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Assessment of hoki (*Macruronus novaezelandiae*) in 2019

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EXECUTIVE SUMMARY

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

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An updated 2019 assessment is presented for hoki, which was based on the 2018 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 2018 research trawl survey on Chatham Rise, and a winter 2018 acoustic survey on the west coast South Island. New proportions-at-age data came from the Sub-Antarctic research trawl survey, commercial spawning and non-spawning fisheries for the west and east stocks.

In the 2018 assessment two-stock base model run, 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. An update of this model run was conducted for the 2019 assessment.

However, estimates of biomass for an updated two-stock model seemed implausible given recent downward trends for biomass indices and standardised CPUE, and the perception of the state of the fishery. For this reason, alternative two-stock model runs were investigated in which the biomass indices were fitted better, focusing on either the western stock or the eastern stock. A simplified western stock only model, in which the eastern areas and data were dropped, was also constructed to assess the impact of the two-stock model data and assumptions.

None of these runs was considered a base model, but rather showed the range of possible biomass estimates, when different weightings were given to fitting the eastern or western biomass indices.

The current western biomass was estimated to be 56%B_0 (median value) for the updated two-stock model, 34%B_0 (western stock only model), and 29%B_0 (two stock with a west focus). Current eastern biomass estimates were 66%B_0 (two stock update) and 64%B_0 (two stock with east focus).

Five-year projections were carried out for the four model runs by selecting future recruitments at random from two scenarios: (i) from those estimated for 2008–2017, and (ii) from those estimated for 1975–2017. Total catch was assumed to equal that in 2019 of 135 500 t with 64 000 t catch for the east stock and 71 500 t for the west stock.

The projections indicate that the eastern biomass will increase slightly over the next five years and remain above the target zone. The western biomass will increase in either scenario under the two stock (update) model and remain above the target zone. For the other two model runs where the Sub-Antarctic trawl survey is fitted better (two stock with a western focus, western only) the future western biomass is scenario dependent: (i) with recruitment from 2008–2017 the western biomass is flat and likely to remain under the target zone, and (ii) with recruitment from 1975–2017 the western biomass will increase and likely be in the target zone by the end of the projection period.

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).

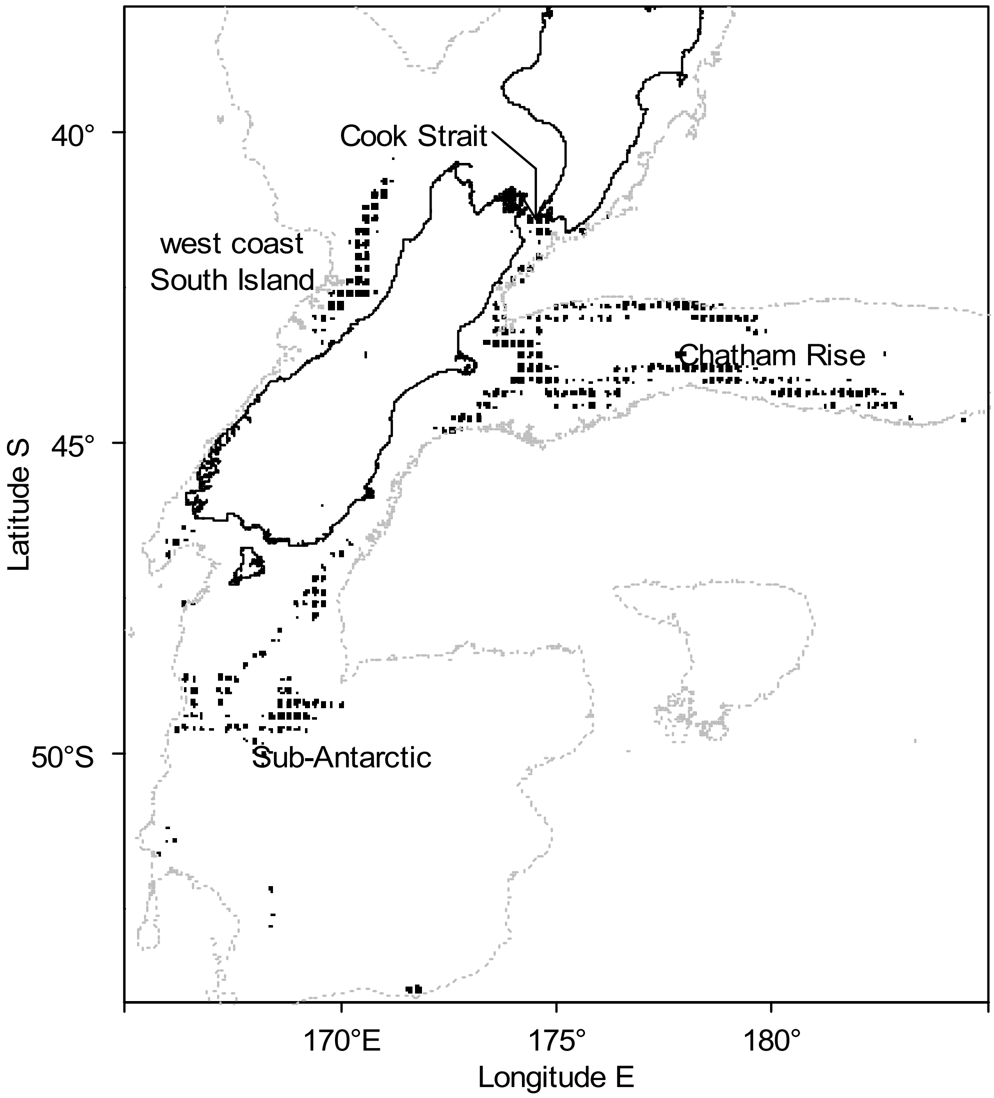

Figure 1: Southern New Zealand showing the main hoki fishing grounds, the 1000 m contour (broken grey line), and the position of all 2017–18 tows from TCEPRs (Trawl Catch and Effort Processing Returns) in which at least 10 t of hoki was caught (dots). Positions are rounded to the nearest 0.2 degrees and jittered.

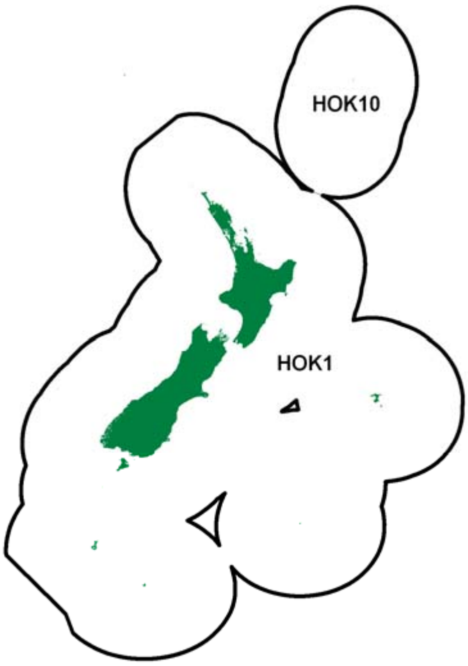

Figure 2: The Quota Management Areas for hoki.

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 2019 assessment of HOK 1, which is the eighteenth assessment to use NIWA's general-purpose stock-assessment model CASAL (Bull et al. 2012). Since the last assessment in 2018 (McKenzie 2019) there has been a winter 2018 acoustic survey on the west coast South Island (O'Driscoll & Ballara 2019), and a trawl survey on the Sub-Antarctic in November/December 2018 (MacGibbon et al. in prep.).

The work reported here addresses objective 2 of the Ministry for Primary Industries project HOK201801: *To update the stock assessment of hoki including estimates of biomass, risk and yields.*

2. MODEL ASSUMPTIONS AND INPUTS FOR 2019

This section provides a summary of all model assumptions and inputs for the 2019 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 2019 assessment there were four final model runs: (i) an update of the two-stock base run from the 2018 assessment, (ii) a western stock only model, (iii) two stock model (western focus), and (iv) two stock model (eastern focus). The western and eastern focus model runs have the same model structure as the two-stock base run, but different data weightings.

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 are much more time consuming to produce. For this reason, only MPD runs were used for the initial exploratory analyses (Section 4). Final model runs were full Bayesian MCMC, and provide the results for the formal stock assessment (Section 6).

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 2018 is referred to as the 2019 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.

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 2018 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 (but with shelving of catch for the western stock). The total catch taken was 135 500 t, with 72 100 t from the western stock and 63 400 t from the eastern stock.

For the current year (2019) the TACC and catch split remains unchanged from 2018, but with shelving of catch from the western spawning stock and spawning closures. It was estimated that the total catch for 2019 will equal 123 400 t: Ensp (28 500 t), Esp (32 400 t), Wnsp (6 200 t), Wsp (56 300 t) (Charles Heaphy, Sealord, pers. comm.). In the model the non-spawning fishery is split into two parts (Table 4) and it is assumed that the 2019 split proportions are the same as 2018. Subsequently this 2019 catch estimate was revised (Section 5.3).

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	27 000	14 800	9 000	6 500	21 600	56 600	135 500
2019[1]	18 400	10 100	3 600	2 600	32 400	56 300	123 400

[1] **2019 catches are assumed**

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 about 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

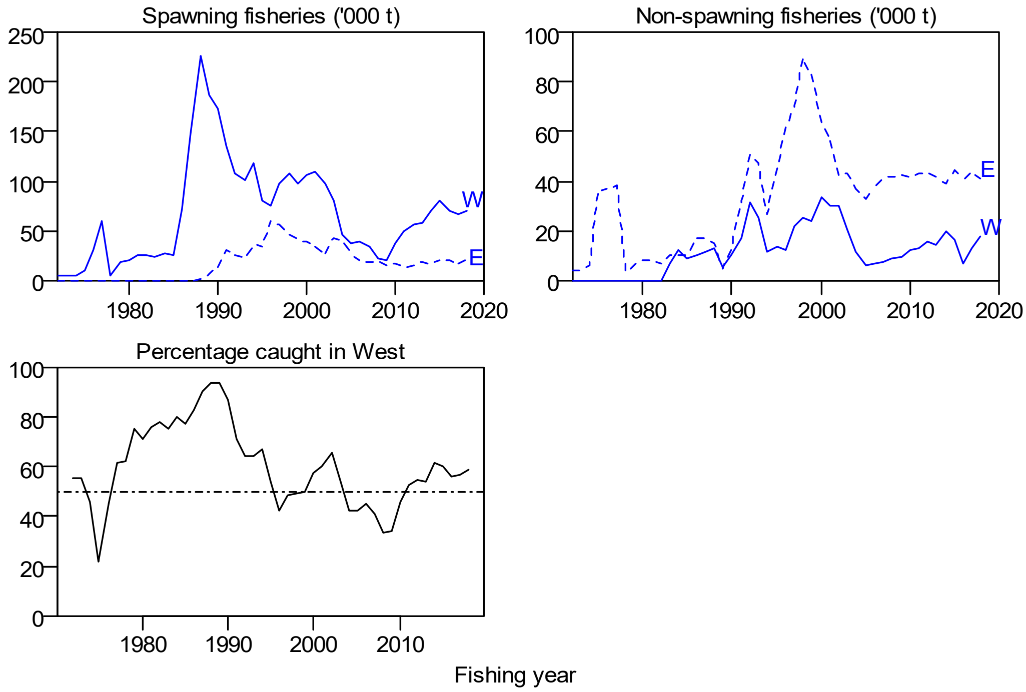

Figure 3: Annual catches by fishery for the spawning (top left panel) and non-spawning (top right panel) fisheries, and annual percentage of catch caught in western fisheries (Wsp, Wnsp1, Wnsp2) (bottom panel).

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 two-stock final model 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.

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

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

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 2019).

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	2018	Mean				
298	300	301	300	301	297	300	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

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

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 three YCSs were estimated for each stock, for 1975 to 2017, inclusive. YCSs for the initial years (1970 to 1974) were fixed at 1. The E and W YCSs for 2017 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 2018 acoustic survey on the west coast South Island, and a November/December 2019 trawl survey on the Sub-Antarctic.

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

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 (but in model runs process errors for CRsumbio and SAsumbio are estimated within the model).

	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)	–	–	–	**123 (0.15,0.46)**
2019	–	**31 (0.11,0.23)**	–	–	–

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–**2018**	otoliths
SA	WnspOLF	Catch at age	1992–94, 96, 99–00	OLF
	Wnspage	Catch at age	2001–04, 06–14, 2016, **2018**	otoliths
	SAsumage	Trawl survey	1992–94, 2001–10, 12, 13, 15, 17, **2019**	otoliths
	SAautage	Trawl survey	1992, 96, 98	otoliths
CS	Espage	Catch at age	1988–10, 2014–**2018**	otoliths
CR	EnspOLF	Catch at age	1992, 94, 96, 98	OLF
	Enspage	Catch at age	1999–**2018**	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

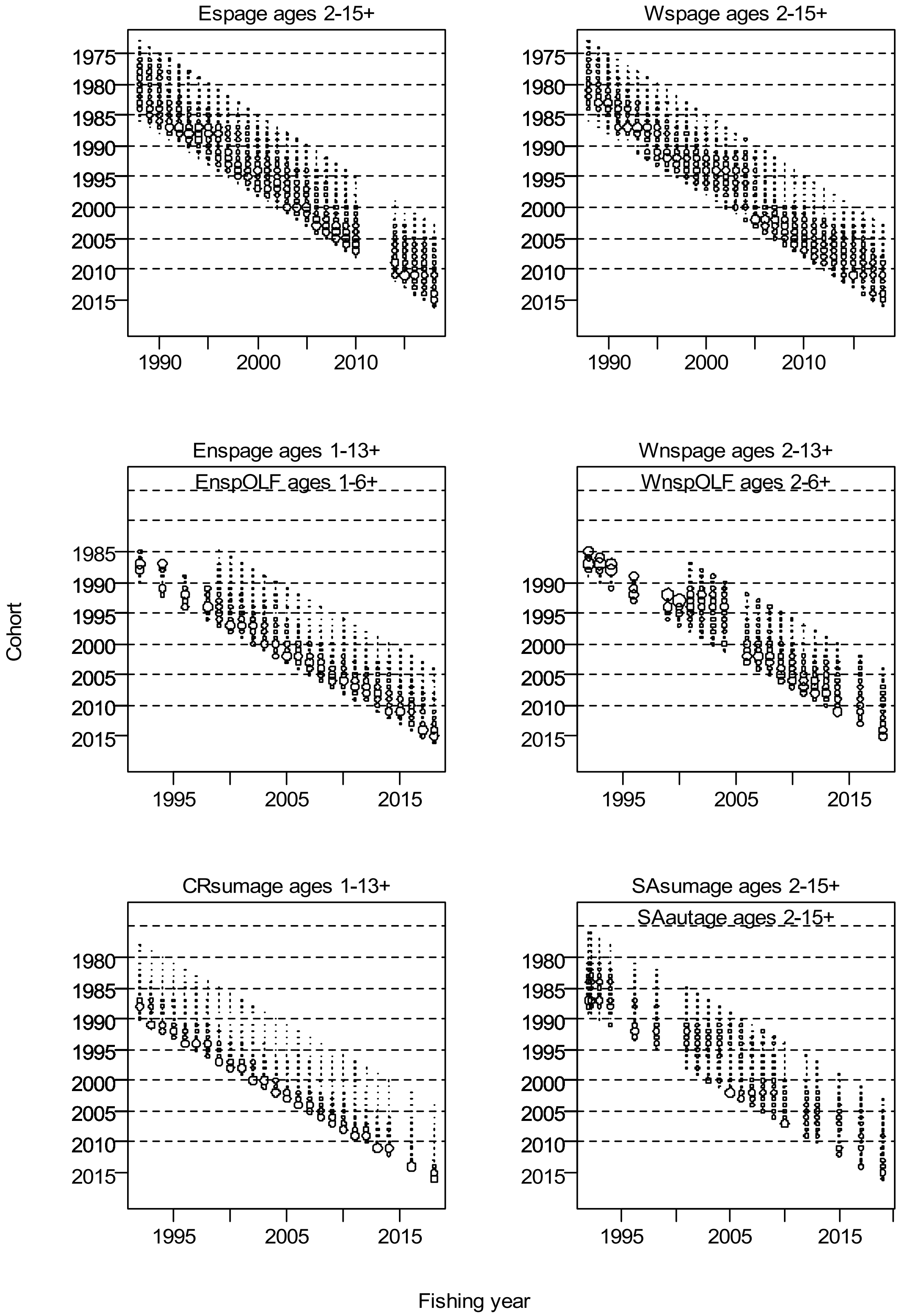

Figure 4: Proportions-at-age data, plotted by cohort and fishing year, with both sexes combined. The area of each circle is proportional to the associated proportion at age. Circle positions for the SAautage data in 1992 have been offset horizontally to allow them to be plotted on the same panel as the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

3. PRE-ASSESSMENT MODEL RUNS

3.1 Introduction

All model runs in the following Sections 3.2 and 3.3 are variations on the base run 1.1 for the 2018 stock assessment, which is a sexed model with an age-varying natural mortality (McKenzie 2019). In the first section we explore in detail what is driving the estimate of the western virgin biomass, and in the second section we examine what determines the height of the right limb for the male age-varying natural mortality and how this is related to biomass estimates.

3.2 Investigating drivers of the estimated western virgin biomass

In this section we investigate what factors (data and priors) are driving the MPD estimate of the western biomass in the hoki stock assessment base model. It is already known from the previous assessment that the trawl biomass indices for the Sub-Antarctic (SAsumbio) and the west coast South Island acoustic survey (WCacous) catchability prior are important drivers of the estimated western stock biomass (Tables 13–14). Profiles show that the composition data is also one of the drivers (McKenzie 2018, figure 40, p. 44).

We investigate the data and priors involved by presenting:

(i) Likelihood and prior profiles for the western virgin biomass

(ii) Likelihood and prior profiles for the right-hand limb of the male age-varying naturally mortality (the value of which is correlated with the estimated western biomass).

Table 13: Runs taken through to MCMC for the 2018 assessment (from McKenzie 2019).

Run	Short name	Model description
1.1	base	natal fidelity *M* is age-dependent single q for Sub-Antarctic trawl series process error of CRsumbio and SAsumbio estimated in MPD run
1.2	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.

Table 14: Estimates of spawning biomass for the 2018 assessment (medians of marginal posterior, with 95% credible intervals in parentheses). $B_{current}$ is the biomass in mid-season 2018 (from McKenzie 2019).

	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)

3.2.1 Profile on western virgin biomass

Note that in the assessment the virgin western biomass is a derived quantity. In the model, parameter estimates are made for the total virgin biomass (east and west) and the proportion of this that is eastern.

For the profiles, the process errors for the Sub-Antarctic trawl survey (SAsumbio) and Chatham Rise trawl survey (CRsumage) are kept constant at their estimated values in the base case.

Profiles for the western virgin biomass are shown in Figure 5, with a simplified version in Figure 6 showing just the components with the most change in their objective function. The components showing the most change are Composition (i.e. all at-age data combined), SAsumbio (Sub-Antarctic summer trawl survey), with a more muted change for Priors (i.e. all priors combined). With increasing virgin western biomass, the Composition likelihood goes down, but goes up for SAsumbio, and they substantially cancel each other leaving a total objective function profile similar to the Priors component.

To understand which individual data and priors components are important, the combined Composition and Priors sets are broken up further.

The Composition component is split into the data sets for eastern and western stocks (Figure 8–9). The eastern composition data fits better with a higher western virgin biomass for nearly all at-age components: CRsumage (Chatham Rise trawl survey), Enspage (eastern non-spawning fishery), Espage (eastern spawning fishery). The western composition data for Wspage (western spawning fishery) fits better with a lower western virgin biomass; but essentially just as well (less than 0.5 change in likelihood) for other data sets. These trends for eastern and western at-age data are summarised in Table 15.

Table 15: At-age data sets that are better fitted with a higher western virgin biomass (↑) or lower western virgin biomass (↓), or essentially no change (–).

	Fishery			Trawl survey
	Spawning	Non-spawning (early)	Non-spawning (late)	
Eastern	↑	–	↑	↑
Western	↓	–	–	–

As a sensitivity run for the eastern at-age data, a model run 1.9 was done in which the effective sample size was arbitrarily halved for the most influential at-age components: CRsumage, Enspage, Espage. For this run the western current biomass was estimated at 44% (B_0) instead of 55% in the base case (Figure 10).

Selectivities, ogives, natural mortality, and YCSs are compared between the 2018 base model and the model 1.9 where the effective sample sizes are halved for the selected eastern at-age data (CRsumage, Enspage, Espage). There are many small differences across these, as opposed to a few overt differences (Figures 11–14).

The Priors component is split into the data sets for eastern and western stocks (Figures 15–17). Two of the eastern priors are more consistent with a higher western virgin biomass: [CSacous].q (Cook Strait acoustic survey catchability) and recruitment[E].YCS (eastern year class strength). The other eastern priors are consistent with a wide range for the western virgin biomass: eastern spawning migration ogives, Chatham Rise trawl survey catchability, Chatham Rise trawl survey selectivity, eastern spawning and non-spawning fishery selectivities.

Three of the western priors are more consistent with a lower western virgin biomass: recruitment[W].YCS (western year class strengths), q[SAaut].q (Sub-Antarctic autumn trawl survey catchability), and q[SAsum].q (Sub-Antarctic summer trawl survey catchability). The prior q[WCacous].q is more consistent with a higher western virgin biomass.

The most influential priors are those for the year class strengths and the catchabilities for the Sub-Antarctic trawl and both acoustic surveys (Table 15).

Table 16: Priors by stock that are more consistent with a higher western virgin biomass (↑) or lower western virgin biomass (↓), or essentially no change (–).

Stock	Trawl catchability	Acoustic catchability	YCSs
Eastern	–	↑	↑
Western	↓	↑	↓

In summary, except for the pre-1999 non-spawning fishery at-age, all other eastern at-age data (fishery and trawl) fit better with a higher estimated western virgin biomass. The western spawning at-age data fits better with a lower estimated western virgin biomass, with little difference for the other western composition data. Arbitrarily halving the effective sample size for the most influential eastern at-age data gives a current western biomass of 44% (B_0) versus 55% (B_0) for the base case model.

The most influential priors are those for the western year class strengths, and the catchabilities for the Sub-Antarctic trawl and the two acoustic surveys.

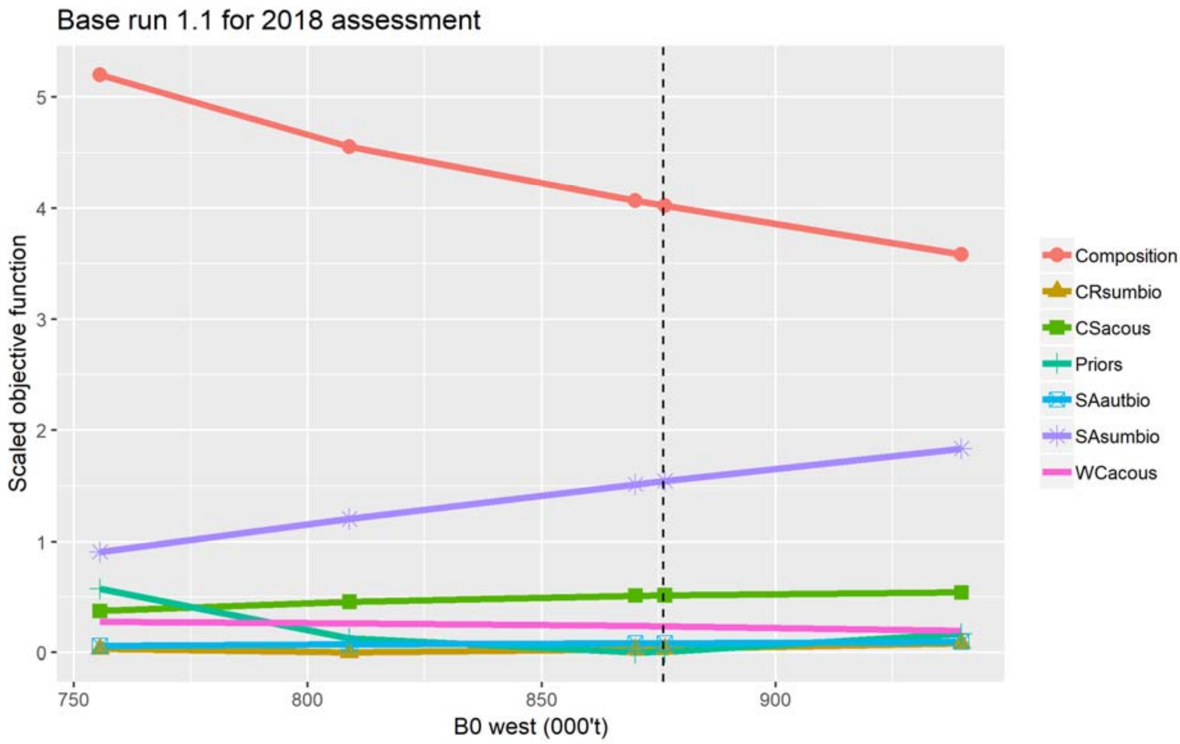

Figure 5: Profile for run 1.1, with the trawl survey process errors fixed at their estimated values for the run (0.15 for CRsumbio and 0.38 for SAsumbio). Likelihood components are scaled so that they are zero at their minimum value. The "Composition" component includes all at-age data, and the "Priors" component all priors. 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. The vertical dashed line shows the MPD estimate in the base case.

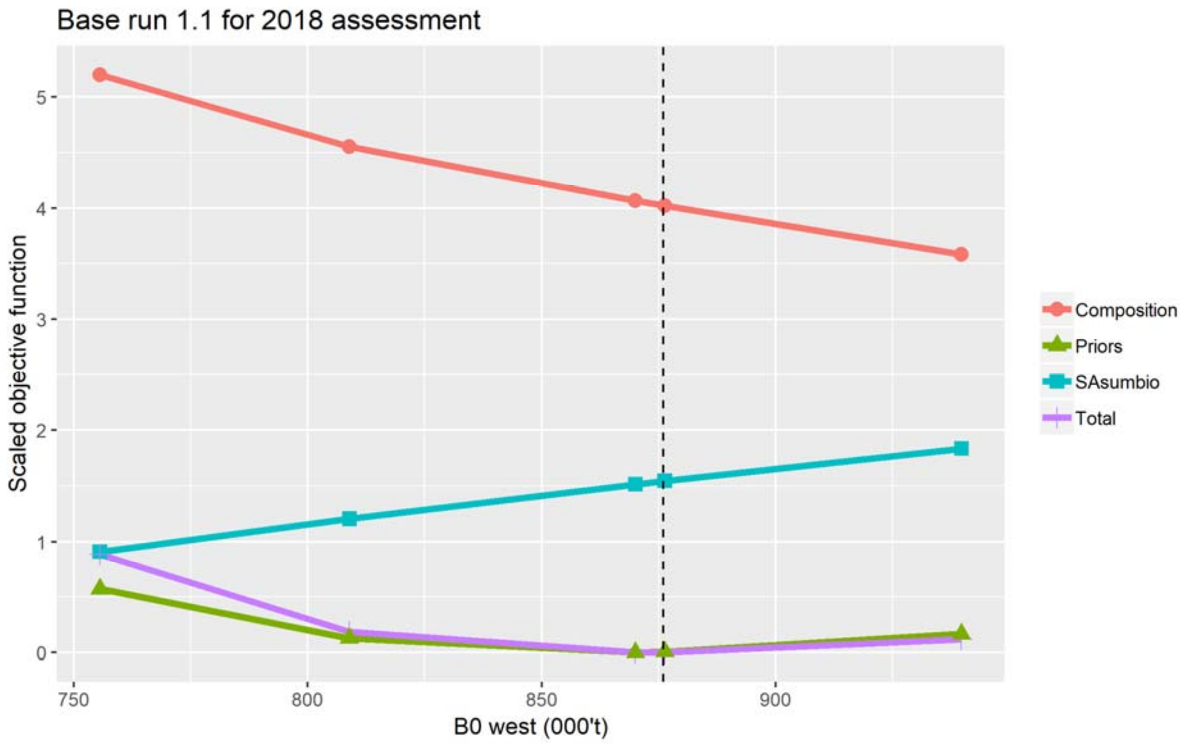

Figure 6: As in Figure 5, but simplified to show selected components that show the most change as the western virgin biomass varies.

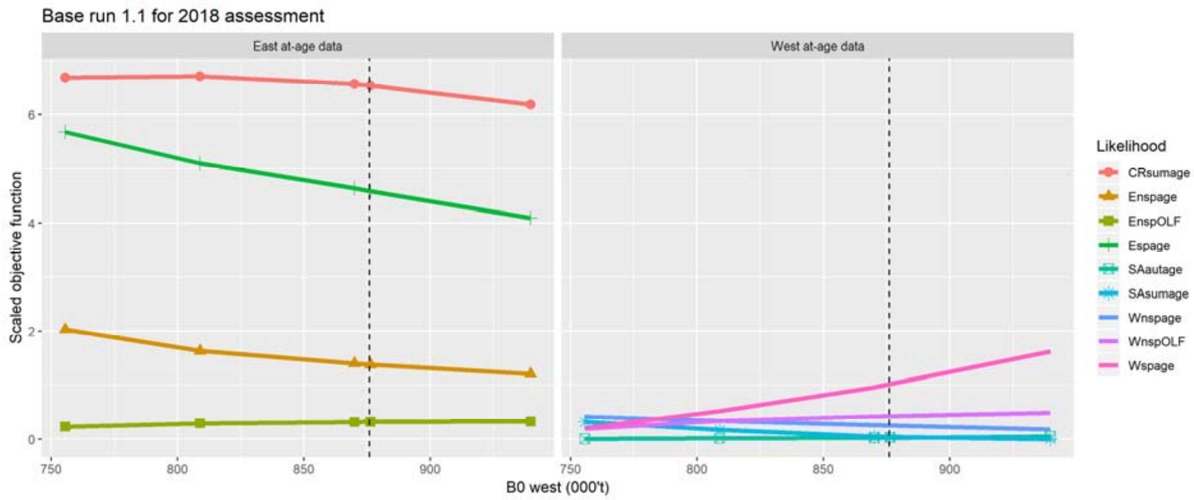

Figure 7: Eastern and western at-age data and likelihood profile on the virgin western biomass.

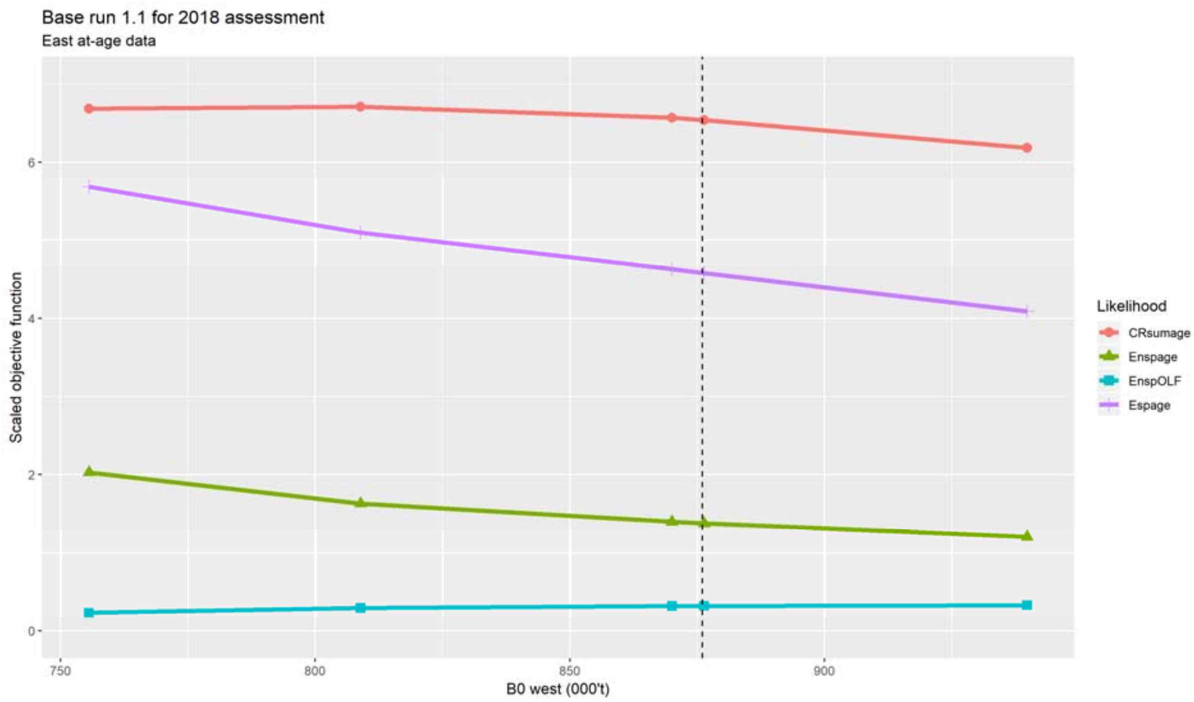

Figure 8: Eastern at-age data and likelihood profile on the virgin western biomass.

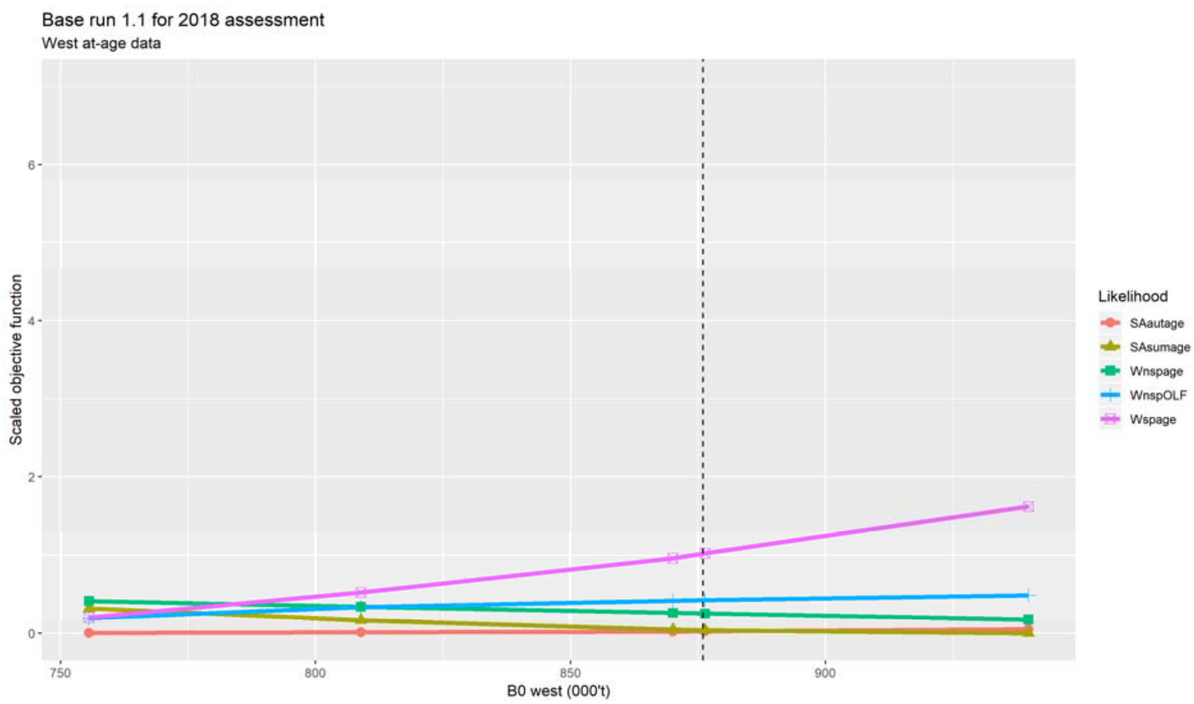

Figure 9: Western at-age data and likelihood profile on the virgin western biomass.

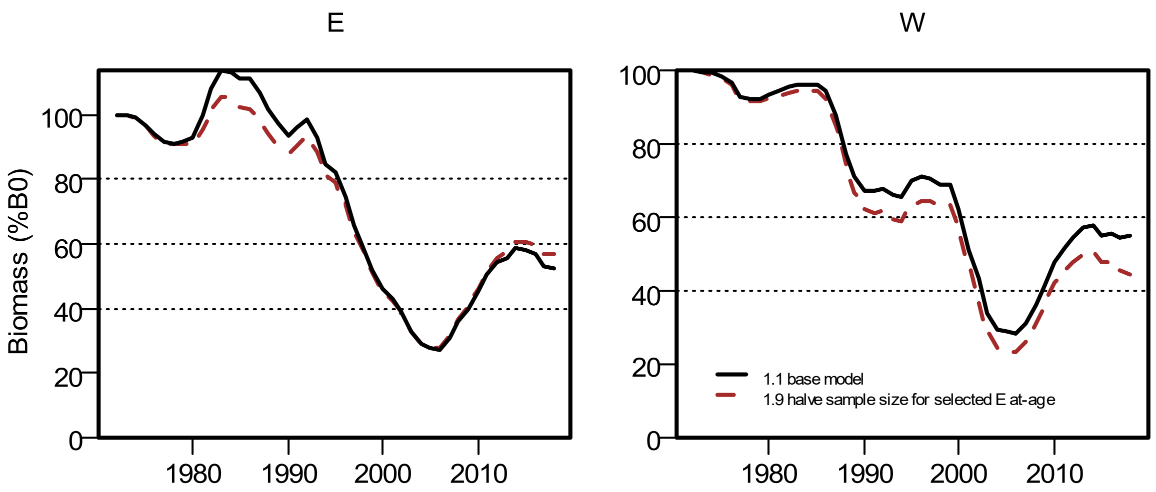

Figure 10: Comparison of biomass trajectories from different runs: E stock (left column) and W stock (right stock). The graphs compare the base run 1.1 (solid black line) with the sensitivity run 1.9.

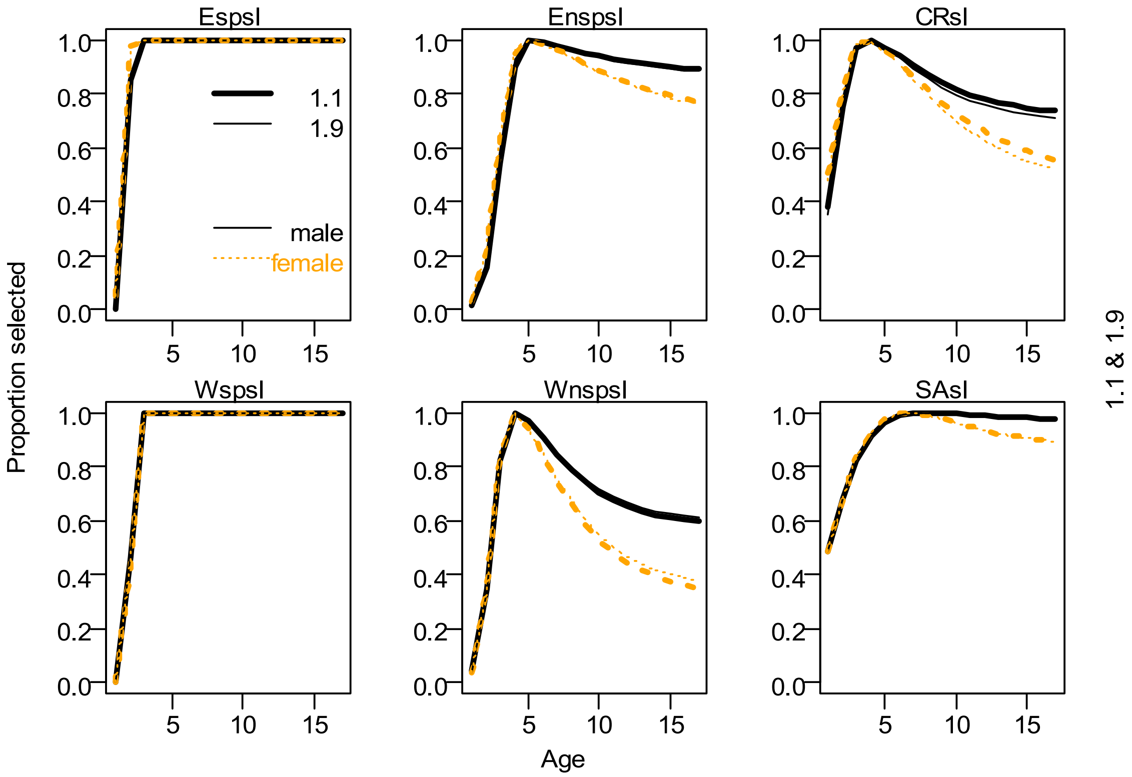

Figure 11: Estimated selectivity curves for the new model run 1.1 from 2019 (heavy lines) and model run 1.9 with effective sample sizes halved for selected eastern at-age data (light lines). Males are shown by a solid black line, females by a dotted orange line.

