



## Assessment of hoki (*Macruronus novaezelandiae*) in 2014

New Zealand Fisheries Assessment Report 2015/09

A. McKenzie

ISSN 1179-5352 (online)  
ISBN 978-0-477-10550-7 (online)

February 2015



Requests for further copies should be directed to:

Publications Logistics Officer  
Ministry for Primary Industries  
PO Box 2526  
WELLINGTON 6140

Email: [brand@mpi.govt.nz](mailto:brand@mpi.govt.nz)  
Telephone: 0800 00 83 33  
Facsimile: 04-894 0300

This publication is also available on the Ministry for Primary Industries websites at:  
<http://www.mpi.govt.nz/news-resources/publications.aspx>  
<http://fs.fish.govt.nz> go to Document library/Research reports

**© Crown Copyright - Ministry for Primary Industries**

## CONTENTS

|  |    |
|--|----|
| 1. INTRODUCTION .....  | 2  |
| 2. MODEL ASSUMPTIONS AND INPUTS FOR 2014 .....                                 | 4  |
| 2.1 Model structure and catches.....   | 5  |
| 2.2 Ogives .....   | 9  |
| 2.3 Other structural assumptions.....  | 10 |
| 2.4 Observations .....   | 10 |
| 2.5 Error assumptions .....  | 14 |
| 2.6 Parameters, priors, and penalties.....                                     | 14 |
| 2.7 No natal fidelity model structure .....                                    | 15 |
| 3. PRE-ASSESSMENT MODEL RUNS.....  | 16 |
| 3.1 Background .....   | 16 |
| 3.2 Posterior profile on run 1.7 from the 2013 assessment .....                | 17 |
| 3.3 Other posterior profiles .....   | 24 |
| 3.4 MCMC with Haist and uniform.....   | 26 |
| 3.5 Conclusions.....   | 29 |
| 4. INITIAL EXPLORATORY MODEL RUNS.....   | 29 |
| 4.1 Comparison to a final model run from the previous assessment in 2013 ..... | 30 |
| 4.2 2014 MPD results: trawl upweighting and data sensitivities .....           | 34 |
| 5. FINAL MODEL ASSESSMENT RESULTS.....   | 40 |
| 6. PROJECTIONS .....   | 60 |
| 7. FISHING PRESSURE .....  | 62 |
| 8. CALCULATION OF $B_{MSY}$ .....  | 62 |
| 9. DISCUSSION .....  | 63 |
| 10. ACKNOWLEDGMENTS .....  | 63 |
| 11. REFERENCES .....   | 64 |
| Appendix 1: Files defining the final runs .....                                | 65 |
| Appendix 2: Changes in stock-assessment model assumptions.....                 | 65 |
| Appendix 3: Reweighting the 2014 assessment at-age data .....                  | 66 |



## EXECUTIVE SUMMARY

McKenzie, A. (2015). Assessment of hoki (*Macruronus novaezelandiae*) in 2014.

*New Zealand Fisheries Assessment Report 2015/09. 68 p.*

An updated assessment is presented for hoki that is based on the 2013 assessment. The assessment uses the same program (CASAL), stock structure (two stocks in four fishing grounds), and estimation procedure (Bayesian with lognormal errors, including a distinction between observation and process errors) as in previous assessments. Three data types were used: biomass indices (from trawl and acoustic surveys), proportions-at-age and sex (from trawl surveys and the four fisheries), and proportion spawning. The biomass indices new to this assessment were a trawl survey from the Chatham Rise in January 2014, an acoustic survey of spawning hoki for Cook Strait in winter 2013, and an acoustic survey of spawning hoki on the west coast South Island in winter 2013. New proportions-at-age data came from the four commercial fisheries and the Chatham Rise research trawl survey.

The Deepwater Working Group agreed on a single base model run. In this base model the problem of the lack of old fish in both fishery-based and survey-based observations is dealt with by allowing natural mortality to be age dependent. To improve fits to the Southern Plateau survey series two alternative models were investigated where two catchabilities were fitted to the Southern Plateau series instead of just one: (i) a different catchability from other years was used for 2004–07 inclusive, and (ii) a different catchability from other years was used for 2008–13 inclusive. However, it was decided that for a time series of the length of the Southern Plateau series it was not unexpected statistically for there to be a series of years where the biomass was consecutively low/high, and two catchabilities were not needed.

Both the eastern and western hoki stocks are estimated to be increasing after reaching their lowest levels in about 2006. The western stock is estimated to be 48–66%B<sub>0</sub> and the eastern stock 59–67%B<sub>0</sub> (values are ranges for the medians of model runs). The western stock experienced an extended period of poor recruitment from 1995 to 2001 inclusive. However, recruitment has been near or above average since 2001, except for in 2010 and 2012 where it was likely to have been below average (although estimated with high uncertainty for both years).

Five-year projections were carried out with future recruitments selected at random for those estimated in 2003–2012. Future catches for each fishery were assumed to be equal to those assumed for 2014. The projections indicate that with this assumed catch, the eastern and western biomasses are likely to remain stable or rise slightly over the next 5 years.

## 1. INTRODUCTION

Hoki (*Macruronus novaezelandiae*) is the most abundant commercial finfish species in New Zealand waters, and has been our largest fishery since the mid 1980s. It is widely distributed throughout New Zealand's Exclusive Economic Zone in depths of 50–800 m, but most commercial fishing is at depths of 200–800 m. There are four main fisheries: two on spawning grounds (west coast South Island and Cook Strait), and two on feeding grounds (Chatham Rise and Southern Plateau) (Figure 1). Since the introduction of the QMS (Quota Management System), hoki has been managed as a single fishstock, HOK 1; HOK 10 is purely administrative (Figure 2). Before 2003–04, the TACC fluctuated between 200 000 t and its initial (1986–87) level of 250 000 t. In response to a series of poor recruitments the TACC was dropped to 180 000 t for 2003–04, to 100 000 t for 2004–05, and to 90 000 t in 2007–08 (Ministry of Fisheries 2010). More recent assessments indicated that stock status had improved, and consequently the TACC was increased, with the last increase being to 160 000 t for 2014–15.

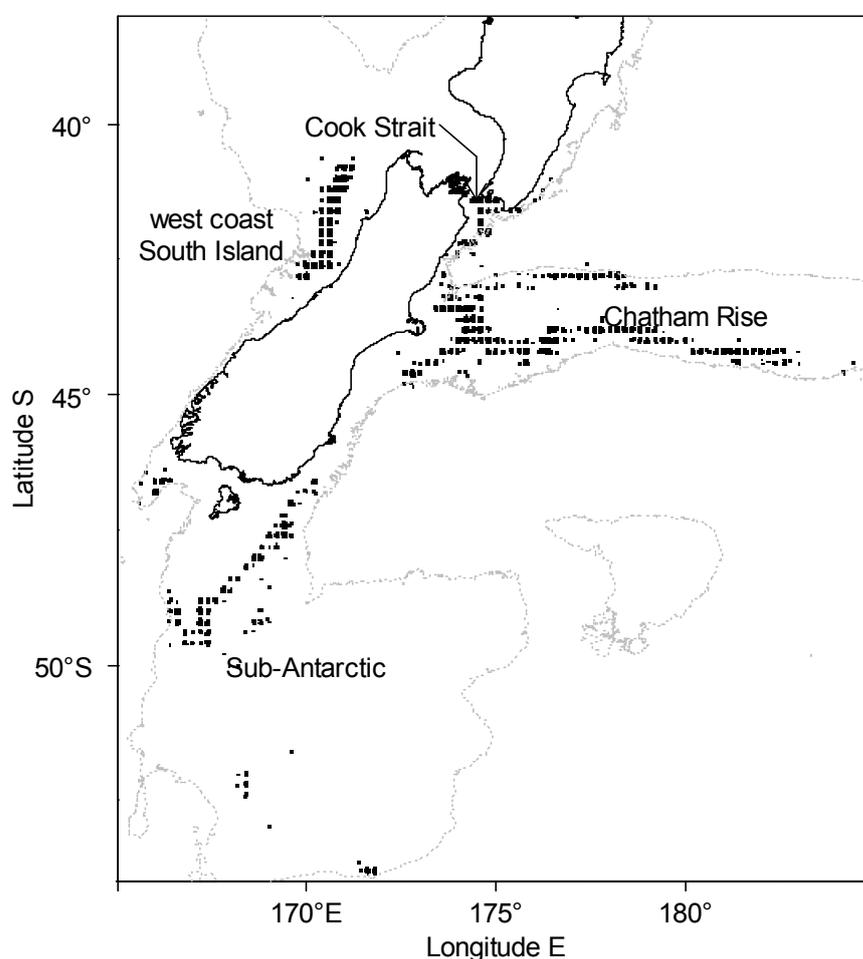
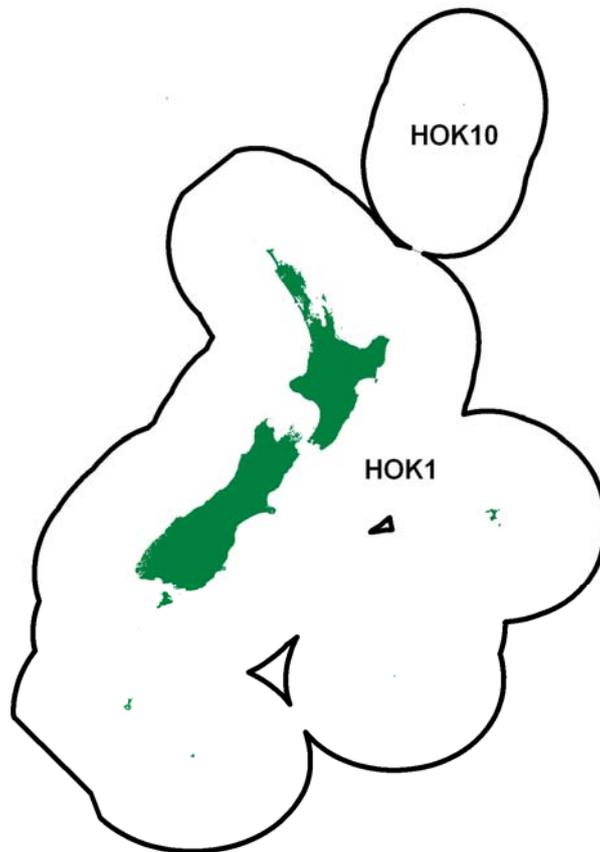


Figure 1: Southern New Zealand showing the main hoki fishing grounds, the 1000 m contour (broken grey line), and the position of all 2012–13 tows from TCEPRs (Trawl Catch and Effort Processing Returns) in which at least 10 t of hoki was caught (dots). Positions are rounded to the nearest 0.2 degrees and jittered.



**Figure 2: The Quota Management Areas for hoki.**

Within HOK 1 two stocks are recognised — eastern and western — and these have been assessed separately since 1989. Originally, the two stocks were assessed in parallel models. Since 1998, the stocks have been assessed simultaneously, using two-stock models. The complicated interactions inherent in a two-stock model, together with the large array of data sets that are available for HOK 1, make this one of the most complex of all New Zealand assessments (e.g., the 2004 NIWA assessment used more than 1800 individual observations spread over 15 data sets (Francis 2005)).

This report documents the 2014 assessment of HOK 1, which is the thirteenth hoki assessment to use NIWA’s general-purpose stock-assessment model CASAL (Bull et al. 2012). Since the last assessment in 2013 (McKenzie 2015) there has been another trawl survey on the Chatham Rise in January 2014 (Stevens et al. 2015), an acoustic survey of spawning hoki for Cook Strait in winter 2013 (O’Driscoll et al. 2015b), and an acoustic survey of spawning hoki on the west coast South Island in winter 2013 (O’Driscoll et al. 2015a).

The work reported here addresses objective 1 for the 2014 year of the Ministry for Primary Industries project DEE201002HOK: *To update the stock assessment of hoki including estimates of biomass, risk and yields.*

## 2. MODEL ASSUMPTIONS AND INPUTS FOR 2014

This section provides a summary of all model assumptions and inputs for the 2014 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. A change from the 2013 assessment is that the Haist parameterisation is used for year class strengths, instead of the Francis parameterisation.

The model uses Bayesian estimation. In describing the model assumptions it will sometimes be necessary to distinguish between different types of model runs: MPD versus MCMC, or initial versus final. MPD runs are so called because they estimate the Mode of the Posterior Distribution, which means they provide a point estimate, whereas MCMC (or full Bayesian) runs provide a sample from the posterior distribution using a Markov Chain Monte Carlo technique (this sample is sometimes referred to as a chain). MCMC runs are more informative, but much more time consuming to produce. For this reason only MPD runs were used for the initial exploratory analyses (Section 4). These runs were used to define the assumptions for the final model runs (Section 5), which were full Bayesian, and whose results provide the formal stock assessment.

The model is based on the fishing year starting on 1 October, which is labelled by its second part, so 1990 refers to the 1989–90 fishing year. This convention is applied throughout, so that, for instance, the most recent Southern Plateau survey, carried out in November–December 2012 is referred to as the 2013 survey.

A number of abbreviations are used to describe the model and its data inputs (Table 1).

**Table 1: Abbreviations used in describing the model and observations.**

| Quantity    | Abbreviation             | Description   |
|-------------|--------------------------|---|
| Stock       | E                        | eastern stock   |
|             | W                        | western stock   |
| Area        | CR                       | Chatham Rise  |
|             | CS                       | Cook Strait   |
|             | SA                       | Southern Plateau  |
|             | WC                       | west coast South Island   |
| Fishery     | Esp                      | E spawning fishery  |
|             | Wsp                      | W spawning fishery  |
|             | Ensp1, Ensp2             | first and second parts of E non-spawning fishery                        |
|             | Wnsp1, Wnsp2             | first and second parts of W non-spawning fishery                        |
| Observation | CSacous                  | CS acoustic biomass index   |
|             | WCacous                  | WC acoustic biomass index   |
|             | CRsumbio, CRsumage       | biomass index and proportions-at-age from CR summer trawl survey        |
|             | SAsumbio, SASumage       | biomass index and proportions-at-age from SA summer trawl survey        |
|             | SAautbio, SAautage       | biomass index and proportions-at-age from SA autumn trawl survey        |
|             | pspawn                   | proportion spawning (estimated from SA autumn trawl survey)             |
|             | Espage, Wnspage, etc     | proportions-at-age in catch from given fishery (from otoliths)          |
| Migrations  | EnspOLF, WnspOLF         | proportions-at-age in catch from given fishery (from OLF <sup>1</sup> ) |
|             | 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 | Epsl, Wpsl, Enpsl, Wnpsl | selectivity in commercial fisheries                                     |
|             | CRsl, SASl               | selectivity in trawl surveys  |

<sup>1</sup>OLF is a computer program that estimates proportions-at-age from length frequency data (Hicks et al. 2002).

