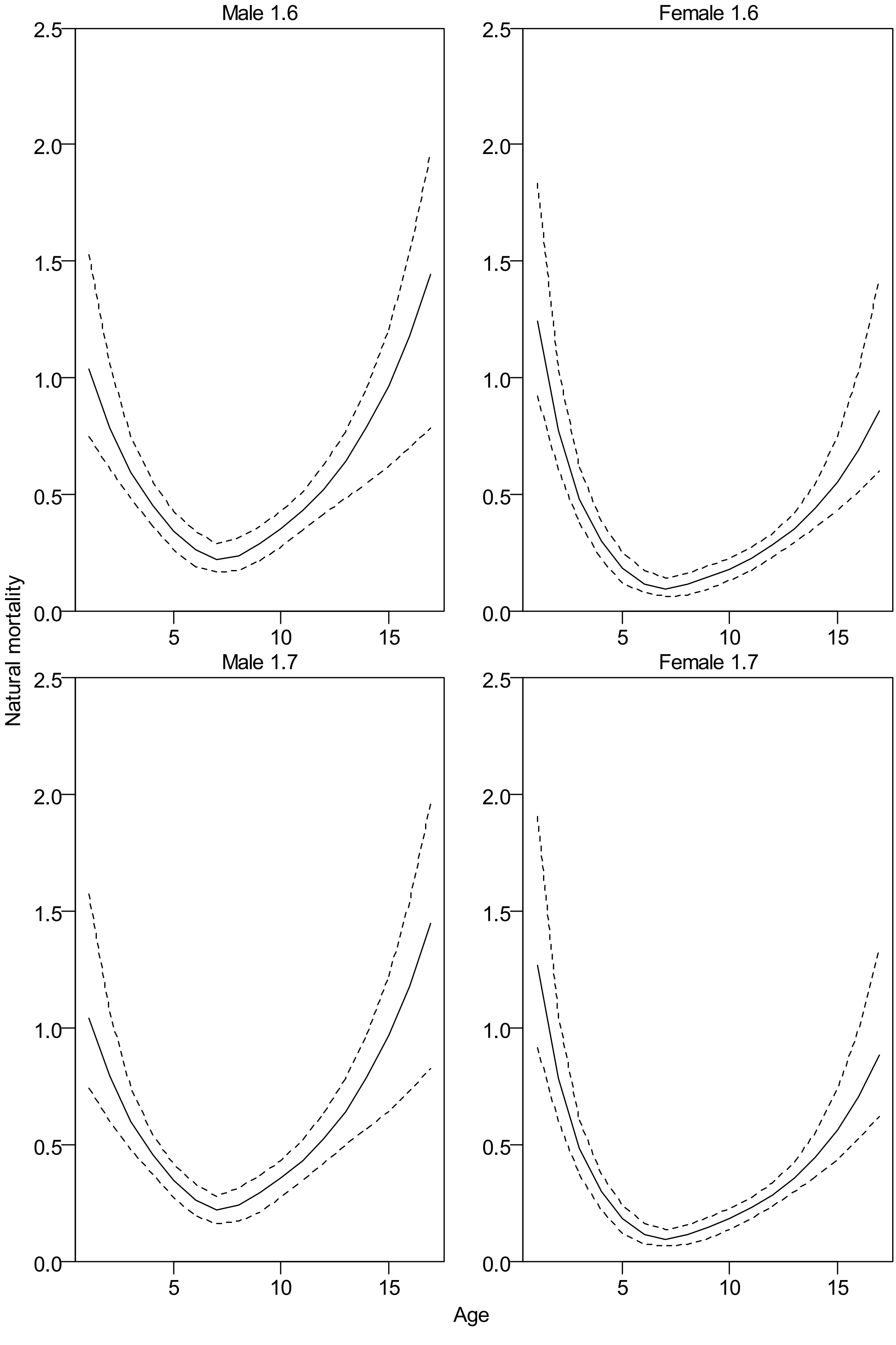

Figure 51: Assessment estimates of age-dependent natural mortality ogives for the MCMC runs showing median estimates (solid lines) and 95% credible intervals (broken lines) for each sex.

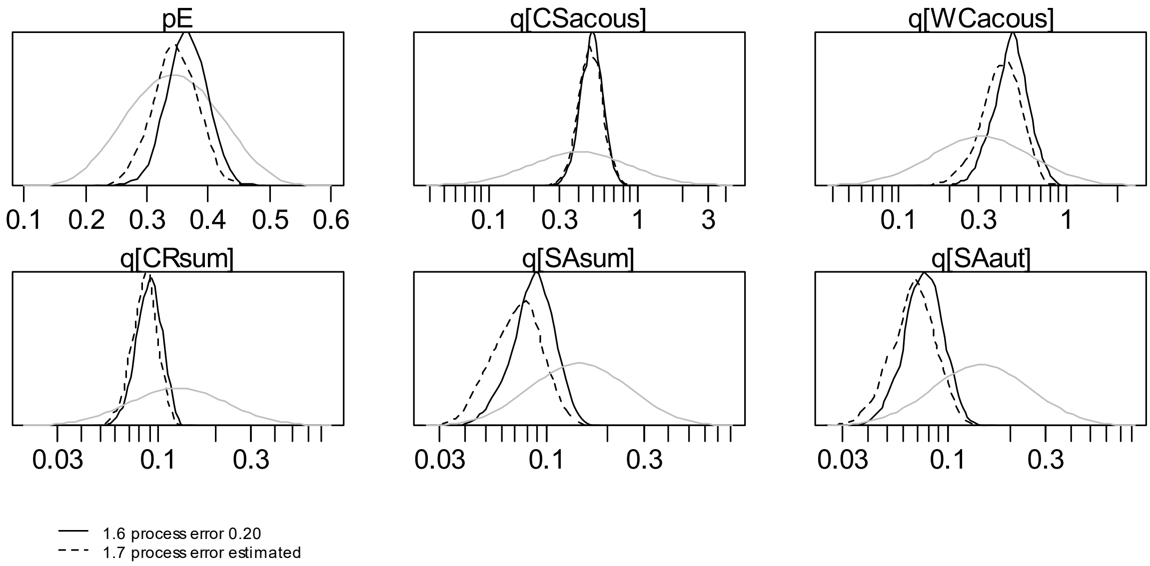

Figure 52: 2016 assessment prior (grey lines) and estimated posterior (black lines, solid for run 1.6, broken for run 1.7)) distributions for the following parameters: pE (proportion of B_0 in E stock), and survey catchabilities (acoustic and trawl). Note that the priors for CSacous and WCacous were changed for the 2016 assessment.