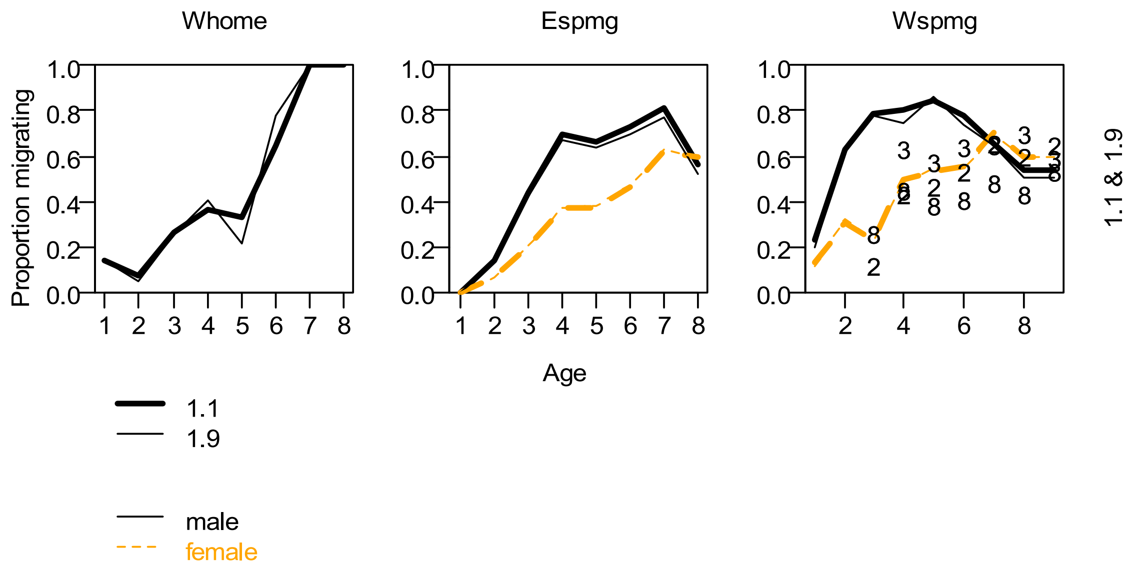

Figure 12: Estimated migration ogives for new run 1.1 from 2019 (heavy lines) and model run 1.9 with effective sample sizes halved for selected eastern at-age data (light lines). Where ogives differ by sex, female ogives are plotted as broken orange lines. The observations pspawn are also plotted in the rightmost panel, with the plotting symbol identifying the year of sampling ('2' = 1992, '3' = 1993, '8' = 1998).

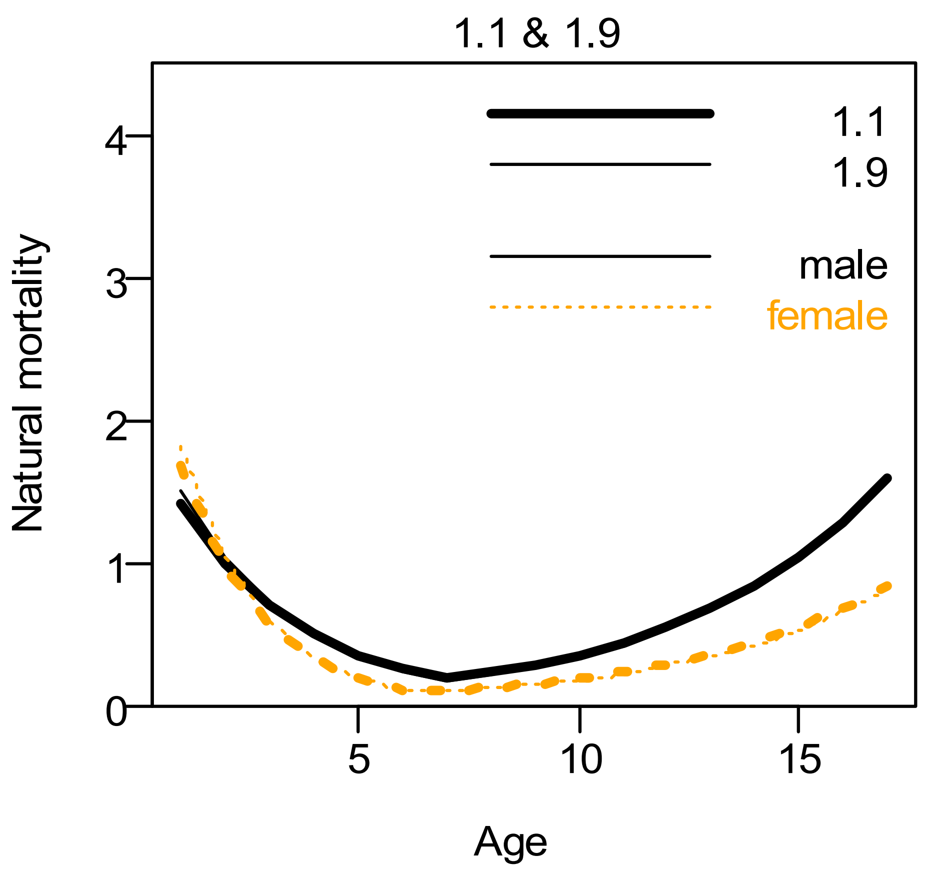

Figure 13: Comparison between age-dependent natural mortality estimated in the new run 1.1 from 2019 (heavy lines) and model run 1.9 with effective sample sizes halved for selected eastern at-age data (light lines).

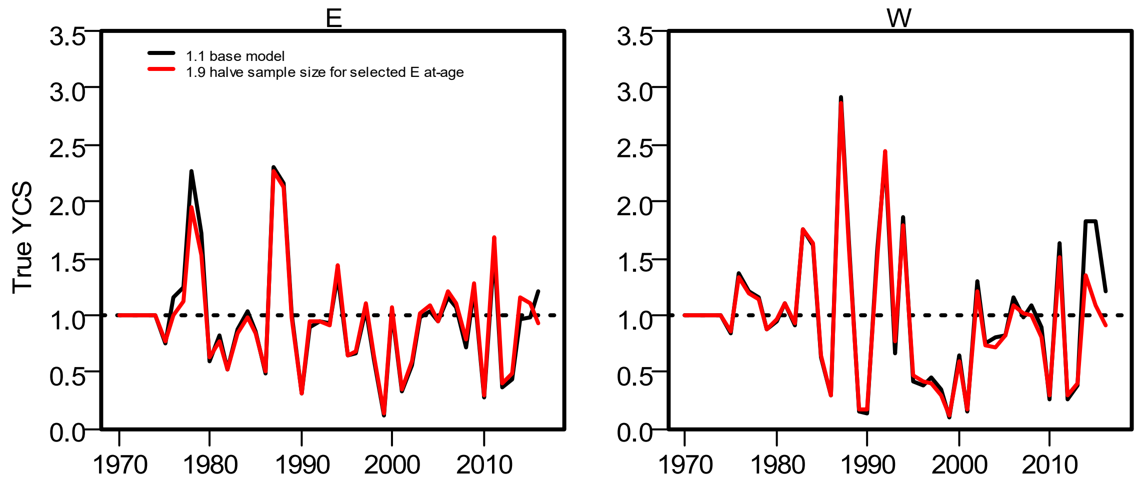

Figure 14: True YCS estimates for the base run 1.1 from 2018 (black lines) and model run 1.9 with effective sample sizes halved for selected eastern at-age data (red lines).

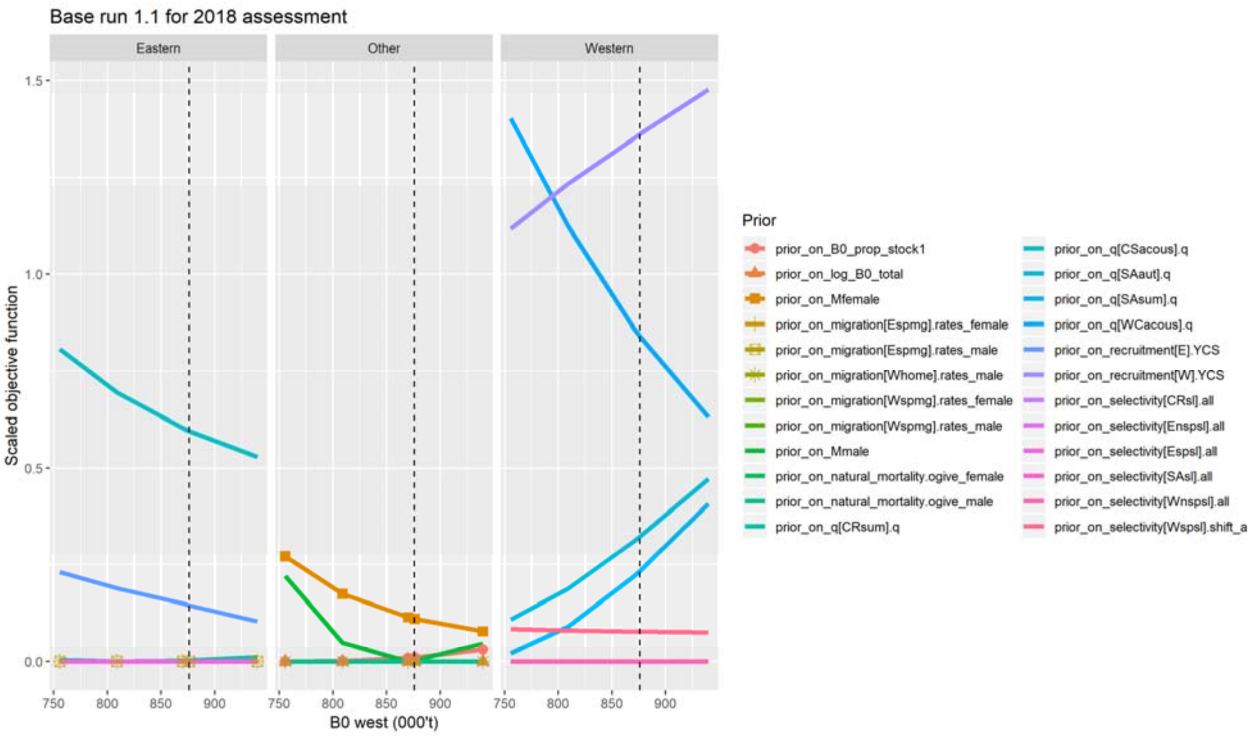

Figure 15: Priors and likelihood profile on the virgin western biomass.

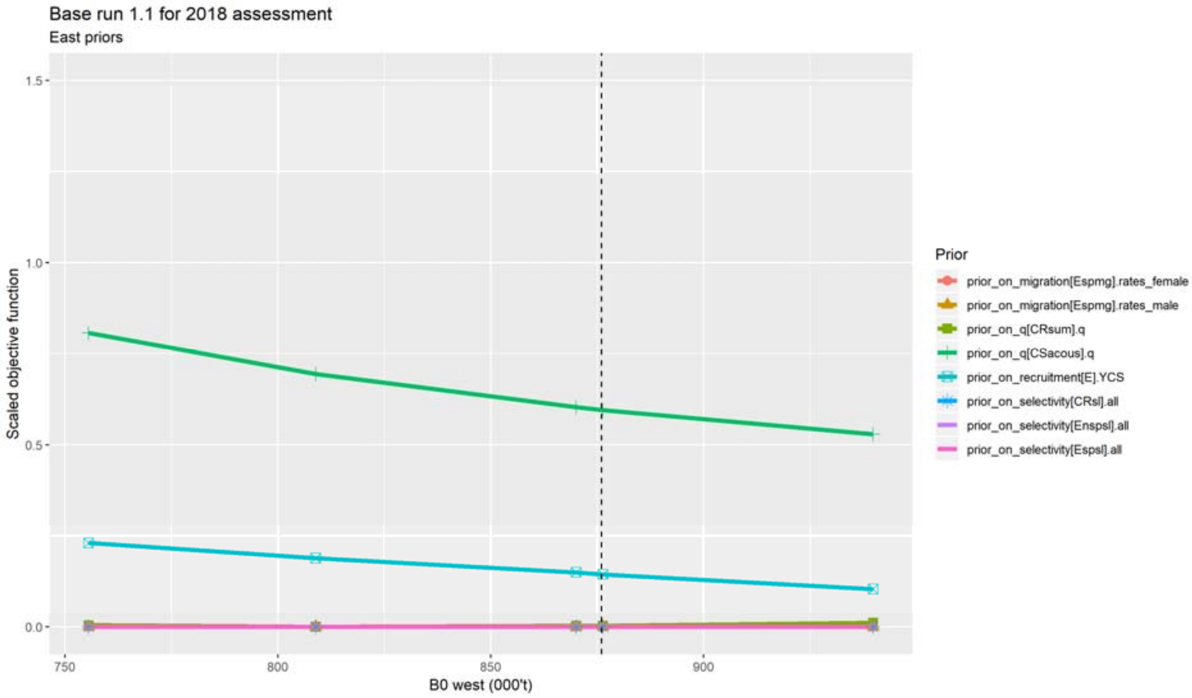

Figure 16: Eastern priors and profile on the virgin western biomass.

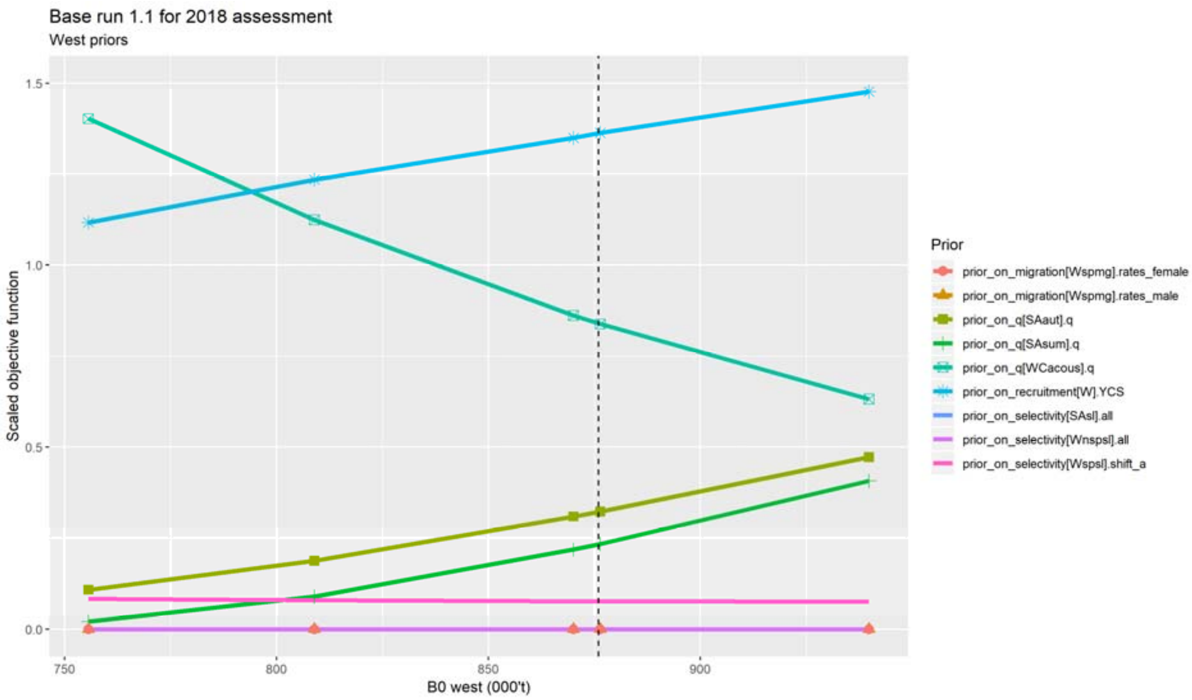

Figure 17: Western priors and profile on the virgin western biomass.

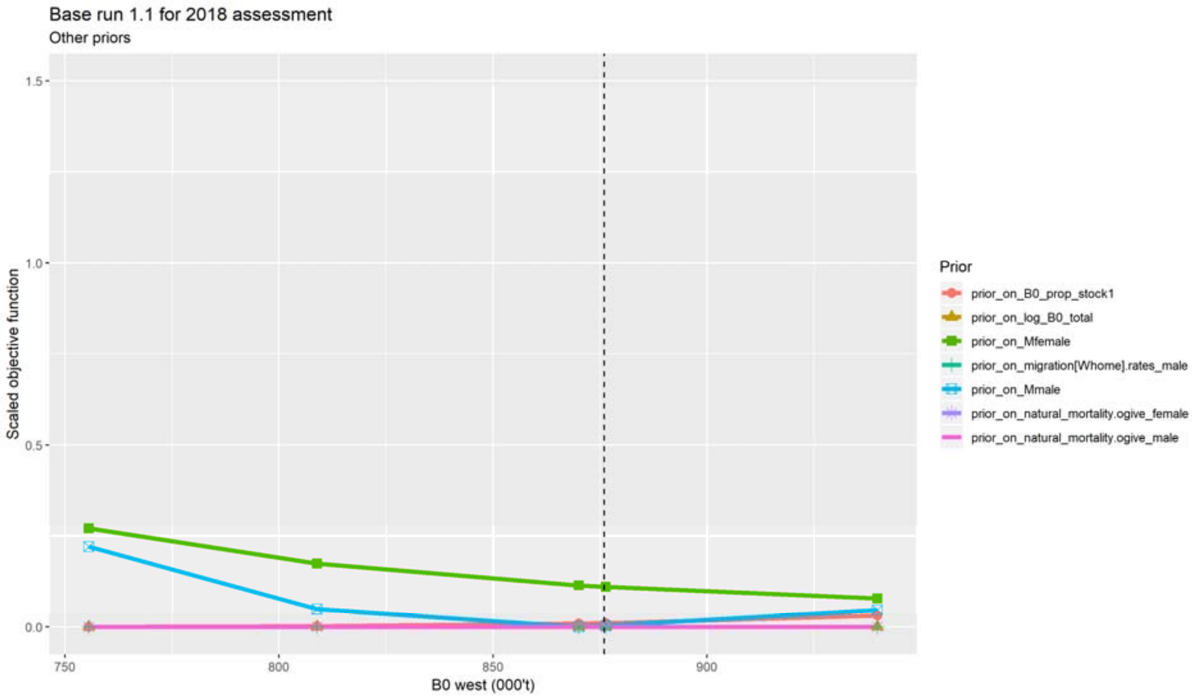

Figure 18: Other priors and profile on the virgin western biomass.

3.3 Profile on right limb for male age-varying natural mortality

For the hoki stock assessment base model run an age-varying natural mortality that differs by sex is assumed. This is parameterised as a double exponential curve, where if the curve is "U" shaped, the estimated parameters are the position of the minimum, and the value of the left-hand and right-hand limbs at ages one and seventeen respectively (Bull et al. 2012, p. 52). A prior on the natural mortality for all ages (not sexed) was developed by Cordue (2006), which is denoted as the "New" prior in Figure 19. Subsequently this prior was revised so that only the parts between and including ages 5 y and 9 y are used (Francis (2008), p. 15). See Figures 20–21 for the 2018 base case estimated age-varying natural mortality.

The right-hand limb values are of particular interest for the age-varying natural mortality, estimated in the MPD base run as 1.60 for males and 0.83 for females. The values estimated for these are linked to stock status. For example, Dunn & Langley (2018, table 3, p. 14) forced the values to be 0.30 for both male and female, producing a western current biomass (%B_0) of 31% instead of 48% for the 2017 hoki base assessment. Note that the value of 0.30 is outside the 95% credible interval for both males and females.

When the right-hand limb was forced to be 0.30 for male and female, the fits to Espage (eastern spawning at-age) and SAsumage (Sub-Antarctic summer trawl survey at-age) were degraded, suggesting that they are the drivers for the estimated right-hand limb. We investigate this in more detail with a profile on the right-hand limb parameter for the males (which has the highest value for the right-hand limb) and look at the effect of the priors. In the profile the process errors for the Sub-Antarctic trawl survey and Chatham Rise trawl survey are kept constant at their MPD estimated values (0.39 and 0.14 respectively).

The profile indicates that Composition (all composition data combined) and Priors (all priors combined) are the main drivers for the right-hand limb estimate (Figures 22–23). When breaking up the Composition profile by east and west stocks, it is clear that the Espage (eastern spawning at-age data) is a strong driver for a higher estimated right-limb value (Figures 24–25). For the other eastern at-age data the change in likelihood for different values of the right-hand limb are small. For the western at-age data likelihood differences are small, but WnspOLF (western non-spawning at-age before 2001) and Wnspage (western non-spawning at-age from 2001 onwards) are fitted better with a lower right-hand limb, and SAsumage (Sub-Antarctic summer trawl survey) and Wspage (western spawning at-age) with a higher right-hand limb.

Of the priors, the most important driver of the right-hand estimate is the prior on the male natural mortality (Figure 26–29). In summary, the estimate of the right-hand limb for the male natural mortality is mainly driven by the eastern spawning at-age data and the prior on the male natural mortality.

If the right-hand limb is forced to a very low value (i.e., 0.30) relative to what is compatible with the data and priors and model structure, then this certainly impacts on the estimated western biomass. What impact do more intermediate values have? A run was conducted in which the right-hand limb for the male age-varying natural mortality was forced to be 0.80, which is about half of the MPD estimate for the base run, and at the lower bound for the 95% credible interval from the MCMC (see Figure 21). For this run current western biomass (%B_0) was estimated to be 54% (versus 55% in the base case), and there was little difference in the biomass trajectory for either stock (Figure 30). Apart from the forced right-hand-limb for males, there is little difference between the new run and the base run, for the estimated age-varying natural mortality (Figure 31).

The natural mortality prior constrains the age-varying natural mortality between ages 5–9 inclusive to be near 0.20. Removing this constraint results in an increased current biomass for the eastern stock (57%B_0 versus 52%B_0 in the base case) and very little change for the western stock (54%B_0 versus 55%B_0) (Figure 32). The age-varying natural mortality estimates are very similar, except that the right-hand estimate for males is lower (Figure 33).

In summary, the estimate of the right-hand limb for the male natural mortality is mainly driven by the eastern spawning at-age data and the prior on the male natural mortality, both of which are more compatible with a higher estimated value. However, halving the height of the right-hand limb makes little difference to current biomass estimates (%B_0) and removing the prior has a small impact on current biomass estimates (%B_0).

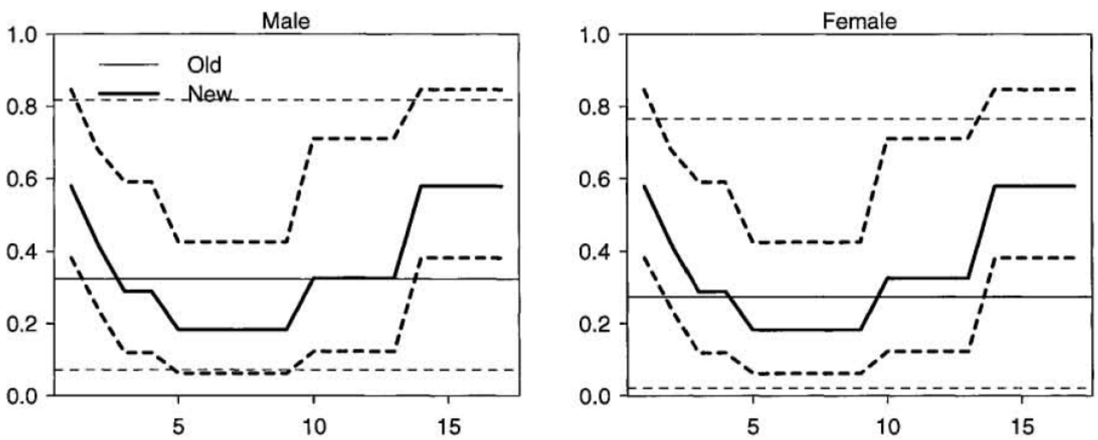

Figure 19: Reproduced from Francis 2008 (figure 10). Comparison between old and new priors for M, for use in model runs in which the estimated M varies with age. The new priors are lognormal at each age; solid lines show the means of the priors, broken lines show 95% confidence intervals. Note that the prior was subsequently revised so that only the parts between and including ages 5 y and 9 y are used.

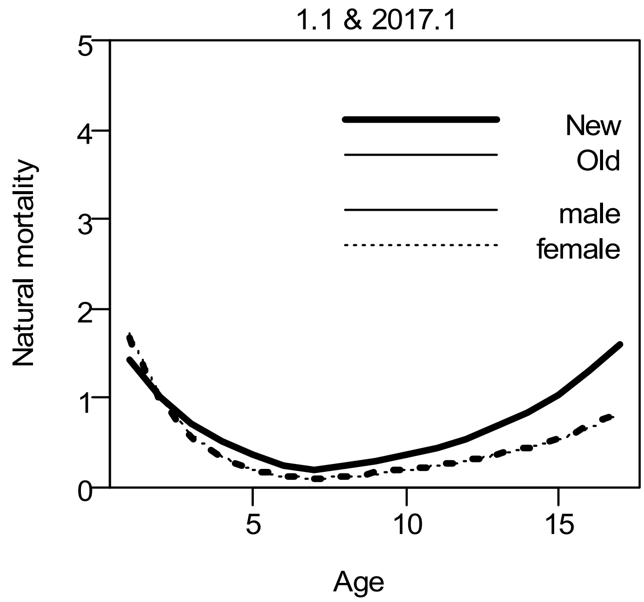

Figure 20: Comparison between age-dependent natural mortality estimated in the new run 1.1 from 2018 (heavy lines) and the analogous model run from the previous assessment (light lines). The label 2017.1 denotes run 1.1 for the 2017 assessment (McKenzie 2018).

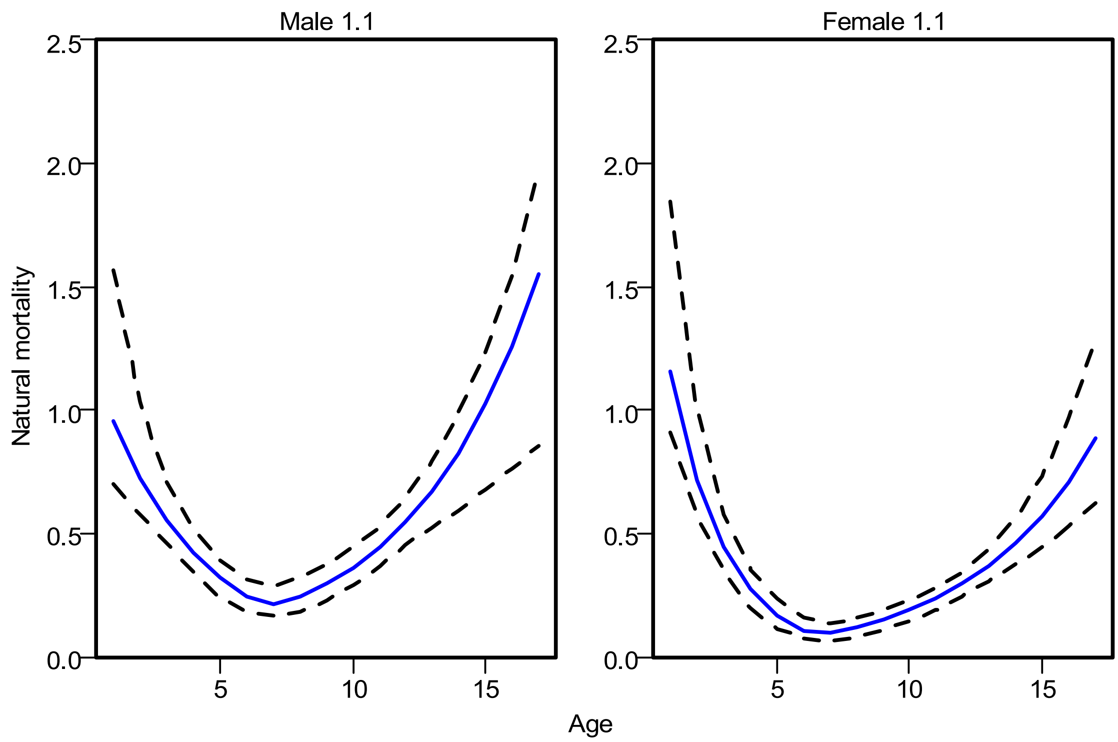

Figure 21: Assessment estimates of age-dependent natural mortality ogives for the MCMC runs showing median estimates (solid blue lines) and 95% credible intervals (broken lines) for each sex. Base run 1.1 for the 2018 hoki stock assessment (McKenzie 2019).

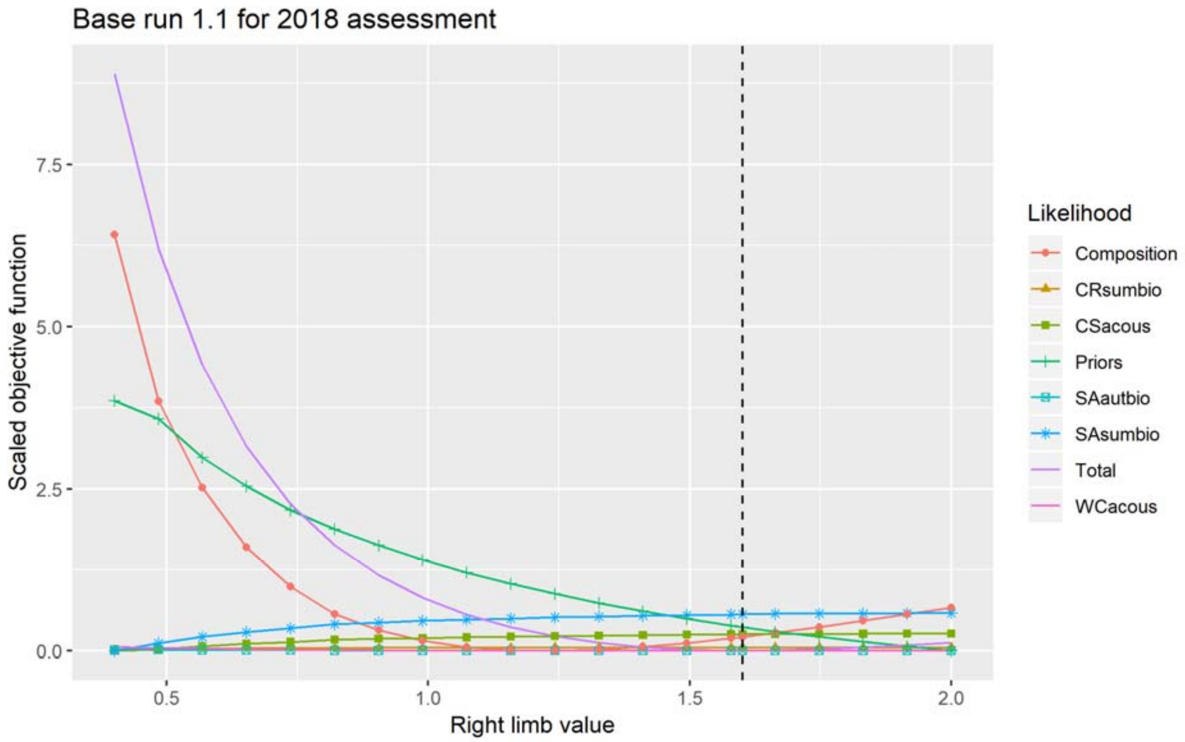

Figure 22: Likelihood profile on the right-hand limb parameter for the male age-varying natural mortality. The vertical dashed line shows the value of the MPD estimate of the right-hand limb.

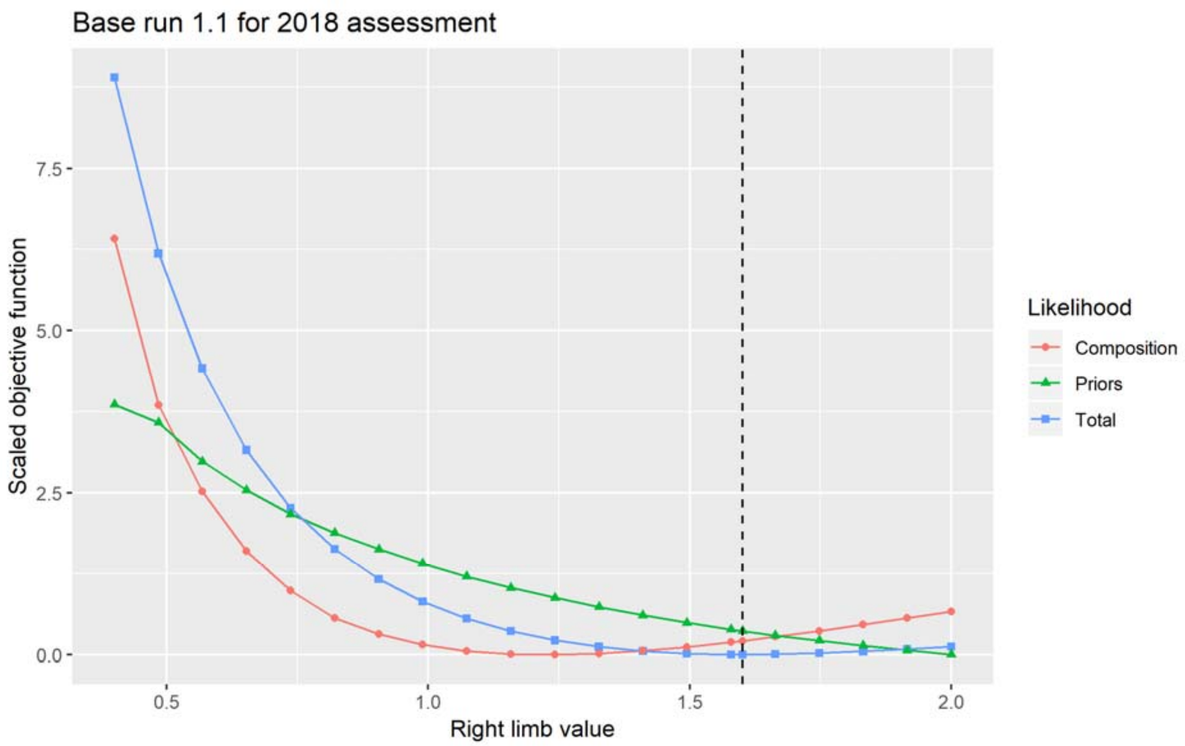

Figure 23: As in Figure 22, but for the components that show the most change as the right-hand limb parameter changes.

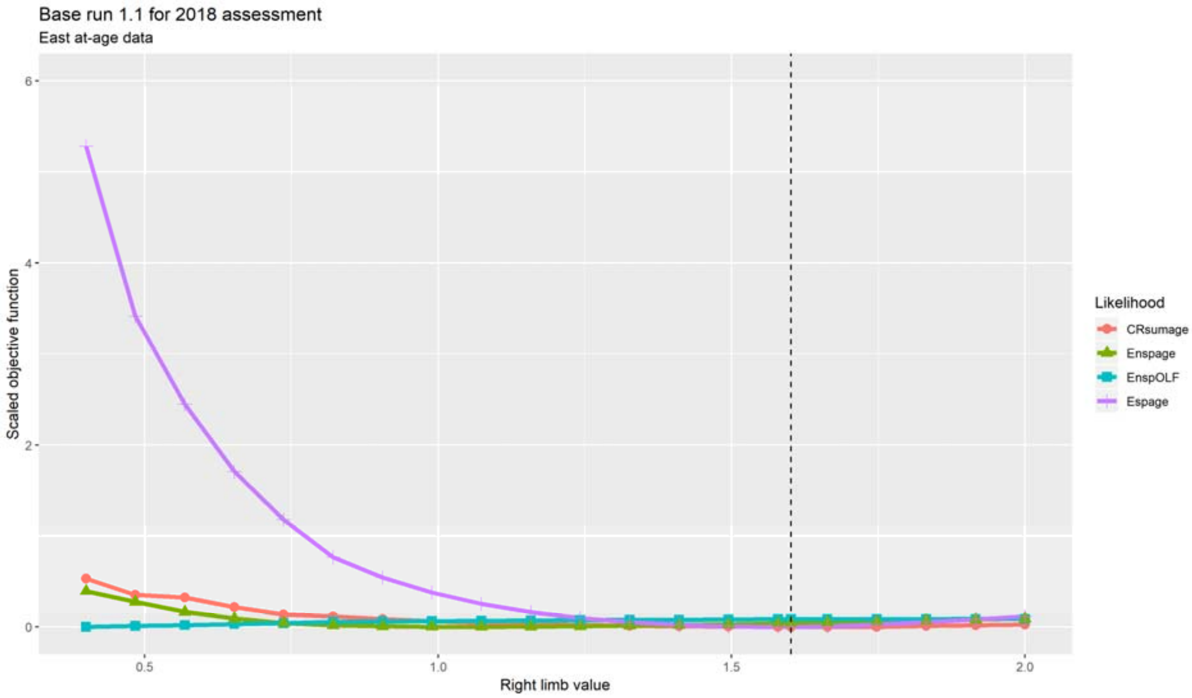

Figure 24: Eastern at-age data and profile on the right-limb value for the male natural mortality.

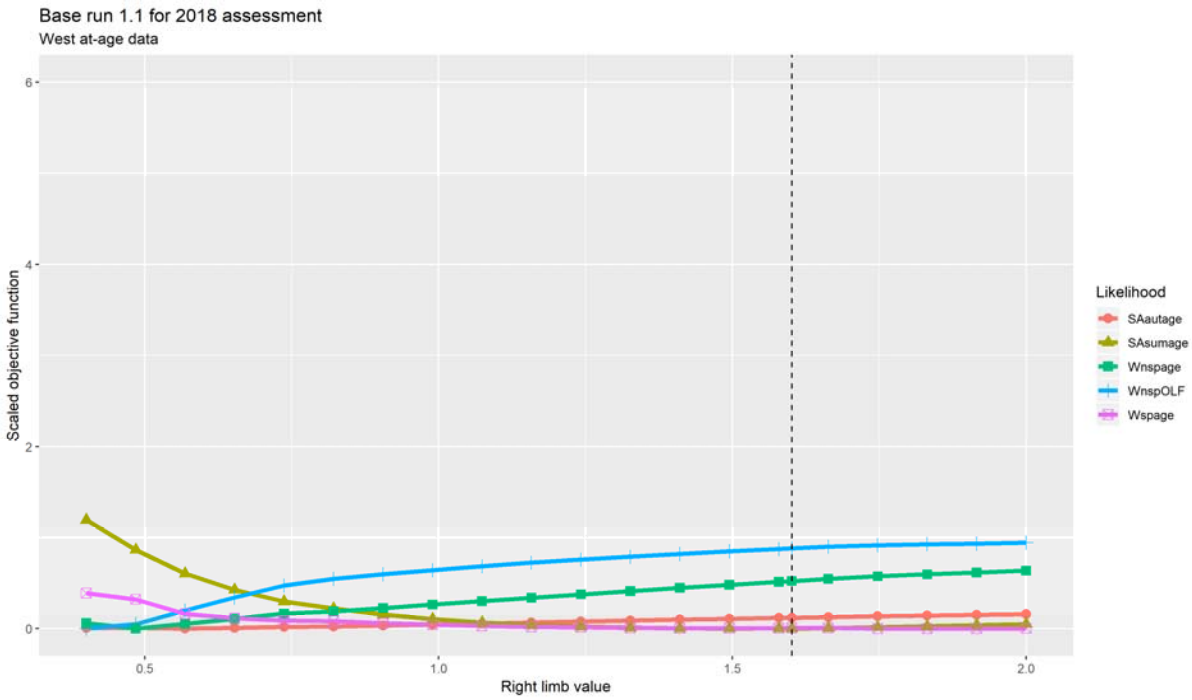

Figure 25: Western at-age data and profile on the right-limb value for the male natural mortality.