## 2.1 Model structure and catches

Two stocks are assessed. Fish from the eastern (E) stock spawn in Cook Strait (CS) and have their home grounds in Chatham Rise (CR); the western (W) stock spawn on the west coast South Island (WC) and have their home grounds in the Southern Plateau (SA) (Figure 1). Soon after being spawned, all juveniles move to CR. In the assessment two alternative assumptions concerning the juveniles are modelled. One assumption is that the juveniles show natal fidelity – that is, they spawn on the ground where they were spawned. Under this assumption, the stock to which a fish belongs is determined at birth. At some time before age 8 all W fish migrate to their home ground, SA. The alternative assumption, used first in 2006, is that there is no natal fidelity. There is no direct evidence of natal fidelity for hoki, and its life history characteristics would indicate that 100% natal fidelity is unlikely (Horn 2011).

The model partition divides the population into two sexes, 17 age groups (1 to 17+), four areas corresponding to the four fisheries (CR, CS, SA, and WC), and two stocks (E and W). The annual cycle (Table 2) is the same as in the previous assessment. In the model the non-spawning fishery is split into two parts, separated by the migration of fish from CR to SA, giving a total of six fisheries in the model (henceforth referred to as the model fisheries).

**Table 2: Annual cycle of the assessment model, showing the processes taking place at each time step, their sequence within each time step, and the available observations (excluding catch at age). This is unchanged from that used in the 2012 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  | <i>M</i> fraction | Age fraction | Observations    |             |
|------|----------------|--|-------------------|--------------|-----------------|-------------|
|      |                |  |                   |              | Label           | Prop. mort. |
| 1    | Oct-Nov        | Migrations Wrtn: WC→SA, Ertn: CS→CR  | 0.17              | 0.25         | –               |             |
| 2    | Dec-Mar        | Recruitment at age 1+ to CR (for both stocks) part1, non-spawning fisheries (Ensp1, Wnsp1) | 0.33              | 0.60         | SAsum           | 0.5         |
|      |                |  |                   |              | CRsum           | 0.6         |
| 3    | Apr-Jun        | Migration Whome: CR→SA part2, non-spawning fisheries (Ensp2, Wnsp2)                        | 0.25              | 0.90         | SAaut<br>pspawn | 0.1         |
| 4    | End Jun        | Migrations Wspm: SA→WC, Espm: CR→CS  | 0.00              | 0.90         | –               |             |
| 5    | Jul-Sep        | Increment ages spawning fisheries (Esp, Wsp)   | 0.25              | 0.0          | CSacous         | 0.5         |
|      |                |  |                   |              | 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. For the current year (2014), the TACC is 150 000 t with a catch split arrangement for 90 000 t to be taken from the western stock and 60 000 t from the eastern stock.

It was estimated that the increase in quota of 20 000 t between 2013 and 2014 would be taken (in 2014) as 3000 t from Southern Plateau and 17 000 t from the west coast South Island (Graham Patchell, pers. comm.). This was incorporated into the stock assessment as the assumed value for 2014 by: (i) scaling the 2013 catch from 131 600 t down to 130 000 t, (ii) adding in 3000 to the non-spawning fishery, using the same proportions as in 2013 to split the catch into two parts (Wnsp1, Wnsp2), and (iii) adding in 17 000 t to the spawning fishery (Wsp).

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).

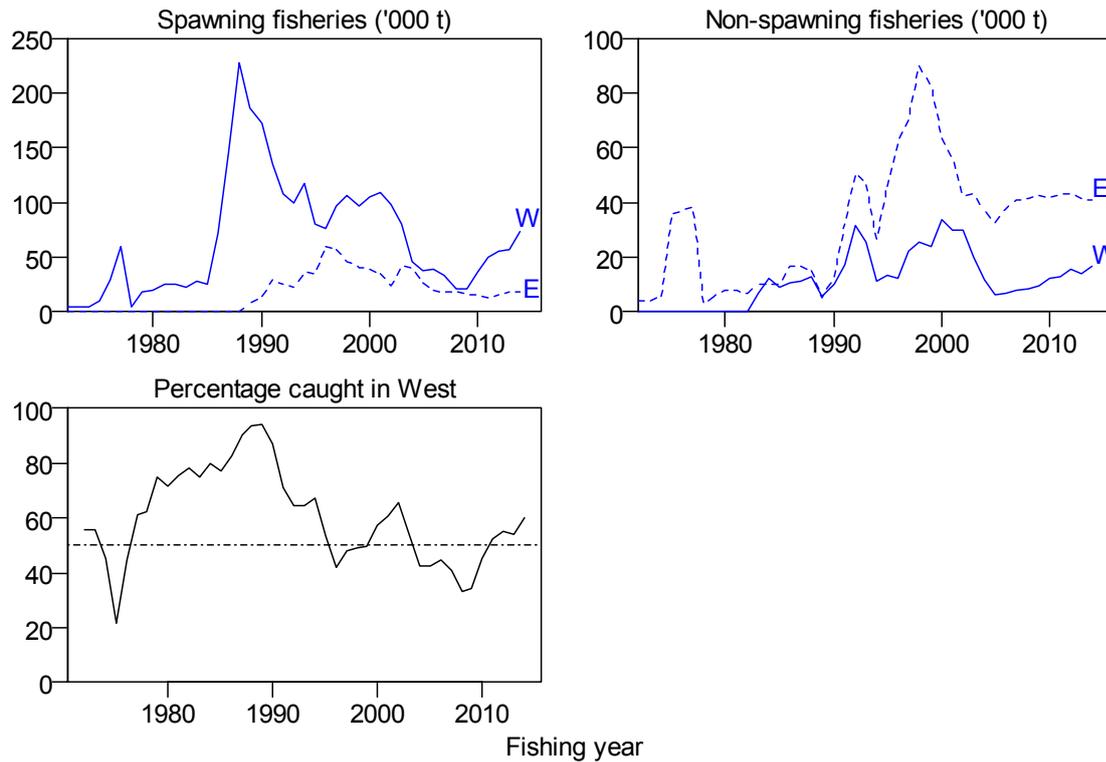
**Table 3: Catches (t) by fishery and fishing year (“1972” means fishing year 1971–72), as used in the assessment.**

| Year | Fishery |        |        |        |        |         | Total   |
|------|---------|--------|--------|--------|--------|---------|---------|
|      | Ensp1   | Ensp2  | Wnsp1  | Wnsp2  | Esp    | Wsp     |         |
| 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 | 29 500  | 11 700 | 7 800  | 9 100  | 18 400 | 73 500  | 150 000 |

**Table 4: Method of dividing annual catches by area and month into the six model fisheries (Esp, Wsp, Ensp1, Ensp2, Wnsp1, and Wnsp1). The small amount of catch reported in the areas west coast North Island and Challenger (typically 100 t per year) was prorated across all fisheries.**

| Area  | Oct–Mar | Apr–May | Jun–Sep |
|---|---------|---------|---------|
| West coast South Island; Puysegur   | Wsp     | Wsp     | Wsp     |
| Southern Plateau  | Wnsp1   | Wnsp2   | Wnsp2   |
| Cook Strait; Pegasus  | Ensp1   | Ensp2   | Esp     |
| Chatham Rise; east coasts of South Island and North Island; null <sup>1</sup> | Ensp1   | Ensp2   | Ensp2   |

<sup>1</sup> 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.**

| Type  | Symbol       | All fish              | W stock |        |       | E stock |        |       | Source |
|---|--------------|-----------------------|---------|--------|-------|---------|--------|-------|--------|
|   |              |                       | Male    | Female | Both  | Male    | Female | Both  |        |
| Growth  | $L_{\infty}$ |                       | 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<br>[W(kg)=aL(cm) <sup>b</sup> ] | $a$          | $4.79 \times 10^{-6}$ |         |        |       |         |        |       | 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, Wpspl, Enpspl, Wnpspl), two trawl survey ogives (in areas CR and SA: CRsl, SAsl), and three migration ogives (for migrations Whome, Espmg, and Wspmg). Two alternative sets of ogive assumptions were used for the final runs and associated sensitivities (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, Wpspl) are logistic, but natural mortality is allowed to vary with age (e.g., run 1.11). Alternatively, the spawning selectivities are domed, with natural mortality the same for all ages (i.e., run 1.15). When the domed selectivities were used it was also necessary to combine sexes in the model and make the selectivities age-based (Francis 2005).

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

**Table 6: Ogive assumptions for the final runs and associated sensitivities (see Section 5 for further explanation of these runs). In the ogive constraints,  $O_{7,F,E}$  refers to the ogive value at age 7 for female fish from the E stock, etc.**

| Runs | Ogive type               | Description                 | Constraints   |
|------|--------------------------|-----------------------------|---|
| 1.11 | Spawning selectivity     | Length-based, logistic      | Same for M and F, same for E and W  |
|      | Non-spawning selectivity | Length-based, double-normal | Same for M and F, must be domed <sup>1</sup>  |
|      | Survey selectivity       | Length-based, double-normal | Same for M and F, must be domed <sup>1</sup>  |
|      | Spawning migration       | Free, ages 1–8              | $O_{8,M,E} = O_{8,M,W}$ , $O_{8,F,E} = O_{8,F,W} \geq 0.6$<br>$O_A = O_8$ for $A > 8$ |
|      | Home migration           | Free, ages 1–7              | Same for M and F, =1 for age > 7  |
| 1.15 | Spawning selectivity     | Age-based, double-normal    | Same for E and W  |
|      | Non-spawning selectivity | Age-based, double-normal    |   |
|      | Survey selectivity       | Age-based, double-normal    |   |
|      | Spawning migration       | Free, ages 1–8              | $O_A = O_8$ for $A > 8$   |
|      | Home migration           | Free, ages 1–7              | =1 for age > 7  |

<sup>1</sup> 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 Wpspl (the selectivity ogive for W spawning fishery). Following the recommendation of Francis (2006), these changes were restricted to years for which there were Wspage data (i.e., from 1988 onwards). The changes were driven by the median day of the fishery, this being the day when half of the year's catch had been taken (Table 7). Annual changes in the selectivity for the other fisheries were not estimated because these were shown not to improve model fits in 2003 (Francis 2004).

**Table 7: Median day of the Wsp fishery, by year, as used in estimating annual changes in the selectivity Wpspl. The values represent the numbers of days since the previous 1 October. The overall mean value (305) was used for all years for which there was catch but no Wspage data (i.e., before 1988 and in 2014).**

|      |      |      |      |      |      |      |      |      |      |      |      |
|------|------|------|------|------|------|------|------|------|------|------|------|
| 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 | Mean |      |      |      |      |      |      |      |      |      |
| 298  | 300  | 305  |      |      |      |      |      |      |      |      |      |

## 2.3 Other structural assumptions

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

$$R_y = R_0 \times YCS_{y-2} \times SR(SSB_{y-2}),$$

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

Thirty-eight YCSs were estimated for each stock, for 1975 to 2012, inclusive. YCSs for the initial years (1970 to 1974) were fixed at 1. The E and W YCSs for 2012 were constrained (by a penalty function) to be equal for MPD runs, with the constraint removed for full Bayesian runs (Francis 2006, p. 9).

The maximum exploitation rates assumed were the same as in previous years: 0.3 in each part of the two non-spawning fisheries (which is approximately equivalent to 0.5 for the two parts combined), and 0.67 for both spawning fisheries. 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 (Tables 8), proportions-at-age (by sex) (Table 9, Figure 4), and proportion spawning (Table 10). Biomass indices new to this assessment are from a trawl survey on Chatham Rise in January 2014 (Stevens et al. 2015), an acoustic survey of spawning hoki for Cook Strait in winter 2013 (O'Driscoll et al. 2015b), and an acoustic survey of spawning hoki on the west coast South Island in winter 2013 (O'Driscoll et al. 2015a).

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 2011a, 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 data for this assessment.**

|      | <u>CRsumbio</u>        | <u>SASumbio</u> | <u>SAautbio</u> | <u>CSacous</u>      | <u>WCacous</u>      |
|------|------------------------|-----------------|-----------------|---------------------|---------------------|
| 1988 | –                      | –               | –               | –                   | 417 (0.22,0.60)     |
| 1989 | –                      | –               | –               | –                   | 249 (0.15,0.38)     |
| 1990 | –                      | –               | –               | –                   | 255 (0.06,0.40)     |
| 1991 | –                      | –               | –               | 191 (0.13,0.41)     | 341 (0.14,0.73)     |
| 1992 | 120 (0.08,0.21)        | 80 (0.07,0.21)  | 68 (0.08,0.22)  | –                   | 345 (0.14,0.49)     |
| 1993 | 186 (0.10,0.22)        | 87 (0.06,0.21)  | –               | 613 (0.15,0.52)     | 549 (0.07,0.38)     |
| 1994 | 146 (0.10,0.22)        | 100 (0.09,0.22) | –               | 597 (0.06,0.91)     | –                   |
| 1995 | 120 (0.08,0.21)        | –               | –               | 411 (0.12,0.61)     | –                   |
| 1996 | 153 (0.10,0.22)        | –               | 89 (0.09,0.22)  | 196 (0.09,0.57)     | –                   |
| 1997 | 158 (0.08,0.22)        | –               | –               | 302 (0.12,0.40)     | 655 (0.10,0.60)     |
| 1998 | 87 (0.11,0.23)         | –               | 68 (0.11,0.23)  | 170 (0.10,0.44)     | –                   |
| 1999 | 109 (0.12,0.23)        | –               | –               | 245 (0.10,0.36)     | –                   |
| 2000 | 72 (0.12,0.23)         | –               | –               | –                   | 397 (–,0.28)        |
| 2001 | 60 (0.10,0.22)         | 56 (0.13,0.24)  | –               | 217 (0.12,0.30)     | –                   |
| 2002 | 74 (0.11,0.23)         | 38 (0.16,0.26)  | –               | 307 (0.13,0.35)     | –                   |
| 2003 | 53 (0.09,0.22)         | 40 (0.14,0.24)  | –               | 222 (0.17,0.34)     | –                   |
| 2004 | 53 (0.13,0.24)         | 14 (0.13,0.24)  | –               | –                   | –                   |
| 2005 | 85 (0.12,0.23)         | 18 (0.12,0.23)  | –               | 124 (0.11,0.32)     | –                   |
| 2006 | 99 (0.11,0.23)         | 21 (0.13,0.24)  | –               | 128 (0.17,0.34)     | –                   |
| 2007 | 70 (0.08,0.22)         | 14 (0.11,0.23)  | –               | 225 (–,0.46)        | –                   |
| 2008 | 77 (0.11,0.23)         | 46 (0.16,0.26)  | –               | 179 (–,0.30)        | –                   |
| 2009 | 144 (0.11,0.23)        | 47 (0.14,0.24)  | –               | 359 (–,0.39)        | –                   |
| 2010 | 98 (0.15,0.25)         | 65 (0.16,0.26)  | –               | –                   | –                   |
| 2011 | 94 (0.14,0.24)         | –               | –               | 298 (0.18,0.35)     | –                   |
| 2012 | 88 (0.10,0.22)         | 46 (0.15,0.25)  | –               | –                   | 412 (–,0.34)        |
| 2013 | 124 (0.15,0.25)        | 56 (0.15,0.25)  | –               | <b>353 (–,0.30)</b> | <b>357 (–,0.35)</b> |
| 2014 | <b>102 (0.10,0.22)</b> | –               | –               | –                   | –                   |