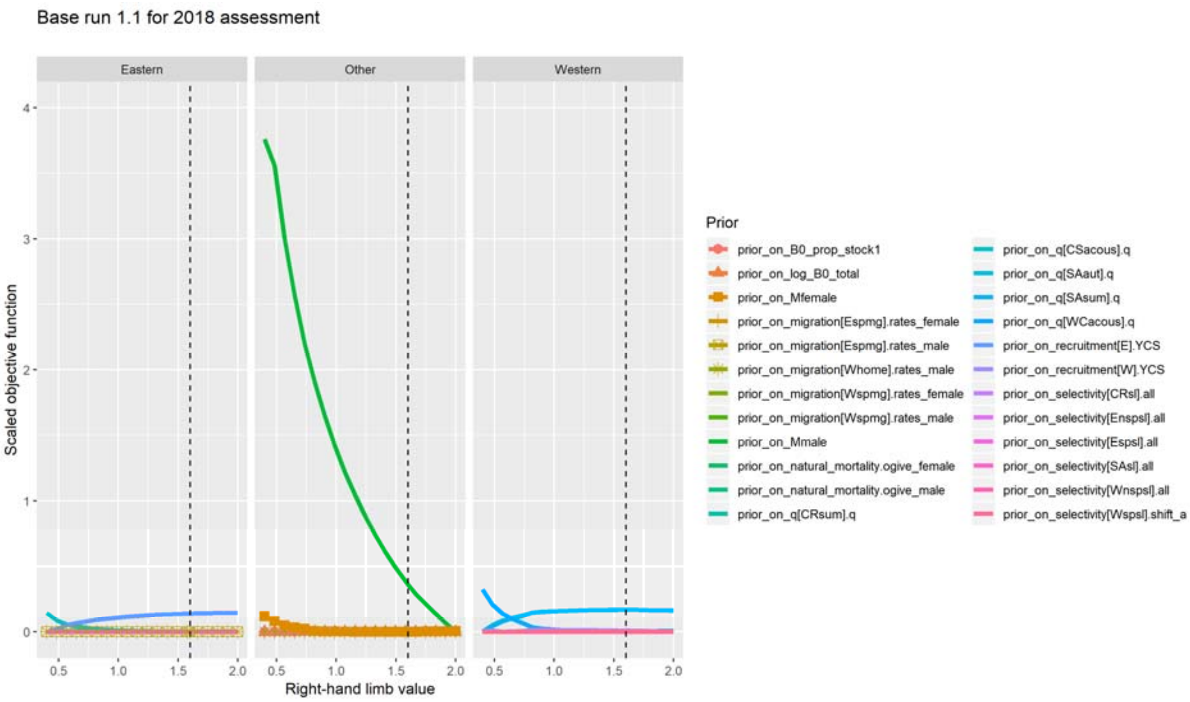

Figure 26: Priors and profile on the right-hand limb for the male natural mortality. Broken up by eastern, western, and other priors.

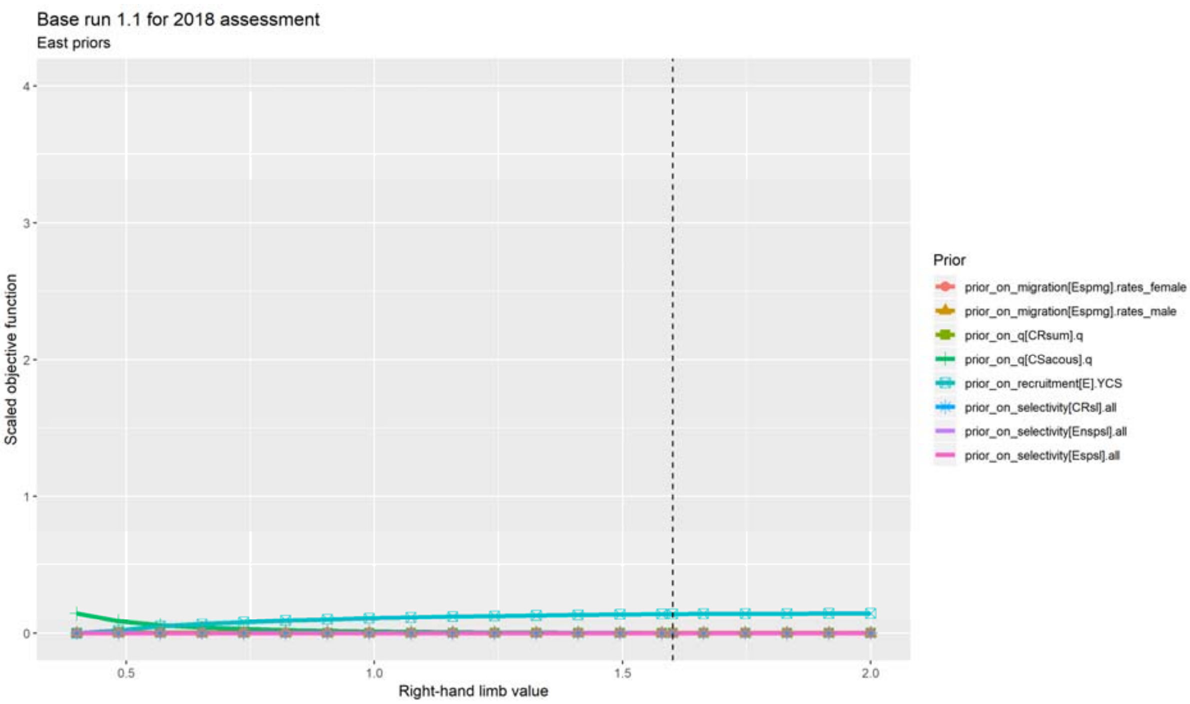

Figure 27: Eastern priors and profile on the right-hand limb for the male natural mortality.

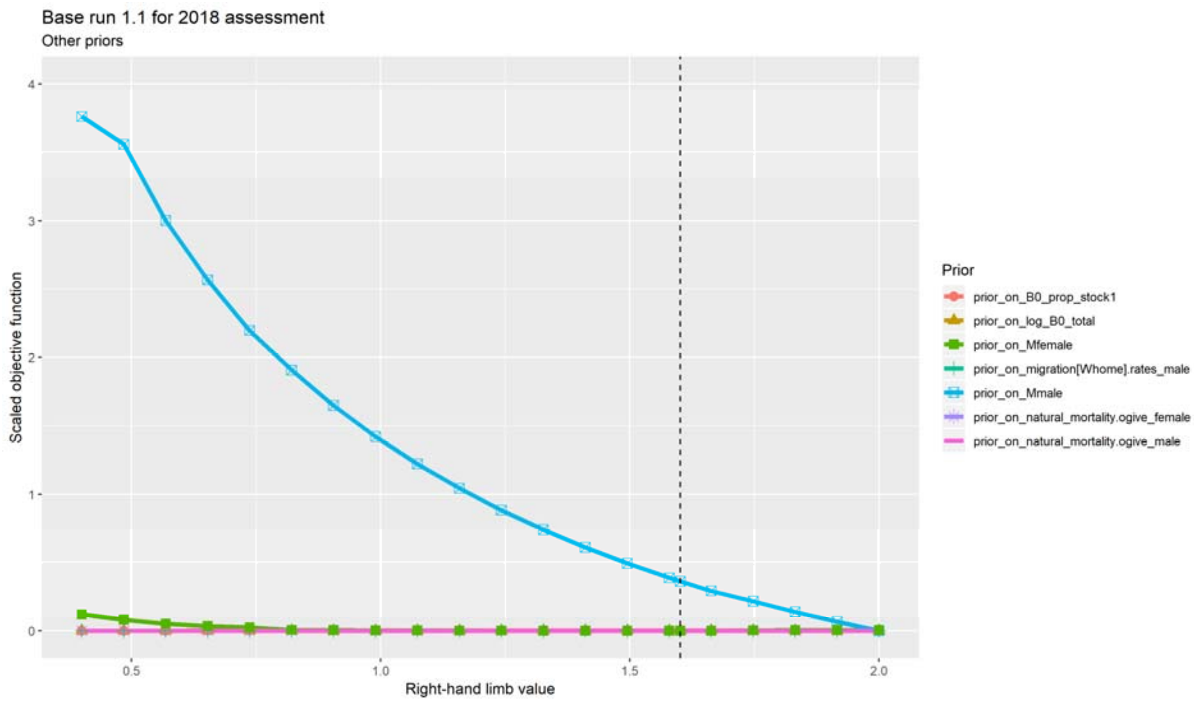

Figure 28: Other priors and profile on the right-hand limb for the male natural mortality.

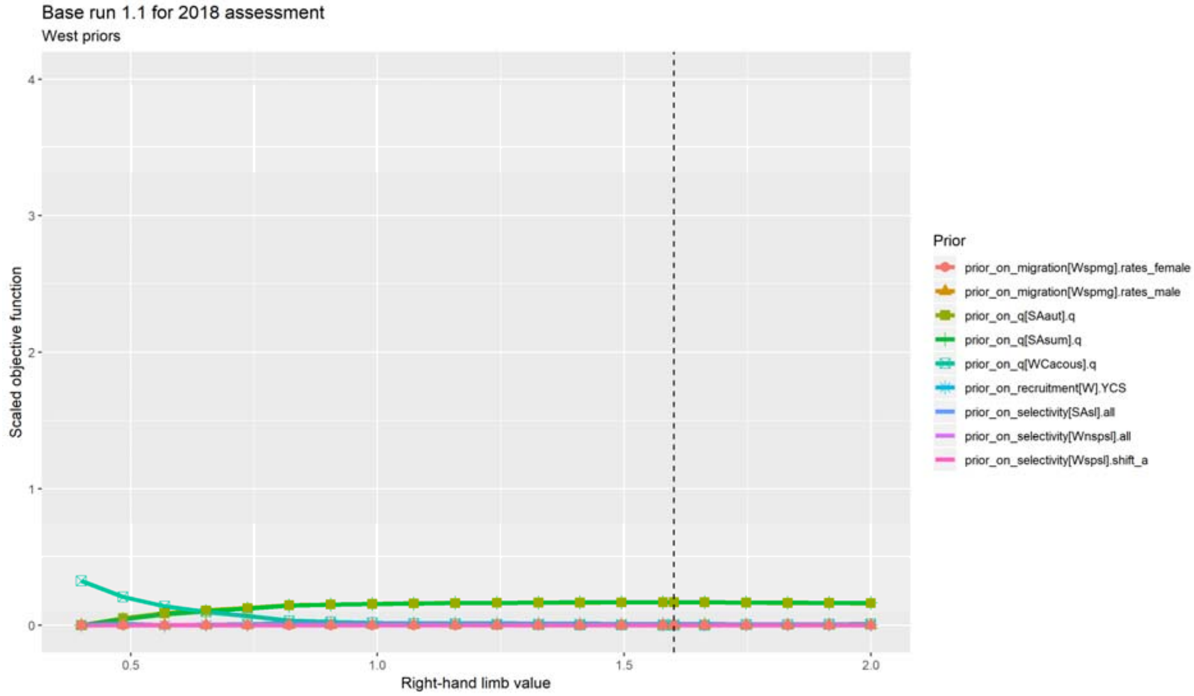

Figure 29: Western priors and profile on the right-hand limb for the male natural mortality.

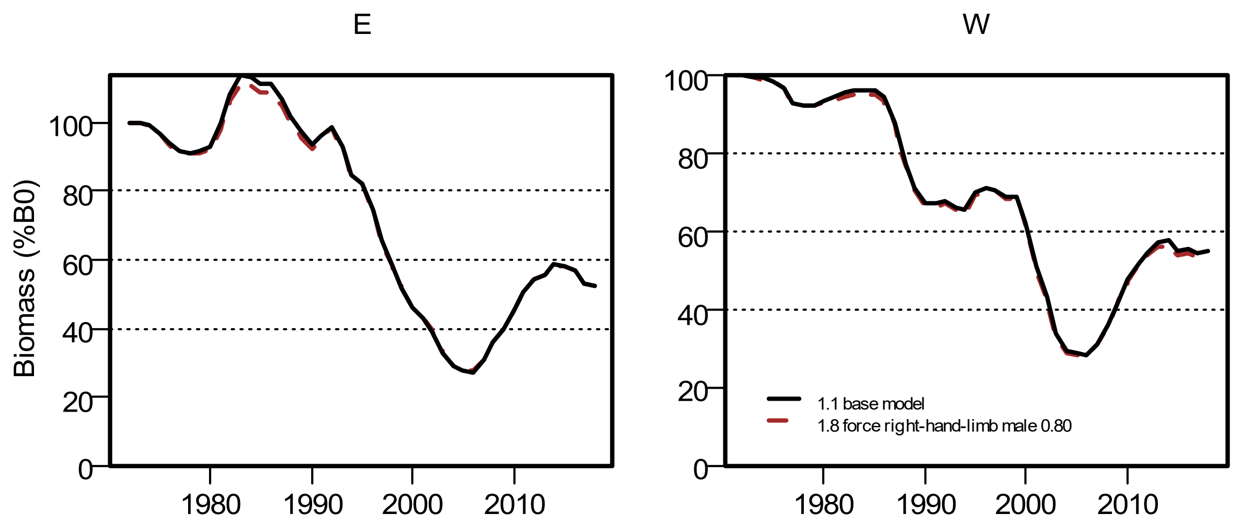

Figure 30: Comparison of biomass trajectories from different runs: E stock (left column) and W stock (right stock). The graphs compare the base run 1.1 (solid black line) with the sensitivity run 1.8.

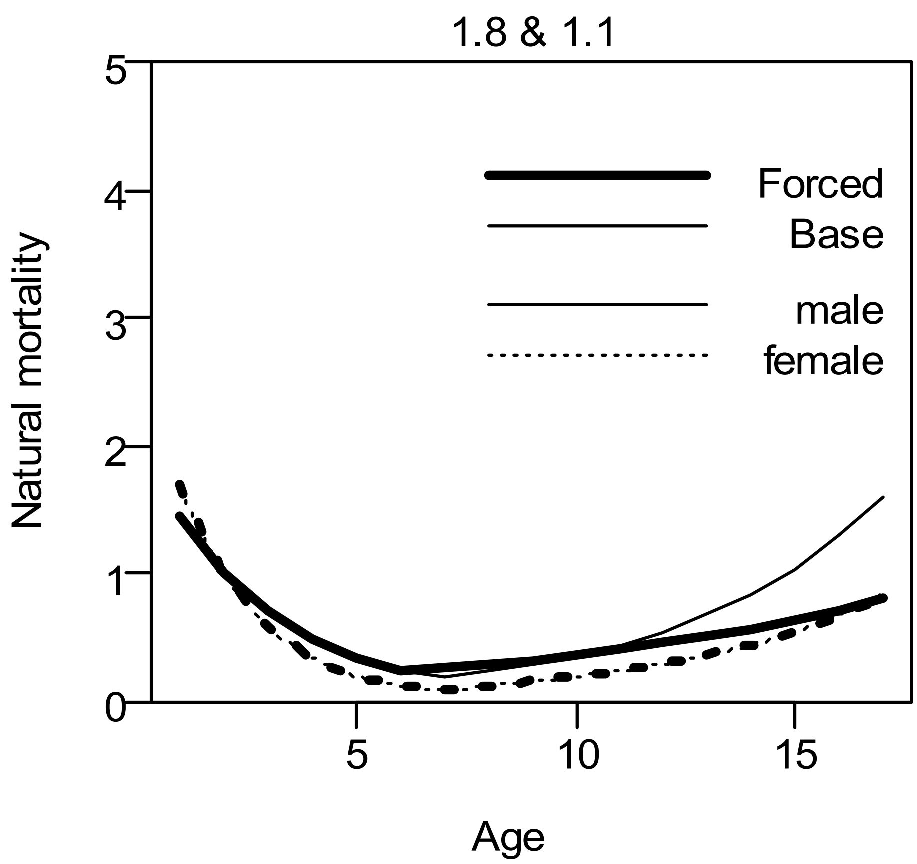

Figure 31: Comparison between age-dependent natural mortality estimated in the run with the right-hand limb for male natural mortality forced to be 0.80 (heavy lines) and the base model run (light lines).

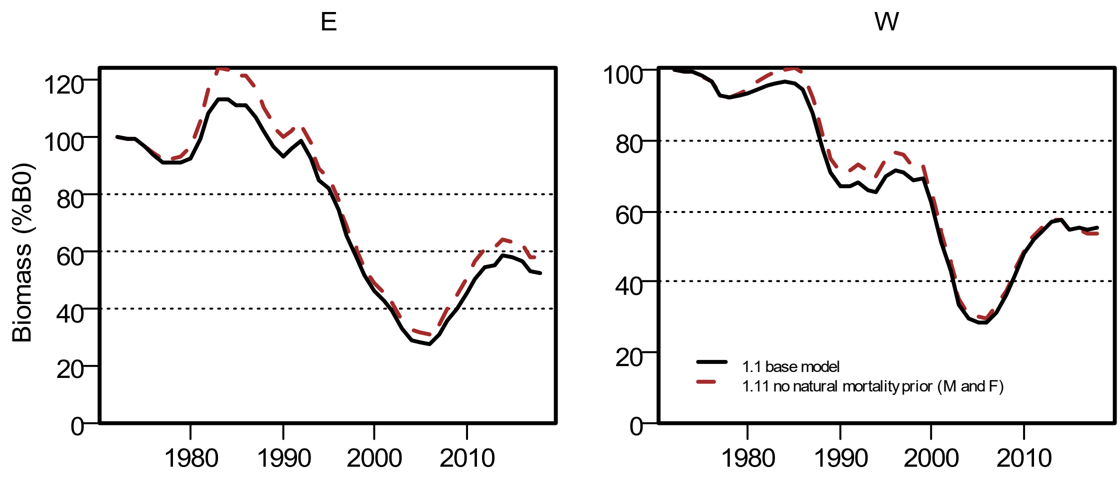

Figure 32: Comparison of biomass trajectories from different runs: E stock (left column) and W stock (right stock). The graphs compare the base run 1.1 from 2018 (solid black line) with a run 1.11 where the natural mortality prior for the ages 5 – 9 (inclusive) is removed.

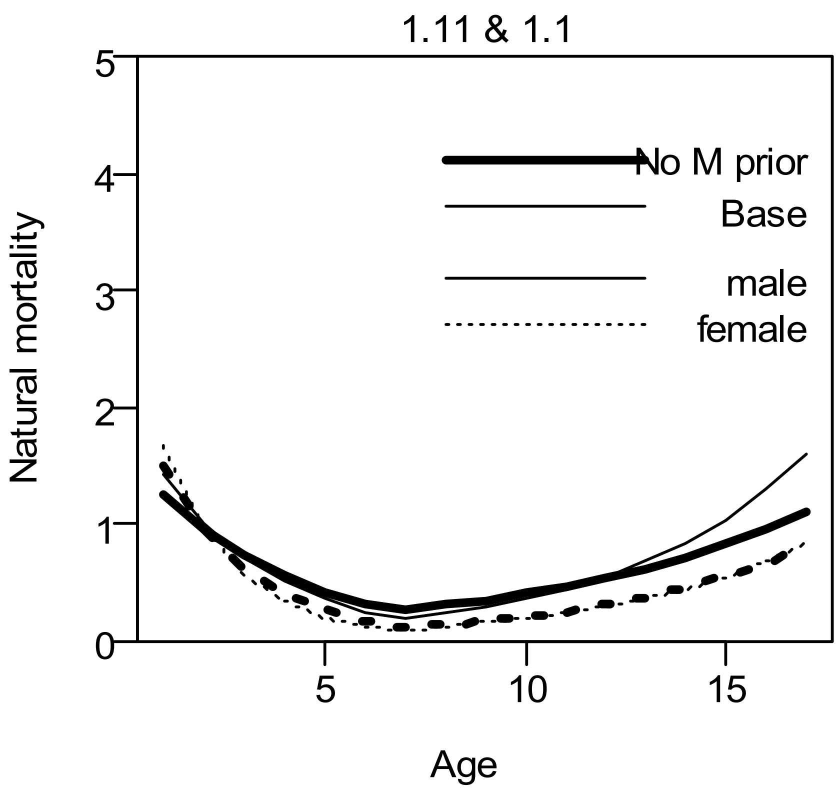

Figure 33: Comparison between age-dependent natural mortality estimated in base run 1.1 from 2018 (heavy lines) with a run 1.11 (“No M prior”) where the natural mortality prior for the ages 5 – 9 (inclusive) is removed.

4. INITIAL MPD RUN: UPDATE OF BASE CASE FROM 2018 ASSESSMENT

For the 2018 hoki stock assessment final model MCMC runs there was a single base run, and six sensitivity runs (Table 17). 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. We update this base run from the 2018 assessment with new data, first running an MPD fit and calling this model run 1.1.

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 17: 2018 hoki stock assessment. Distinguishing characteristics for all MCMC final model runs, including all sensitivity runs based on the base run 1.1.

Run	Short name	Model description
1.1	base	natal fidelity *M* is age-dependent single q for Sub-Antarctic trawl series process error of CRsumbio and SAsumbio estimated in MPD run
1.2	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.

4.1 Comparison to base model from the last assessment in 2018

For the updated 2019 model run 1.1, the biomass trajectory is compared to the analogous model run during last year's assessment (Table 18, Figure 34). For the updated assessment model, the eastern stock biomass (%B_0) is higher and the western stock much lower in the last few years. The main drivers of the lower estimate for western biomass are the new western biomass indices: the 2018 west coast South Island acoustic survey, and the 2019 Sub-Antarctic trawl survey (Figure 35).

In the updated assessment there are differences in the 2015 and 2016 year class strength estimates compared to the previous assessment, with those for the eastern stock estimated to be higher, and those for the western stock lower (Figure 36, Table 19). As was noted for the 2018 assessment, model estimates of the last three year class strength are very uncertain, and can differ significantly between assessments (Figures 37–38). Differences for the 2019 assessment are partially driven by the new 2018 eastern spawning at-age data (Figures 39–40).

For the updated model run 1.1 the process error for the Chatham Rise and Sub-Antarctic trawl survey were estimated to be 0.15 and 0.35 respectively (compared to 0.14 and 0.39 respectively for the previous assessment).

Other graphs show selectivities, migration ogives, and fitted age-varying natural mortality, all of which are very similar to the previous assessment (Figures 41–43). The selectivity (a_shift) was estimated to be -0.095 for the updated model and -0.098 for the previous assessment.

Fits to the biomass indices are shown in Figure 44. Fits and residuals for the at-age data are shown in Appendix 4.

Table 18: Comparison of old and new biomass estimates for the stocks E and W. The label 2018.1 refers to the base run 1.1 from the 2018 assessment (see Table 17), while run 1.1 is the updated version of this for the 2019 assessment.

	B_0('000 t)		B_{2018}(%B_0)		B_{2019}(%B_0)	
Run	E	W	E	W	E	W
2018.1	433	876	52	55	–	–
1.1	439	815	58	43	68	46

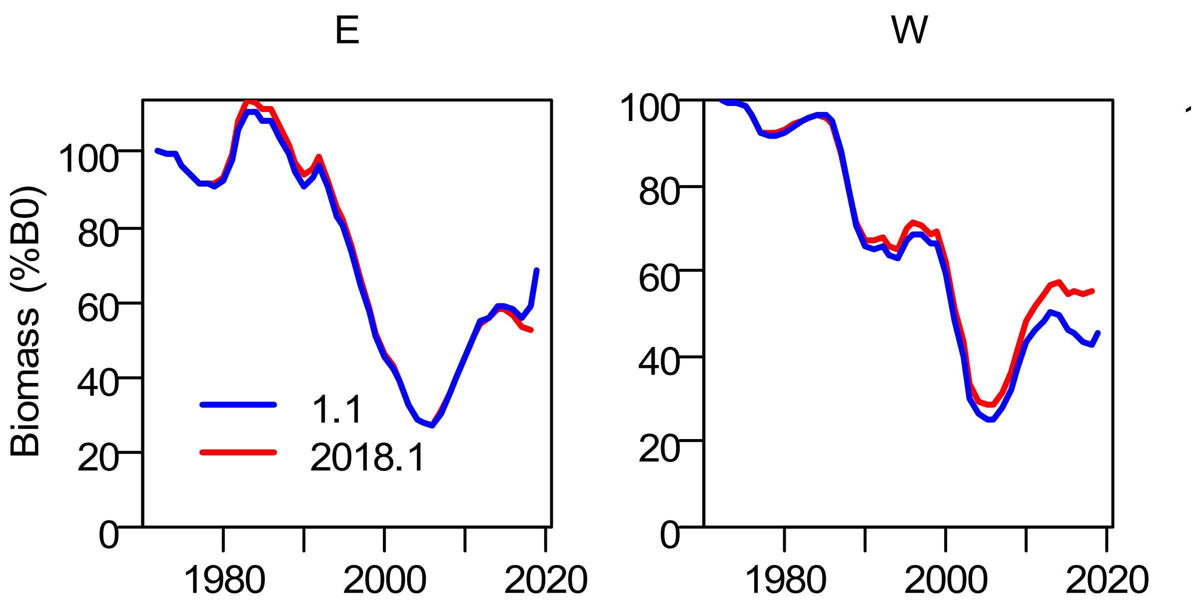

Figure 34: Comparison of biomass trajectories from different runs: E stock (left column), W stock (middle column). The graphs compare run 1.1 from 2019 (blue lines) with the corresponding run from 2018 (red lines). The label 2018.1 denotes run 1.1 from the 2018 assessment.

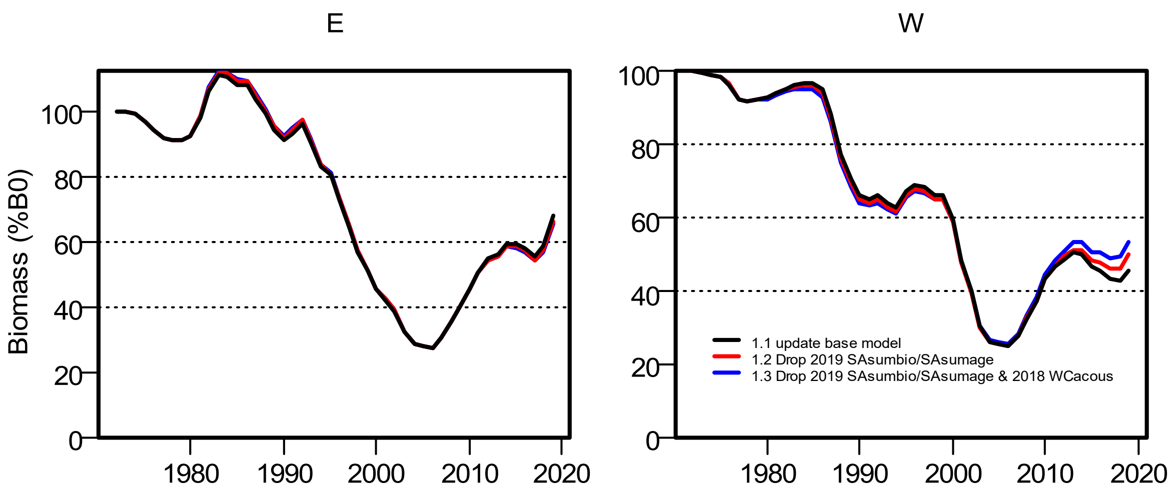

Figure 35: Biomass trajectories for different model runs. Comparing the updated model run 1.1. with one where the 2019 SAsumbio and 2019 SAsumage data are dropped, and another where the 2018 WCacous index is dropped as well.

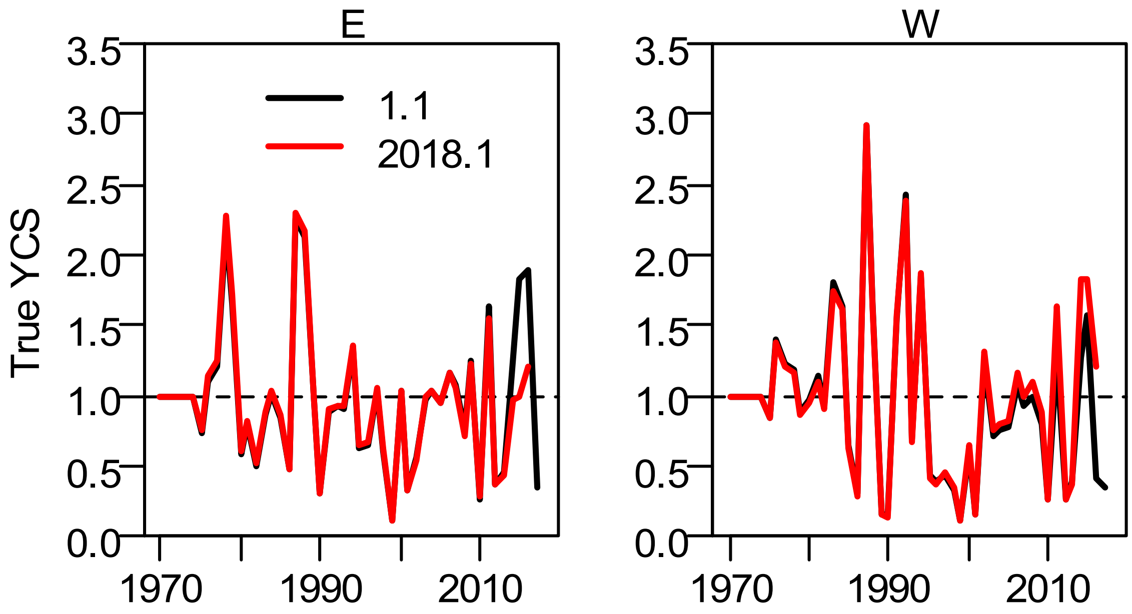

Figure 36: True YCS estimates for new run 1.1 from 2019 (black lines) and the analogous run from last year's assessment (red lines). The label 2018.1 denotes run 1.1 from the 2018 assessment.

Table 19: True YCSs (last five years) for the updated 2019 model 1.1.

Fishing year	2013	2014	2015	2016	2017
E stock	0.45	1.27	1.83	1.90	0.36
W stock	0.39	1.27	1.58	0.42	0.34

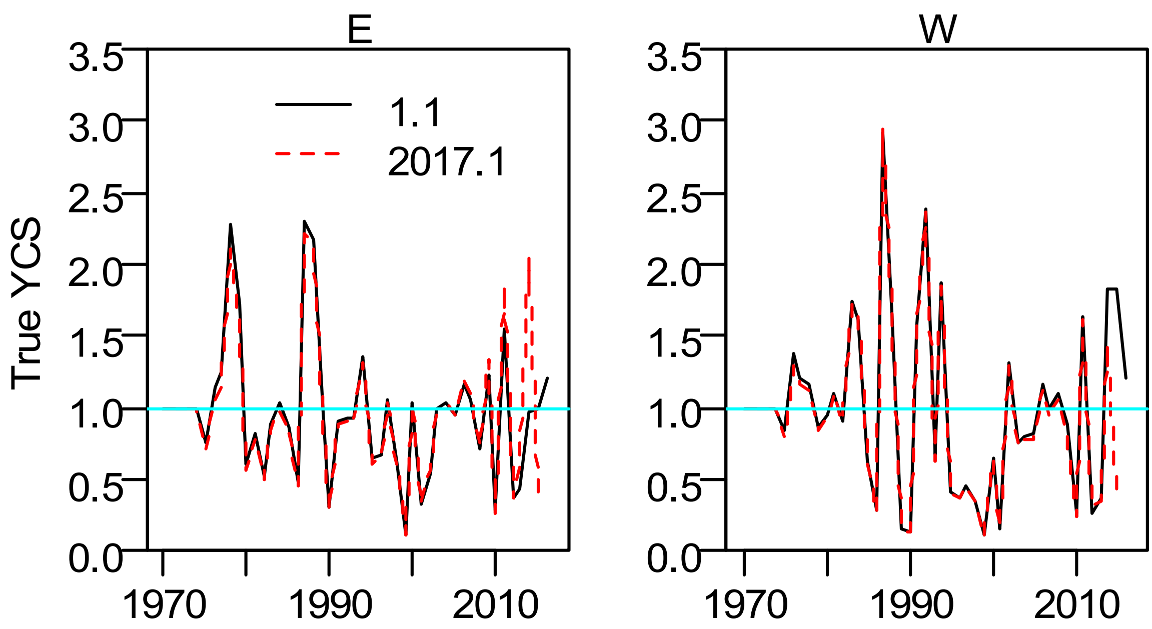

Figure 37: Hoki 2018 stock assessment. True YCS MPD estimates for new run 1.1 from 2018 (black lines) and the analogous run from the previous year's assessment (red lines). The label 2017.1 denotes run 1.1 from the 2017 assessment. Reproduced from McKenzie (2018).

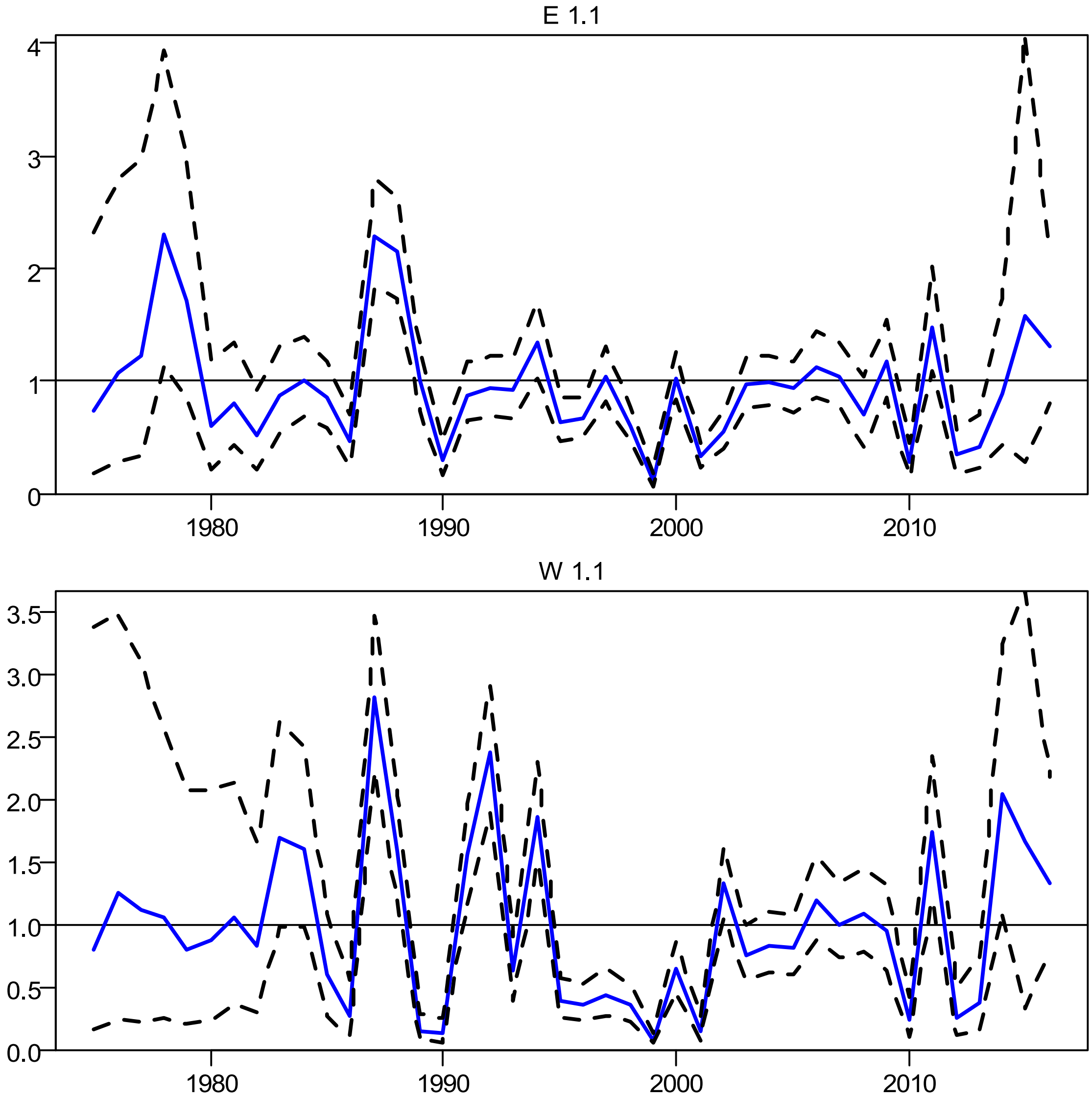

Figure 38: Hoki 2018 stock assessment. Estimated true year-class strengths (YCSs) from the run 1.1 showing medians (solid lines) and 95% credible intervals (broken lines) by run for E (top panels), W (bottom panel). Reproduced from McKenzie (2019).

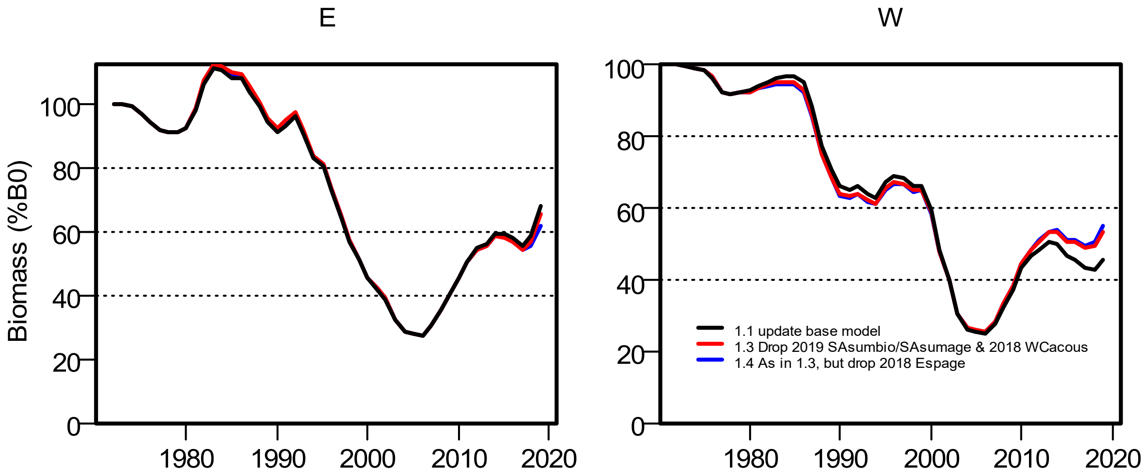

Figure 39: Biomass trajectories for different model runs. Comparing the updated 2019 model run 1.1. with models runs where selected new 2018 and 2019 data are dropped.

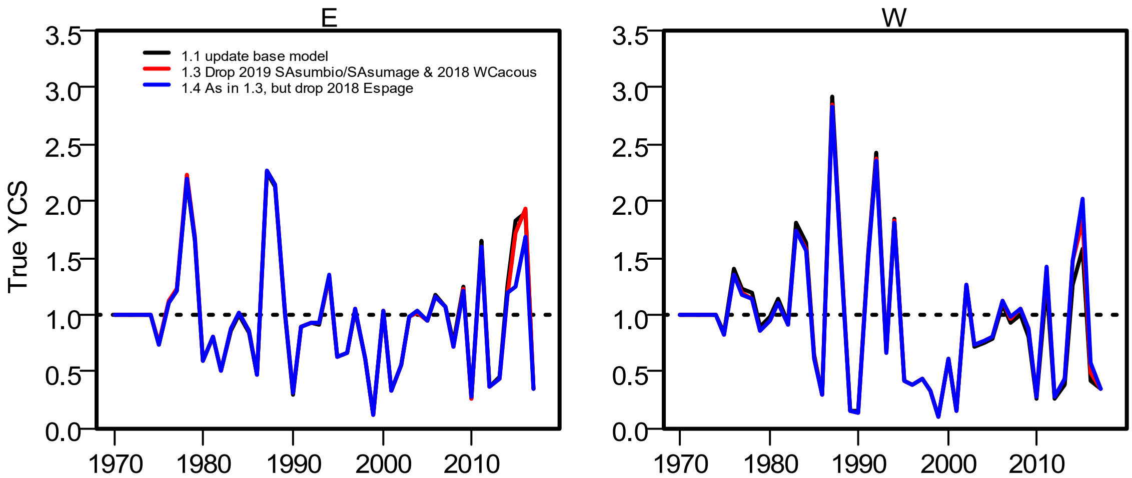

Figure 40: True YCS estimates for new run 1.1 from 2019 (black lines), compared to model runs where selected new 2018 and 2019 data are dropped.

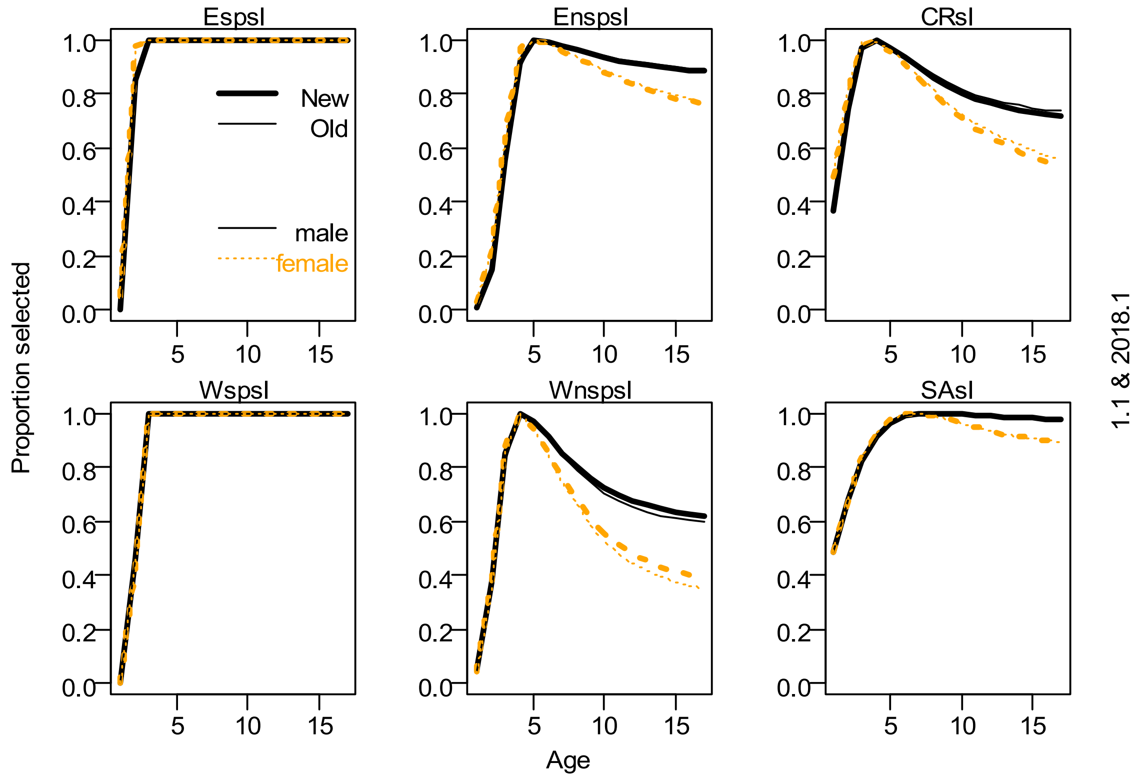

Figure 41: Estimated selectivity curves for the new model run 1.1 from 2019 (heavy lines) and analogous model run from the previous assessment (light lines). Males are shown by a solid black line, females by a dotted orange line. The label 2018.1 denotes run 1.1 for the 2018 assessment.

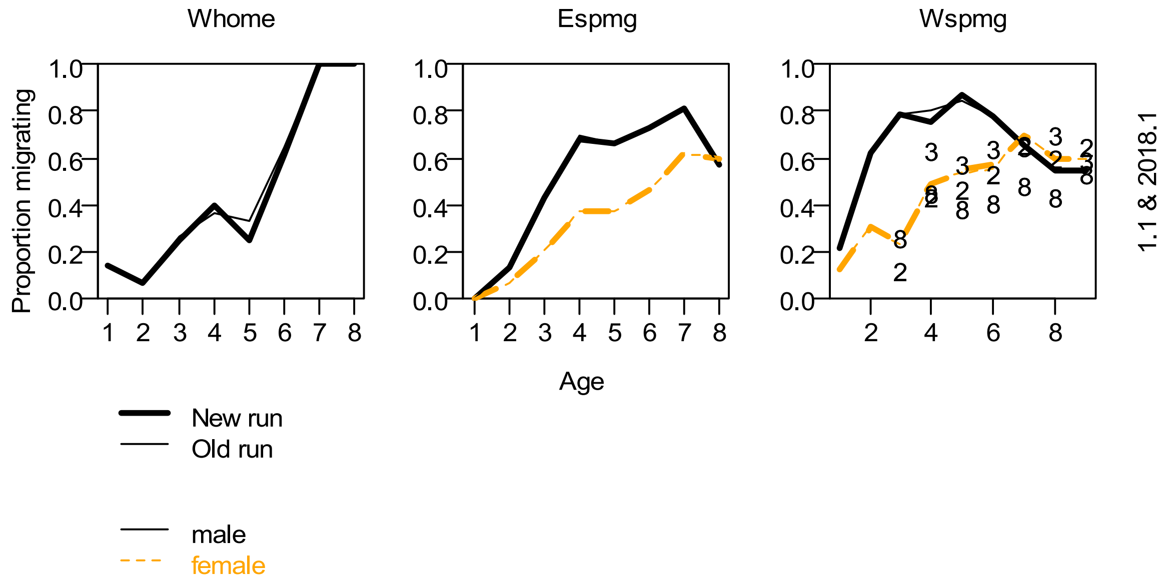

Figure 42: Estimated migration ogives for new run 1.1 from 2019 (heavy lines) and the analogous model run from the previous assessment (light lines). Each row of plots compares ogives from the new run (heavy lines) with that from the previous assessment (light lines). Where ogives differ by sex, female ogives are plotted as broken orange 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 2018.1 denotes run 1.1 for the 2018 assessment.

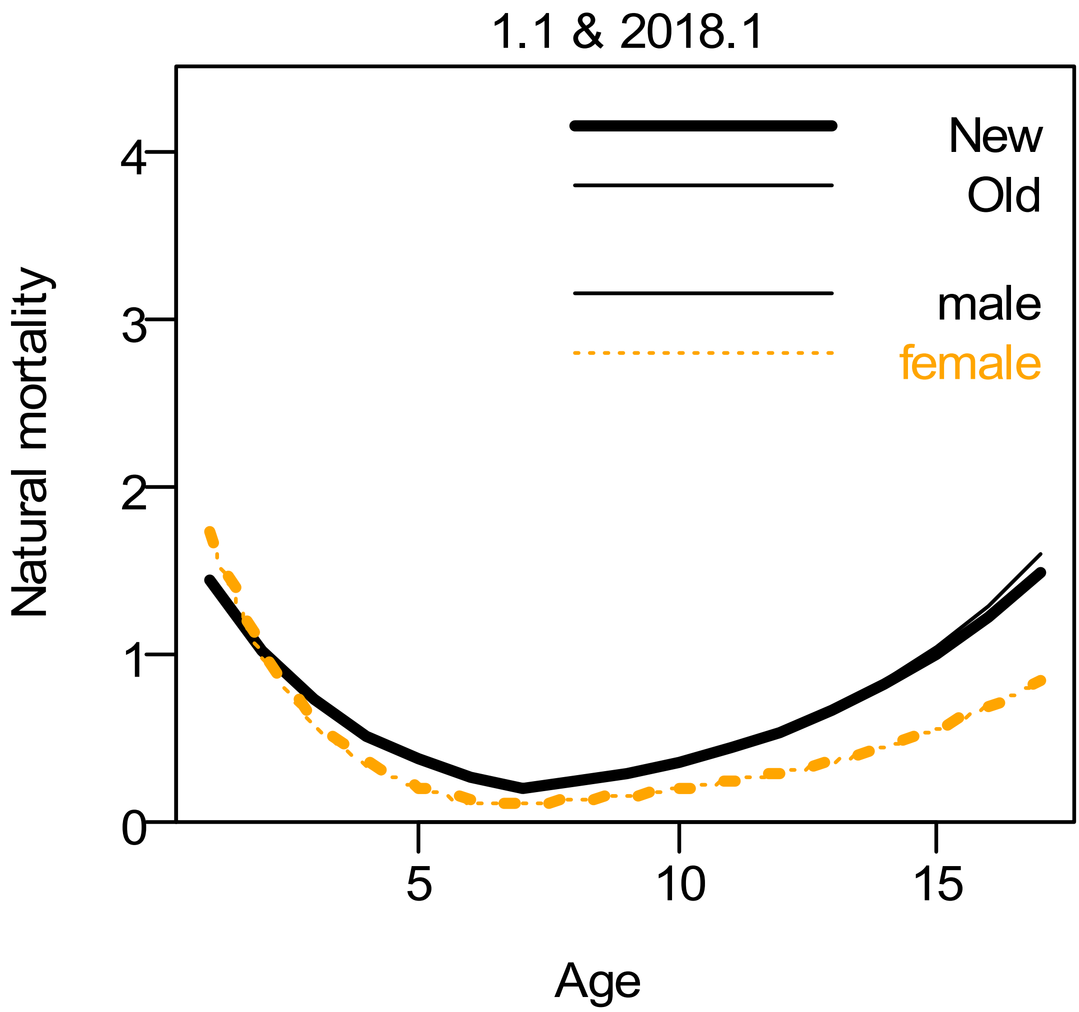

Figure 43: Comparison between age-dependent natural mortality estimated in the new run 1.1 from 2019 (heavy lines) and the analogous model run from the previous assessment (light lines). The label 2018.1 denotes run 1.1 for the 2018 assessment.

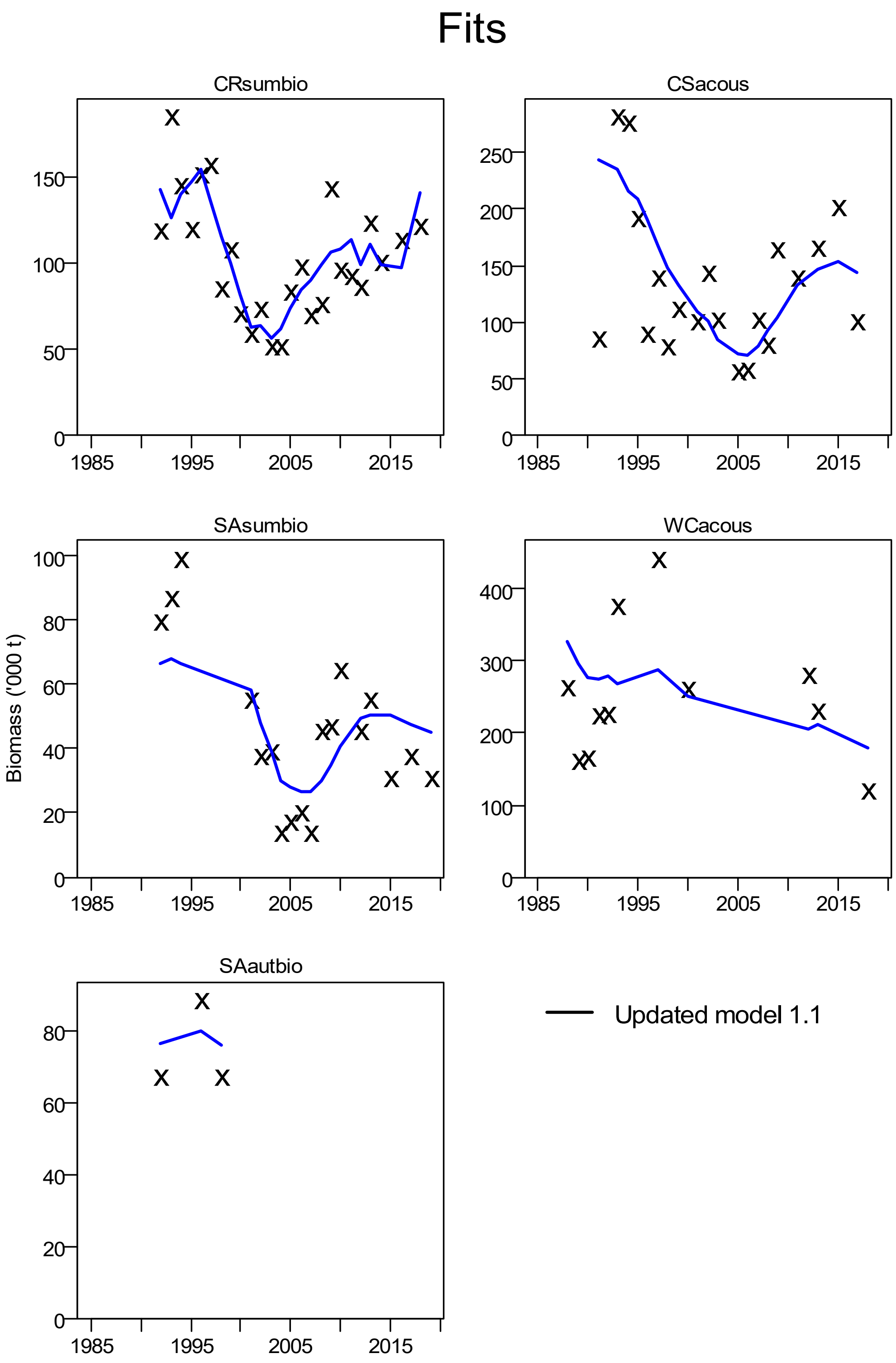

Figure 44: Fits to the biomass indices for updated model run 1.1. for the 2019 assessment. Shown are observed ('x') and expected values (lines).

5. FOLLOW-UP WORK FOR INITIAL MODEL RUNS

5.1 Introduction

Some variation on the initial model runs are explored here: (i) step changes in the western selectivities, to see how much this improves the fit to the western at-age data and affects biomass estimates, (ii) a simplified western only model, to eliminate the impact of the eastern data for the estimate of western biomass (see Section 3.2).

5.2 Step changes in the western selectivities for the hoki 2019 assessment

For hoki stock model runs, it is assumed that the selectivities do not change over time, except for the west coast South Island spawning selectivity (Wspsl). For the model runs here we introduce step changes in the selectivities, for the western stock, for which the largest changes in the mean age occur and which the model has the most difficulty fitting (Appendix 3).

5.2.1 Step changes and model set-up

The years for the step changes were determined by the updated evaluation of a technical sub-committee (Appendix 5). We choose to evaluate three of these for the western stock, i.e., the two considered the most influential for the spawning stock, and the one considered the most influential for the non-spawning stock (Table 20). It was also recommended by the sub-committee that when a step in the Wsp selectivity is to be considered, the year-to-year variation that has been allowed in this selectivity be restricted to the period before 1999.

Table 20: Step changes in selectivity that were investigated. Interpretation: the first line of the table describes two steps for the Wsp fishery, one in 1999 and 2005. This means that selectivities are estimated for the early period before 1999 (WspslE), middle period from 1999 to 2004 (WspslM), and a late period for 2005 onwards (Wspsl).

Fishery	Step year(s)	Selectivities estimated
Wsp	1999, 2005	WspslE, WspslM, WspslL
Wnsp	2006	WnspE, WnspL

The starting model run was run 1.7, a variation on model 1.1 for the 2019 assessment which incorporates the recalculated Cook Strait at-age data (1990–1998). The 2018 catch was assumed for 2019 in lieu of a better estimate being available (see ahead to Section 5.3), and the data is reweighted.

Model 1.7 was changed to model run 1.8, for which year-to-year variation in Wsp selectivity is restricted, as recommended by the technical subcommittee, to the period before 1999 (see Table 7). All other runs are modifications of 1.8. In those runs in which step changes were allowed in the western spawning fisheries there was a need to modify the constraint Espsl = Wspsl that applies in run 1.8 (see Table 6). In these runs, it was decided to apply this constraint just to the earliest selectivity in each of these two fisheries.

Data weights are kept the same for most runs, to directly determine the impact of step changes in selectivity, and to allow comparison of likelihoods between runs. However, another run is done where all steps changes in Table 20 are incorporated, but the effective sample sizes for the main western stock at-age data are tripled (Wspage, Wnspage, SAsumage). This is in lieu of doing a formal data reweighing, which technically is difficult. A tripling was chosen partially arbitrarily, but also to give the western at-age data a weighting akin to that for the eastern at-age data, such as Espage and Wspage (Appendix 3).

Some results from this series of runs are presented in Table 21. Improvement in fit is small and at most nine likelihood points when all step changes are included (run 1.13).

Tripling the effective sample size for selected western at-age data gives a lower current stock status for the western stock and higher stock status for the eastern stock (Table 22). For the western spawning stock, there are small improvements in the model expected mean age following the mean observed ages for the year 1988–1991 (Figures 45–46). The fit to the Sub-Antarctic trawl is worse in early years, but better for later years (Figure 47).

Table 21: Comparison of runs investigating step changes in selectivity. The improvement in fit is for the overall objective function.

		Additional parameters	Improvement in fit	$B_{current}$ ($\%B_0$)	
Run	Selectivity steps	(relative to run 1.8)	(relative to run 1.8)	E	W
1.8	None	0	0	69	43
1.9	Wsp(1999)	2	6	80	41
1.10	Wsp(2005)	2	4	76	42
1.11	Wnsp(2006)	3	2	69	43
1.12	Wsp(1999, 2005)	4	7	80	41
1.13	Wsp(1999, 2005), Wnsp(2006)	7	9	82	40
1.7	None	0	0	68	44

Table 22: Further comparison of runs investigating step changes in selectivity, and data weighting (run 1.14). N = effective sample size.

		$B_{current}$ ($\%B_0$)	
Run	Selectivity steps	E	W
1.7	None	68	44
1.13	Wsp(1999, 2005), Wnsp(2006)	82	40
1.14	Triple N for Wspage, Wnspage, SAsumage	91	34

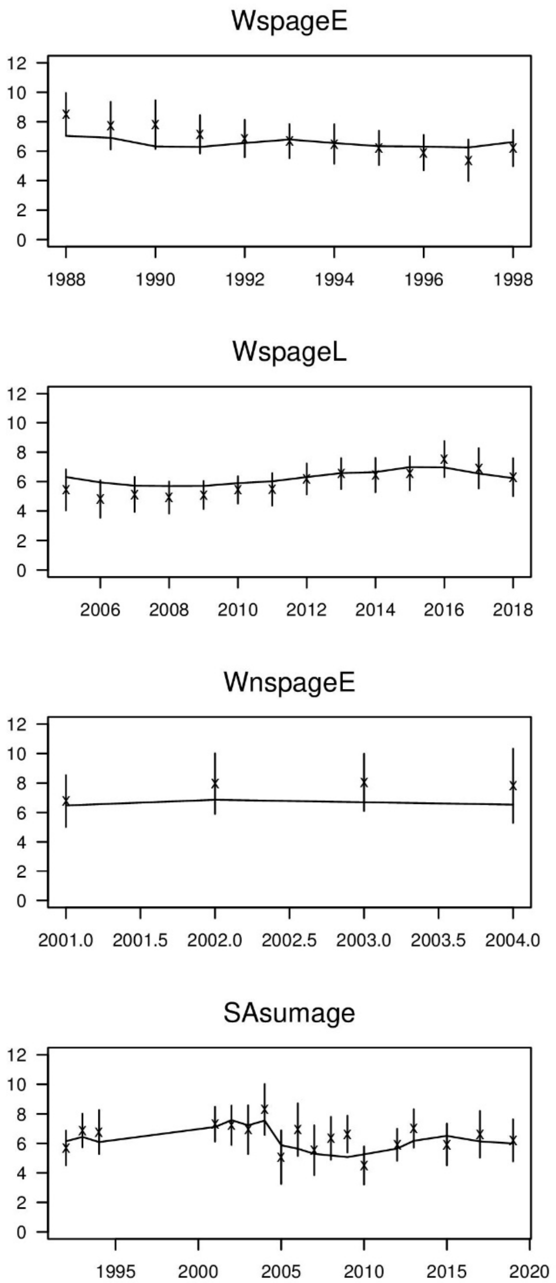

Figure 45: Model 1.8. Observed ('x', with 95% c.i.s. as vertical lines) and expected (lines) for the western at-age data sets.

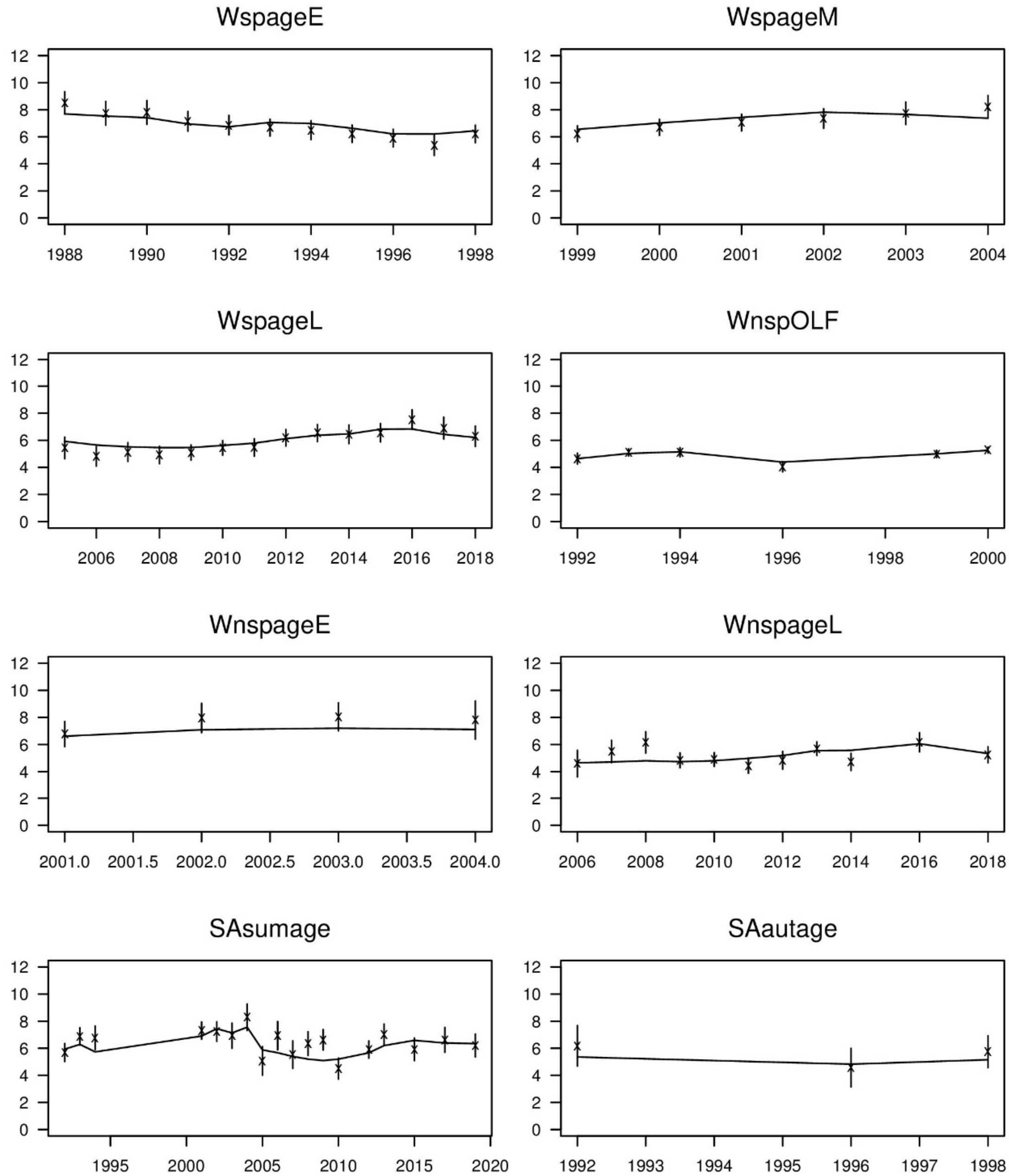

Figure 46: Model 1.14. Observed ('x', with 95% c.i.s. as vertical lines) and expected (lines) for the western at-age data sets.

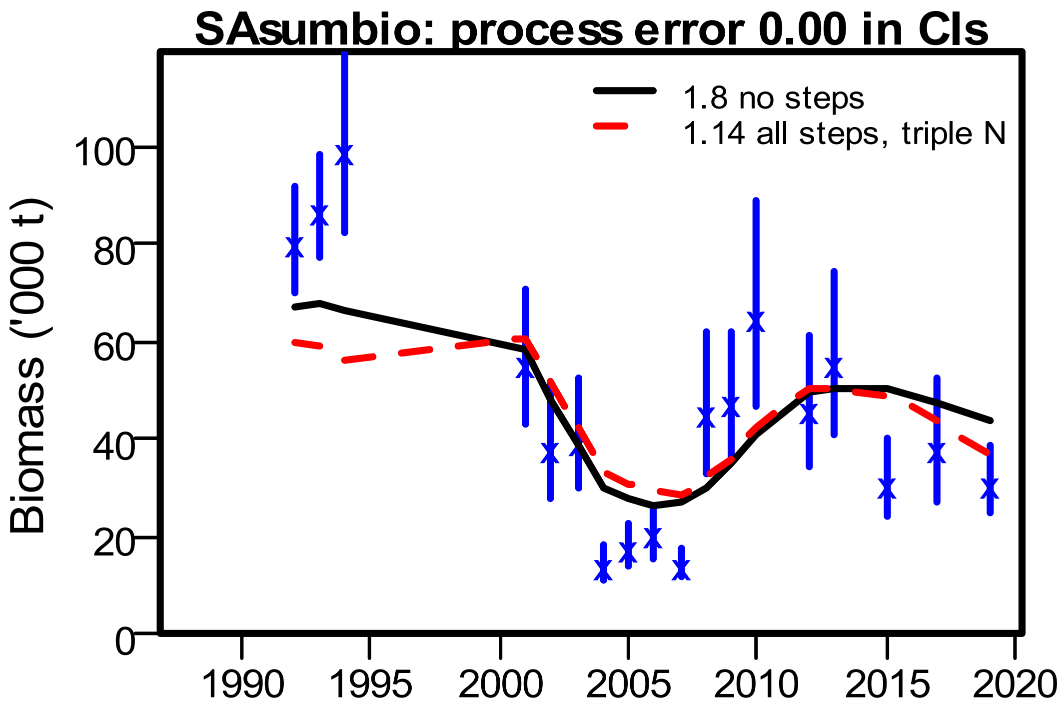

Figure 47: Fits to the Sub-Antarctic trawl survey, with vertical lines showing 95% confidence intervals for observations.

5.3 Revised data for the 2019 assessment

After initial model MPD runs were completed, some of the input data were slightly revised. For the eastern spawning fishing at-age data (Espage), a more consistent analysis of historical data for the fishing years 1990–1998 (inclusive) was presented (Ballara 2019a, b). It was also decided that the catch estimate for the 2019 fishing year was inappropriate. Subsequent model runs used the revised data (as do all subsequent model runs presented in this document).

5.3.1 Impact of recalculated Espage at-age data in the model

For the new run 1.6 the recalculated Espage data were put into the updated model 1.1, using the same data weights, and model results for biomass trajectories and YCS estimates were very similar (Figures 48–49).

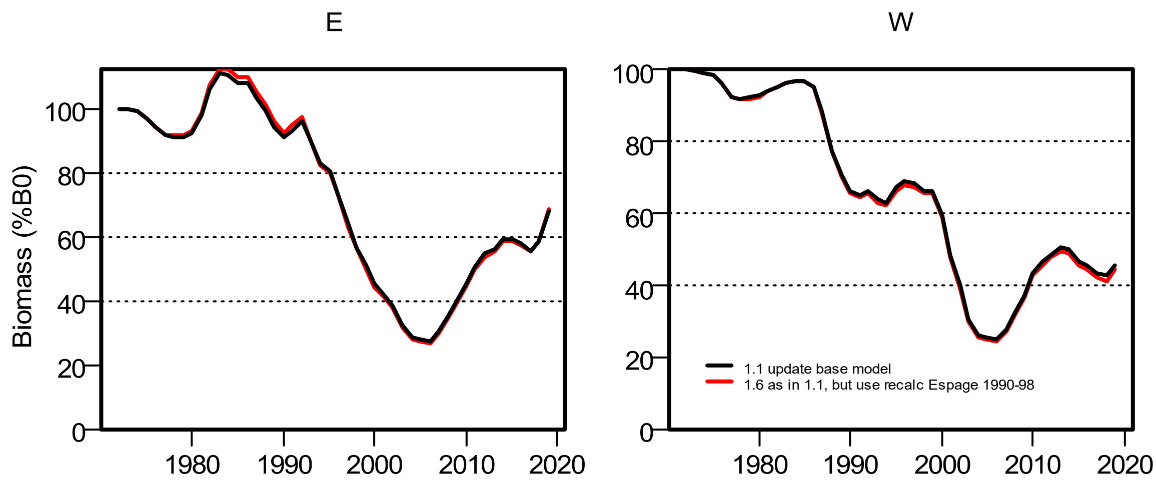

Figure 48: Biomass trajectory for new run 1.6 compared to the updated model run 1.1 for the 2019 assessment.

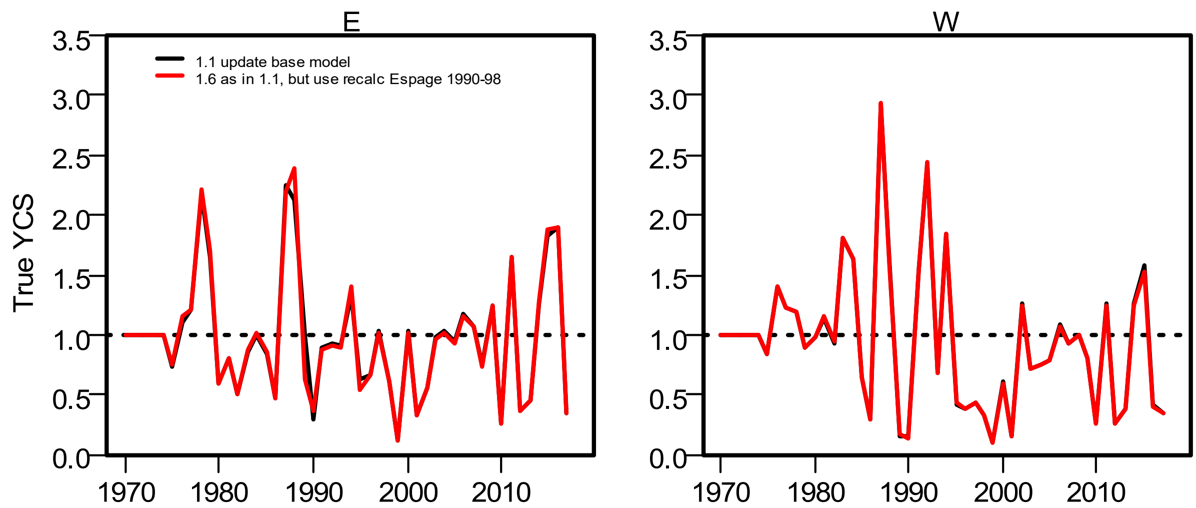

Figure 49: True YCS estimates for new run 1.6 compared to the updated model 1.1 from the 2019 assessment.

5.3.2 Revised 2019 catch estimate

For the initial model stock assessment runs, a catch estimate for the current fishing year sourced from the fishing industry was used. The Deepwater Working Group decided that this estimate was inappropriate, and another was obtained (George Clement, Deepwater Group, pers. comm). The values for this are (for a total catch of 135 500 tonnes):

east spn	15,000 t
east nonspn	49,000 t
west spn	62,500 t
west nonspn	9,000 t

It was expected that this would make very little difference to model run results.

5.4 Explorations of a western only model for the 2019 assessment

The two-stock hoki model has interactions between the eastern and western stock, which makes it difficult at times to understand how the model is functioning and what the impact of data sets on biomass estimates might be. Furthermore, analyses described in Section 3.2 indicated that the eastern at-age data is one of the drivers of the western biomass estimate. A previous analysis done outside the CASAL framework looked at a western-only stock model for the 2018 hoki stock assessment, but required additional simplifications and approximations (Dunn & Langley 2018).

To help understand how the model functions, and to eliminate the impact of eastern at-age data on western biomass estimates, a simpler western only stock model was developed based on the two-stock model. Variations on this simpler model investigate the impact of data weighting and attempt to improve the fits to the data (primarily the Sub-Antarctic trawl survey).

5.4.1 Model runs

The starting two-stock model run is 1.17 which incorporates the recalculated spawning Cook Strait at-age data for 1990–1998, and the revised catch estimate for the 2019 fishing year (see Section 5.3). Also revised is the median catch day by year for before 1988, updated from 305 to 304 (the mean value from 1989–2018), which has a minuscule impact on assessment results.

To make an analogous western stock only model the following changes were made:

1. Drop all the eastern data (Chatham rise trawl survey and all eastern at-age data)
2. Remove the eastern areas from the model (Chatham Rise and Cook Strait)
3. Make western fish recruit into the Sub-Antarctic instead of the Chatham Rise

This starting western stock only model was denoted run 1.25. Note that the catch of western fish on the Chatham Rise is not explicitly incorporated into this starting model, but as will be seen in model fits, this is in part adjusted for by an increased natural mortality on younger fish. It would be more realistic in the western stock only model to have fish recruit at an older age than two years (the two-stock model recruitment age), however, this was not possible in the CASAL model configuration.

Other model runs were variations on the starting western stock only model 1.25 (Table 23):

1) **Run 1.27**. Estimate constant natural mortality (i.e. not varying by age) separate for male and female. For this model run the penalty prior for male and female natural mortality ages 5–9 was dropped, and a uniform prior between zero and one was used for the two estimated natural mortalities (male and female).

2) **Run 1.28.** Widen the bounds on some of the Sub-Antarctic trawl survey selectivity parameters (SAsl). This selectivity is a length-based double normal, and in the starting western stock only model the centre and right-hand limb parameters were estimated at bounds.

3) **Run 1.29.** Set the process error on the Sub-Antarctic trawl survey at 0.10 which is about one-quarter of values estimated in run 1.25.

4) **Run 1.31.** Halve the effective sample size for most of the western-at-age data, which a profile on the virgin biomass indicates are overly influential in the biomass estimation (see Section 3.2.1). The at-age data sets for which the effective sample sizes are halved are: Sub-Antarctic trawl survey (SAsumage), fishery non-spawning OLF (WnspOLF), and fishery non-spawning (Wnspage).

The at-age effective samples are kept at the values for the two-stock model, except for the run 1.31 where they are halved for selected sets. The process error for the Sub-Antarctic trawl is estimated in all runs, except for run 1.29 where it is fixed at 0.10.

Table 23: Summary of model runs.

Run	Short name
1.17	two stock
1.25	starting western only
1.27	western only, constant M
1.28	western only, SAsl wider bounds
1.29	western only, SAsumbio pe = 0.10
1.31	western only, halve N for selected series

5.4.2 Starting western only model (1.25) compared to the two-stock model (1.17)

The most obvious difference between the starting western model and the two-stock model is the much higher natural mortality for fish less than about three years old (Figure 50). Associated with this is a large change in virgin recruitment (R_0) estimated at 3.3×10^9 (two stock model) versus 4.4×10^{10} (western only model). These changes are interpreted as a proxy for a sequence of processes dropped from the two-stock model for western fish: (a) recruitment to Chatham Rise, (b) catch at the Chatham Rise, and (c) migration from Chatham Rise to the Sub-Antarctic.

There is probably substantial correlation between the estimates of the left-hand limb for the natural mortality and virgin recruitment. If the left-hand limb is forced to be 2.5 (instead of the upper bound estimate of 5.0 in model run 1.25) virgin recruitment is estimated to be 4.3×10^9 (instead of 4.4×10^{10}), but the estimate of current biomass is unchanged at 44%B_0.

Absolute western spawning biomass is estimated to be higher for the western only stock model, but trajectories are closer as a percentage of virgin biomass (Figures 51–52). Fits to the Sub-Antarctic trawl survey and west coast South Island acoustic survey are similar for western only and two stock models (Figures 53–54). Estimates of year class strength are very similar (Figure 55). The western spawning migration is similar for females, but for the western only model fewer male fish are estimated to migrate to spawn, particularly for ages less than seven (Figure 56). The selectivities differ for the right-hand limb of the western non-spawning fishery (Figure 57).

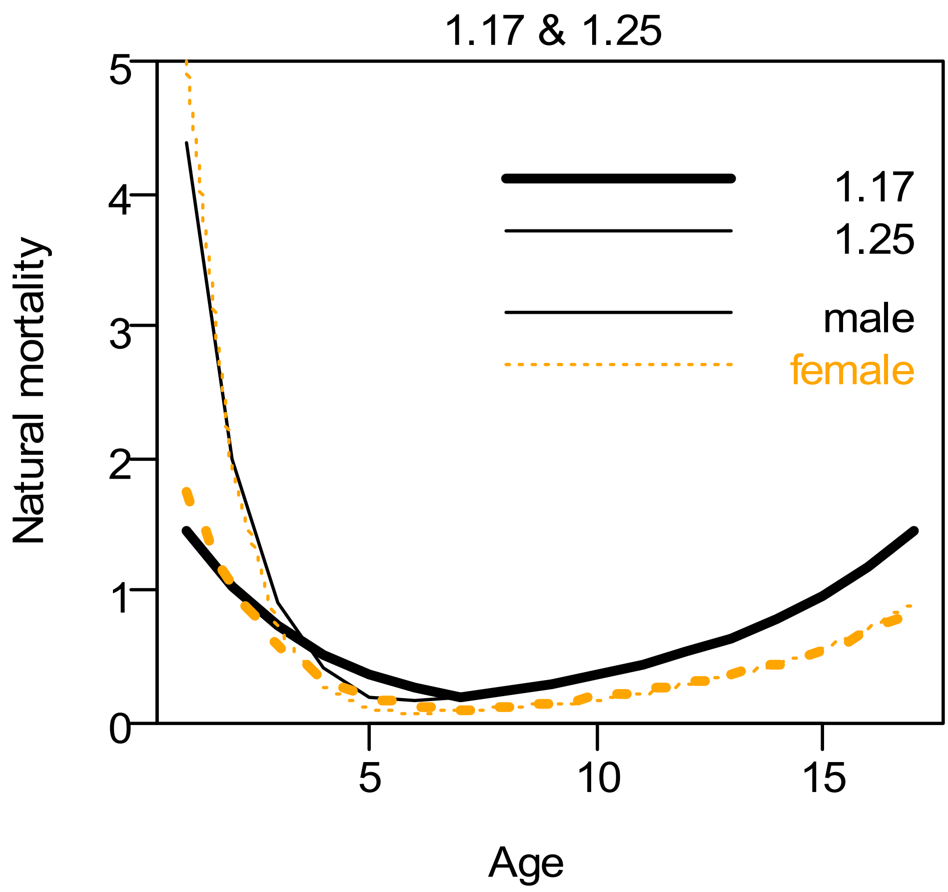

Figure 50: Comparison between age-dependent natural mortality estimated in the two-stock model run 1.17 (heavy lines) and the starting western only model 1.25 (light lines).