**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– <b>13</b>          | otoliths           |
| SA   | WnspOLF  | Catch at age | 1992–94, 96, 99–00       | OLF                |
|      | Wnspage  | Catch at age | 2001–04, 06– <b>13</b>   | otoliths           |
|      | SAsumage | Trawl survey | 1992–94, 2001–10, 12, 13 | otoliths           |
|      | SAautage | Trawl survey | 1992, 96, 98             | otoliths           |
| CS   | Espage   | Catch at age | 1988– <b>13</b> *        | otoliths           |
| CR   | EnspOLF  | Catch at age | 1992, 94, 96, 98         | OLF                |
|      | Enspage  | Catch at age | 1999– <b>13</b>          | otoliths           |
|      | CRsumage | Trawl survey | 1992– <b>14</b>          | otoliths           |

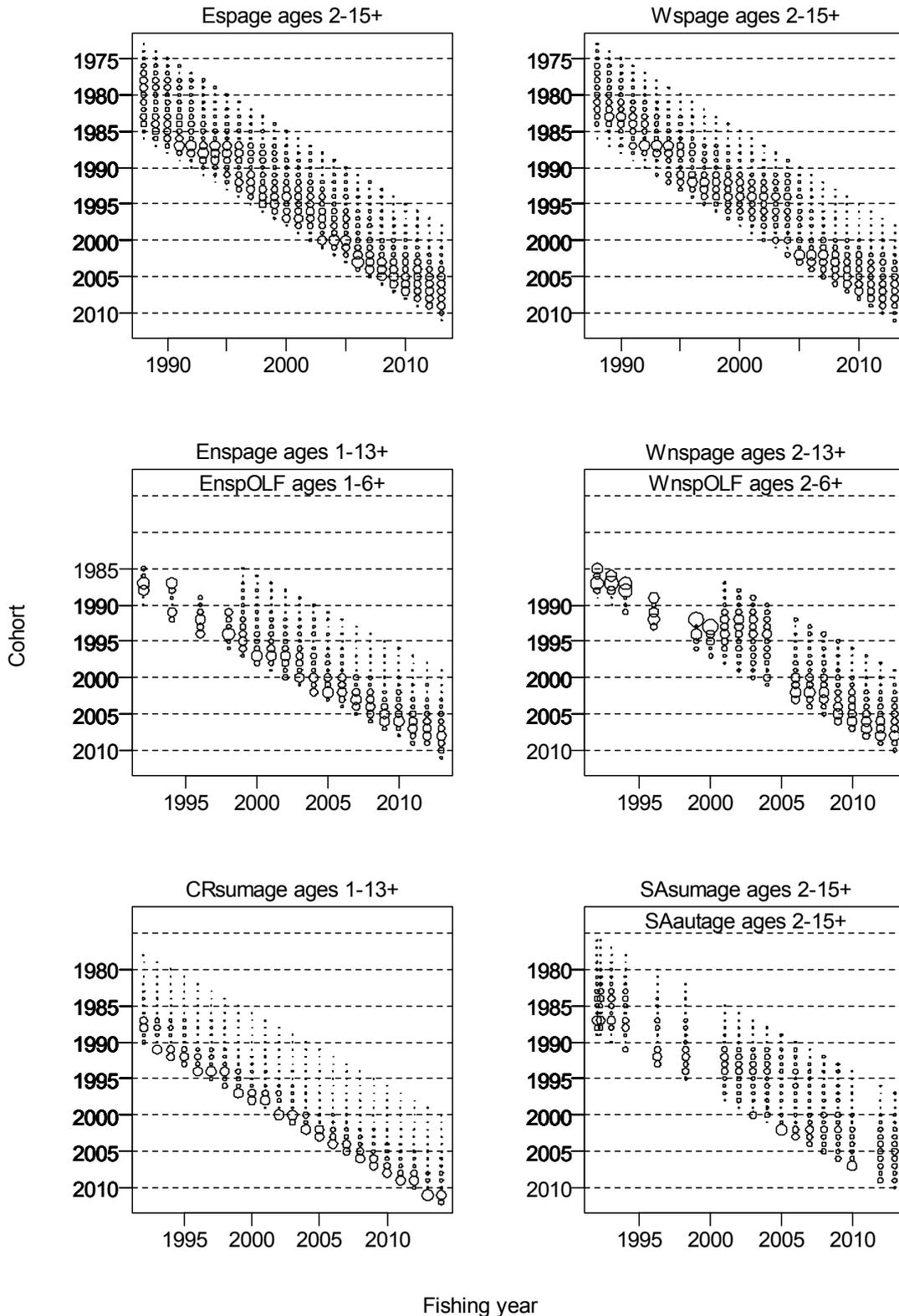
\* 2011, 2012, 2013 values not included in initial model runs, except for a sensitivity run.

**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).**

| Year | Age  |      |      |      |      |      |      |
|------|------|------|------|------|------|------|------|
|      | 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.**

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



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

## 2.5 Error assumptions

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

The error distributions assumed were lognormal for all other data. This means that the weight assigned to each datum was controlled by an error CV. For the biomass indices, two alternative sets of CVs were available (see Table 8). The total CVs represent the best estimates of the uncertainty associated with these data, and were used in all initial model runs. The total CVs for the acoustic indices were calculated using a simulation procedure intended to include all sources of uncertainty (O'Driscoll 2002), and the observation-error CVs were calculated in a similar way but including only the uncertainty associated with between-transect (and within-stratum) variation in total backscatter. For the trawl indices, the total CVs were calculated as the sum of an observation-error CV (using the standard formulae for stratified random surveys, e.g., Livingston & Stevens (2002)) and a process-error CV, which was set at 0.2, (following Francis et al. 2001) (note that CVs add as squares:  $CV_{total}^2 = CV_{process}^2 + CV_{observation}^2$ ). In some initial model runs (see below) it was decided to upweight some trawl biomass indices by using their observation, rather than total, CVs. For final model runs there was no upweighting of the trawl biomass indices.

For the proportion of fish that migrate to spawn (pspawn) the error distribution was lognormal, for which an arbitrary CV of 0.25 was assumed following Cordue (2001).

## 2.6 Parameters, priors, and penalties

The number of parameters estimated in the final model runs was 153 (for runs where age-varying natural mortality is estimated) or 131 (where a domed spawning selectivity is used instead) (Table 12). Most of the associated prior distributions were intended to be uninformative; the main exceptions were those for the catchabilities (O'Driscoll et al. 2002), the proportion of the initial stock that is in the east stock, pE (Francis 2003 p. 34, Smith 2003, 2004, McKenzie 2015 - Appendix 3), constant natural mortality (Smith 2004), and age-varying natural mortality (Cordue 2006, Francis 2008 p. 17). For the parameter used to estimate annual changes in the selectivity ogive for the W spawning fishery ([Wspsl].shift\_a) normal priors were used with standard deviations more or less arbitrarily chosen to discourage extreme values (see section 7.1 of Francis (2006)). For year class strengths lognormal priors were used with a mean of one and CV of 0.95 (Francis 2004, p. 32).

As in previous assessments, the model estimated natural mortality separately by sex (when sex was included in the model) because of the trends with age in the sex ratio. A double exponential curve was used to parameterise the age-varying natural mortality (Bull et al. 2012).

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

| Parameter(s)               | Description                                      | Type                       | Distribution |       | No. of 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] <sup>a</sup> | 0.344        | 0.072 | 1                 |
| recruitment.YCS            | year-class strengths                             | lognormal <sup>b</sup>     | 1            | 0.95  | 76                |
| q[CSacous].q               | catchability, CSacous                            | lognormal                  | 0.77         | 0.77  | 1                 |
| q[WCacous].q               | catchability, WCacous                            | lognormal                  | 0.57         | 0.68  | 1                 |
| q[CRsum].q                 | catchability, CRsumbio                           | lognormal                  | 0.15         | 0.65  | 1                 |
| q[SAsum].q                 | catchability, SAsumbio <sup>c</sup>              | lognormal                  | 0.17         | 0.61  | 1                 |
| q[SAAut].q                 | catchability, SAAutbio                           | lognormal                  | 0.17         | 0.61  | 1                 |
| natural_mortality          | $M_{\text{male}} \& M_{\text{female}}$ ages 1–17 | uniform                    | various      |       | 8,0               |
| natural_mortality.all      | $M$  | lognormal                  | 0.298        | 0.153 | 0,1               |
| process error CVs          |  | uniform                    | 0.1          | 1     | 7                 |
| selectivity[Wspsl].shift_a | Wspsl shift                                      | normal                     | 0            | 0.25  | 1                 |
| migrations                 | Whome, Wspmg, Espmg                              | uniform                    | various      |       | 40,24             |
| comm. selectivities        | Epsl, Wpsl, Enpsl, Wnpsl                         | uniform                    | various      |       | 8,9               |
| surv. selectivities        | CRsl, SAsl                                       | uniform                    | various      |       | 6                 |
|                            |  |                            |              |       | <u>153,131</u>    |

<sup>a</sup> This is a beta distribution scaled to have its range from 0.1 to 0.6, rather than the usual 0 to 1

<sup>b</sup> In one run a uniform prior was used

<sup>c</sup> In some runs two catchabilities are estimated

In addition to the priors, bounds were imposed for all parameters with non-uniform distributions. The catchability parameters were those calculated by O'Driscoll et al. (2002) (where they are called “overall bounds”); for other parameters they were usually set at the 0.001 and 0.999 quantiles of their distributions.

For the 2003 assessment update a uniform prior was used for pE. However in the update to the 2003 assessment this gave implausibly high values for pE and introduced other problems for the assessment (Francis 2004). For this reason an informed prior was introduced for the 2003 assessment and has been used since, and is used in this assessment. A sensitivity MCMC model run indicates that recent stock assessments are insensitive to the prior (McKenzie 2015, Appendix 3).

Penalty functions were used for three purposes. First, any parameter combinations that caused any exploitation rate to exceed its assumed maximum (Section 2.3) were strongly penalised. Second, the most recent YCSs were forced to be the same for E and W (normally this penalty is dropped for Bayesian runs, but it has little impact on the results) (Section 2.3). The third use of penalty functions was to link the spawning migration ogives for the two stocks (according to the constraints in Table 6).

## 2.7 No natal fidelity model structure

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

There have been a number of attempts to implement an adult fidelity model in CASAL, the first being for the 2006 assessment. However, these CASAL models have been problematic due to difficulties defining the eastern and western spawning stock biomasses and the uncertainty in these from Bayesian runs (section 7.3 in Francis 2006, section 3.3 in Francis 2007, sections 3.2 and 3.3 in Francis 2008, section 2.7 in Francis 2009, McKenzie 2009, McKenzie 2012). However, the problems appear to have been resolved, and in this section we give more detail as to how the no natal fidelity model is implemented in CASAL. The key point to remember is that the no natal fidelity model is a modification of the natal fidelity model run which is sexed with an age-varying natural mortality. Apart from the obvious modification of reducing from two biological stocks to one, the two other main modifications are to the home migration ogive (Whome) and to how year class strengths are estimated.

The interpretation of the home migration ogive (Whome) differs depending on whether or not natal fidelity is assumed. With natal fidelity just those fish from the W stock migrate from CR to SA; without natal fidelity any fish in the CR can make this migration. Either way, a fish that migrates to SA will subsequently spawn on the WC and be part of the western spawning stock. Secondly, for the no natal fidelity model, Whome can vary from year to year, with this variation determining what proportion of each year class grow up to become E or W fish (see section 7.3 in Francis 2006 for the initial implementation of this).

For the no natal fidelity model there is just a single stock, so a single vector of YCSs is estimated, this being interpreted as measuring the combined recruitment from the two spawning stocks, which is reflected in the number of juvenile fish seen in CR. For the natal fidelity model run YCSs are estimated for E and W stocks separately.

For the no natal fidelity model a virgin spawning stock biomass for the entire stock is well defined and calculated in the same way as for the natal fidelity models (as the spawning stock biomass under mean recruitment and no fishing pressure). To calculate east and west spawning stock biomasses 500 year projections are done with no fishing pressure and random re-sampling of year class strengths. The last 480 years of these projections are used to find the mean proportion of the spawning biomass that is in the east and west, these proportions are then applied to the virgin biomass for the entire stock to calculate virgin biomasses for east and west. Using proportions in this way ensures that the calculated eastern and western biomass match up with the total. These calculations can be done either for the MPD fit (defining MPD east and west virgin biomasses) or for each sample from the MCMC, the distribution of biomasses defined in this way determine the posterior density for the virgin biomasses.

### **3. PRE-ASSESSMENT MODEL RUNS**

In this section we perform MPD analyses using the previous assessment model from 2013. In particular we explore the impact of how the YCSs are parameterised and what priors are used for them.

#### **3.1 Background**

A review took place of the hoki stock assessment just before the 2014 assessment was started (Butterworth et al. 2014). At the first Deepwater Working Group meeting some concern was expressed at the posterior profile figure produced as part of the hoki review (Figure 5). In particular this figure seems to show that the priors contribute a great deal to contrast in the total objective function, with the suspicion being that this is driven by the priors on the YCSs.