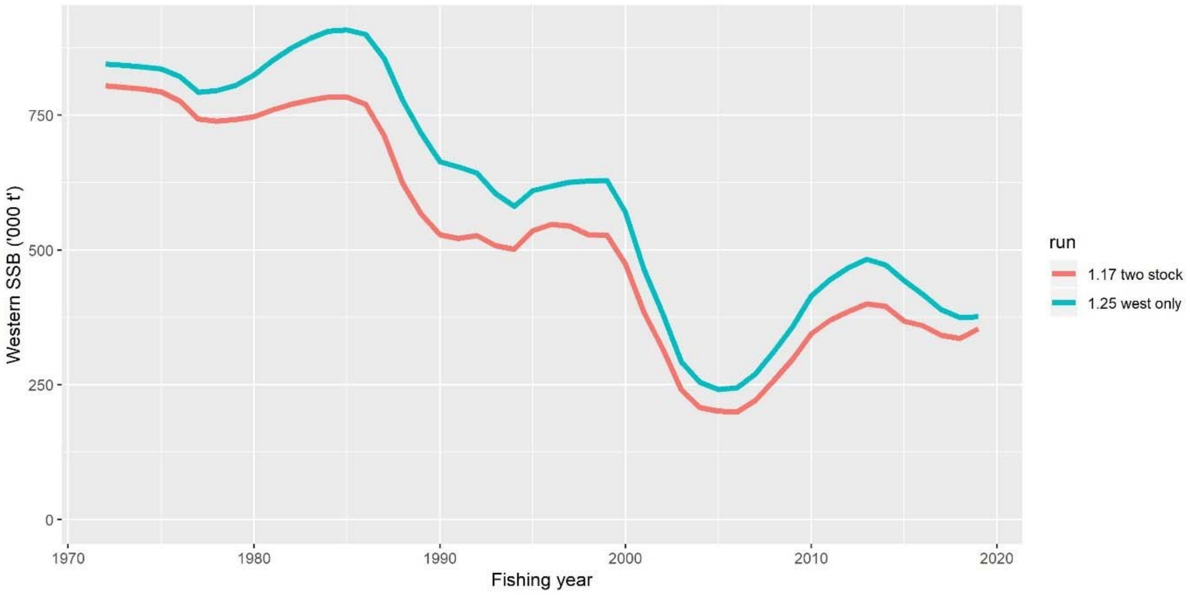

Figure 51: Absolute western spawning biomass for the two-stock model (1.17) and the starting western only model (1.25).

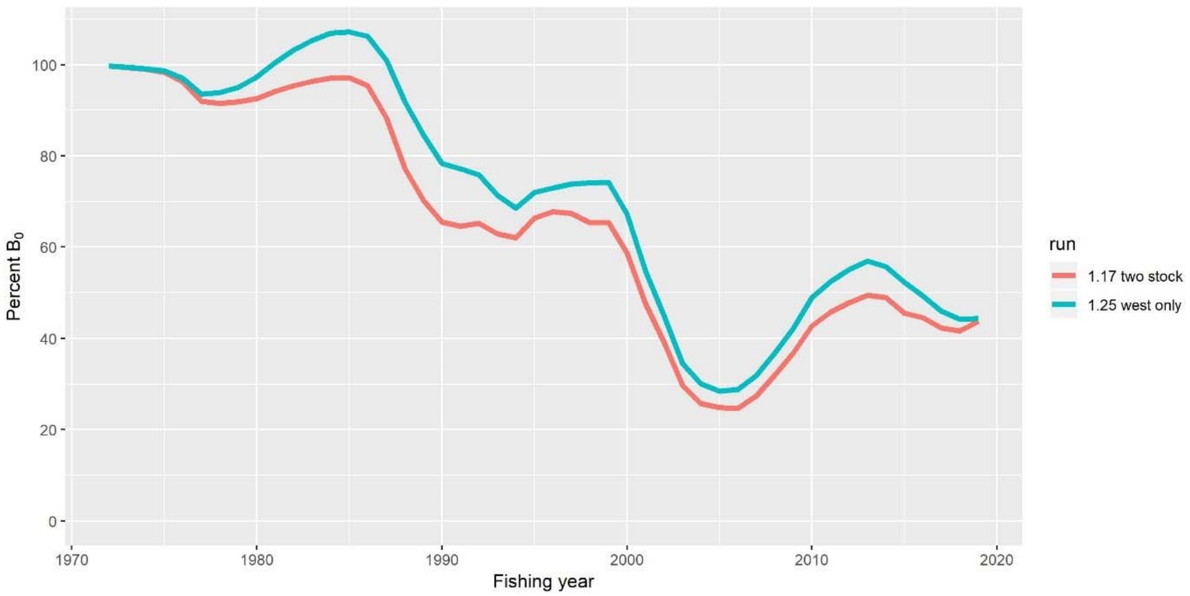

Figure 52: Western spawning biomass as a percentage of virgin biomass. For the two-stock model (1.17) and the starting western only model (1.25).

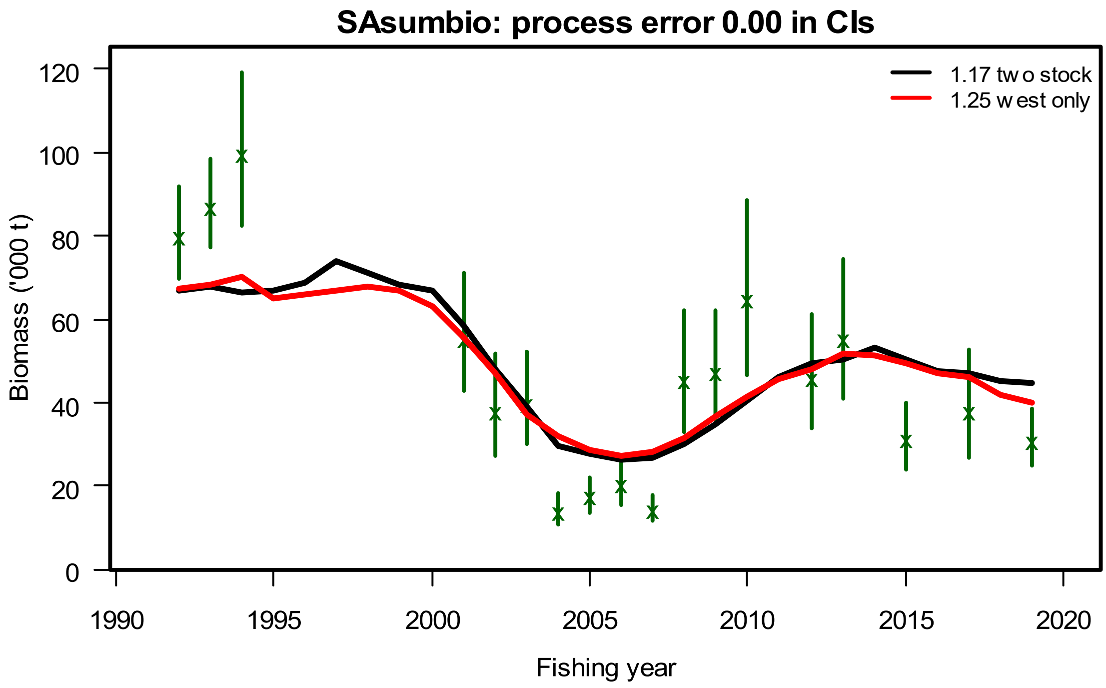

Figure 53: Fits to the sub-Antarctic trawl survey.

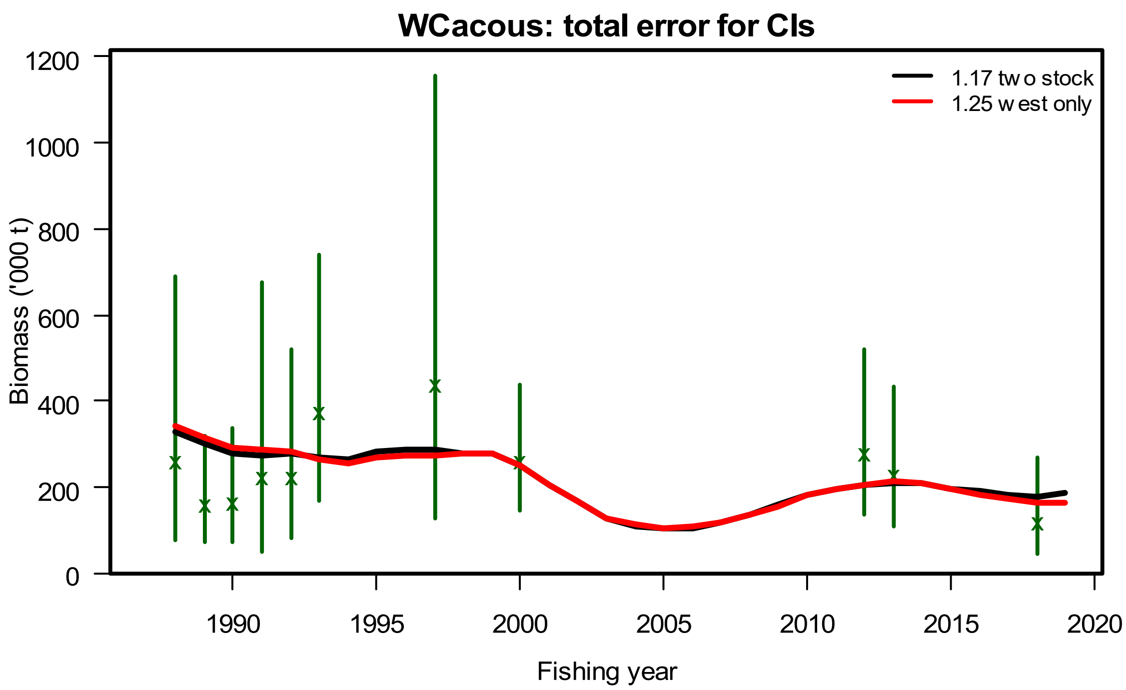

Figure 54: Fits to the west coast South Island acoustic survey.

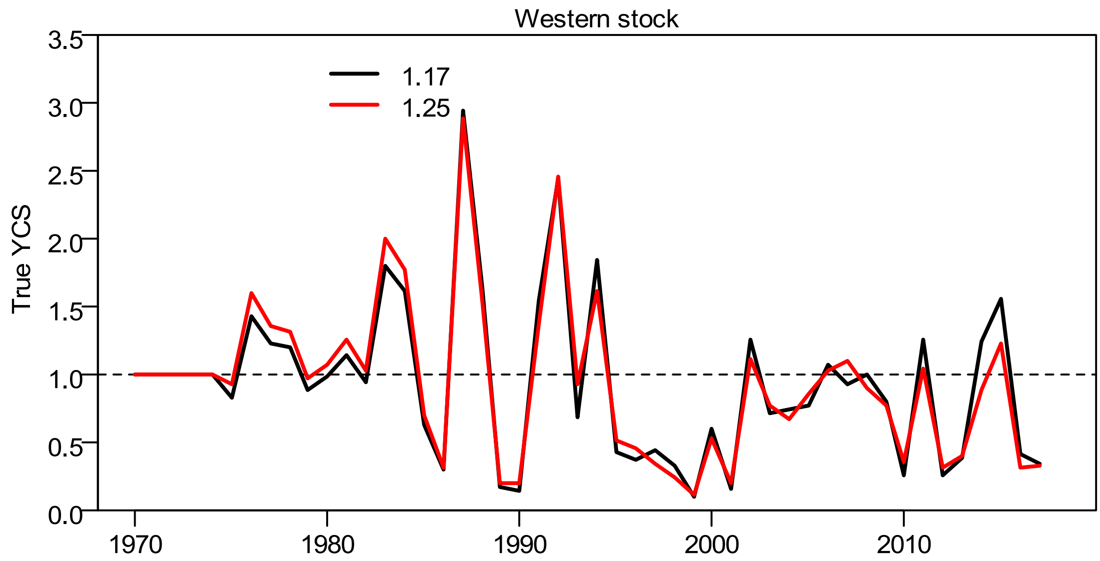

Figure 55: True year class strength estimates.

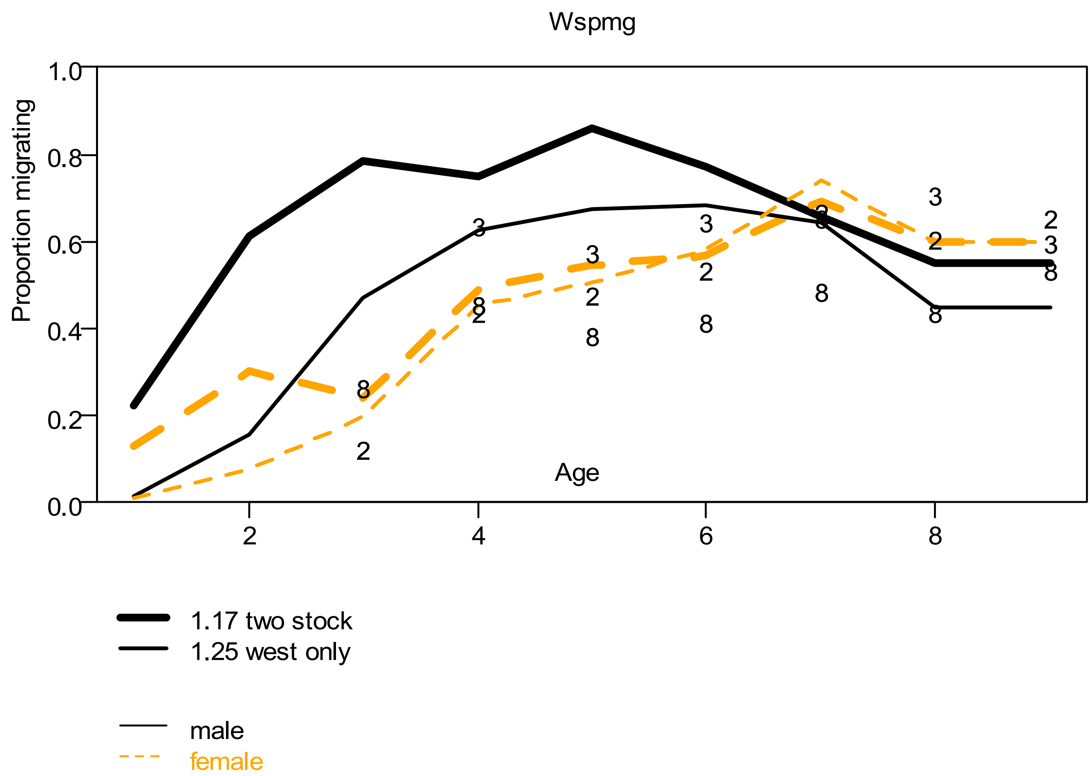

Figure 56: The estimated western spawning migration ogive. The observations pspawn (proportion of females that are expected to spawn) are also plotted, with the plotting symbol identifying the year of sampling ('2' = 1992, '3' = 1993, '8' = 1998).

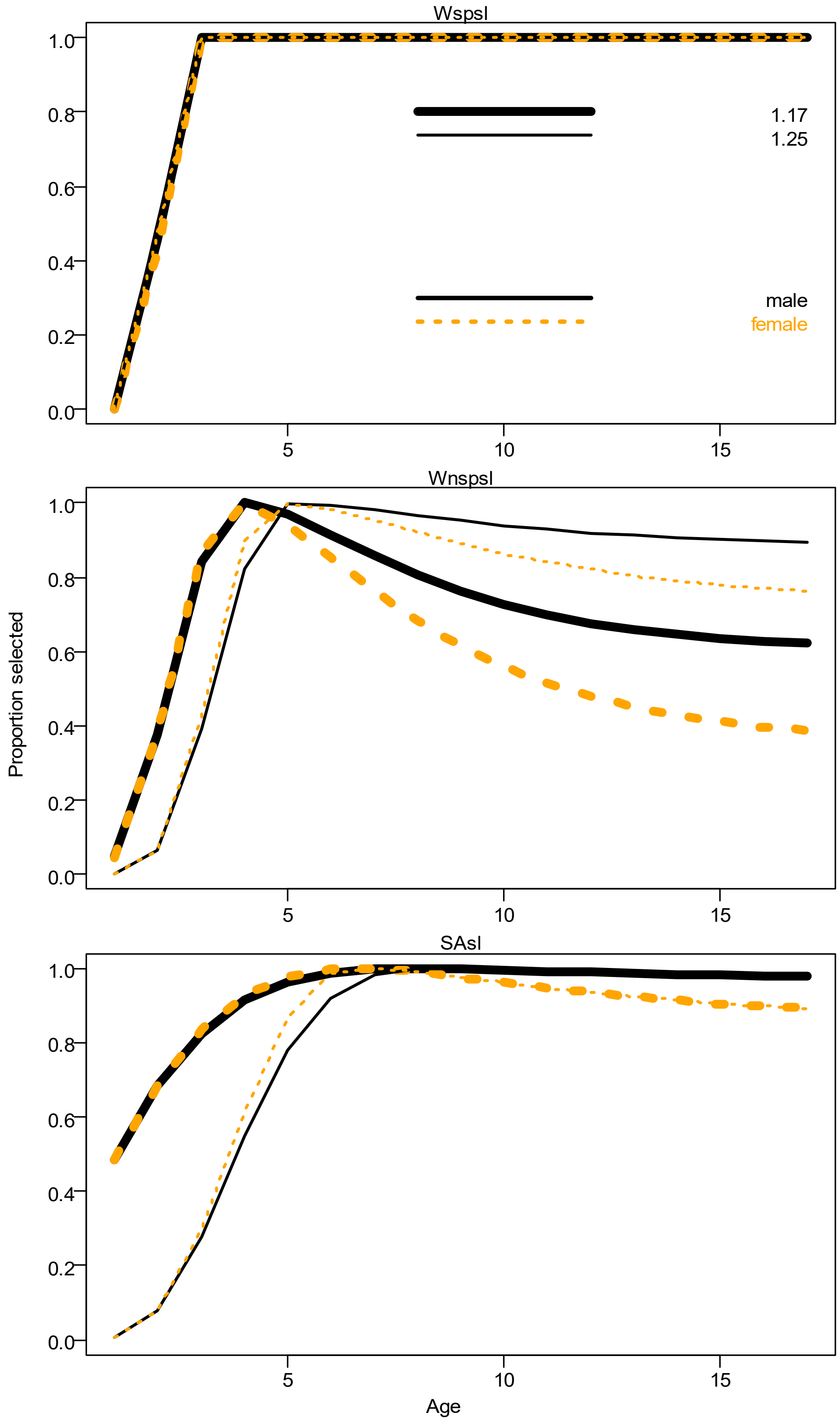

Figure 57: Estimated selectivity curves. Males are shown by a solid black line, females by a dotted orange line.

5.4.3 Results for other model runs

The current biomass estimate (%B_0) only shows a substantial difference if the Sub-Antarctic trawl survey process error is forced to be 0.10 instead of the estimated value of 0.35, giving an estimate of 31%B_0 instead of 44%B_0 (Table 24, Figure 58). The fit to the Sub-Antarctic trawl survey improves with a process error of 0.10, but the differences are small for other model runs (Figure 59). Conversely, the fit to the west coast acoustic survey is worse with a process error of 0.10, with little difference in the other model runs (Figure 60). Forcing a better fit to the Sub-Antarctic trawl survey with a process error of 0.10, degrades the fit to the Sub-Antarctic trawl survey and commercial non-spawning at-age data (Table 25).

Table 24: Summary of model runs results for the western stock.

Run	Short name	Current western biomass (%B_0)	Process error	B0 (‘000 t)
1.17	two stock	44	0.35	807
1.25	starting western only	44	0.35	847
1.27	western only, constant M	39	0.31	921
1.28	western only, SAsl wider bounds	44	0.38	786
1.29	western only, SAsumbio pe = 0.10	31	0.10	765
1.31	western only, halve N	38	0.32	790

Table 25: Difference in objective components between models 1.25 (starting western only) and 1.29 (process error 0.10 for Sub-Antarctic trawl survey). A positive difference indicates a worse fit for the observations.

Objective component	Difference (1.29 – 1.25)
SAautbio	0.1
WCacous	1.2
SAautage	0.3
SAsumage	4.3
WnspOLF	-0.3
Wnspage	2.2
Wspage	-1.0
pspawn	-0.2
pspawn_1993	0.2
prior_on_recruitment.YCS	0.8
prior_on_q[WCacous].q	0.4
prior_on_q[SAsum].q	-0.3
prior_on_q[SAaut].q	-0.2
prior_on_Mmale	-0.1
prior_on_Mfemale	0.1

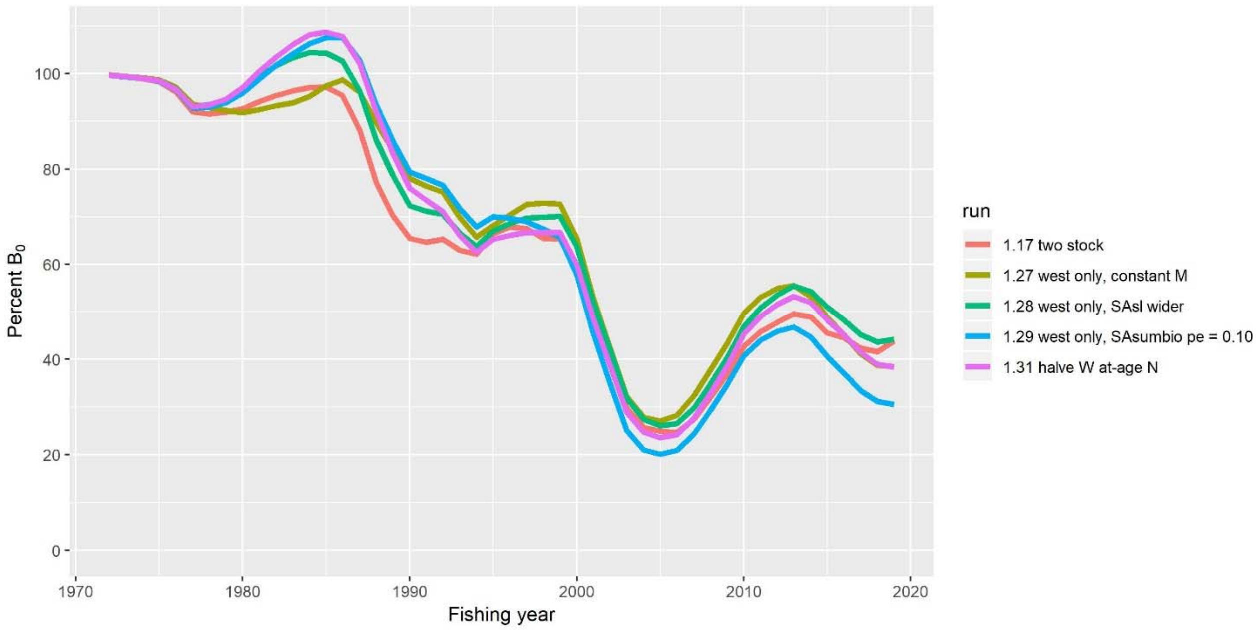

Figure 58: Western biomass trajectory (%B_0) for model runs.

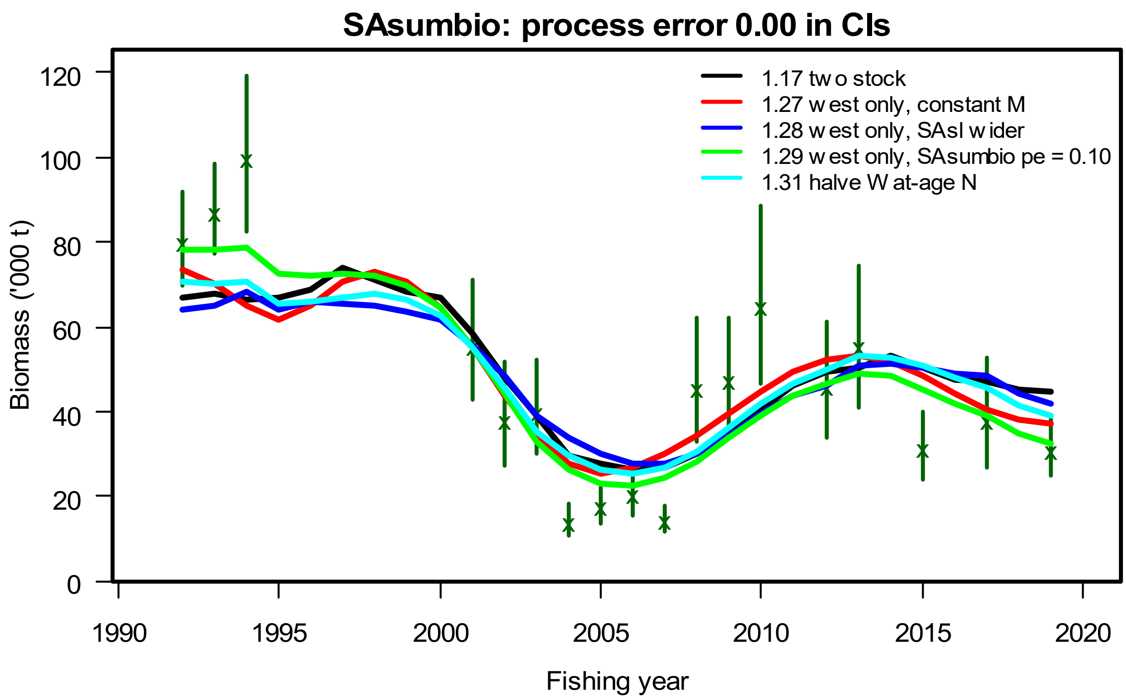

Figure 59: Fits to the Sub-Antarctic trawl survey. Vertical lines show 95% confidence intervals for the observations (with no added process error).

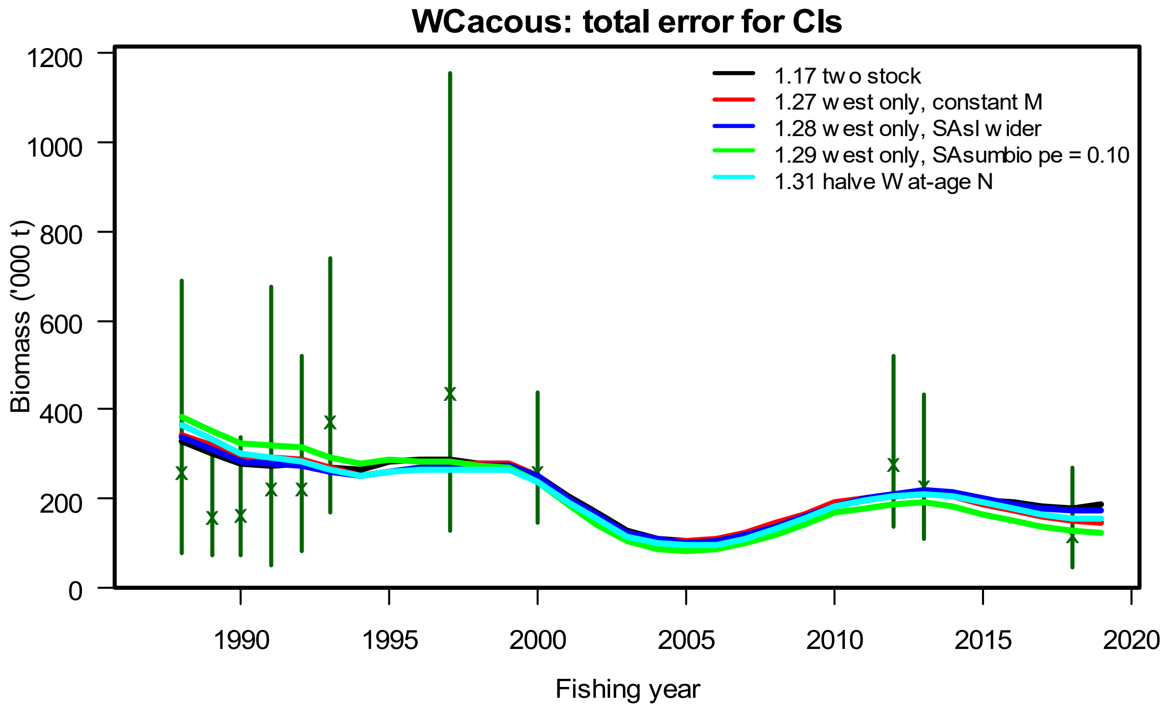

Figure 60: Fits to the west coast South Island acoustic survey. Vertical lines show 95% confidence intervals for the observations with the total error.

5.5 Additional model runs with process error set at zero for biomass indices

Subsequent to the model runs in the previous section, the Deepwater Working Group decided on four final MCMC model runs (see ahead in Section 6). These runs were based on the MPD results already presented, but with process error set to zero for the trawl surveys to induce as best a fit to them as possible. Some MPD analyses for these runs are presented here.

To induce the best possible fit to the Sub-Antarctic trawl survey indices two runs were conducted in which the process error was set to zero for the survey:

1) **Run 1.33**. The same as the western only model 1.29, except the process error is set at zero for the Sub-Antarctic trawl survey.

2) **Run 1.34**. The same as the two-stock update model 1.17, except the process error is set at zero for the Sub-Antarctic trawl survey.

Normalised residual comparisons for these model runs are shown in Figures 61–62.

Three additional model runs investigated the impact of forcing a better fit to the eastern biomass indices (runs 1.35–1.37), these model runs all being variations on the two stock update model run 1.17. Better fits were induced by making process error for the eastern biomass indices zero, and by downweighing the western at-age and biomass data.

Forcing the Chatham Rise trawl survey error to be zero (instead of the estimated value of 0.15) made a small difference to the Chatham Rise trawl fit, but slightly more when the influence of the western data was reduced (Figures 63–65).

A run was conducted where the process error of the Cook Strait acoustic survey was set at zero, along with the Chatham Rise trawl survey process error. However, this degraded the fit to the Chatham Rise trawl survey and the fit to the Cook Strait acoustic survey became unconvincing (Figures 66–67).

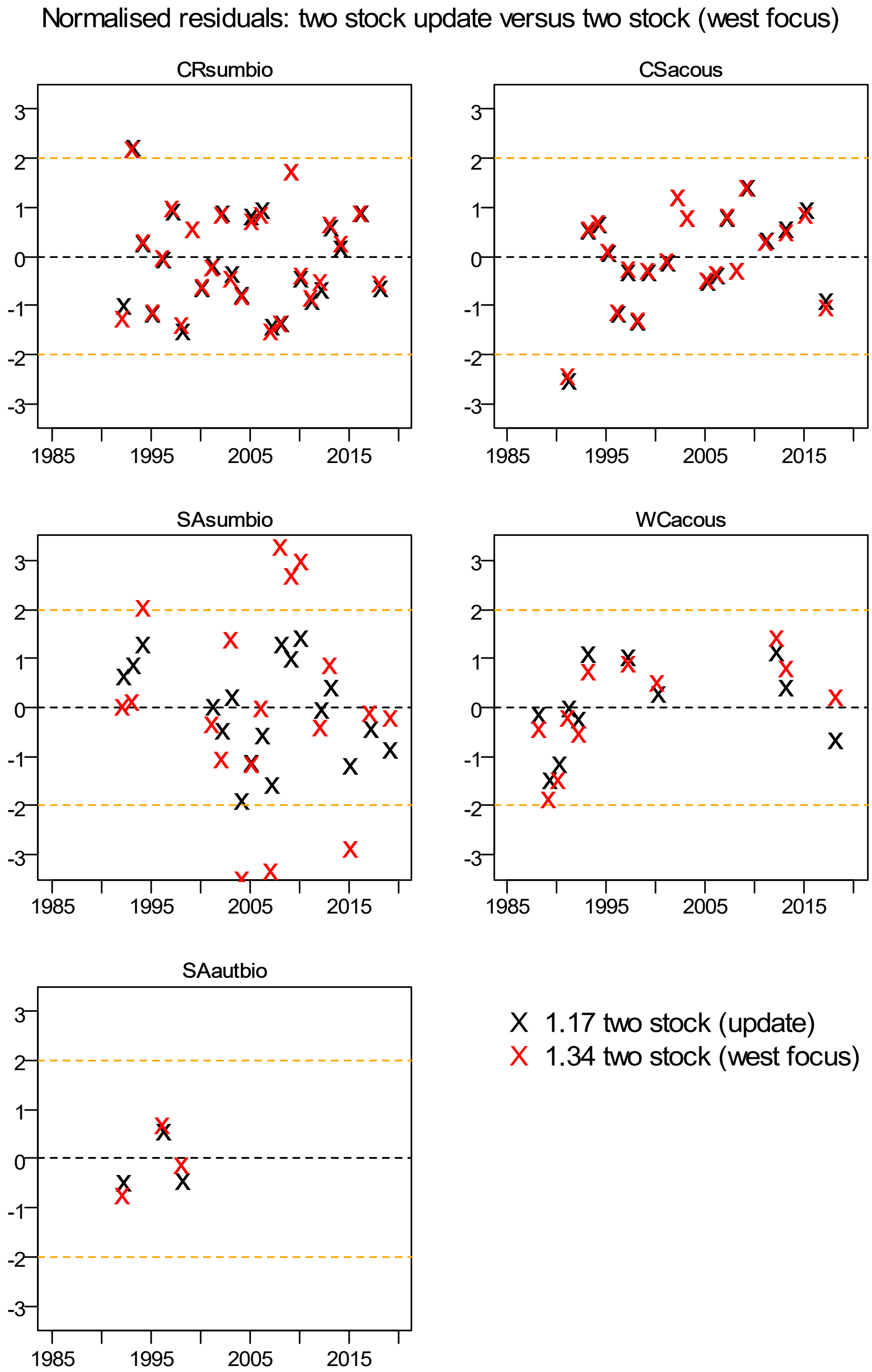

Figure 61: Normalised residuals for fits to the biomass indices for runs 1.17 and 1.34.

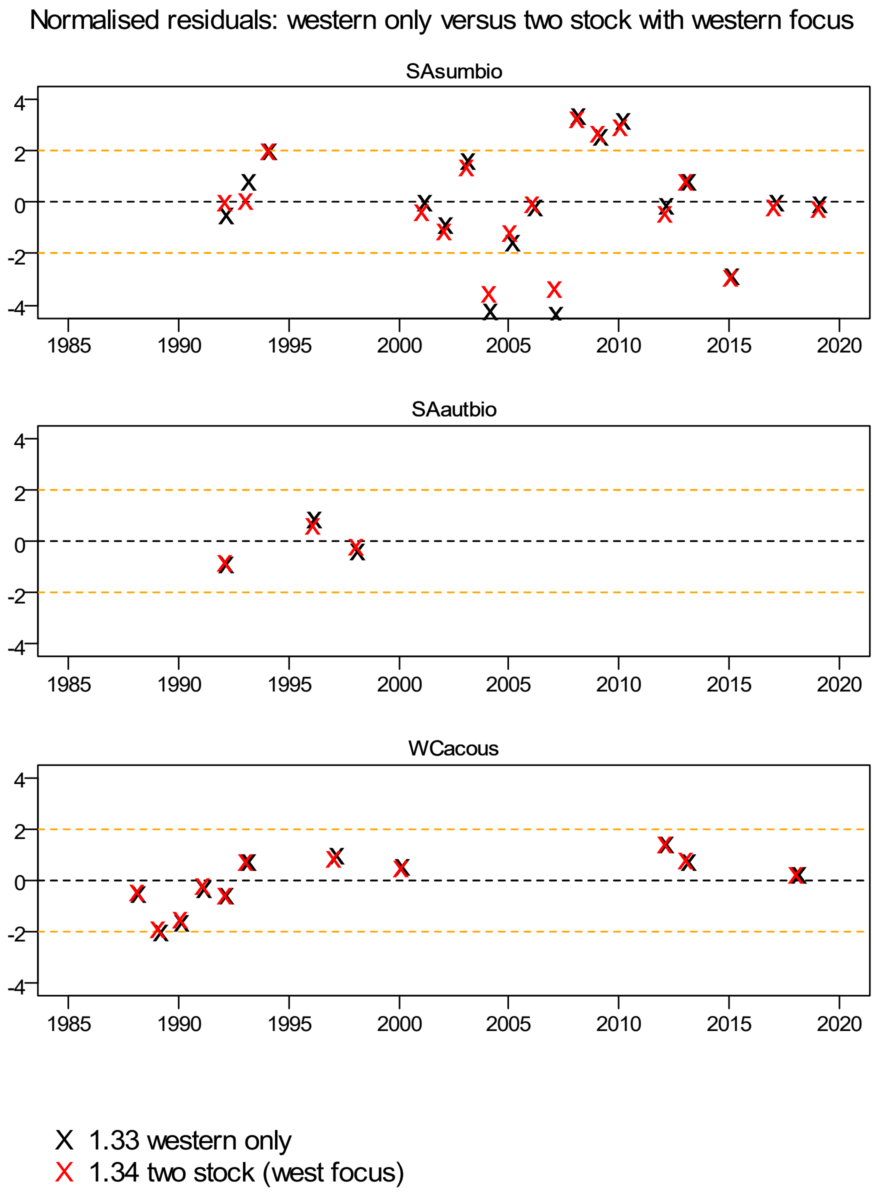

Figure 62: Normalised residuals for fits to the western biomass indices for runs 1.33 and 1.34.

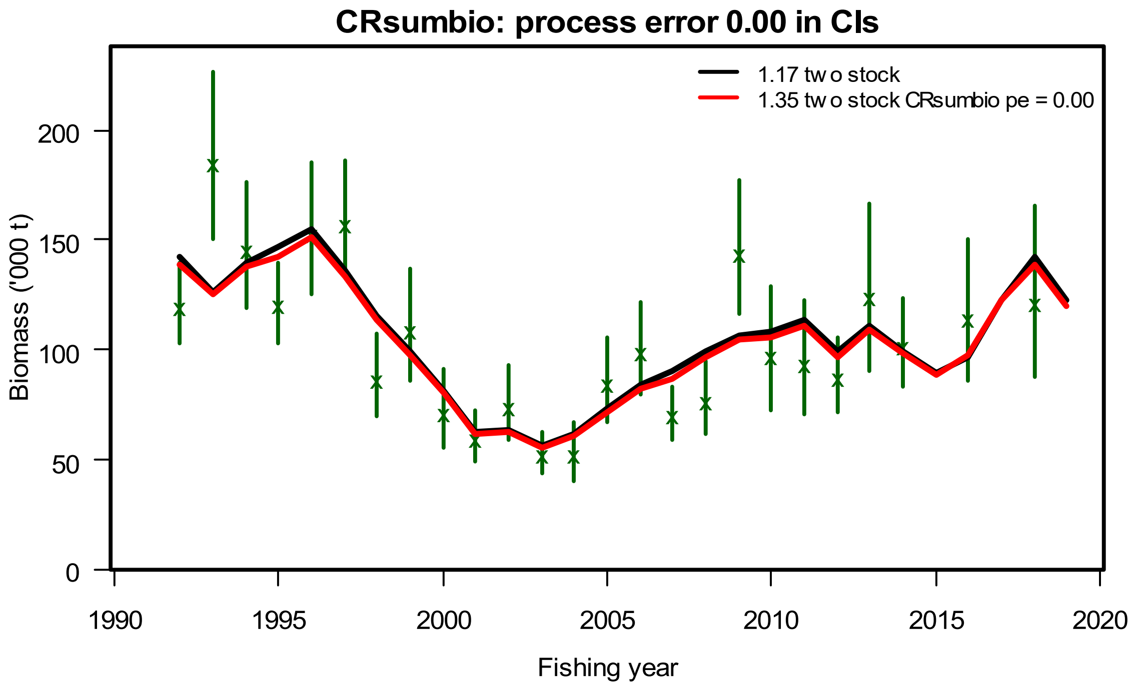

Figure 63: MPD fits to the Chatham Rise trawl survey with estimated process error 0.15 versus setting the process error at 0.00.

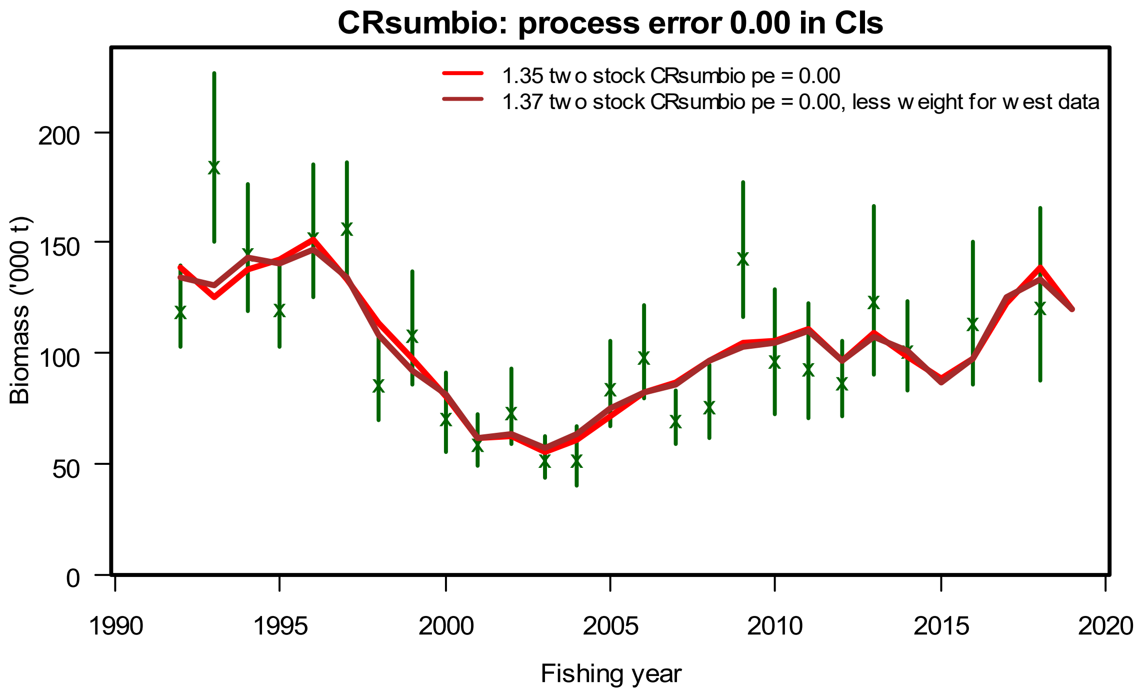

Figure 64: MPD fits to the Chatham Rise trawl survey with process error set at 0.00 versus also reducing the weight for the western data (halving effective sample sizes, and process error or 0.70 for the Sub-Antarctic trawl survey).

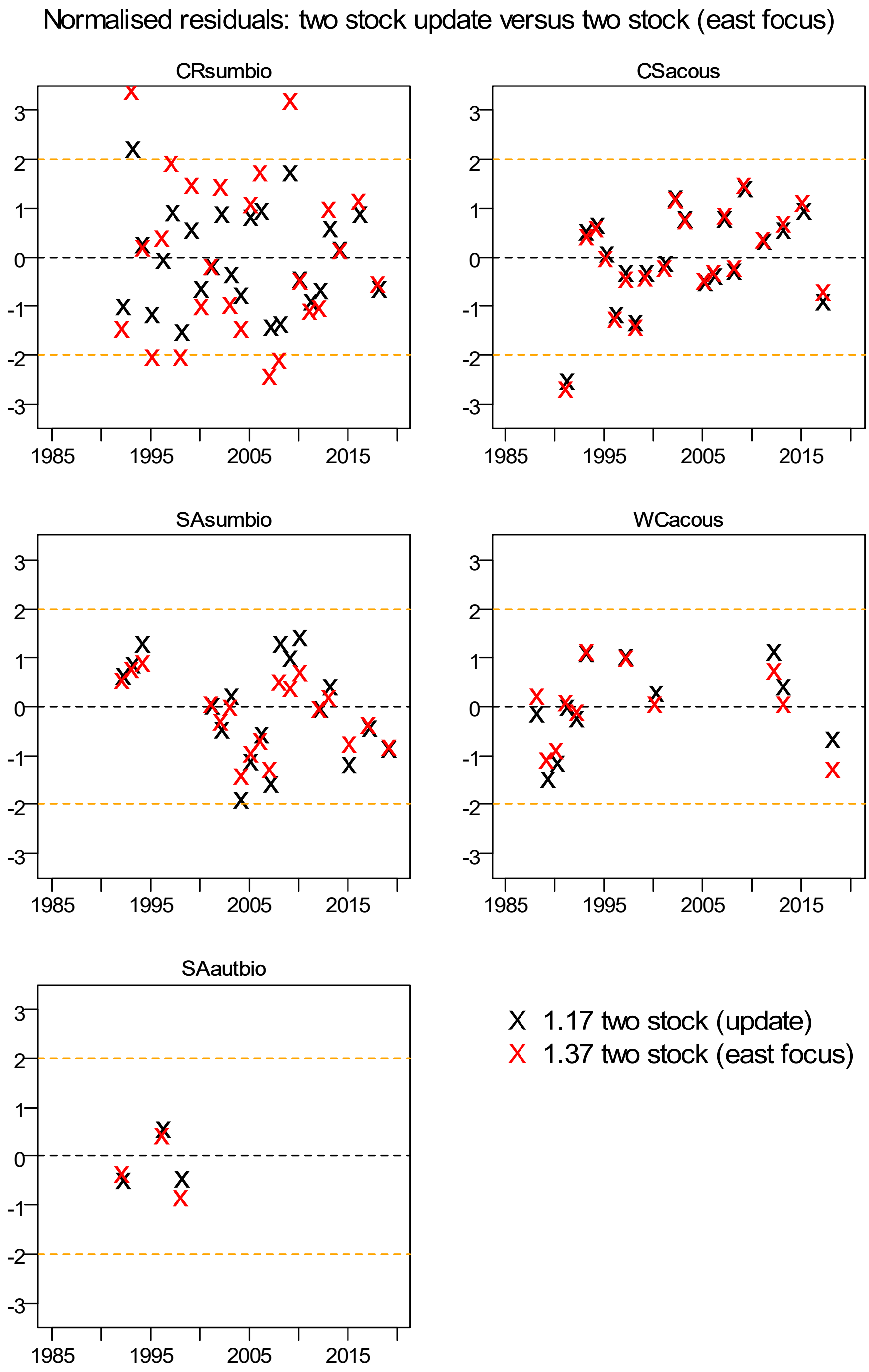

Figure 65: Normalised residuals for fits to the biomass indices for runs 1.17 and 1.37.

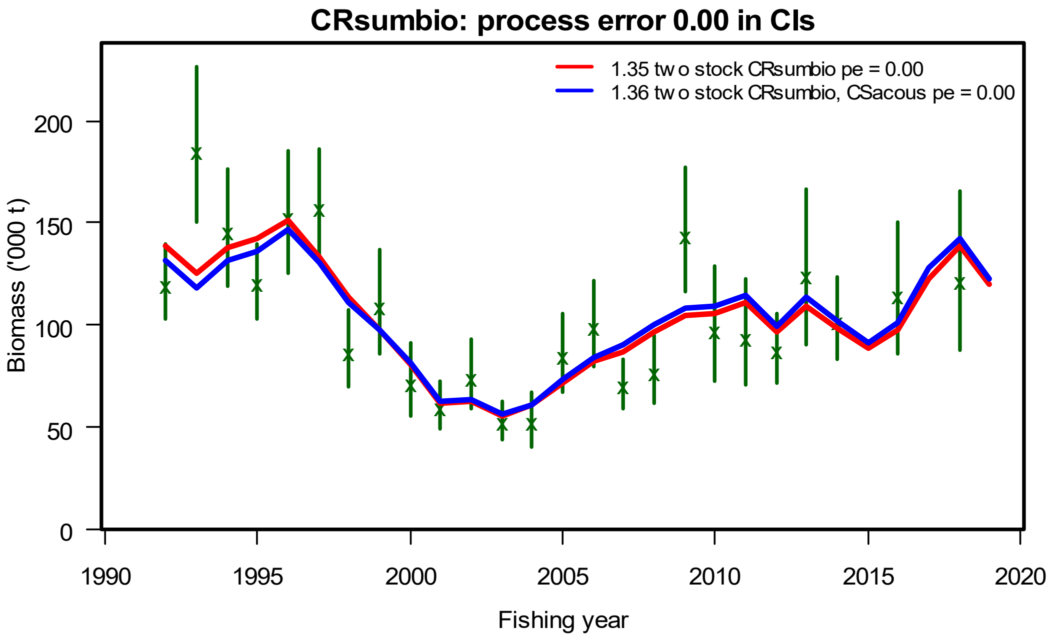

Figure 66: MPD fits to the Chatham Rise trawl survey with a process error of zero (run 1.35) versus additionally setting the process error to zero for the Cook Strait acoustic survey (CSacous) in run 1.36.

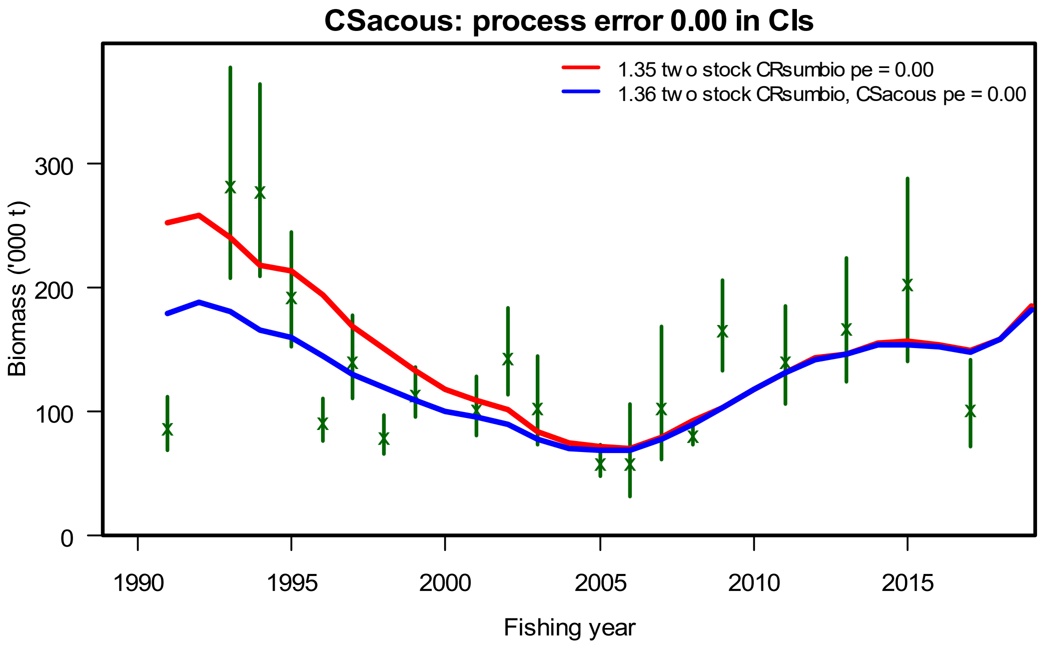

Figure 67: MPD fits to the Cook Strait acoustic survey (CSacous). Comparing a run with a process error of 0.00 for the Chatham Rise trawl survey (run 1.35) versus additionally setting the process error to 0.00 for the Chatham Rise trawl survey (run 1.36).

6. FINAL MODEL ASSESSMENT RESULTS (MCMC)

6.1 Introduction

After consideration of the MPD runs (Sections 4 and 5) it was decided by the Deepwater Working Group to take four runs through to MCMC (Table 26):

1. **Run 1.17**. Updated two stock base model from the 2018 assessment.

2. **Run 1.33**. Western stock only model with a process error of 0.00 for the Sub-Antarctic trawl survey (see Section 5.4 for details of the model setup).

3. **Run 1.34**. Two stock model (west focus) with a process error of 0.00 for the Sub-Antarctic trawl survey.

4. **Run 1.37**. Two stock model (east focus) with a process error of 0.00 for the Chatham Rise trawl survey, process error of 0.70 for the Sub-Antarctic trawl survey, and one-half the effective sample sizes for the western at-age data (relative to the updated base two-stock base model).

None of these runs is considered a base model, but rather show the range of possible biomass estimates, when different weightings are given to fitting the eastern or western biomass indices.

Table 26: Summary of final model runs.

Run	Short name	Main assumptions
1.17	two stock (update)	natal fidelity
		M is age-dependent
		single q for Sub-Antarctic trawl series
		process error of CRsumbio and SAsumbio was estimated
1.33	western only	Similar assumptions to 1.17 but drop eastern areas and data
		process error zero for SAsumbio
1.34	two stock (west focus)	as 1.17 but process error zero for SAsumbio
1.37	two stock (east focus)	as 1.17 but process error zero for CRsumbio
		process error 0.70 for SAsumbio
		halve effective sample sizes for western at-age data

6.2 MCMC setup

The MCMC chains were generated in the same way as in the 2018 assessment (McKenzie 2019). 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 were estimated as free parameters, all migration and selectivity migration were free in the MCMC (whether they run into bounds in the MPD or not), and there was an equality constraint for the last estimated east and west year class strengths (2017 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 68–69). They suggest that convergence was sufficient to estimate key quantities and their uncertainly. 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 MCMC biomass estimates

Virgin and current biomass estimates are summarised in Table 27. For the updated two stock model the current western biomass was estimated to be 56%B_0 (median value), 34%B_0 (western stock only model), and 29%B_0 (two stock with a west focus). Current eastern biomass estimates were 66%B_0 (two stock update) and 64%B_0 (two stock with east focus). Virgin and current biomass estimates are shown in Figure 70, and trajectories in Figures 71–72.

Normalised residuals for the fits to the Sub-Antarctic trawl survey are shown in Figures 73–75. As expected, they increase when the process error is set at zero, and have a similar pattern and spread for the two stock (west focus) and western only models. Normalised residuals for the Chatham Rise trawl survey are shown in Figures 76–77.

Year class strengths are compared for the two stock (update) and two stock (western focus) models in Figures 78–79. For the eastern stock they are very similar; for the western stock the most recent YCSs are very uncertain and are lower for the two stock (west focus) model. The west YCSs for the two stock (western focus) and western only models are similar (Figure 80, Figure 78).

Table 27: Estimates of spawning biomass (medians of marginal posterior, with 95% confidence intervals in parentheses). $B_{current}$ is the biomass in mid-season 2019.

	B_0('000 t)		$B_{current}$('000 t)		$B_{current}$(%B_0)	
Run	E	W	E	W	E	W
two stock (update)	550(438,717)	990(805,1355)	365(235,566)	550(309,999)	66(48,89)	56(37,78)
western only		948(806,1188)		325(210,629)		34(25,58)
two stock (west focus)	533(442,660)	813(716,939)	371(247,541)	239(163,353)	69(51,91)	29(22,39)
two stock (east focus)	566(475,705)	1167(875,1707)	358(243,531)	831(443,1467)	64(46,85)	71(49,94)

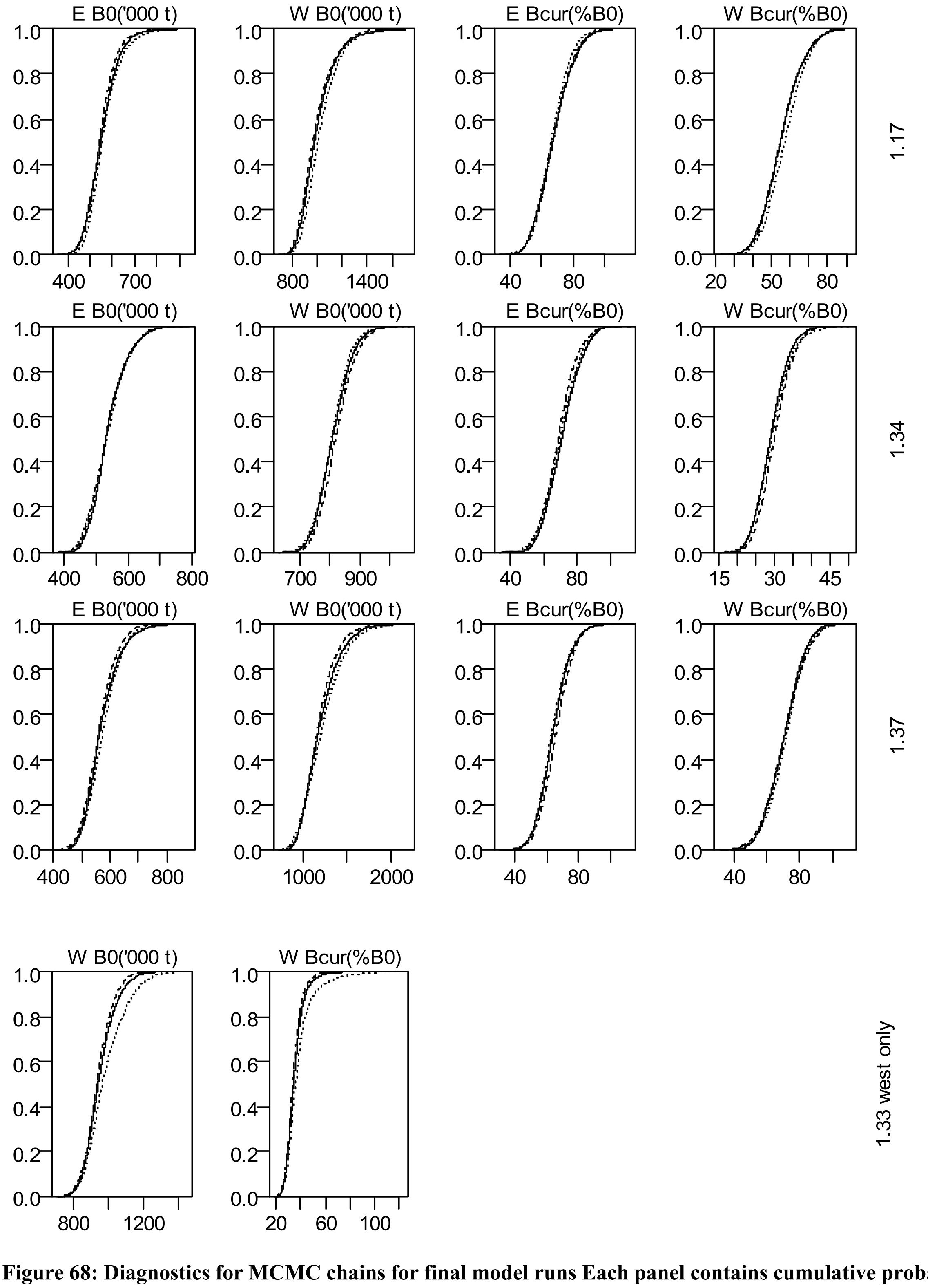

Figure 68: Diagnostics for MCMC chains for final model runs Each panel contains cumulative probability distributions, for B_0 or $B_{current}$, for three chains from the same model run. Samples from the burn in period are discarded for these results.

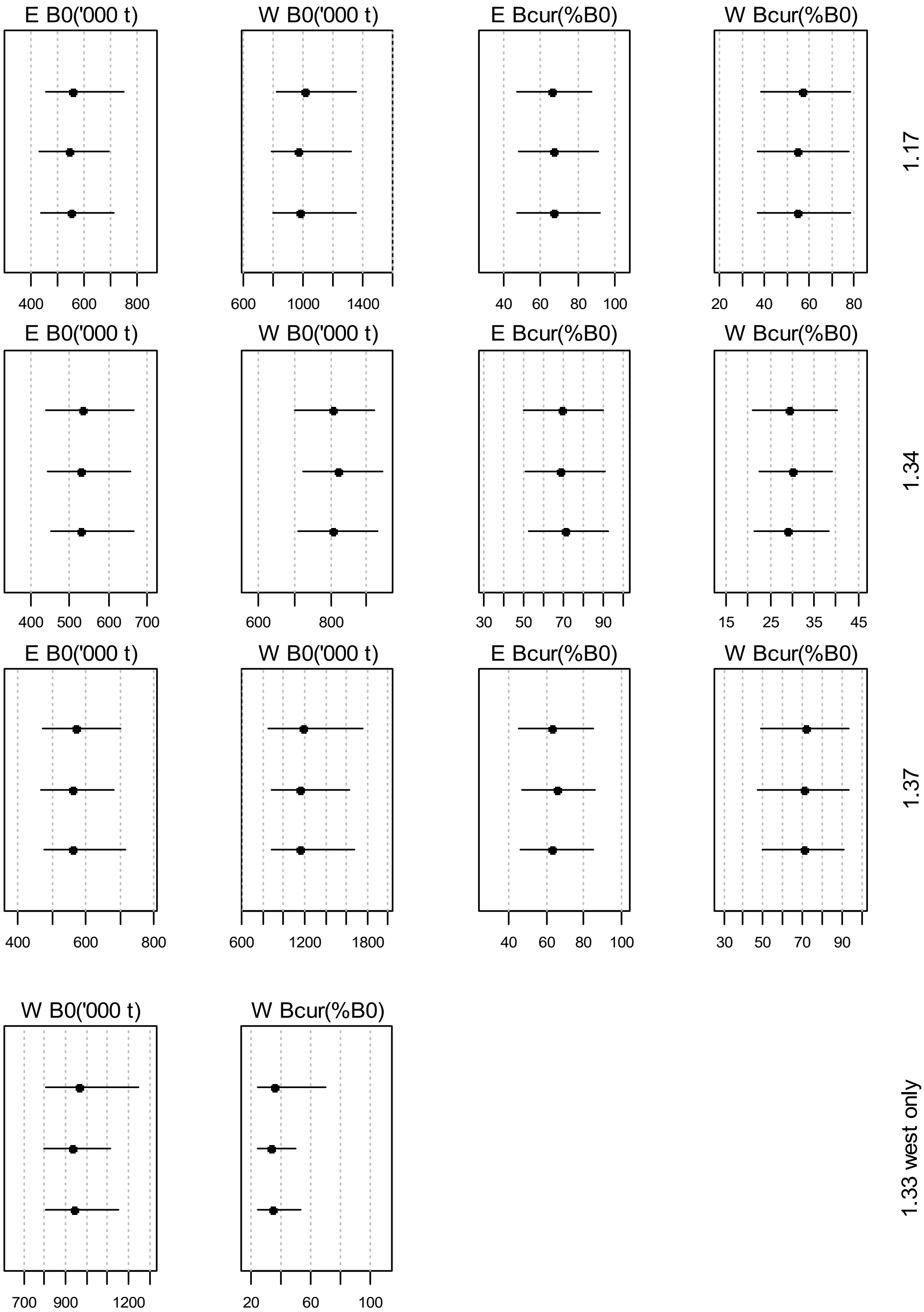

Figure 69: Further diagnostics for MCMC chains for final model runs. Each panel contains the median (solid dot) and 95% confidence interval, for B_0 or $B_{current}$, for three chains from the same model run.

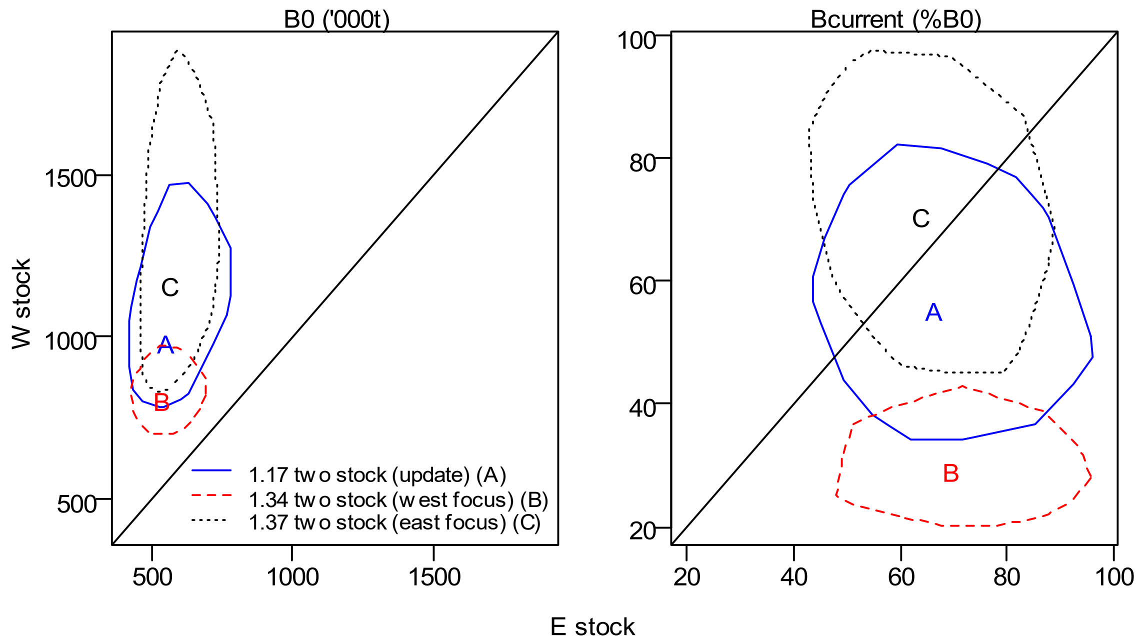

Figure 70: Estimates and approximate 95% credible intervals for virgin (B_0) and current ($B_{current}$ as %B0) biomass by stock for the three runs 1.1 (A), 1.3 (B), and 1.4 (C). In each panel the points 'A', 'B' and 'C' indicate best estimates (median of the posterior distribution) for these three runs, and the polygons (with solid, broken and dotted lines, respectively) enclose approximate 95% credible intervals. Diagonal lines indicate equality (y = x).

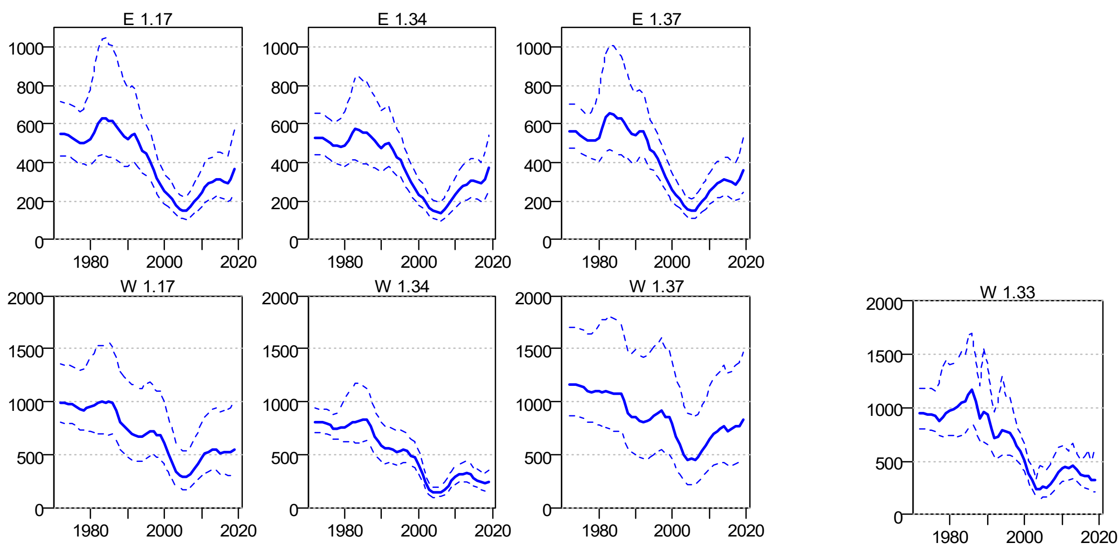

Figure 71: Estimated spawning-biomass trajectories from the MCMC runs, showing medians (solid lines) and 95% confidence intervals (broken lines) by run for E (upper panels) and W (lower panels). The first three columns show the two stock models (base update, west focus, east focus). The fourth column is the western only model.

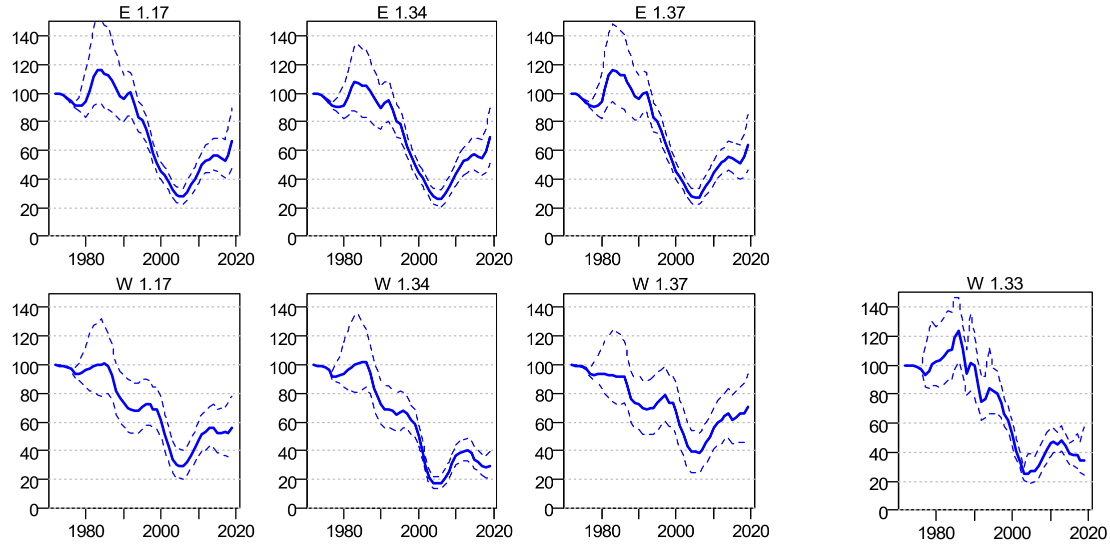

Figure 72: As in Figure 71, but %B_0.

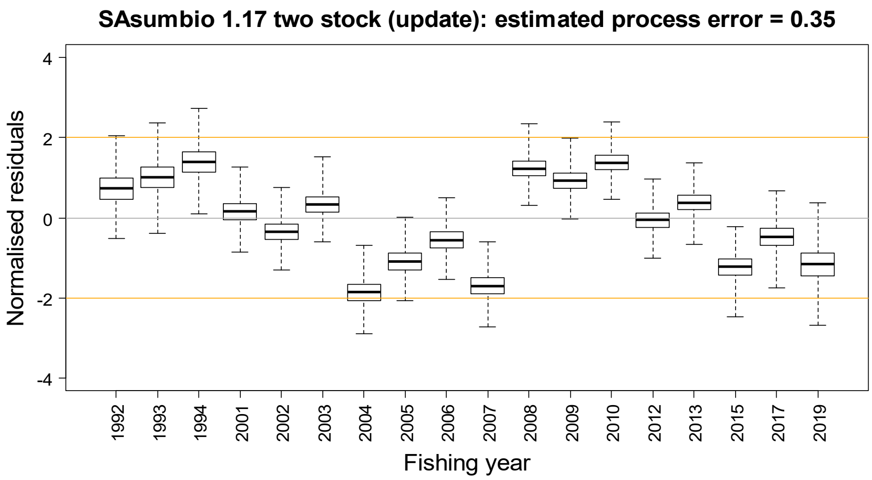

Figure 73: MCMC normalised residuals for model 1.17 and the fit to the Sub-Antarctic trawl survey. Shown are boxplots, where the box covers the lower quartile to upper quartiles (thicker bold line at the median), and the whiskers extend to the most extreme data point which is no more than range times the interquartile range from the box.

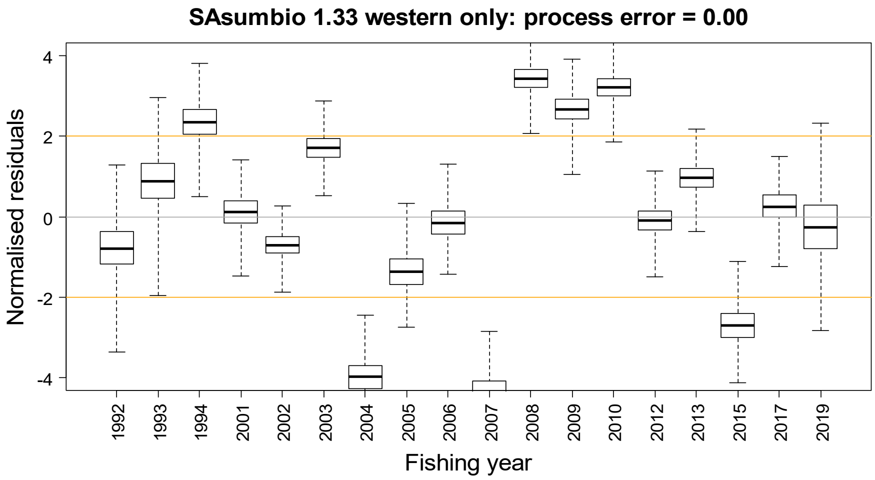

Figure 74: MCMC normalised residuals for model 1.33 and the fit to the Sub-Antarctic trawl survey.

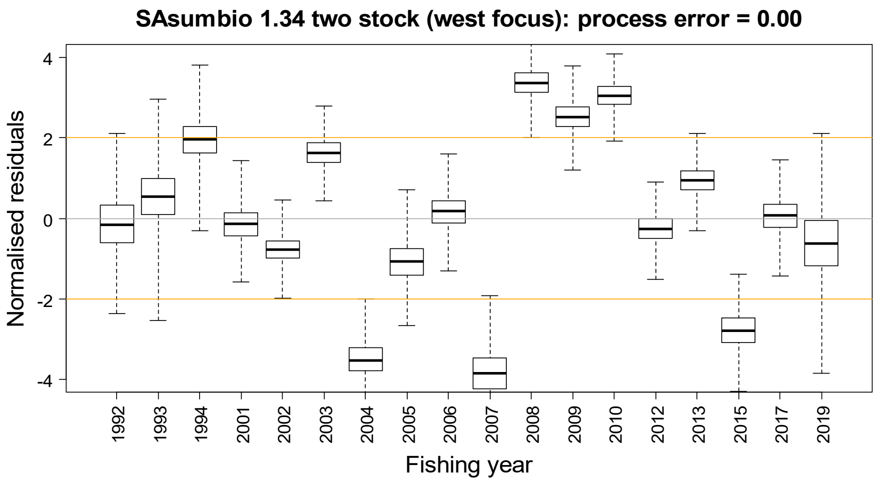

Figure 75: MCMC normalised residuals for model 1.34 and the fit to the Sub-Antarctic trawl survey.

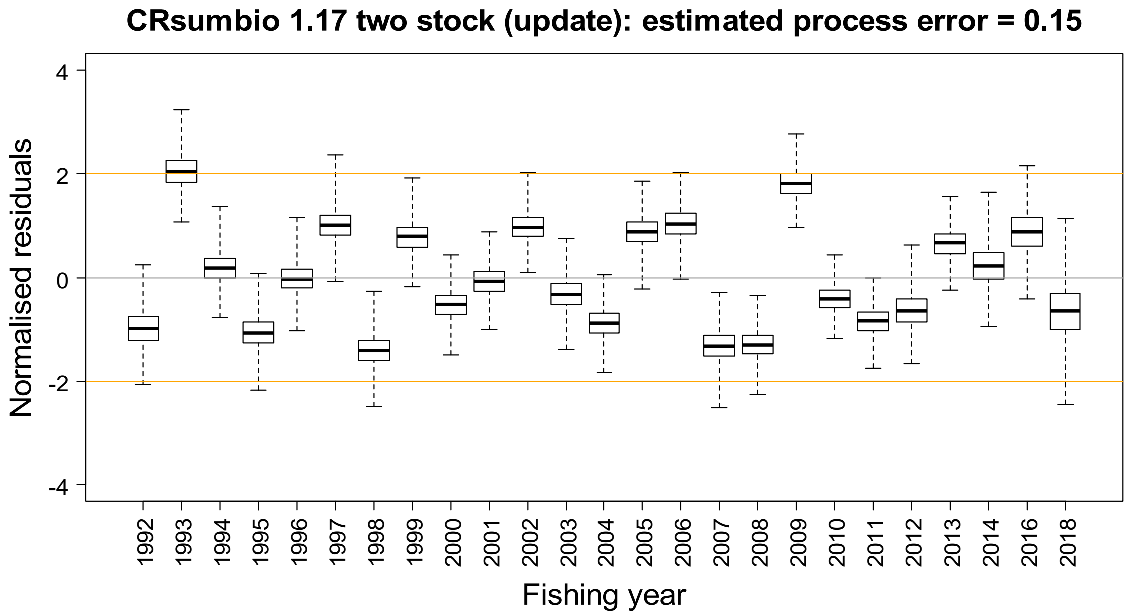

Figure 76: MCMC normalised residuals for model 1.17 and the fit to the Chatham Rise trawl survey.

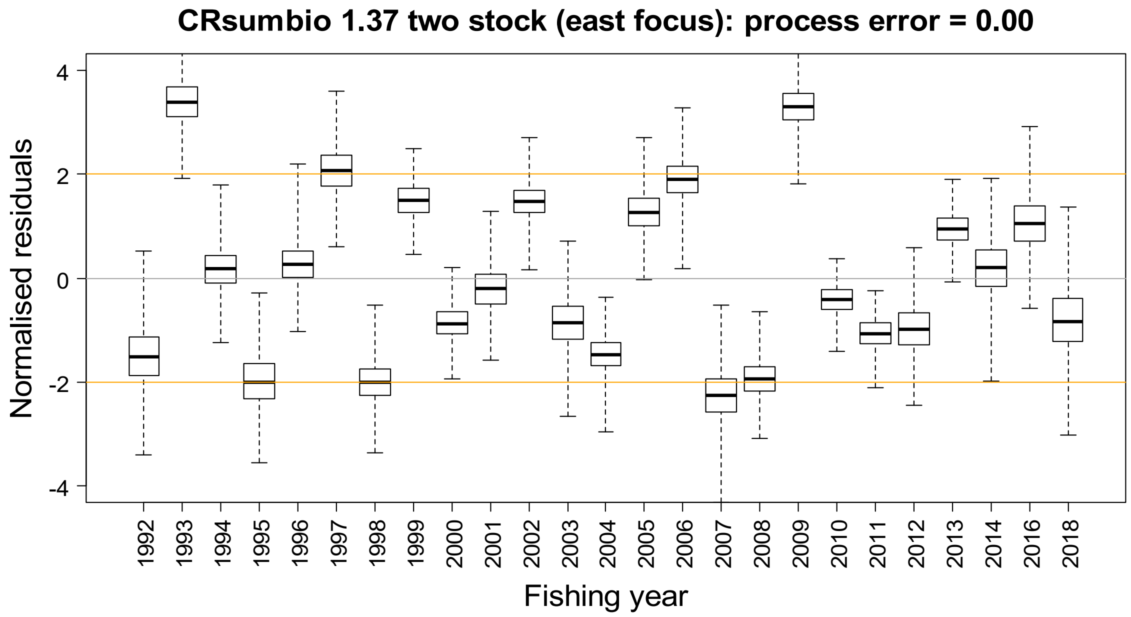

Figure 77: MCMC normalised residuals for model 1.37 and the fit to the Chatham Rise trawl survey.

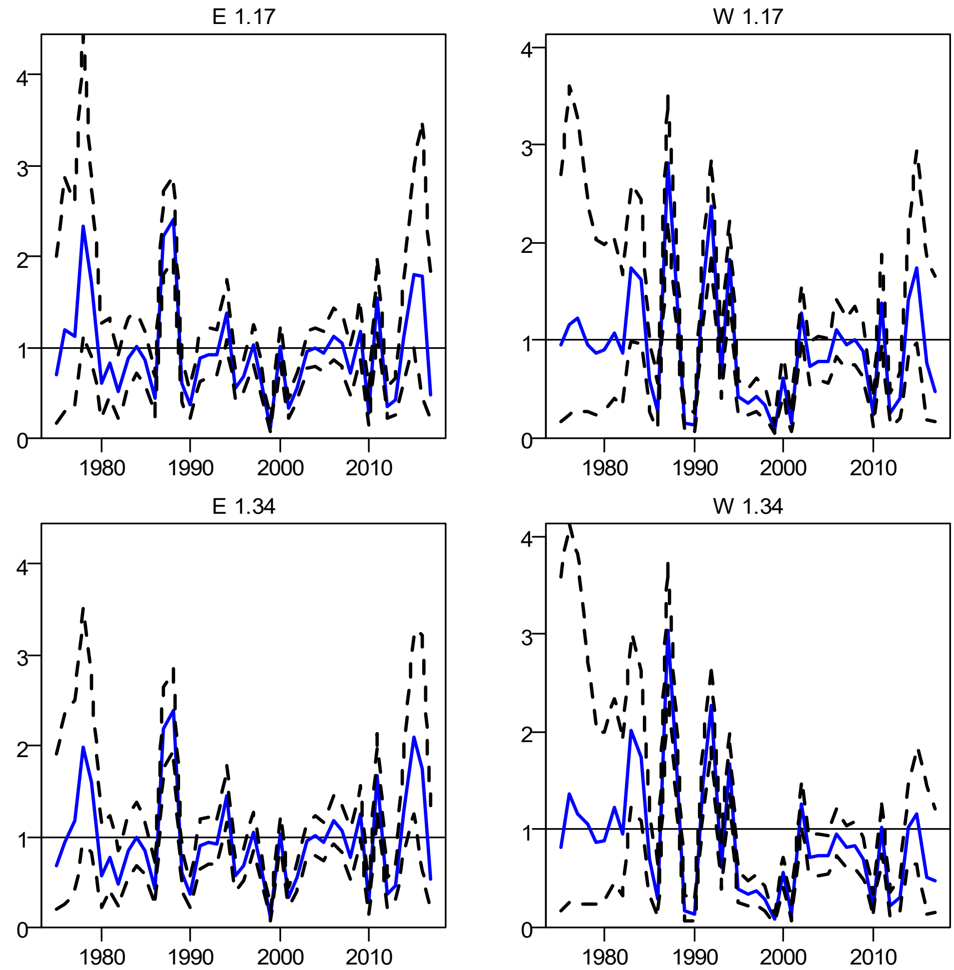

Figure 78: True YCS for model runs with 95% credible intervals.