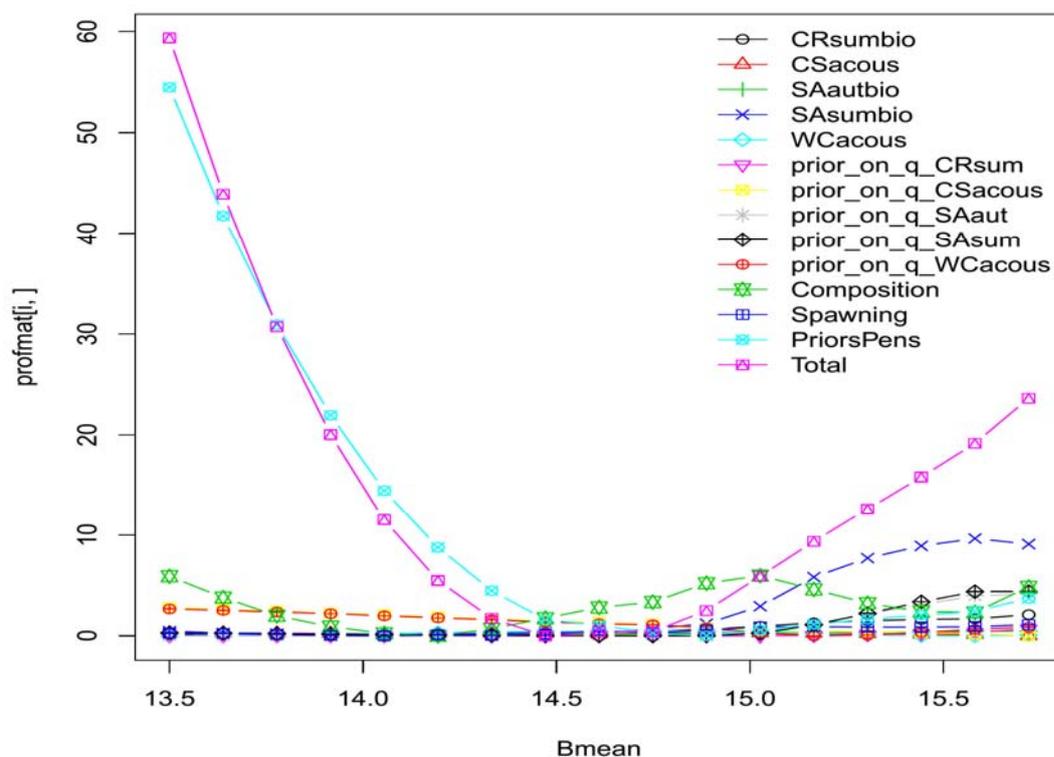
One complicating factor in interpreting this figure is that the profile is on the estimated parameter  $\log\_B_{\text{mean\_tot}}$  (from the Francis parameterisation of YCSs), not the derived parameter  $B_{0,\text{tot}}$ . The Working Group requested that the profile be re-expressed in terms of  $B_{0,\text{tot}}$  and the impact of the priors

on the YCSs be looked at more closely. This work was undertaken using model 1.7 from the previous assessment (2013) where the Francis parameterisation of YCSs was used with lognormal priors.

The working group also asked for:

- i. a posterior profile using the Haist parameterisation and a lognormal prior for the YCSs
- ii. a posterior profile using the Haist parameterisation and a uniform prior for the YCSs
- iii. an MCMC run using the Haist parameterisation and a uniform prior for the YCSs

All results that follow are based on model 1.7 from the 2013 hoki stock assessment. For this model there is age-varying natural mortality, natal fidelity is assumed, and a single catchability is used for the Southern Plateau trawl survey.



**Figure 5: Example likelihood profile (figure 2 from Butterworth et al. 2014). Note that the x-axis is actually  $\log\_Bmean\_tot$ . The profile is assumed to be for model 1.7 from the 2013 assessment.**

### 3.2 Posterior profile on run 1.7 from the 2013 assessment

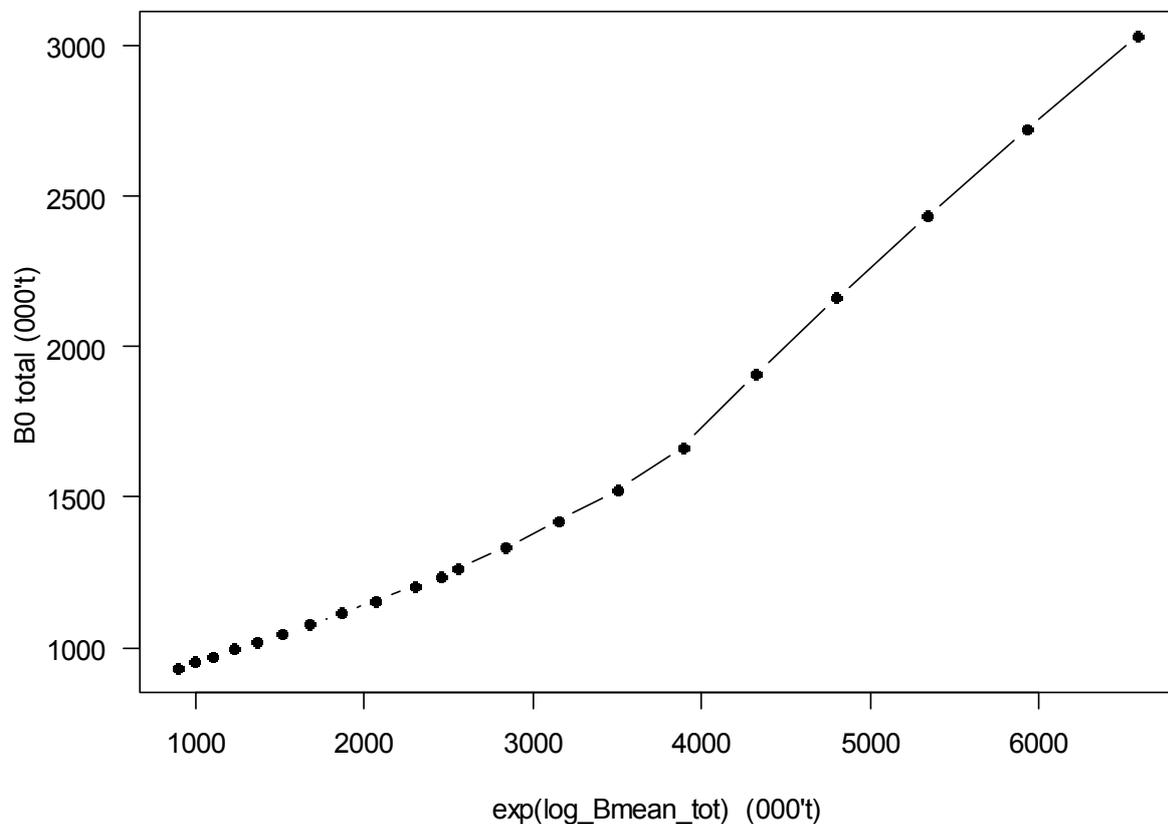
For each fixed  $\log\_Bmean\_tot$  value in the profile analysis there is an associated derived  $B_{0,tot}$  value, although the relationship is not linear (Figure 6).

The objective function components (e.g CRsumage, SASumbio) were scaled to be zero at their minimum value. All the at-age data components were summed under the label “Composition” and similarly for the prior components under the label “Priors”. The total objective function value along with the profiles attributable to total priors, total composition data, and biomass indices are shown in Figures 7–8 . They indicate that the priors and composition data make a substantial contribution to the

total objective function. The objective function attributable to the priors on YCS components for the east and west stock confirms that they are important (Figures 9–10).

Part of the reason for the strong impact of the YCS priors in the objective function seems to be that at lower biomasses the model estimates YCSs with more variability than would be expected under the prior (Figure 11). And this is associated with higher estimates of  $R_0$  at the lower biomass values (Figure 12).

In Figure 7 the composition data profile has a minimum at a lower biomass value than that indicated by the total profile for the MPD fit. A potential explanation for the YCSs prior influence at low biomass is that the model is using the more variable YCSs values to try to fit the at-age data (although at biomass values less than the composition data profile minimum this explanation would not be so tenable). The component of the at-age data showing most contrast in the region of the MPD is CRsumage (Figure 13). A further posterior profile was done where the mean effective sample for CRsumage was reduced by a factor of eight, but this had very little impact on the YCSs priors objective function values (Figures 14 –15).



**Figure 6: Relationship between  $B_{0,tot}$  and  $\exp(\log\_Bmean\_tot)$  in the profile analysis.**

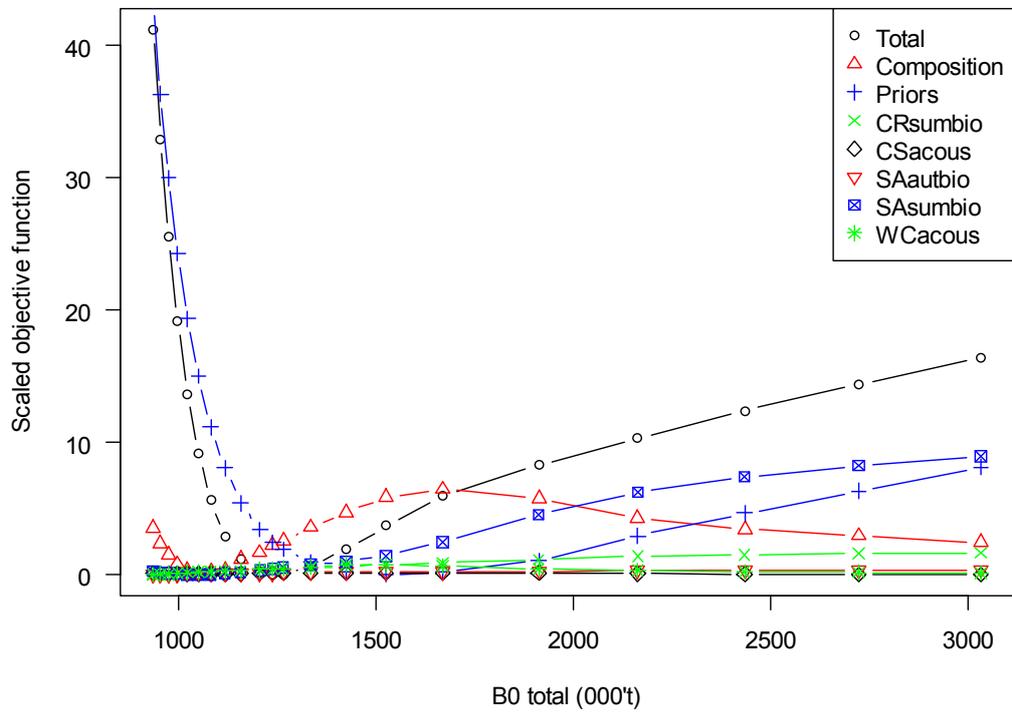


Figure 7: Posterior profile in terms of  $B_{0,tot}$ .

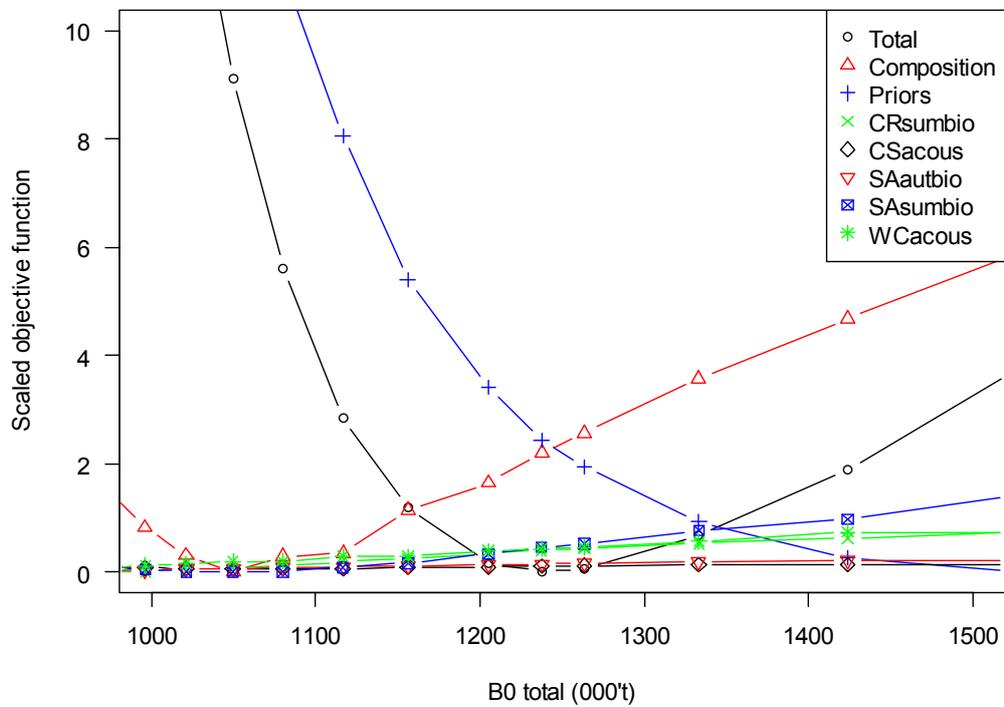
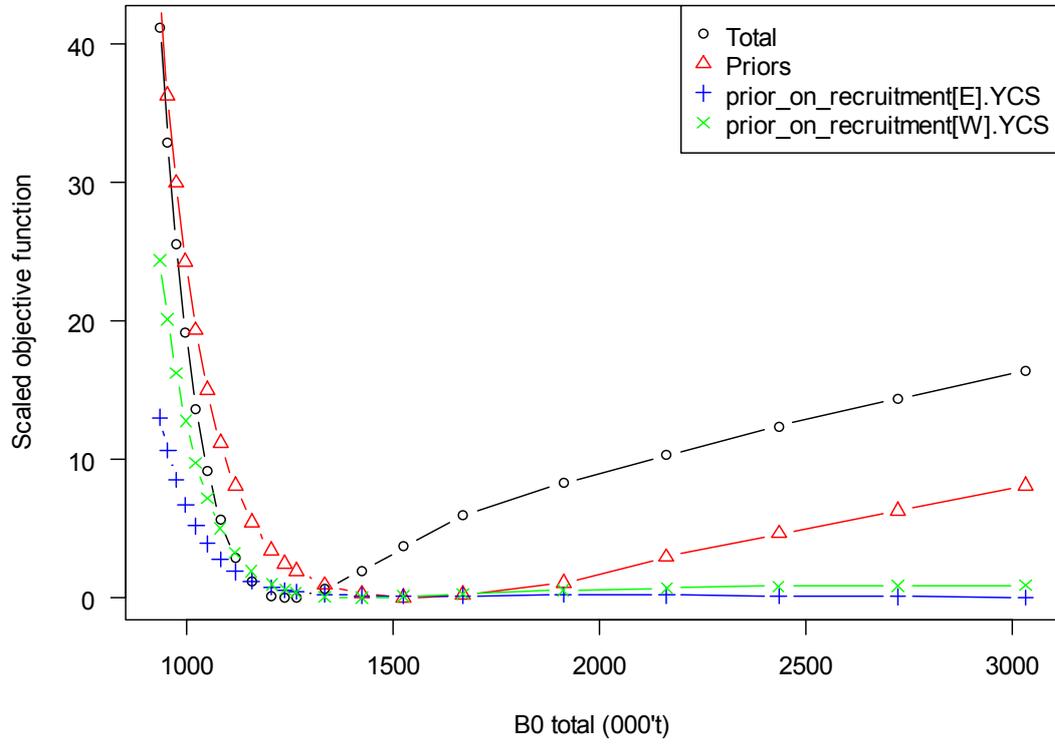
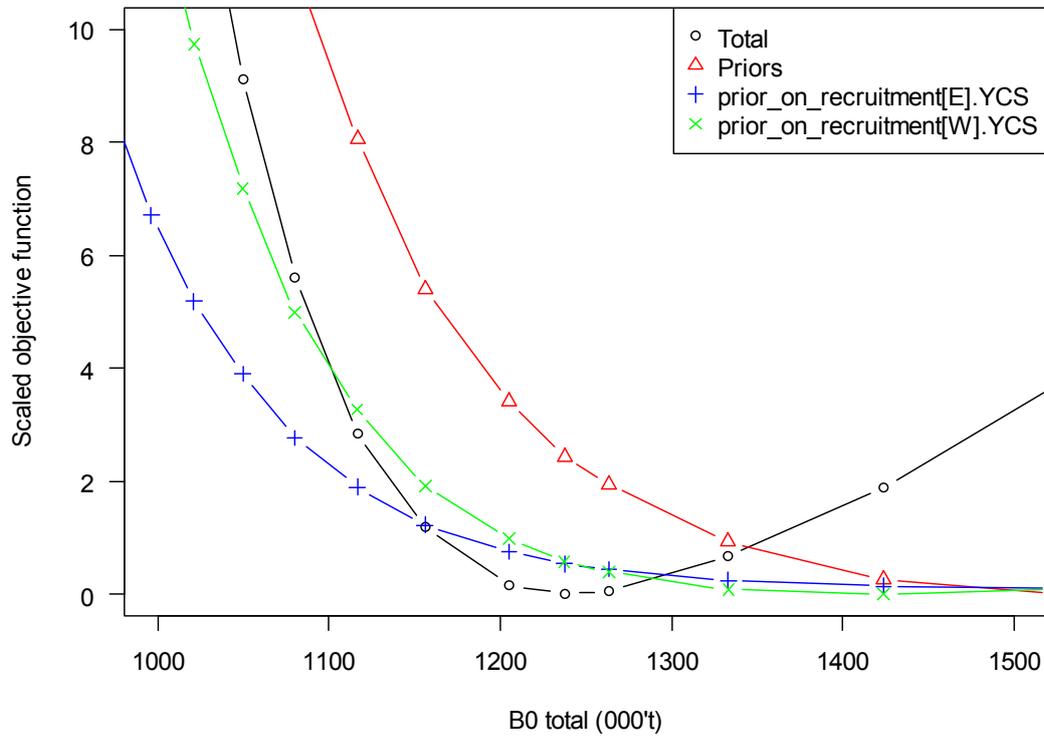