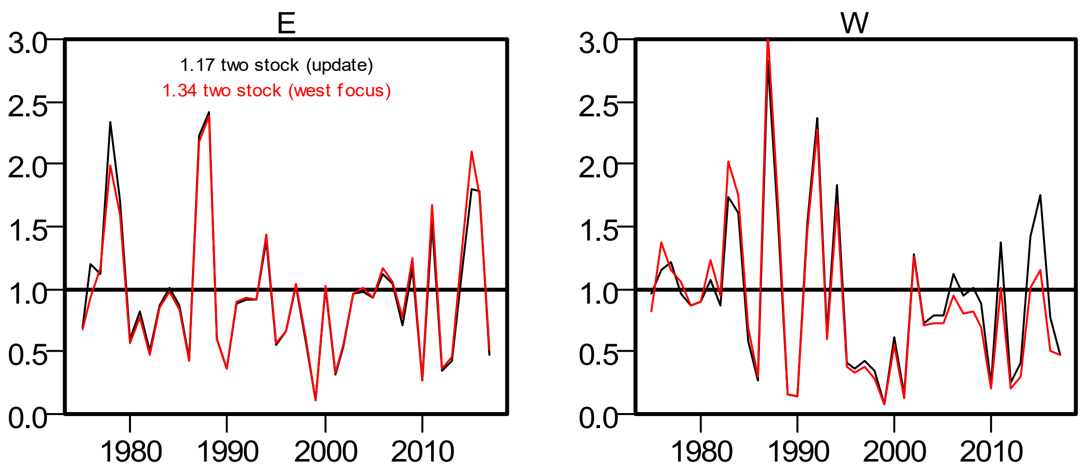

Figure 79: True YCSs (median values).

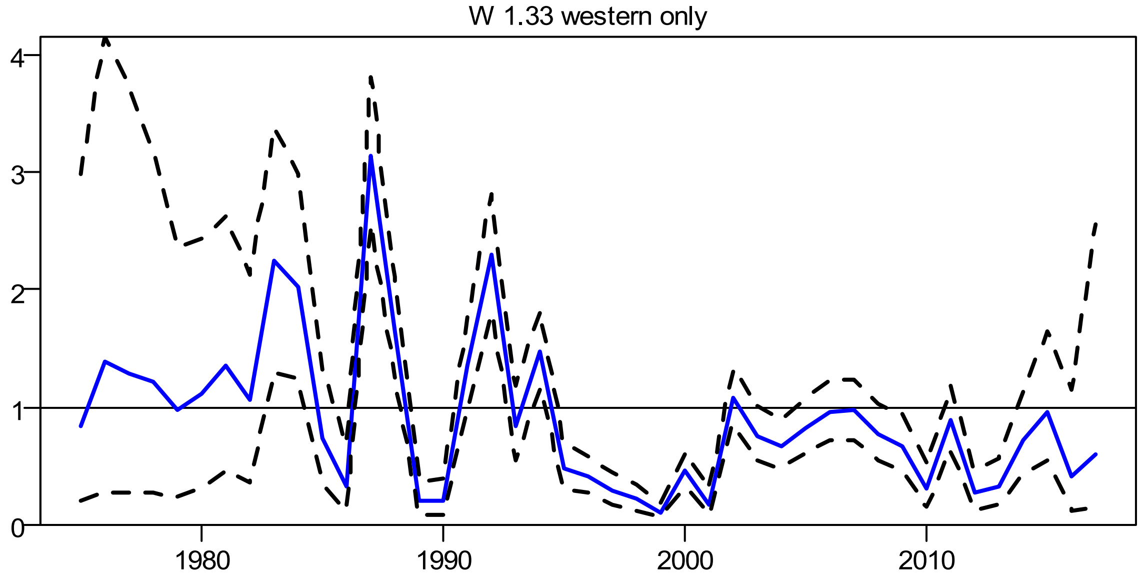

Figure 80: Estimated true year-class strengths (YCSs) from run 1.33 (western only) showing medians (solid lines) and 95% credible intervals (broken lines).

7. PROJECTIONS

Five-year projections were carried out for the four model runs by selecting future recruitments at random from two scenarios: (i) from those estimated for 2008–2017, and (ii) from those estimated for 1975–2017. Total future annual catch was assumed to equal that in 2019 of 135 500 t with 64 000 t catch for the east stock and 71 500 t for the west stock. The projections indicate that the E biomass will increase slightly over the next 5 years and remain above the target zone (Figures 81–82, Tables 28–29). The W biomass will increase in either recruitment scenario under the 1.17 two stock (update) model and remain above the target zone. For the other two model runs where the Sub-Antarctic trawl survey is fitted better (runs 1.33, 1.34) the future W biomass is scenario dependent: (i) with recruitment from 2008–2017 the W biomass is flat and likely to remain under the target zone, and (ii) with recruitment from 1975–2017 the W biomass will increase and likely be in the target zone by the end of the projection period.

For the east stock the estimated probability of being less than the soft or the hard limit at the end of the five year projection period is negligible (Tables 30–31). For the west stock the estimated probability of being less than the hard limit at the end of the five projection period is negligible, but there is a greater than 10% chance of being below the soft limit in 5 years for the model runs where the Sub-Antarctic trawl survey is fitted better (runs 1.33, 1.34).

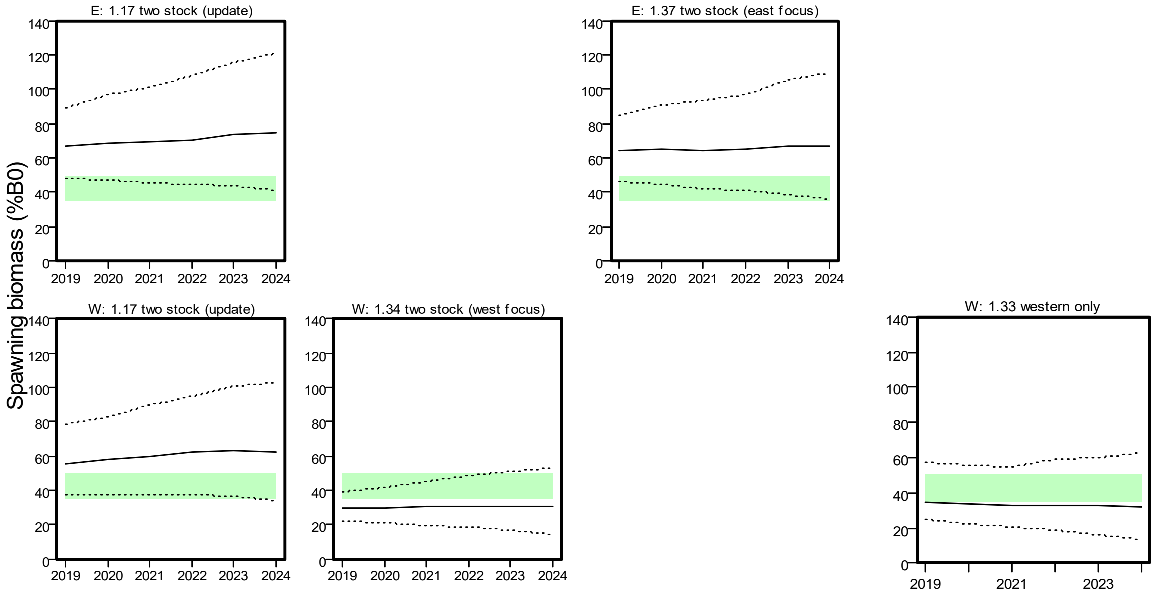

Figure 81: Scenario with random recruitment from 2008–2017. Projected spawning biomass (as %B_0): median (solid lines) and 95% credible intervals (broken lines) for the four final model runs. The shaded green region represents the target management range of 35–50% B_0.

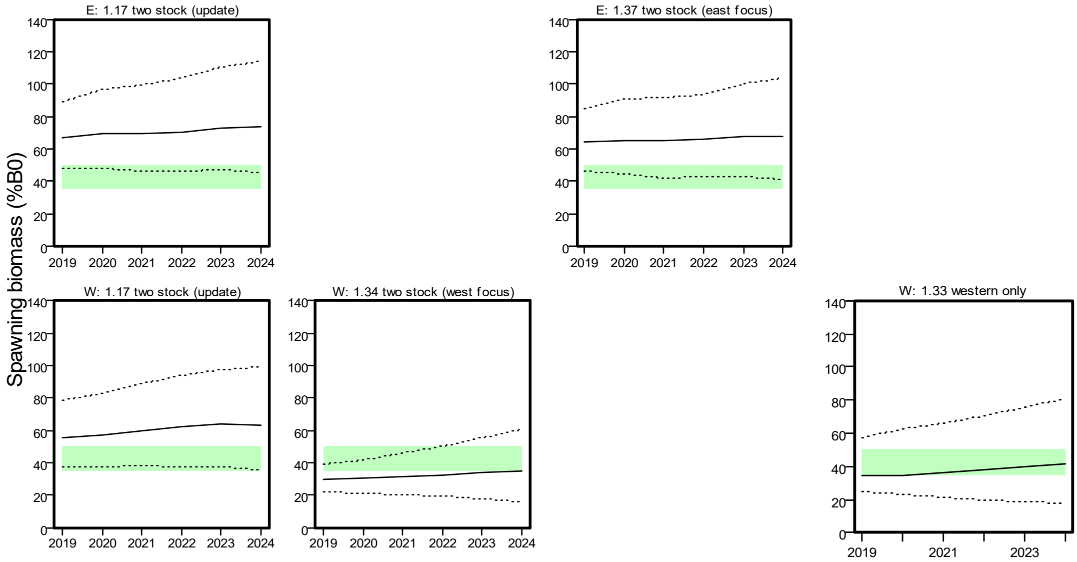

Figure 82: Scenario with random recruitment from 1975–2017. Projected spawning biomass (as %B_0): median (solid lines) and 95% credible intervals (broken lines) for the four final model runs. The shaded green region represents the target management range of 35–50% B_0.

Table 28: SSB (%B_0) associated with projections for the final model runs for 2019 through to 2024. Scenario with random recruitment from 2008–2017.

	2019	2020	2021	2022	2023	2024
EAST 1.17	67	69	70	71	73	74
EAST 1.37	64	65	64	65	67	67
WEST 1.17	56	57	60	62	63	62
WEST 1.34	29	30	30	31	31	30
WEST 1.33	34	34	33	33	33	32

Table 29: SSB (%B_0) associated with projections for the final model runs for 2019 through to 2024. Scenario with random recruitment from 1975–2017.

	2019	2020	2021	2022	2023	2024
EAST 1.17	67	69	69	70	73	74
EAST 1.37	64	65	65	66	68	68
WEST 1.17	56	57	60	63	64	63
WEST 1.34	29	30	31	32	34	35
WEST 1.33	34	35	36	38	40	42

Table 30: Probabilities (to two decimal places) associated with projections for SSB (%B_0) for the final model runs for 2019 through to 2024. Scenario with random recruitment from 2008–2017.

	2019	2020	2021	2022	2023	2024
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	0	0.01
P (SSB<50%B_0)	0.05	0.04	0.06	0.07	0.07	0.09
EAST 1.37						
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	0.01	0.01	0.01	0.02
P (SSB<50%B_0)	0.06	0.08	0.12	0.13	0.13	0.16
WEST 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)	0.01	0.01	0.02	0.01	0.02	0.03
P (SSB<50%B_0)	0.28	0.25	0.21	0.18	0.18	0.22
WEST 1.34						
P (SSB<10%B_0)	0	0	0	0	0	0
P (SSB<20%B_0)	0.01	0.02	0.03	0.05	0.08	0.13
P (SSB<35%B_0)	0.88	0.82	0.76	0.70	0.67	0.67
P (SSB<50%B_0)	1	1	0.99	0.98	0.97	0.96
WEST 1.33						
P (SSB<10%B_0)	0	0	0	0	0	0
P (SSB<20%B_0)	0	0	0.02	0.04	0.07	0.11
P (SSB<35%B_0)	0.55	0.57	0.60	0.57	0.58	0.60
P (SSB<50%B_0)	0.95	0.96	0.95	0.93	0.92	0.91

Table 31: Probabilities (to two decimal places) associated with projections for SSB (%B$_0$) for the final model runs for 2019 through to 2024. Scenario with random recruitment from 1975–2017.

	2019	2020	2021	2022	2023	2024
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	0	0
P (SSB<50%B$_0$)	0.05	0.04	0.06	0.06	0.05	0.06
EAST 1.37						
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	0.01
P (SSB<50%B$_0$)	0.06	0.08	0.10	0.10	0.10	0.11
WEST 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$_0$)	0.01	0.01	0.02	0.01	0.02	0.02
P (SSB<50%B$_0$)	0.28	0.24	0.20	0.15	0.16	0.19
WEST 1.34						
P (SSB<10%B$_0$)	0	0	0	0	0	0
P (SSB<20%B$_0$)	0.01	0.02	0.03	0.04	0.05	0.06
P (SSB<35%B$_0$)	0.88	0.81	0.72	0.62	0.54	0.51
P (SSB<50%B$_0$)	1	1	0.99	0.97	0.93	0.88
WEST 1.33						
P (SSB<10%B$_0$)	0	0	0	0	0	0
P (SSB<20%B$_0$)	0	0	0.01	0.03	0.03	0.04
P (SSB<35%B$_0$)	0.55	0.50	0.45	0.39	0.34	0.32
P (SSB<50%B$_0$)	0.95	0.91	0.86	0.81	0.75	0.70

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 $m_{x\%}U_{\text{current}}$, where the multiplier, $m_{x\%}$ (calculated by interpolation) was that which caused the equilibrium biomass of that stock to be x% B_0.

Fishing intensities 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 83).

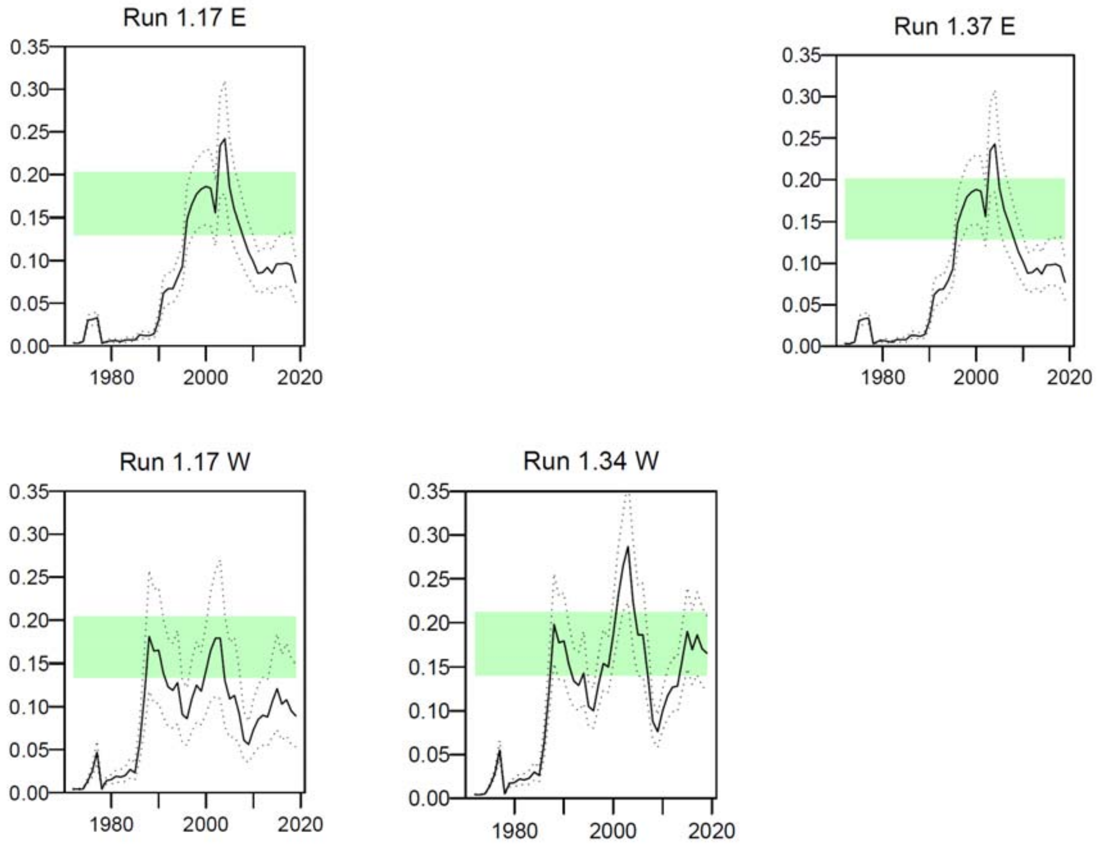

Figure 83: Fishing intensities, U (from MCMCs), for the two stock models (update (run 1.17), west focus (run 1.34), east focus (run 1.37)), plotted by stock. Shown are medians (solid black line) with 95% confidence intervals (dotted lines). Also shown shaded in green is the management range where the 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. DISCUSSION

For the eastern stock, biomass is estimated to be above the target range for all final model runs, and to increase over the next five years with the current catch. The current and projected status for the western stock is more uncertain and depends on the weight given to the western data.

The current western biomass was estimated to be 56%B_0 (median value) for the updated two-stock model, 34%B_0 (western stock only model), and 29%B_0 (two stock with a west focus). Current eastern biomass estimates were 66%B_0 (two stock update) and 64%B_0 (two stock with east focus).

The projections indicate that the eastern biomass will increase slightly over the next five years and remain above the target zone. The western biomass will increase in either scenario under the two stock (update) model and remain above the target zone. For the other two model runs where the Sub-Antarctic trawl survey is fitted better (two stock with a western focus, western only) the future western biomass is scenario dependent: (i) with recruitment from 2008–2017 the western biomass is flat and likely to remain under the target zone, and (ii) with recruitment from 1975–2017 the western biomass will increase and likely be in the target zone by the end of the projection period.

The uncertainty in this assessment is almost certainly greater than is implied by the confidence limits presented above. There are three types of uncertainty. 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.

10. ACKNOWLEDGMENTS

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Appendix 1: Files defining the final runs

Each of the final model runs is completely defined, in the context provided by the CASAL manual (Bull et al. 2012), by two input files — population.csl and estimation.csl — and, for runs with an age varying natural mortality, a user.prior_penalty.cpp file. These files, for the final model runs, 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
2019	No base model, instead a range of models with different weightings given to fitting eastern or western biomass indices.

Appendix 3: Reweighting the 2019 assessment at-age data

The same procedure as in McKenzie (2019) was used to reweight the at-age data for the update model run 1.1. Summary results from the reweighting are shown in the tables and figures below. Mean values for the effective sample size at each stage of the reweighting procedure are shown in Table 32, and final mean N values are very similar to those for the analogous model run 1.1 for the 2018 assessment (Table 33). The west stock is more sensitive than the east stock to the weightings given to the data (Figure 84).

Table 32: 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	667	910	89	339	80	208	1351	574	829
2	58	34	12	40	95	19	85	14	24
3	70	25	12	35	62	17	61	15	16
4	79	23	12	33	59	17	55	16	16
5	84	22	12	32	59	18	53	17	15
Final	85	21	13	32	59	18	52	17	15
Initial/Final	8	43	7	11	1	12	26	34	55

Table 33: Comparing final mean values of N for at age data sets in the model: 1.1 from the 2017 assessment (denoted 2017.1), 1.1 from the 2018 assessment (denoted 2018.1) and the updated version 1.1 for the 2019 assessment (denoted 1.1).

Model	Espage	Wspage	EnspOLF	Enspage	WnspOLF	Wnspage	CRsumage	SAsumage	SAautage
2017.1	84	19	12	38	57	16	63	18	14
2018.1	84	19	14	29	58	16	54	18	14
1.1	85	21	13	32	59	18	52	17	15

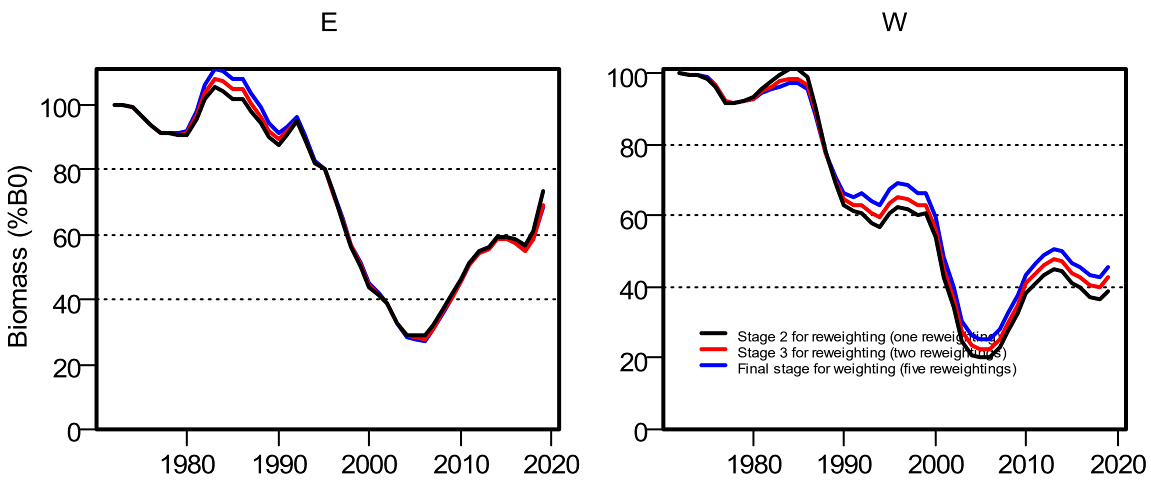

Figure 84: Updated model 1.1. biomass trajectories for different weightings of the data (see Table 32). At stages 2, 3, and final the Sub-Antarctic trawl survey process error is 0.32, 0.34, and 0.35 respectively.

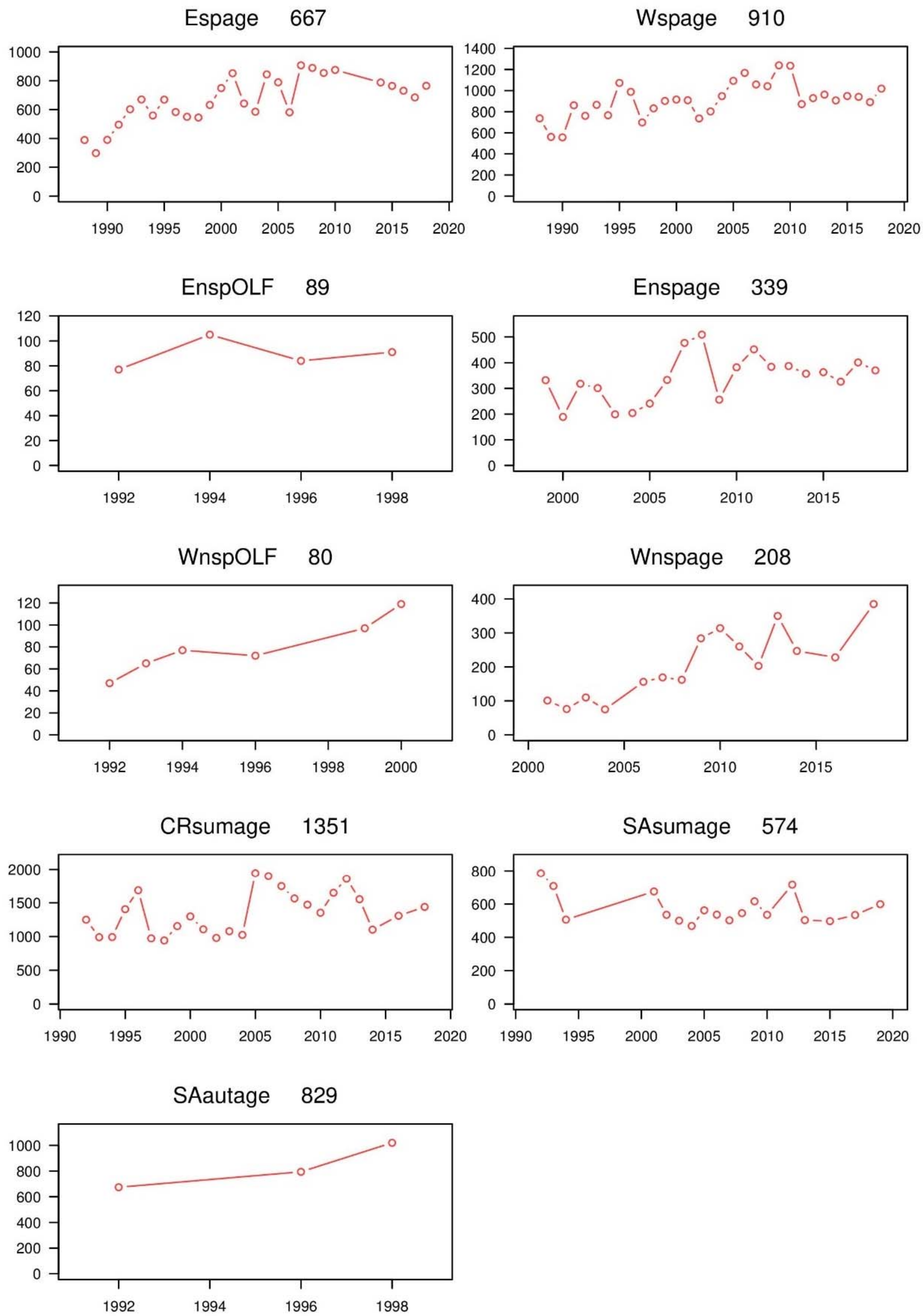

Figure 85: Model 1.1. Equivalent multinomial N values for the observational error. The number above each panel is the mean value over the fishing years.

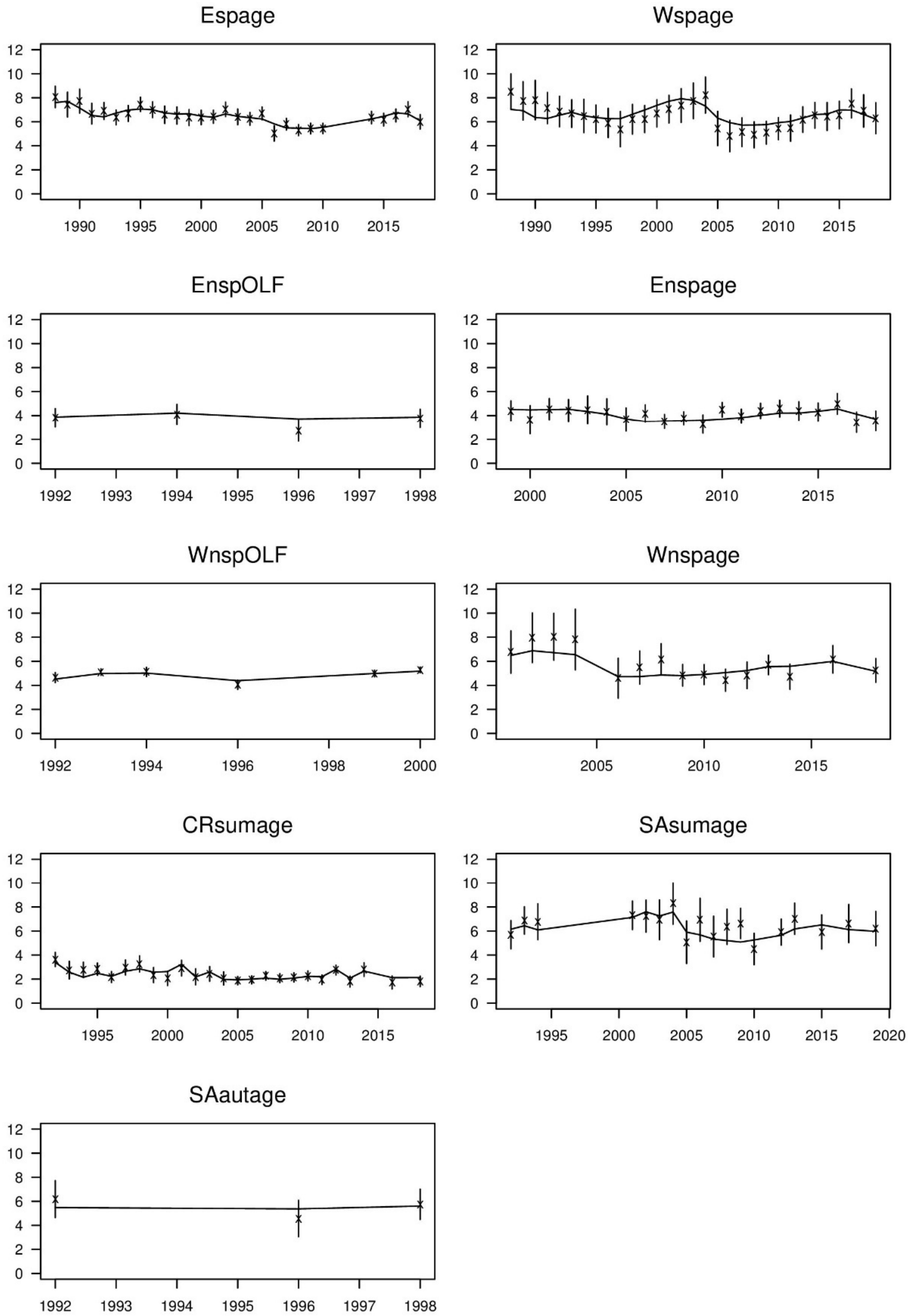

Figure 86: Model 1.1. Observed mean age ('x', with 95% confidence intervals as vertical lines) and expected (lines) for the at-age data sets in updated run 1.1 after reweighting.

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

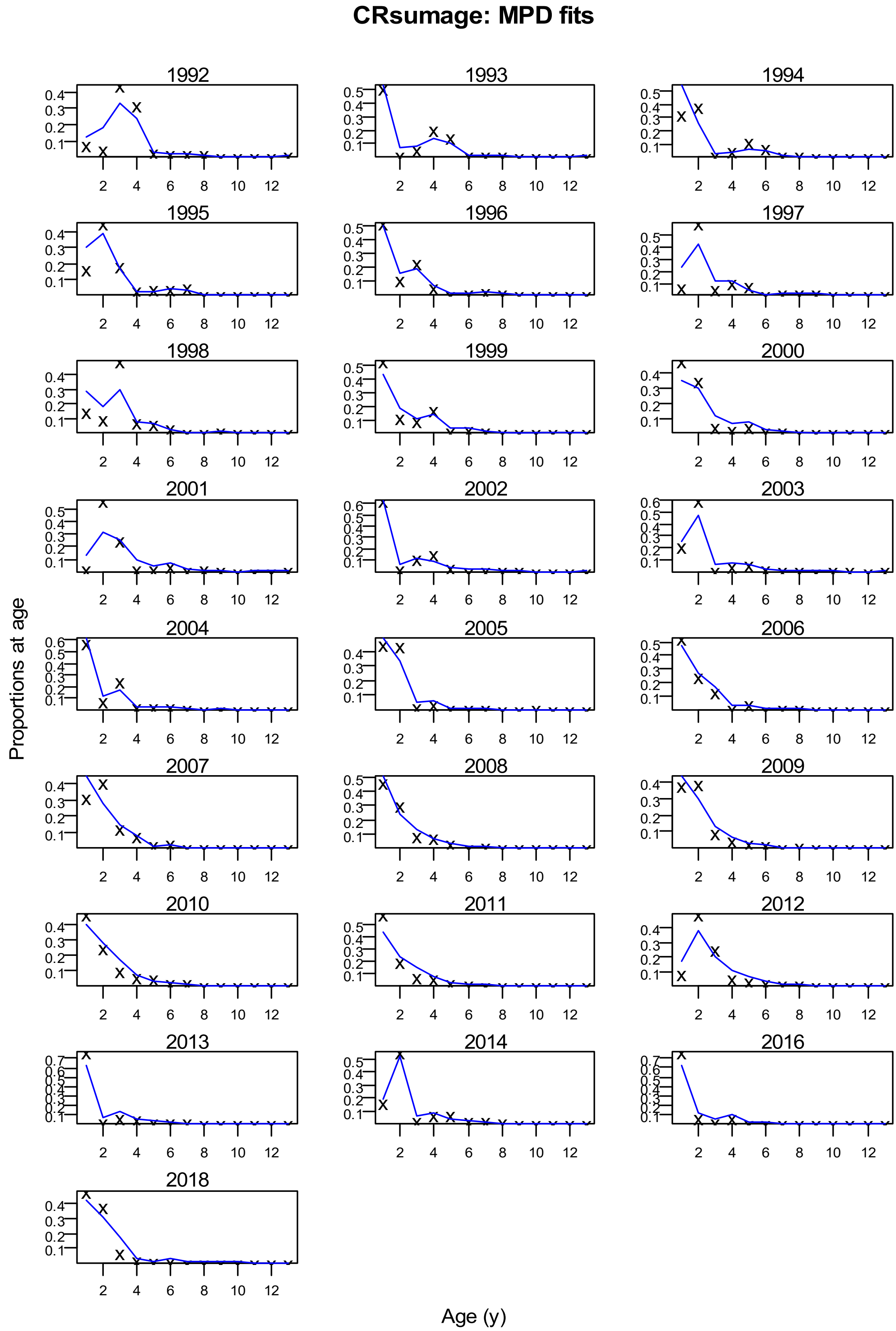

Figure 87: MPD fits to CRsumage. Observed ('×') and expected (lines) for run 1.1. Male and female observed and expected proportions are summed for an age group.

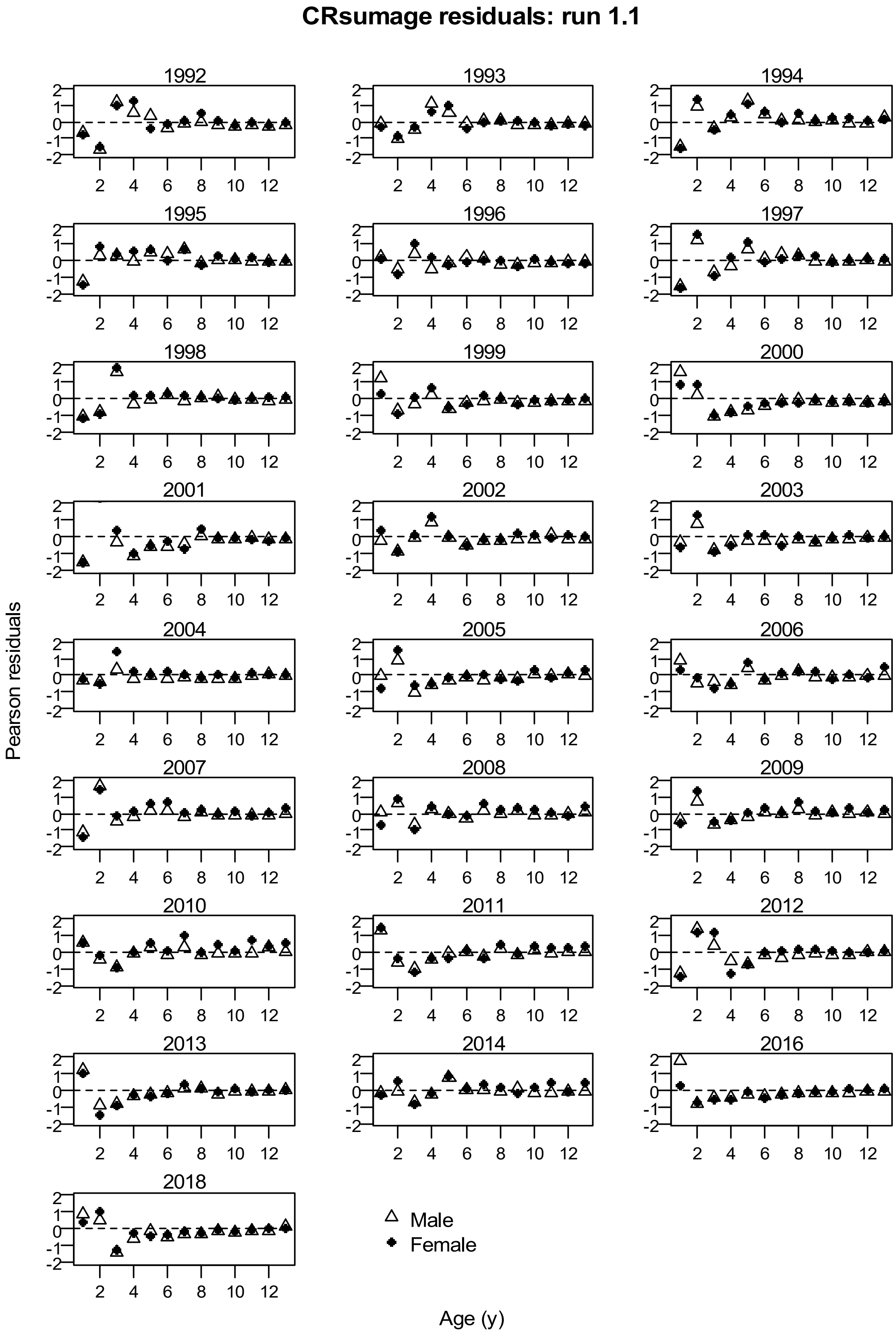

Figure 88: MPD Pearson residuals for the fit to CRsumage for run 1.1.