Figure 8: As for Figure 7, but with restricted axis-limits.



**Figure 9: Posterior profile showing just the total, total on priors, and the priors for the east and west YCSs.**



**Figure 10: As for Figure 9, but with restricted axis limits.**

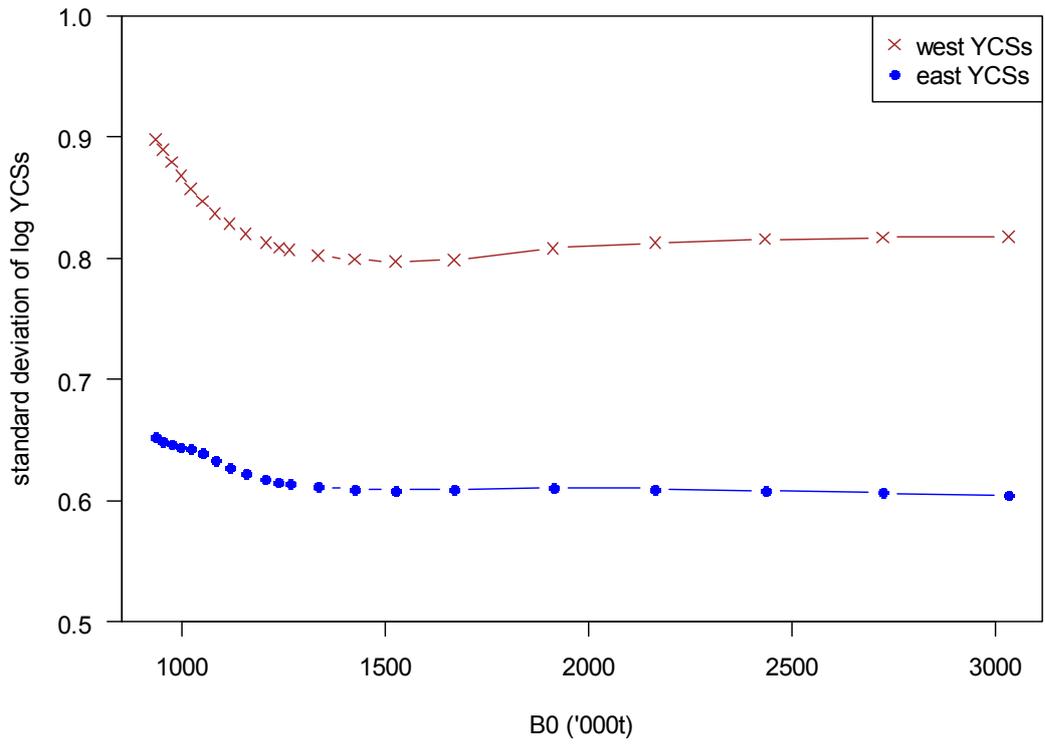


Figure 11: Standard deviation of the log of the YCSs versus B0 total in the posterior profile.

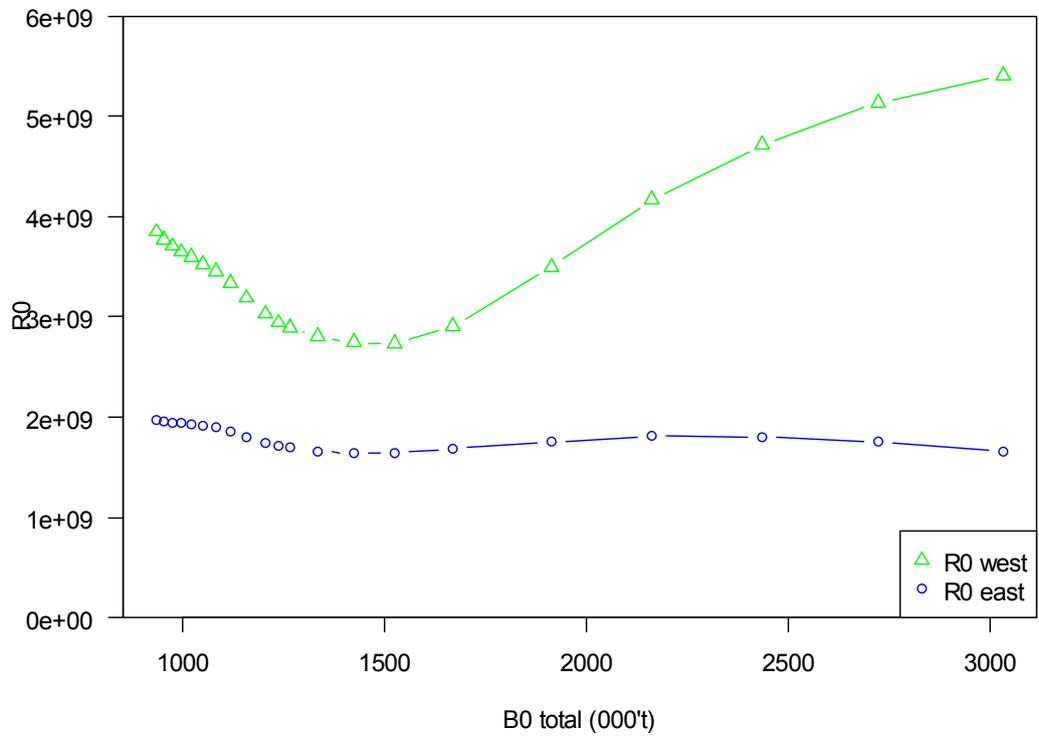


Figure 12: R0 values for the posterior profile in Figure 11.

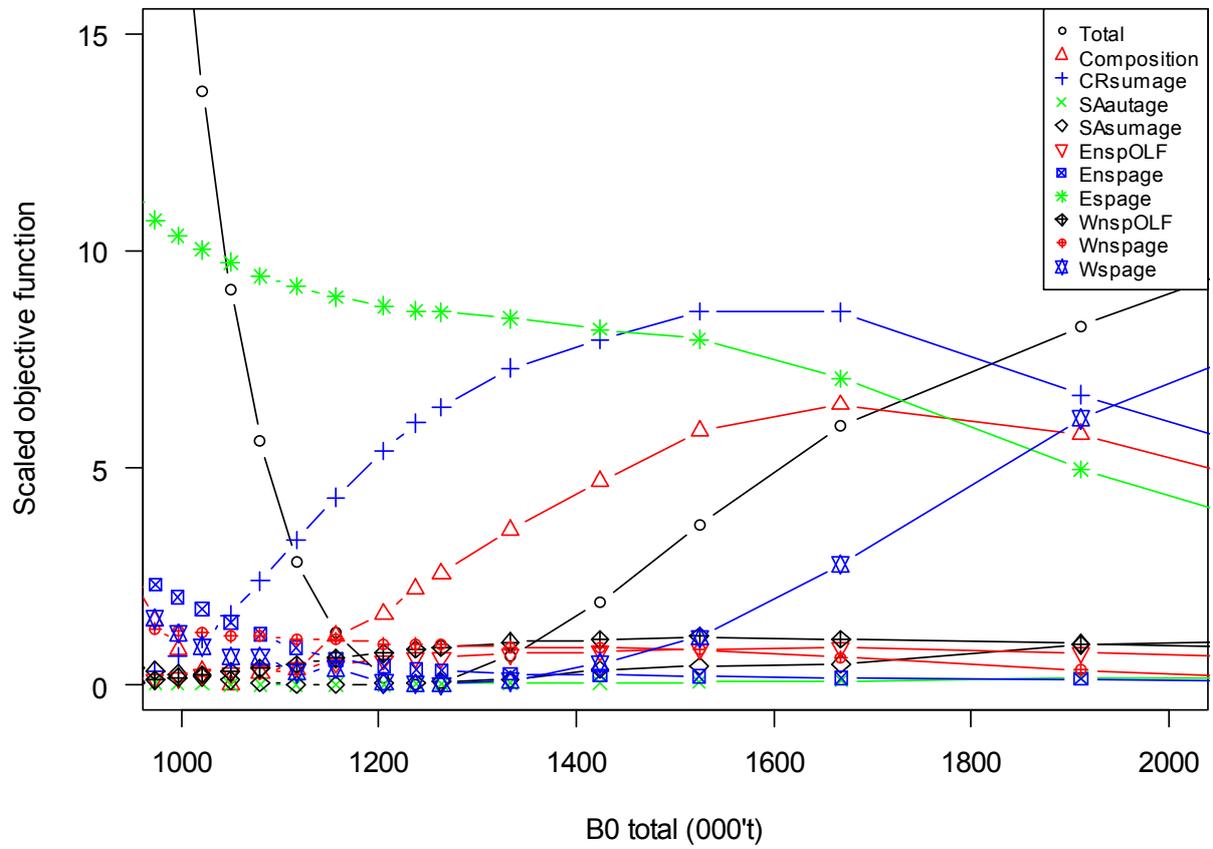


Figure 13: Posterior profile examining the composition data.

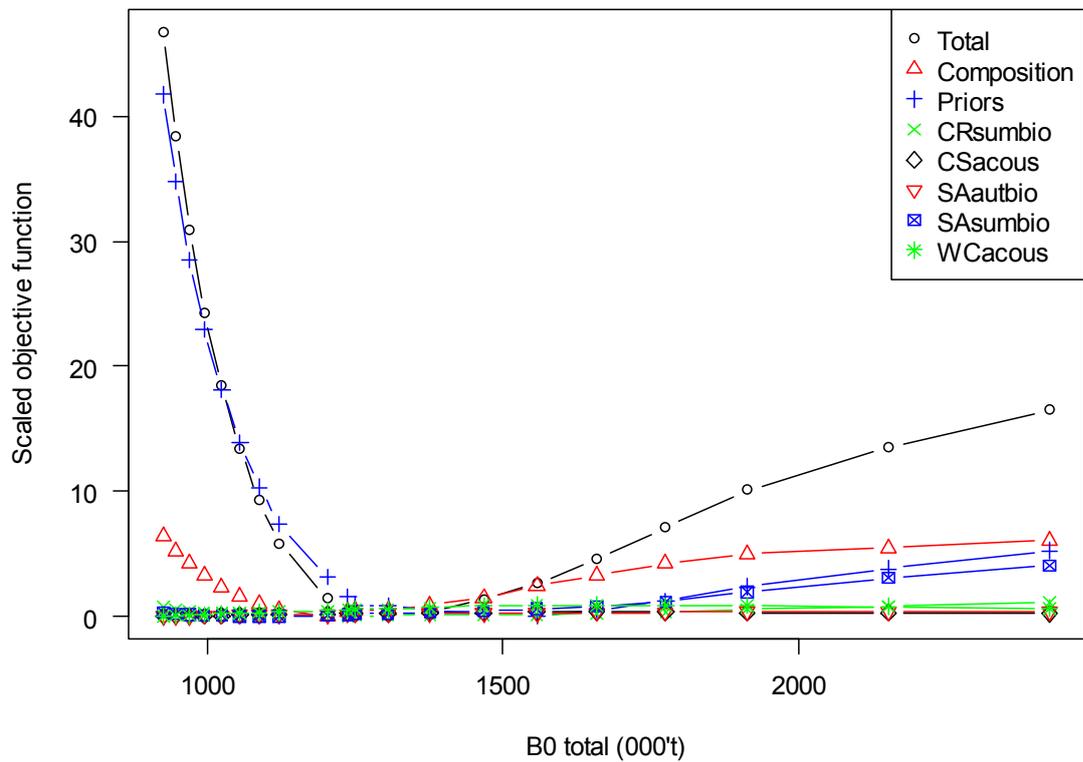


Figure 14: Posterior profile after reducing effective sample sizes for CRsumage.