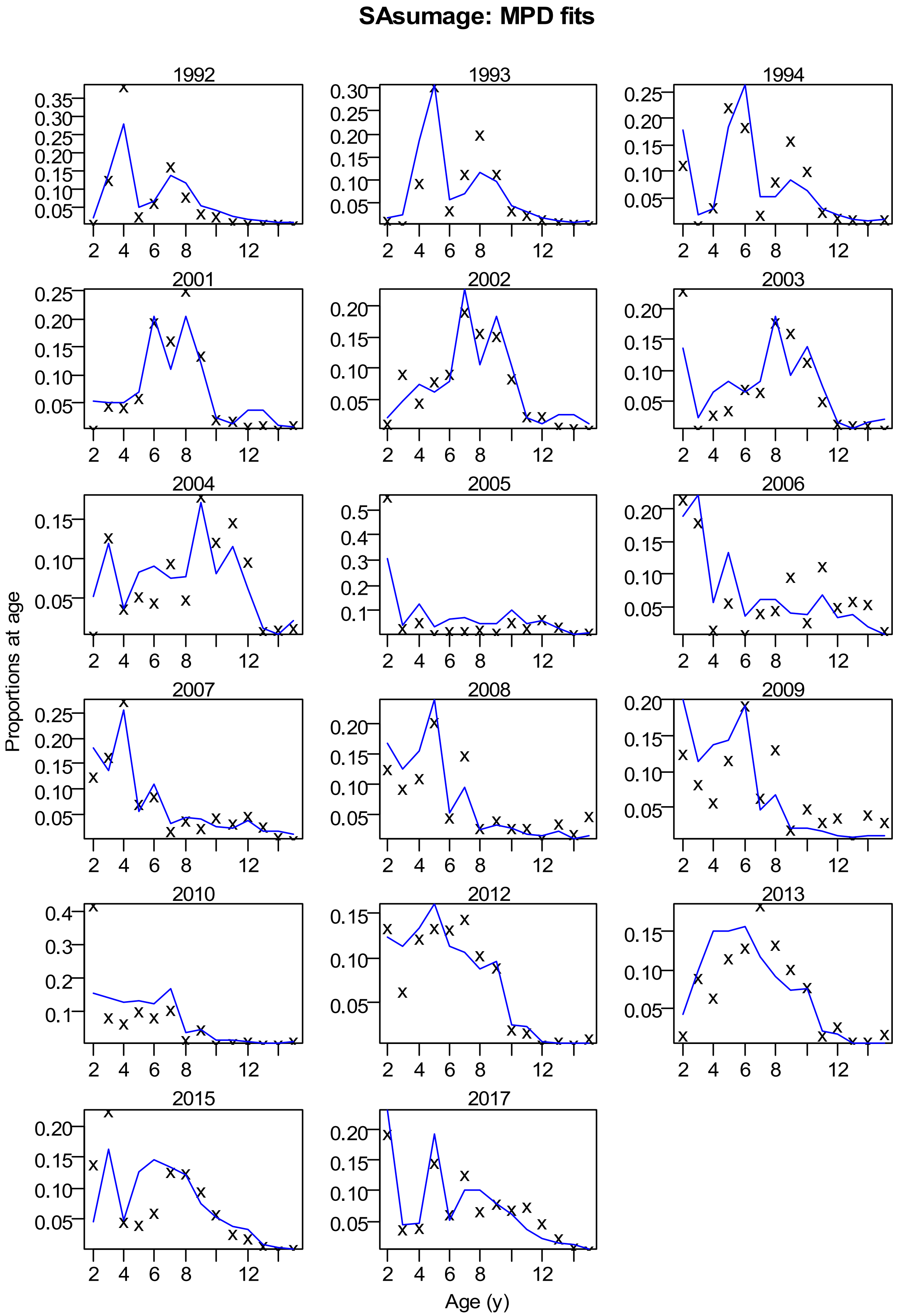

Figure 89: MPD fits to the SAsumage data. Observed (‘×’) and expected (lines) for run 1.1. Male and female observed and expected proportions are summed for an age group.

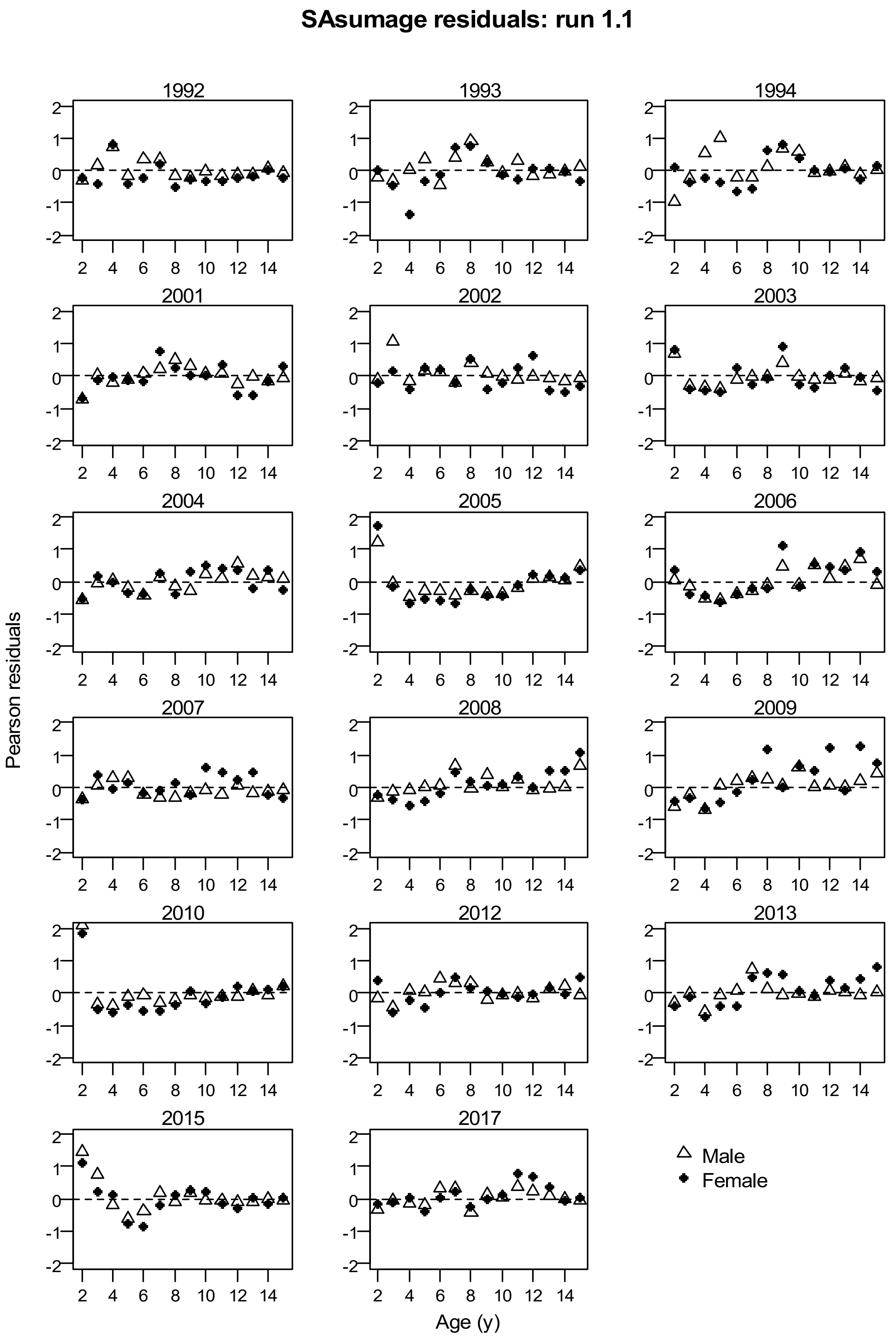

Figure 90: MPD Pearson residuals for the fit to SAsumage for run 1.1.

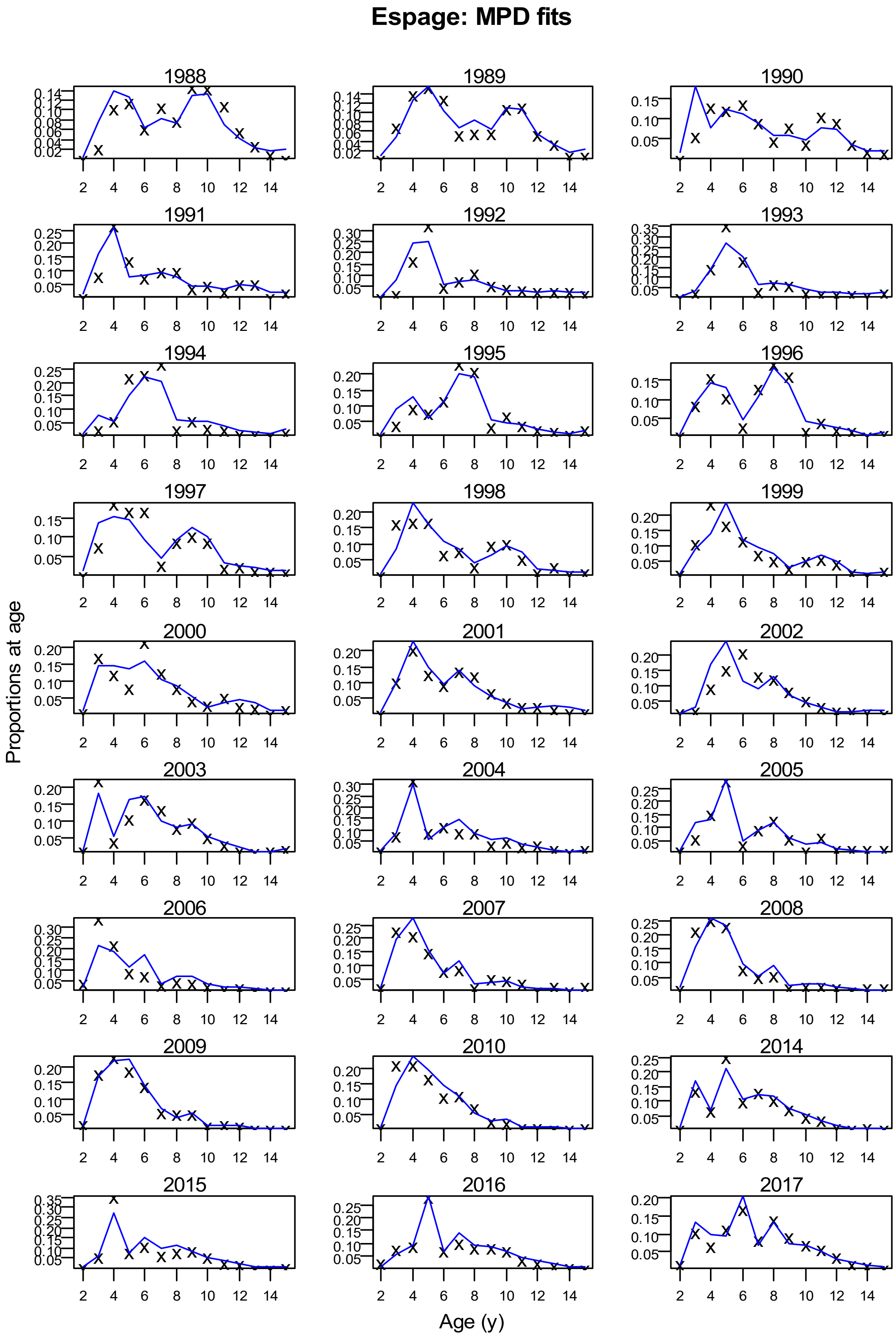

Figure 91: MPD fits to the Espage data. Observed ('×') and expected (lines) for run 1.1. Male and female observed and expected proportions are summed for an age group.

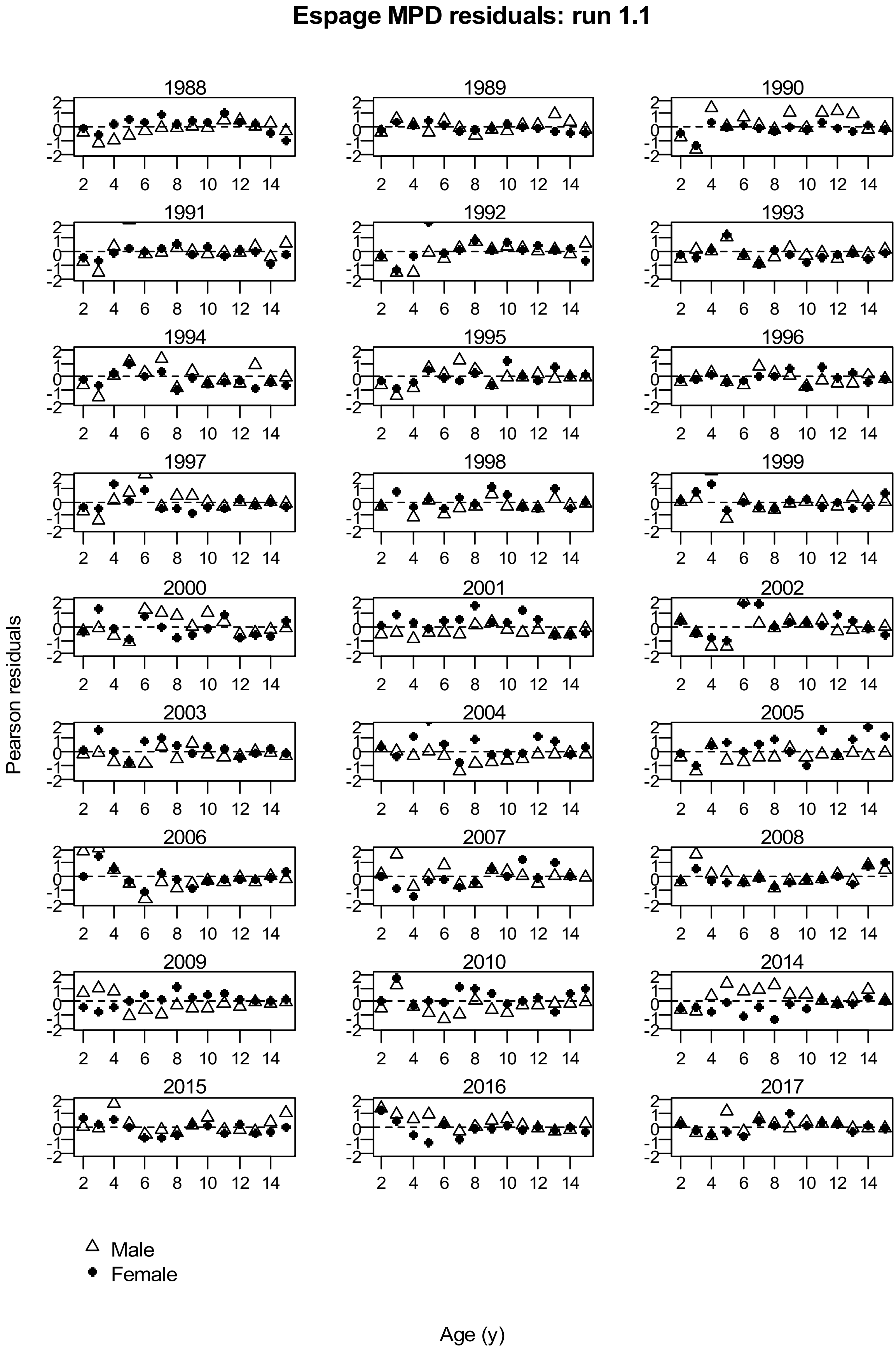

Figure 92: MPD Pearson residuals for the fits to Espage data in run 1.1.

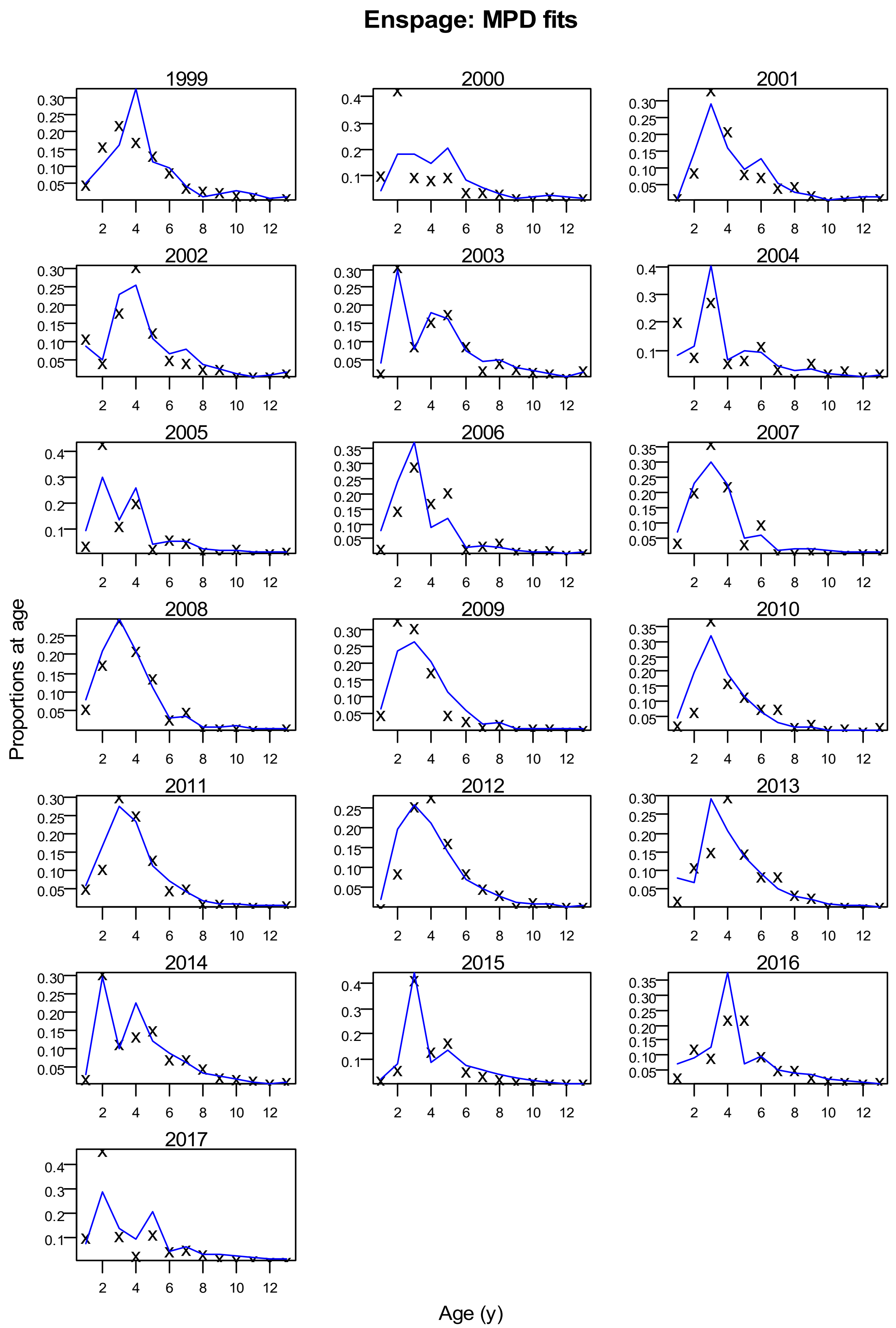

Figure 93: MPD fits to the Enspage data. Observed ('×') and expected (lines) for run 1.1. Male and female observed and expected proportions are summed for an age group.

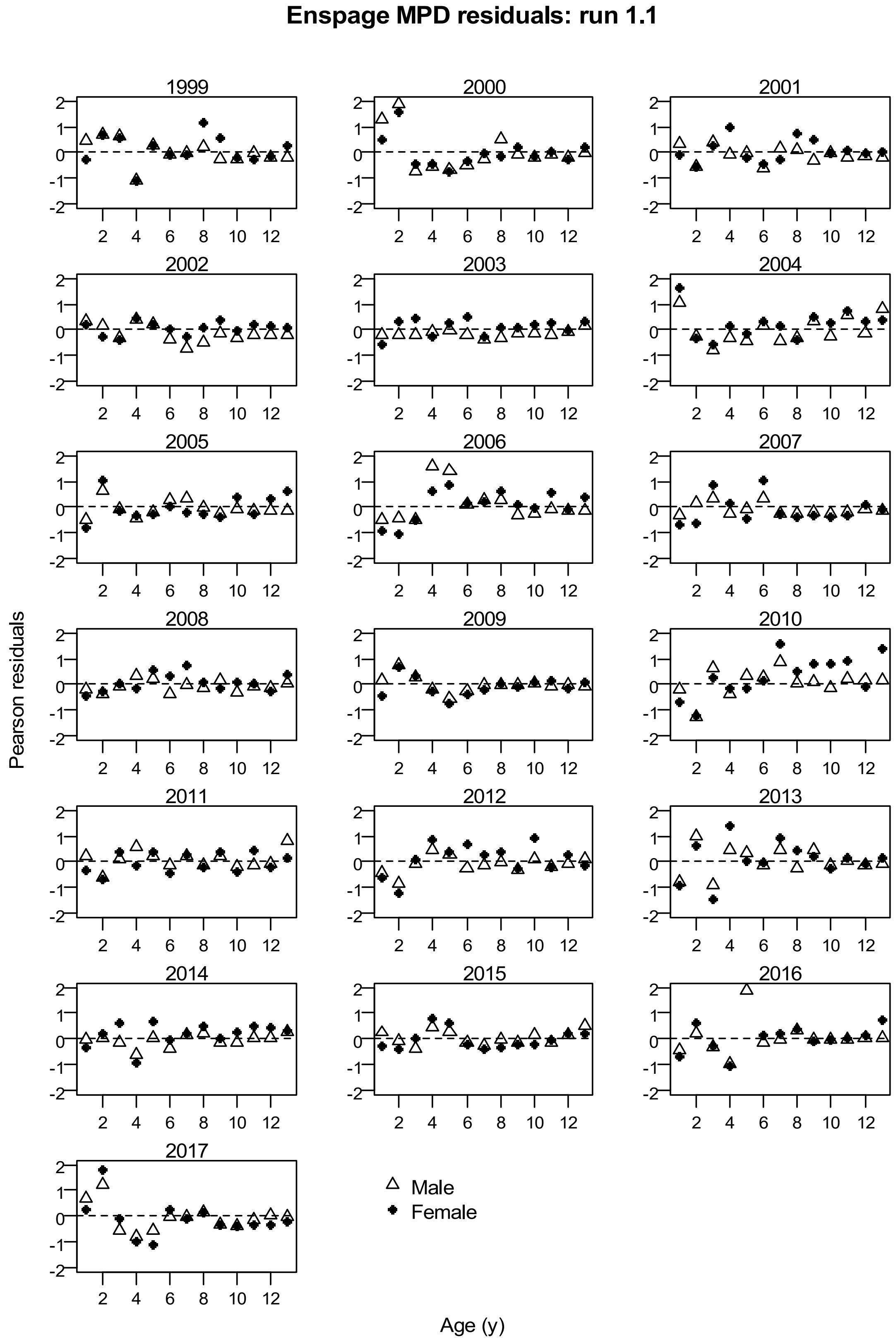

Figure 94: MPD Pearson residuals for the fits to Enspage data in run 1.1.

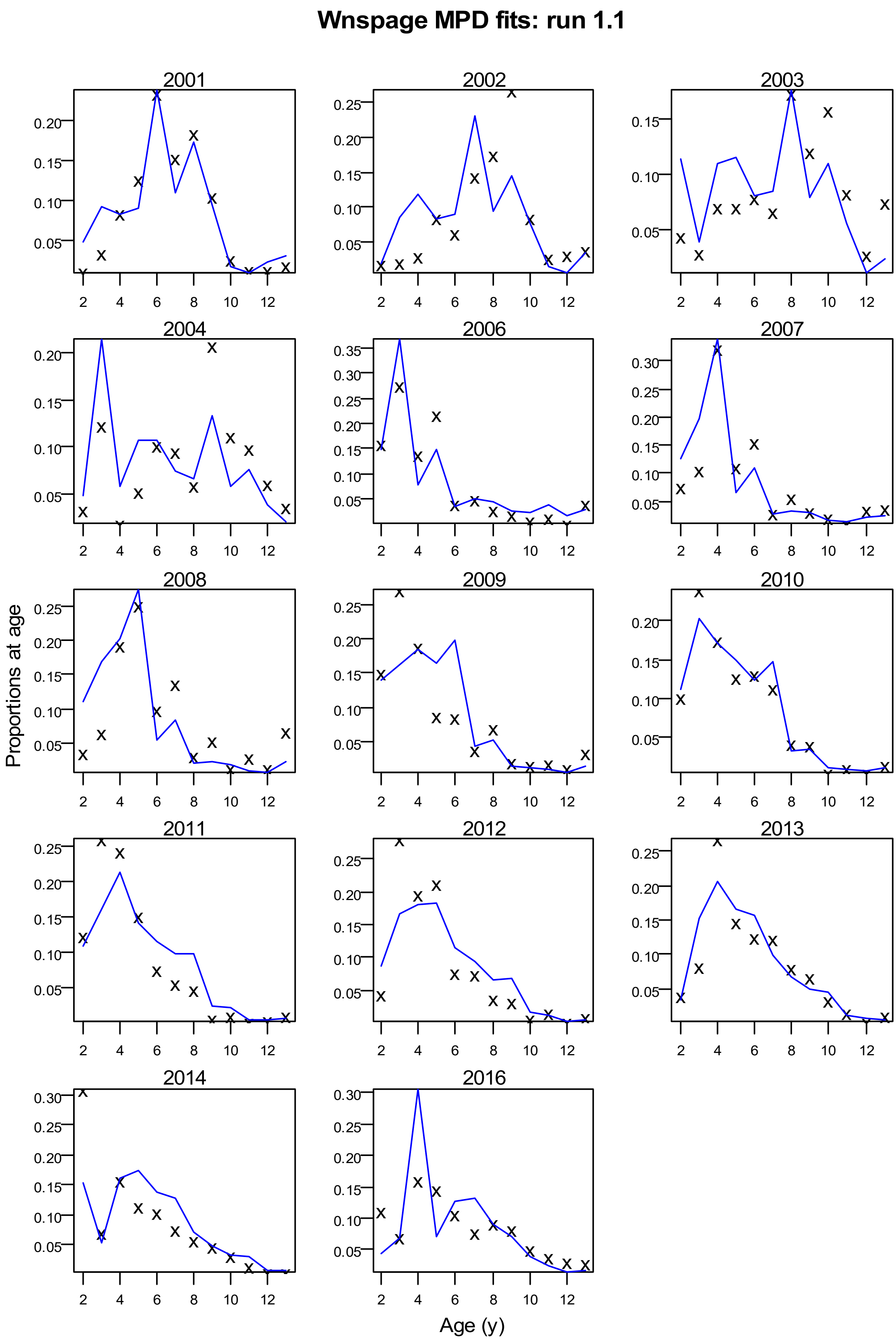

Figure 95: MPD fits to the Wnspage data. Observed ('×') and expected (lines) for run 1.1. Male and female observed and expected proportions are summed for an age group.

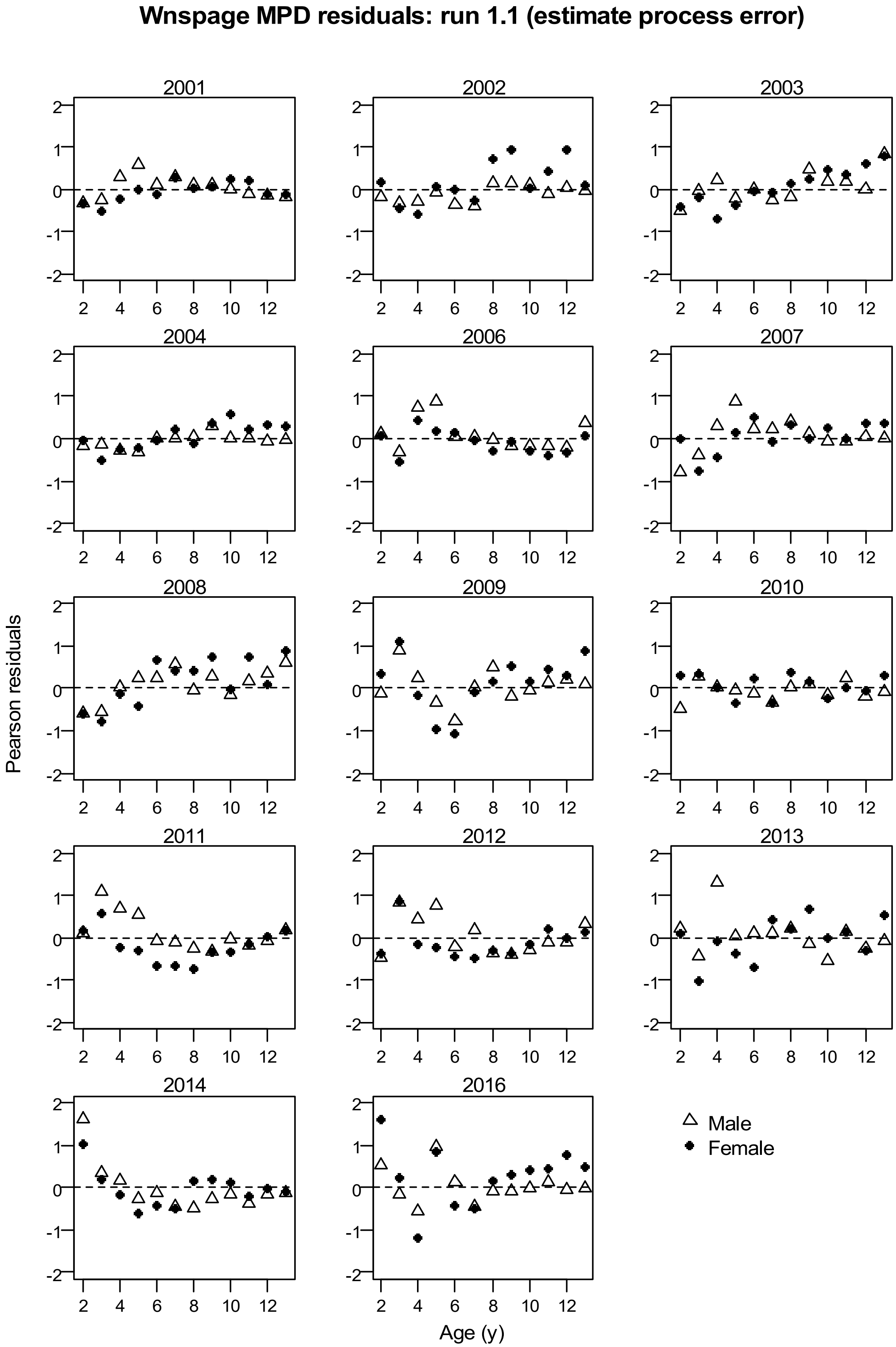

Figure 96: MPD Pearson residuals for the fits to Wnspage data in run 1.1.

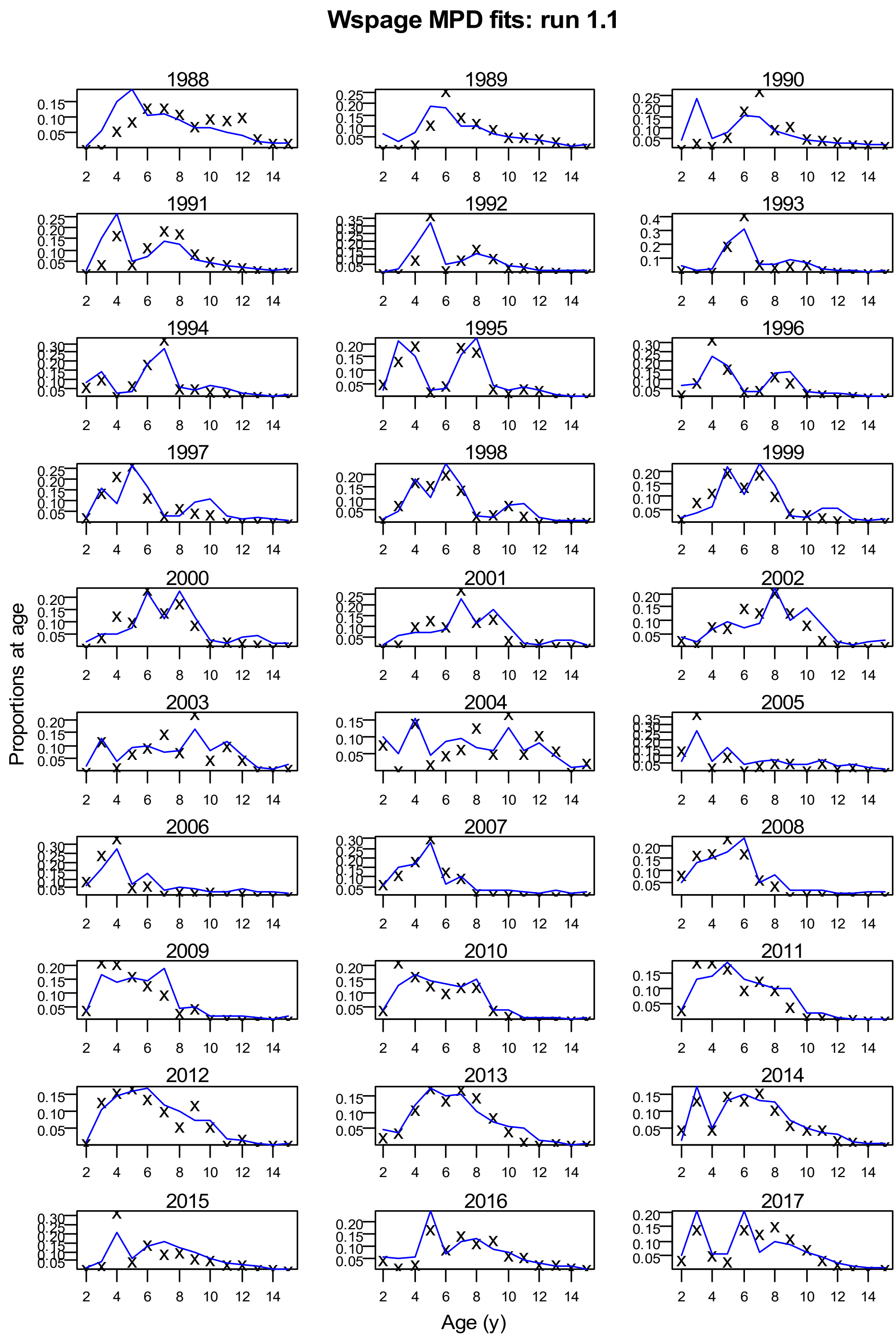

Figure 97: MPD fits to the Wspage data. Observed ('×') and expected (lines) for run 1.1. Male and female observed and expected proportions are summed for an age group.

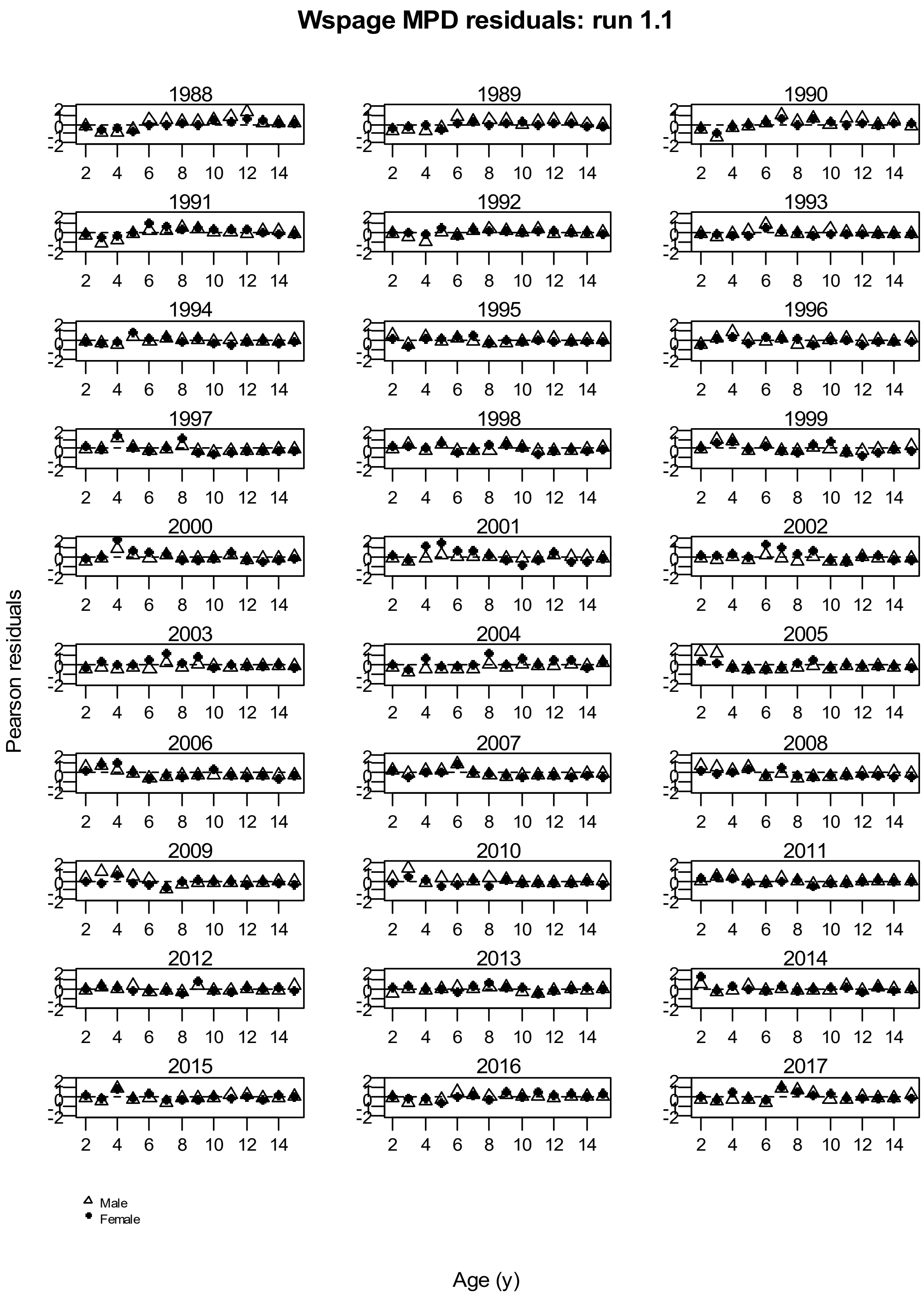

Figure 98: MPD Pearson residuals for the fits to Wspage data in run 1.1.

Appendix 5: 2019 assessment proposed selectivity steps

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13 March 2019

We considered potential selectivity 'break-points' - years at which there may have been a sudden change in the selectivity of the four main hoki fisheries. The report describes the years that were chosen, and the rationale for their choice.

Our starting point was Appendix 5 of *Francis (2008). Assessment of hoki (Macruronus novaezelandiae) in 2007. New Zealand Fisheries Assessment Report 2008/4. 109 p.* This appendix was prepared by a subcommittee convened by Rosie Hurst; other members were Vivian Haist, David Middleton, Richard O'Driscoll, and Richard Wells.

Factors considered by this subcommittee included:

- Change in size/age structure of fished population
- Change in fleet structure (nationality, processing type)
- Change in gear type (twin trawls, BT v. MW trawl)
- Change in fleet operation (e.g., Code of Practice; operation inside restricted areas such as WCSI 25 mile area; issues with mopping up quota at the end of the fishing year)

We re-considered the suggested break-points in Francis (2008), and updated the analysis considering data collected in the past 10 years. We also ranked the potential break-points in order of our feeling about their potential influence.

All of the break-points suggested in Francis (2008) were retained, and are indicated in italics below. New breaks based on more recent data are in plain text.

West coast South Island spawning fishery

1. Break between 2004 and 2005: Potential switch to younger fish observed as shift in mean age with occurrence of some recruitment from 2002 year-class. TACC reductions and change in fleet structure.
2. *Break between 1998 and 1999: Change in fish size through the season no longer apparent; more fishing by larger inshore vessels inside the line (targeting larger fish); surimi fleet much reduced in number and proportion of catch (size of fish was not an issue); about the time of the introduction of twin trawling on WCSI.*
3. Break between 2011 and 2012: Development of May fishery inside the line. Change in fish size during the season once again apparent.
4. Break between 2016 and 2017: Greater proportion of catch taken by twin trawling since 2017 (> 8000 t in 2017 and 2018, when previously low).

Cook Strait

1. *Break between 1995 and 1996: Start of increased catch in northern area (from TCEPR) spawning fishery.*
2. *Break between 1999 and 2000: Reduction of catch in northern area. Note that this reduction happened before introduction of Code of Practice in 2001. Catches in northern area were very low from 2002.*
3. Break between 2004 and 2005: Change in fleet structure with fewer small vessels. Changing fleet structure was accompanied by trend towards fishing in deeper water.

Sub-Antarctic non-spawning fishery

1. *Break between 2004/05 and 2005/06: Proportion of the hoki catch caught by the hoki target fishery declined below 80%. Change in fleet structure.*
2. Break between 2008/09 and 2009/10: Proportion of hoki catch caught by hoki target fishery once again over 80%. Percent of catch taken by twin trawling since exceeds 30%.

Chatham Rise non-spawning fishery

1. *Break between 1994/95 and 1995/96: Evidence of increased targeting of small fish.*
2. *Break between 1999/2000 and 2000/01: Introduction of Code of Practice with measures to increase avoidance of small fish.*
3. Break between 2007/08 and 2008/09. Increase in twin trawling. Percent of catch taken by twin trawling since exceeds 30%.