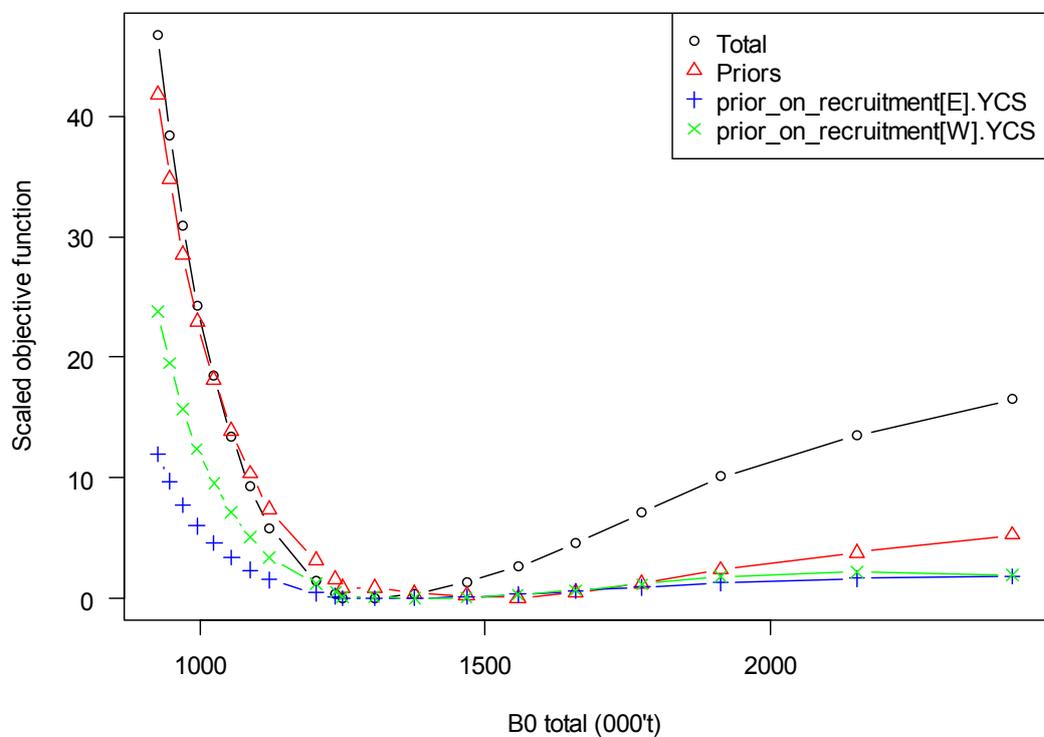
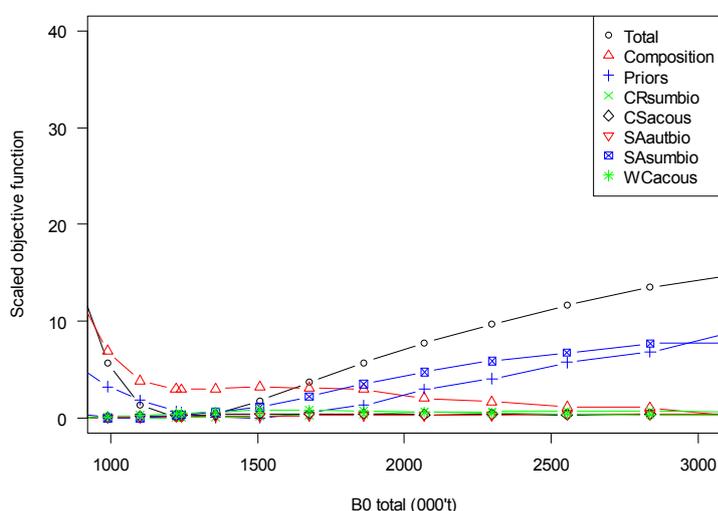


Figure 15: After reducing the effective sample sizes for CRsumage. Posterior profile showing just the total, total on priors, and the priors for the east and west YCSs.

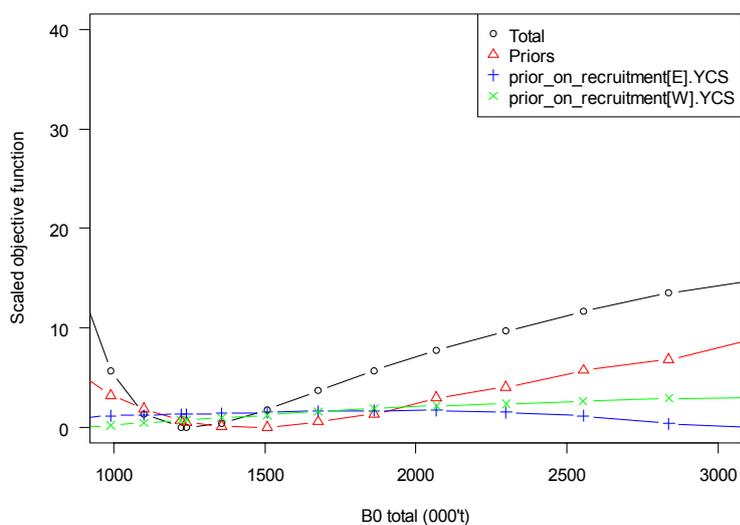
### 3.3 Other posterior profiles

The following work shows how the profiles vary depending on how the YCSs are parameterised (using the Francis or Haist parameterisation) and what priors are used (lognormal or uniform). The profile when using the Francis parameterisation with lognormal priors was shown previously, and highlighted the negative influence of the priors on lower biomasses (Figure 7). Repeating the profile but with the Haist parameterisation, and retaining the lognormal priors, greatly reduces the influence of the priors (Figures 16–17). The profile with the Haist parameterisation and uniform priors is shown in Figures 18–19. In summary, going from the Francis to the Haist parameterisation substantially reduces the influence of the priors, but going from lognormal to uniform priors produces little change (under the Haist parameterisation).

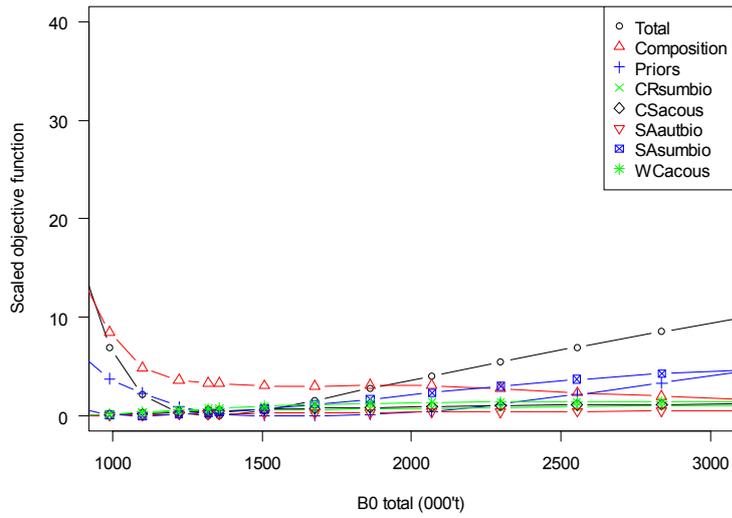
For the MPD biomass trajectories there is some difference between the trajectories under different parameterisations (Figure 20, Table 13). In terms of the current biomass ( $\%B_0$ ) there is a difference for both east and west stocks, with the biggest different being for the west stock in going from lognormal to uniform priors (under the Haist parameterisation).



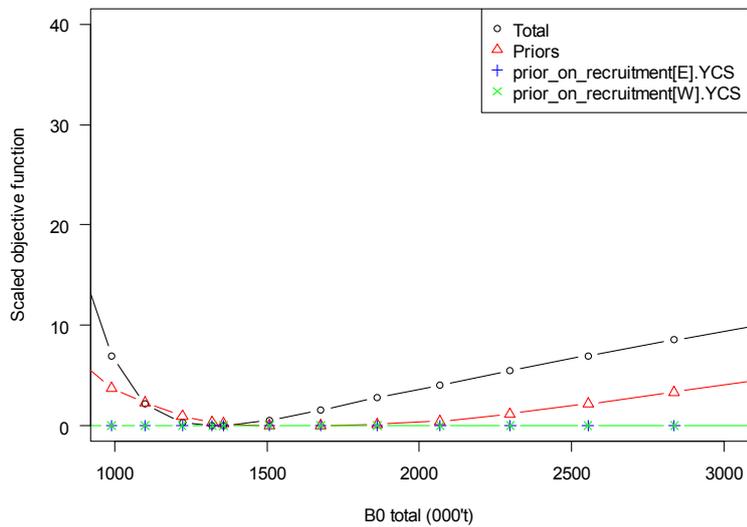
**Figure 16: Posterior profile using the Haist parameterisation with lognormal prior.**



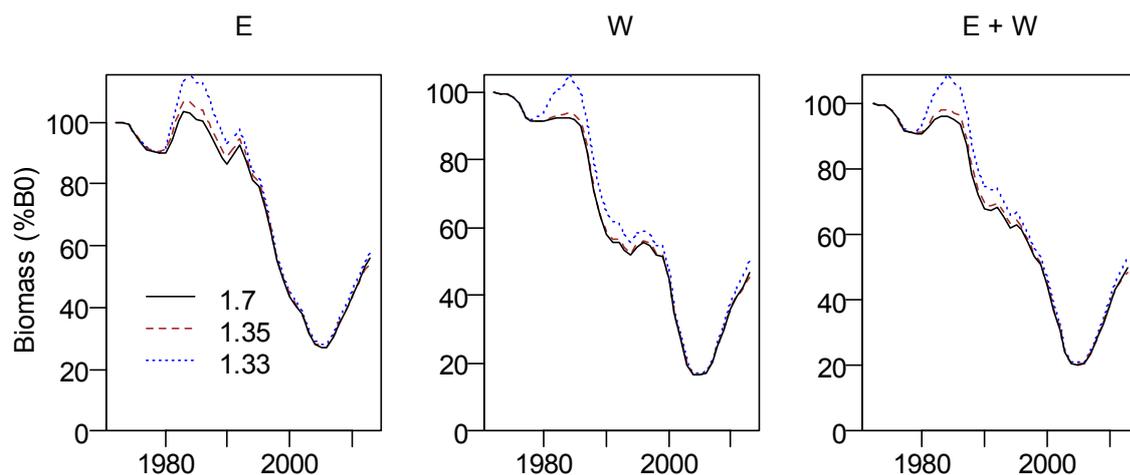
**Figure 17: Haist parameterisation with lognormal prior. Posterior profile showing just the total, total on priors, and the priors for the east and west YCS.**



**Figure 18: Posterior profile for the Haist parameterisation with uniform prior.**



**Figure 19: Haist parameterisation with uniform priors. Posterior profile showing just the total, total on priors, and the priors for the east and west YCS.**



**Figure 20: Biomass trajectories for MPD fits. See Table 13 for descriptions of the model runs.**

**Table 13: Summary of virgin biomass estimates for MPD fits.**

| Run                    | Run number | $B_0$ ('000 t) |     |     |
|------------------------|------------|----------------|-----|-----|
|                        |            | E + W          | E   | W   |
| Francis with lognormal | 1.7        | 1237           | 433 | 804 |
| Haist with lognormal   | 1.35       | 1241           | 442 | 799 |
| Haist with uniform     | 1.33       | 1321           | 469 | 852 |

### 3.4 MCMC with Haist and uniform

An MCMC was done using the Haist parameterisation and uniform priors (model run 1.34) and another with the Francis parameterisation with lognormal priors (model run 1.7). The change in parameterisation increases current biomass ( $\%B_0$ ) for both east and west stocks (Figures 21–22). The impact of the different parameterisation on the YCSs is less clear cut although it seems that in model run 1.34 the early YCSs are estimated with more certainty and the last YCSs with less (Figures 23–24).

Note that model run 1.34 differs slightly from run 1.33 (Table 13) in that there is no equality penalty for the 2012 E & W YCS strengths (as is used for all MPD model runs, but dropped for the corresponding MCMC runs). This equality penalty makes very little difference to the MCMC results, but was inadvertently included in a MCMC run labelled 1.33 (results not shown), so a further MCMC run 1.34 was done where the equality penalty was dropped as it should be.

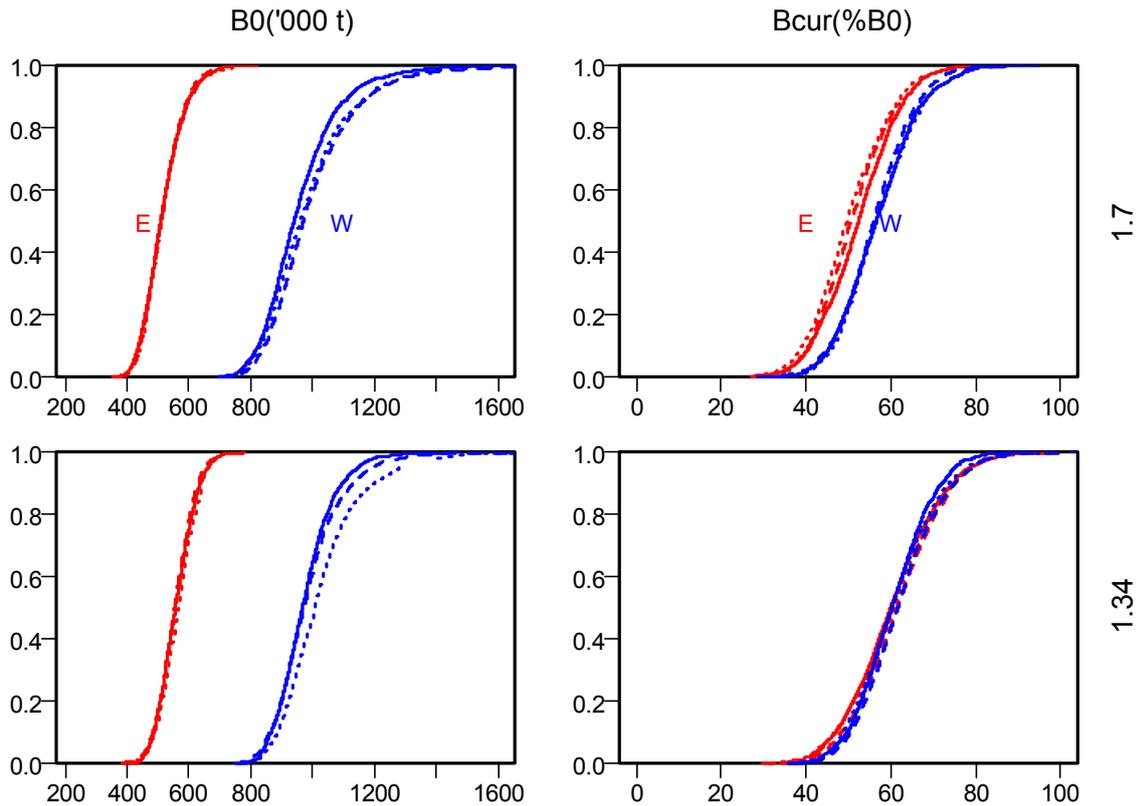


Figure 21: Diagnostics for MCMC chains. Each panel contains cumulative probability distributions, for  $B_0$  or  $B_{current}$ , for three chains from the same model run.

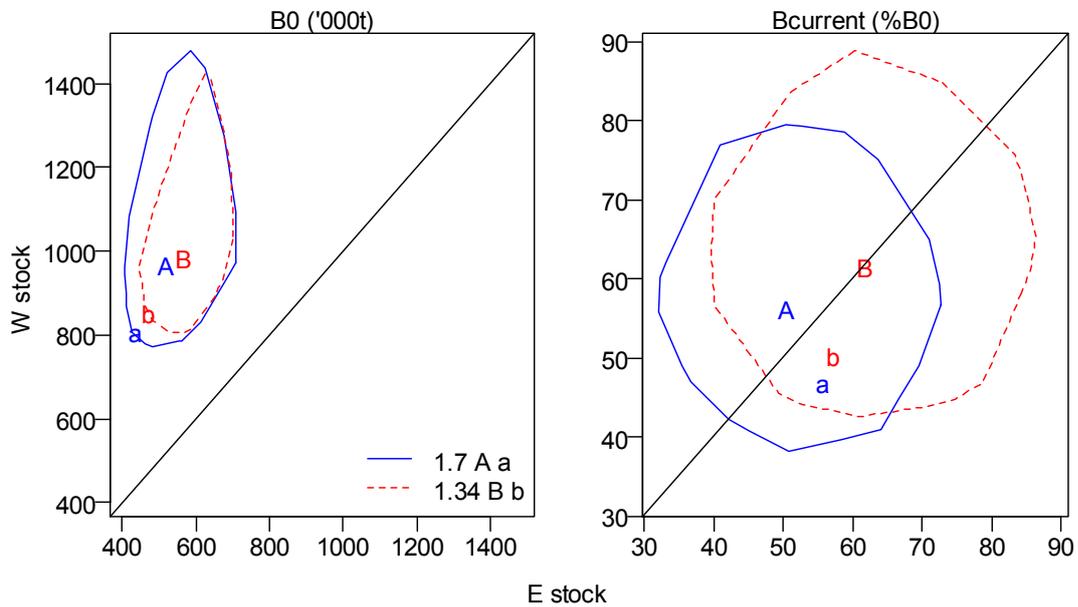


Figure 22: Estimates and approximate 95% confidence intervals for virgin ( $B_0$ ) and current ( $B_{current}$  as  $\%B_0$ ) biomass by stock for the runs 1.7 and 1.34. In each panel the points 'A' and 'B' indicate best estimates (median of the posterior distribution) for these two runs, 'a' and 'b' are the MPD estimates, and the polygons (with solid, broken and dotted lines, respectively) enclose approximate 95% confidence intervals. Diagonal lines indicate equality ( $y = x$ ).

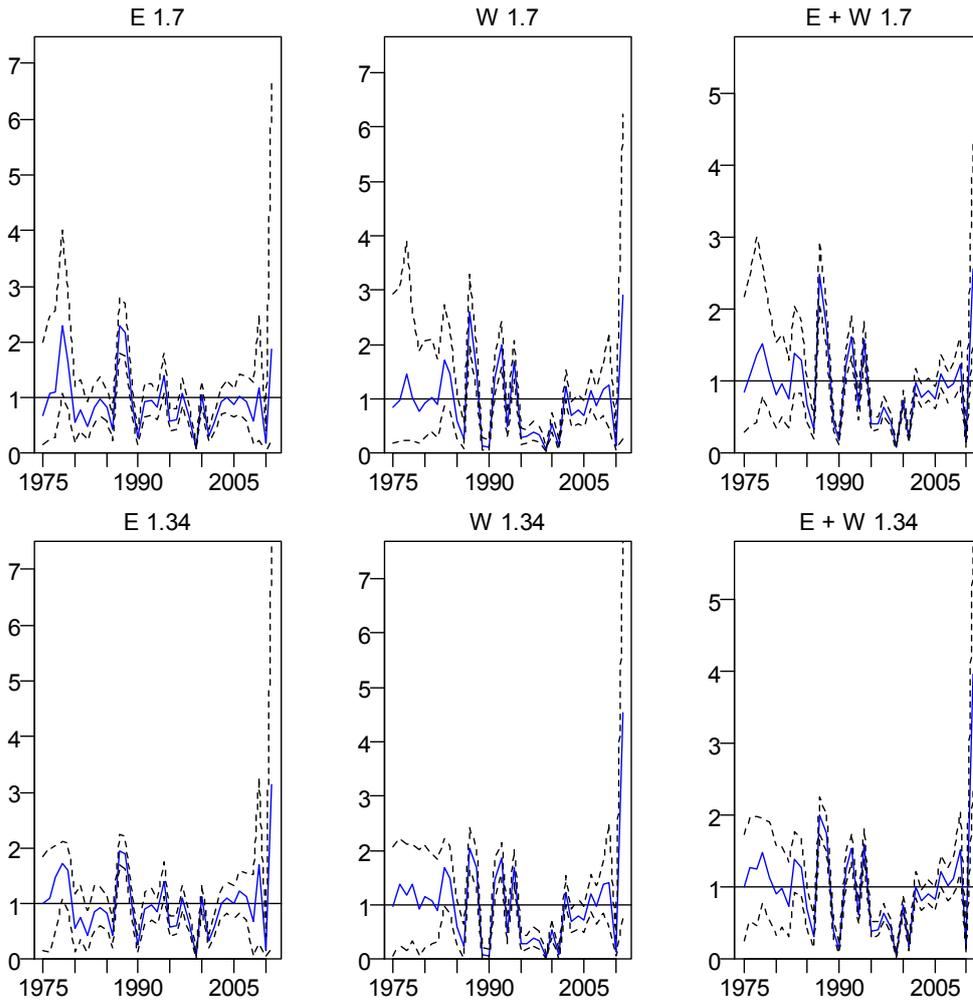


Figure 23: Estimated YCSs showing median (solid lines) and 95% confidence intervals (broken lines).

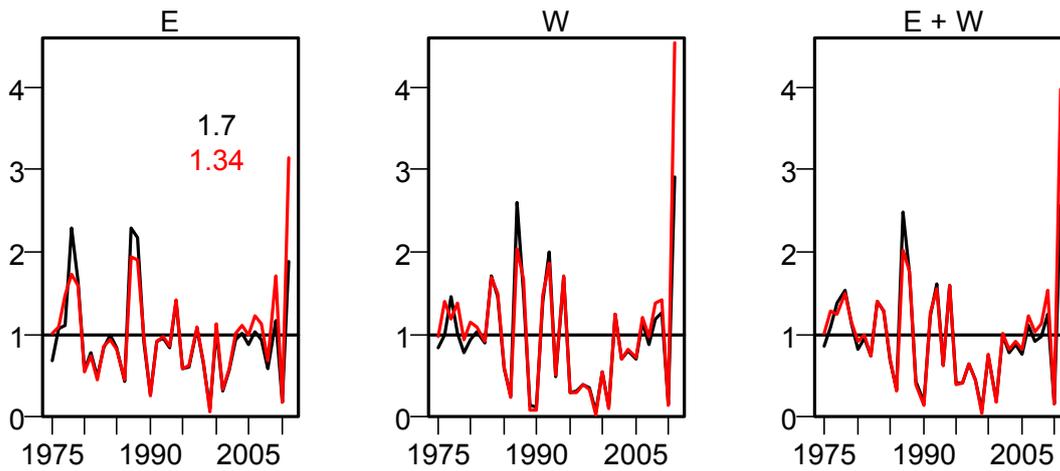


Figure 24: As in Figure 23, but showing just medians.

### 3.5 Conclusions

Moving from the Francis to the Haist parameterisation substantially reduces the influence of the priors in the posterior profile, but going from lognormal priors to uniform priors makes little change (under the Haist parameterisation). Current biomass (%B<sub>0</sub>) is increased using a Haist parameterisation with uniform priors, compared to using the Francis parameterisation with lognormal priors.

The Deepwater Working Group had yet to make any decisions on what YCS parameterisation and priors to use before initial model MPD runs were undertaken, so these retained the Francis parameterisation and lognormal priors of the previous assessment (Section 4). For the final model MCMC runs it was decided to use the Haist parameterisation with lognormal priors, and run sensitivity analyses with variations on parameterisation and priors (Section 5).

## 4. INITIAL EXPLORATORY MODEL RUNS

In this section we describe preliminary MPD analyses with the new data, investigate any problems that arise, and identify which runs should be used in the formal assessment (presented in Section 5).

Three sets of initial exploratory runs were done: (1) incorporating the new data and comparing model fits to the previous assessment (2) investigating whether or not to upweight the trawl surveys to improve the fit to the biomass indices, and (3) a sensitivity analysis with the Espage observational data.

For the 2013 hoki stock assessment there were seven model runs taken through to the MCMC stage, of which three were final model runs and the other four sensitivity analyses (Table 14). All of the three final model runs had age-varying natural mortality, assumed natal fidelity, and trawl survey data that was not upweighted. They differed in whether or not they had a single catchability for the Southern Plateau trawl survey, and, if they had two catchabilities, in the way this was implemented.

For the 2014 assessment an initial model (1.1) was set up with a robustified lognormal error distribution for the at-age data. The function of this model is to determine weights for the at-age data in the reweighting procedure, and after data reweighting the model becomes run 1.4 with a multinomial error distribution used for the at-age data (Table 15). Reweighting results are summarised for this model run in Appendix 3.

Other initial set of MPD runs for the 2014 hoki stock assessment included updates of the three final model runs from the 2013 assessment, with some sensitivity analyses (Tables 15–16). Note that the commercial spawning-at-age data for Cook Strait (Espage) for 2011, 2012, and 2013 is excluded from model runs, except in a sensitivity model run. Where Espage for 2011, 2012, and 2013 is included as a sensitivity analysis, each year's data is assumed to have an effective sample size equal to the mean effective sample size for the three years 2008–2010 of Espage (98). In 2014, a continuity model run 1.4 with a single catchability was completed (this model being similar to one of the final model runs from the 2013 assessment). Trawl survey biomass indices upweighting was investigated in 2014 with the model run 1.7.

Following the practice of the 2013 assessment, the YCSs are parameterised using the Francis parameterisation with lognormal priors. Some concern had been expressed regarding the impact this parameterisation has on the objective function (see Section 3), but as the Deepwater Working Group had made no decision on this the parameterisation was continued for the initial set of runs.

**Table 14: Previous 2013 assessment model runs. Distinguishing characteristics for all model runs taken to MCMC, with the three final runs marked with an asterisk (reproduced from McKenzie 2015). Aspects of a model run that distinguish it from other runs are shown in bold italics. Run 1.4 is a continuity run with the same structure as the base case from the previous assessment in 2012; 1.7 differs from 1.4 in that the trawl survey indices are not upweighted. Run 1.16 is a final run with sensitivities 1.17 and 1.18. Run 1.19 is a final run with sensitivities 1.20 and 1.21.**

| Label | Two catchabilities for SASumbio? | Response to lack of old fish in the observations | Trawl surveys up-weighted? | Sex in model and selectivities length- | Natal fidelity? |
|-------|----------------------------------|--|----------------------------|--|-----------------|
| 1.4   | No                               | M dependent on age                               | Yes                        | Yes                                    | Yes             |
| 1.7*  | No                               | M dependent on age                               | No                         | Yes                                    | Yes             |
| 1.16* | 04–07q different                 | M dependent on age                               | No                         | Yes                                    | Yes             |
| 1.17  | 04–07q different                 | <b>Domed spawning selectivity</b>                | No                         | <b>No</b>                              | Yes             |
| 1.18  | 04–07q different                 | M dependent on age                               | No                         | Yes                                    | <b>No</b>       |
| 1.19* | 08–13q different                 | M dependent on age                               | No                         | Yes                                    | Yes             |
| 1.20  | 08–13q different                 | <b>Domed spawning selectivity</b>                | No                         | <b>No</b>                              | Yes             |
| 1.21  | 08–13q different                 | M dependent on age                               | No                         | Yes                                    | <b>No</b>       |

**Table 15: Hoki stock assessment for 2014: comparison of initial MPD runs. Aspects of a model run that distinguish it from earlier runs are shown in bold italics.**

| Run | Response to lack of old fish in the observations | Two catchabilities for SASumbio? | Trawl surveys up-weighted? | Natal fidelity? | At-age reweighted? |
|-----|--|----------------------------------|----------------------------|-----------------|--------------------|
| 1.4 | M dependent on age                               | N                                | N                          | Y               | Y                  |
| 1.5 | M dependent on age                               | <b>04–07q different</b>          | N                          | Y               | Y                  |
| 1.6 | M dependent on age                               | <b>08–13q different</b>          | N                          | Y               | Y                  |
| 1.7 | M dependent on age                               | N                                | <b>Y</b>                   | Y               | Y                  |

**Table 16: Hoki stock assessment for 2014. Model run labelling for a set of three sensitivities involving the Espage at-age data to the runs 1.4, 1.5, and 1.6 (see Table 15).**

|                                 | initial run |     |      |
|---------------------------------|-------------|-----|------|
|                                 | 1.4         | 1.5 | 1.6  |
| Include Espage 2011, 2012, 2013 | 1.8         | 1.9 | 1.10 |

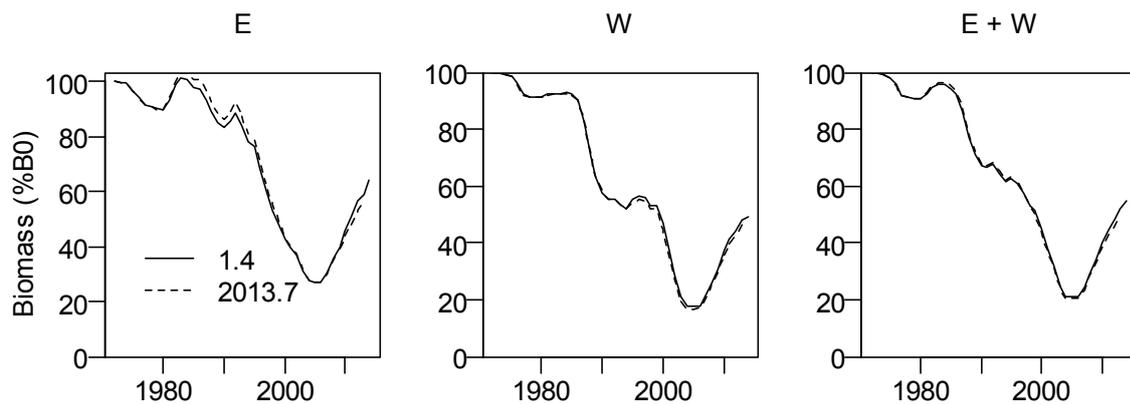
#### 4.1 Comparison to a final model run from the previous assessment in 2013

For the 2014 model run 1.4 with a single catchability and no trawl survey biomass upweighting, the biomass trajectory is compared to the comparable model run 1.7 from the previous assessment in 2013 (Table 17, Figure 25). For the new assessment model runs, the eastern and western virgin biomasses and  $B_{2013}$  as  $\%B_0$  are estimated to be very similar to comparable values from the 2013 assessment.

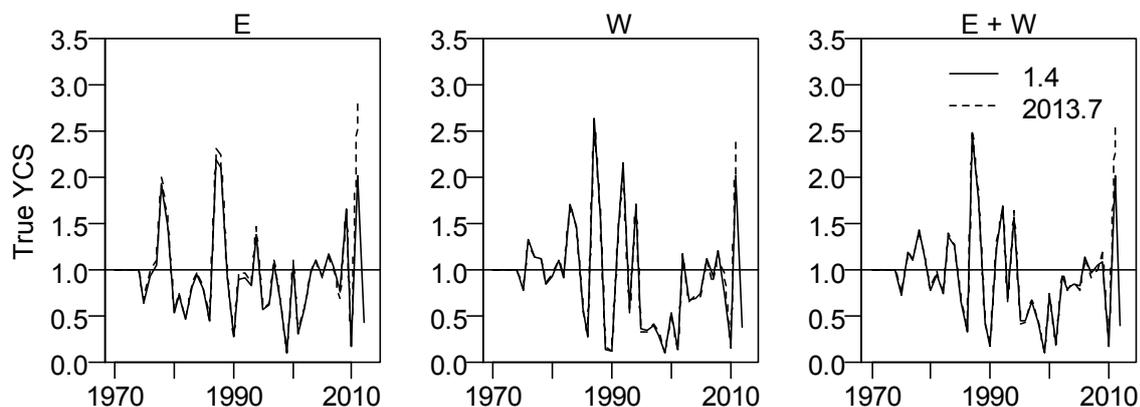
The year class strengths are very similar between the 2013 and 2014 assessments (Figure 26). Other graphs show selectivities, migration ogives, and fitted age-varying natural mortality, and are also very similar between the assessments (Figures 27–29).

**Table 17: Comparison of old and new biomass estimates for the individual stocks, E and W, and the combined E + W stock. The label 2013.7 refers to run 1.7 from the 2013 assessment (see Table 14), while run 1.4 is for the 2014 assessment (see Table 15).**

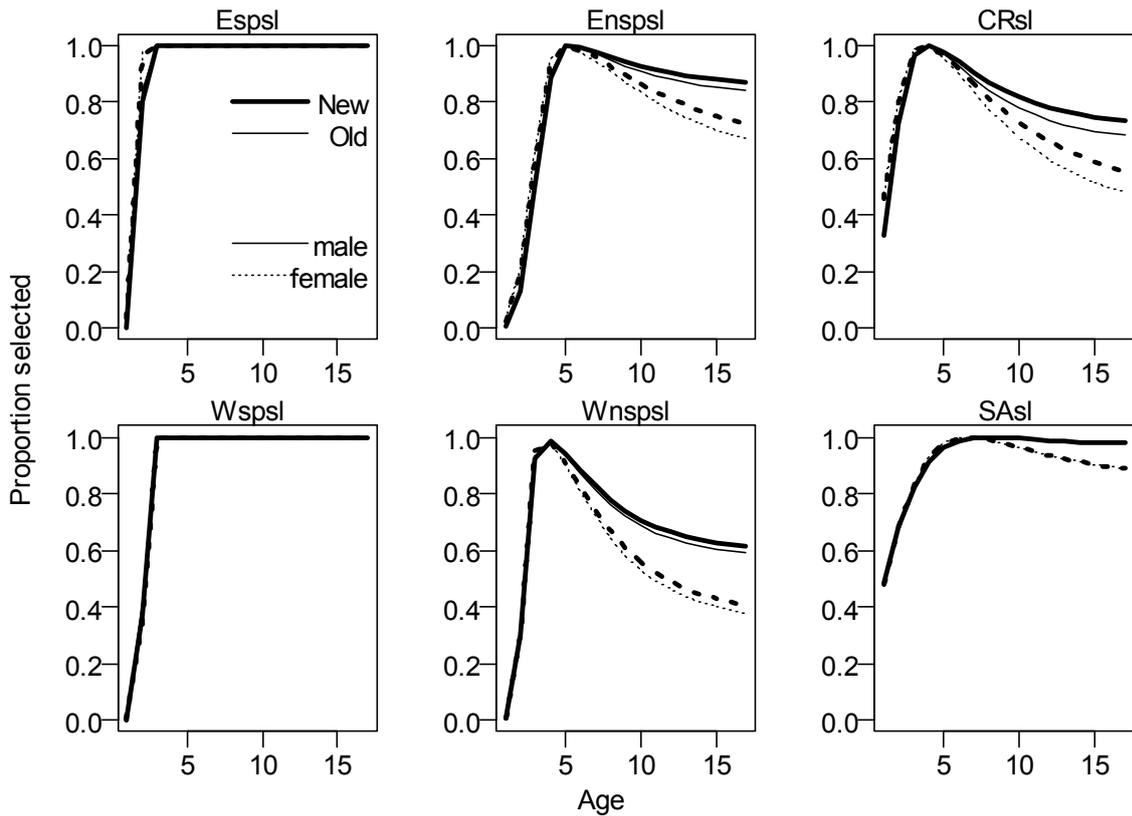
| Run    | $B_0$ ('000 t) |     |      | $B_{2013}(\%B_0)$ |    |     | $B_{2014}(\%B_0)$ |    |     |
|--------|----------------|-----|------|-------------------|----|-----|-------------------|----|-----|
|        | E              | W   | E+W  | E                 | W  | E+W | E                 | W  | E+W |
| 2013.7 | 433            | 804 | 1237 | 56                | 47 | 50  | NA                | NA | NA  |
| 1.4    | 450            | 800 | 1250 | 59                | 48 | 52  | 64                | 49 | 55  |



**Figure 25: Comparison of biomass trajectories from different runs: E stock (left column), W stock (middle column), and E + W stocks combined (right column). The graphs compare run 1.4 from 2014 (solid lines) with the corresponding run from 2013 (broken lines). The label 2013.7 refers to run 1.7 from the 2013 assessment.**



**Figure 26: True YCS estimates for new run 1.4 from 2014 (solid lines) compared to the comparable run from last year's assessment. The label 2013.7 denotes run 1.7 from the 2013 assessment.**



1.4 & 2013.7

Figure 27: Estimated selectivity curves for new run 1.4 from 2014 (heavy lines) and analogous 2013 run (light lines). Males are shown by a solid line, females by a dotted line. The label 2013.7 denotes run 1.7 for the 2013 assessment.

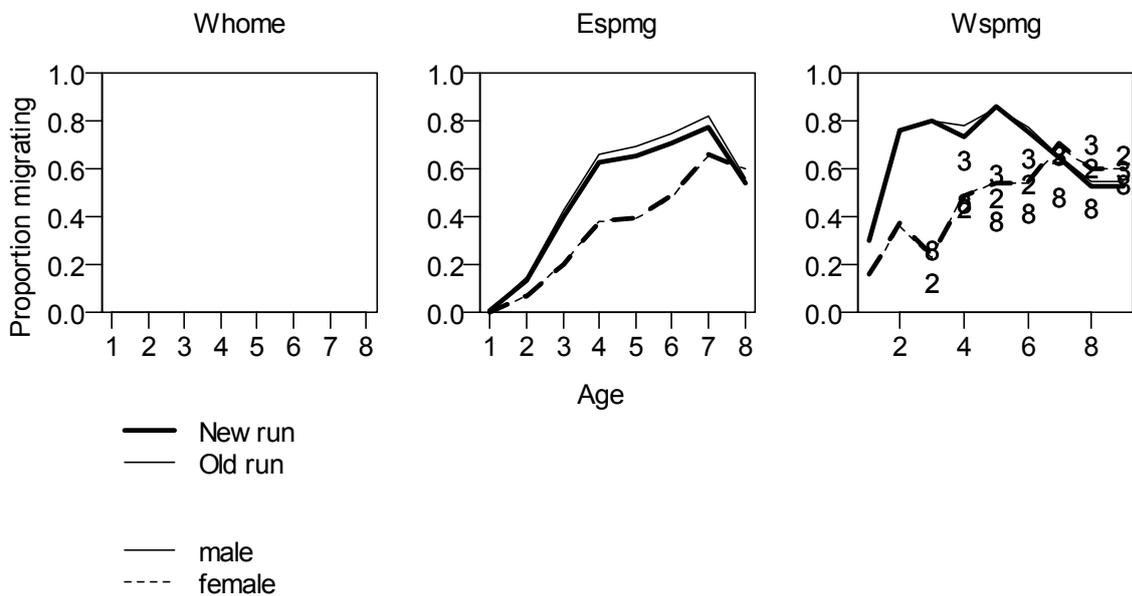


Figure 28: Estimated migration ogives for new (2014, 1.4) and old (2013, 1.7) runs. Each row of plots compares ogives from a new run (heavy lines) with those from the analogous 2013 runs (light lines). Where ogives differ by sex, female ogives are plotted as broken lines. The observations pspawn are also plotted in the rightmost panel, with the plotting symbol identifying the year of sampling ('2' = 1992, '3' = 1993, '8' = 1998).

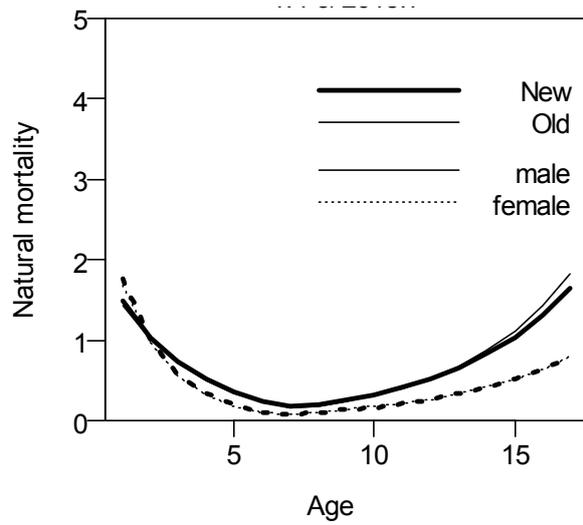


Figure 29: Comparison between age-dependent natural mortality estimated in the new run from 2014 (1.4, heavy lines) and the corresponding run from 2013 (1.7, light lines).

## 4.2 2014 MPD results: trawl upweighting and data sensitivities

All model runs in this section, and those that follow, are for the 2014 assessment. In run 1.7 the trawl surveys are upweighted, unlike run 1.4. Upweighting slightly improves the fit for the last four years of CRsumbio, and about half the years up to 2007 for SAsumbio (Table 18, Figures 30–32). The upweighting produces little difference in the fits to the other biomass data sets SAautbio, CSacous, and WCacous.

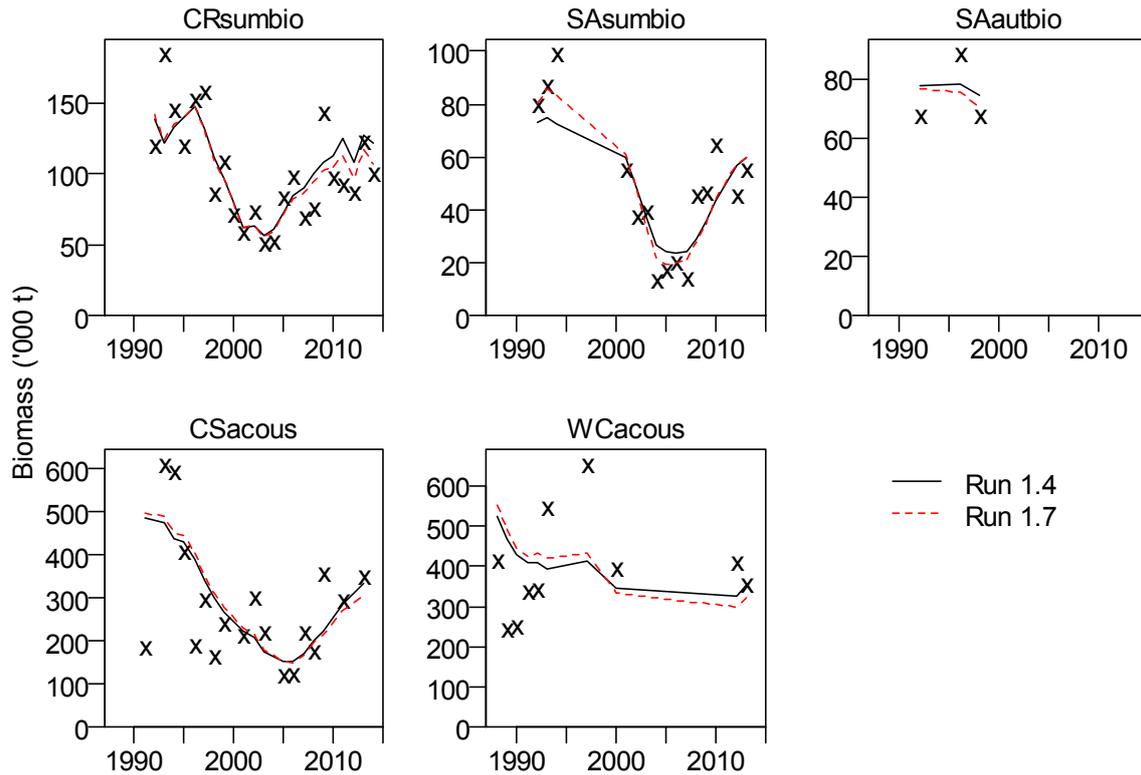
There is some evidence of a change in catchability for SAsumbio (Figure 33), where the change in numbers at age shows a step down in 2003 and a step up in 2007. Run 1.4 uses a single catchability for SAsumbio, whereas runs 1.5 and 1.6 use two. Using two catchabilities improves the fit to SAsumbio (Figure 34, Table 19), with the catchability for 2004–2007 estimated to be half that for other years (run 1.5) or 50% more for 2008–2013 (run 1.6) (Table 20). Biomass trajectories differ for the western stock between the single and two catchability models (Figure 35).

The data for Espage for 2011, 2012, and 2103 were considered of insufficient quality to include in the model, but a set of sensitivities are conducted to explore their possible impact (see Table 16). They all decrease the current biomass (%B<sub>0</sub>) for the east stock and increase it for the west stock (Figure 36). Correspondingly the east stock 2011 YCS decreases and the west stock 2011 YCS increases (Figure 37). There is very little change in the selectivities (Figure 38).

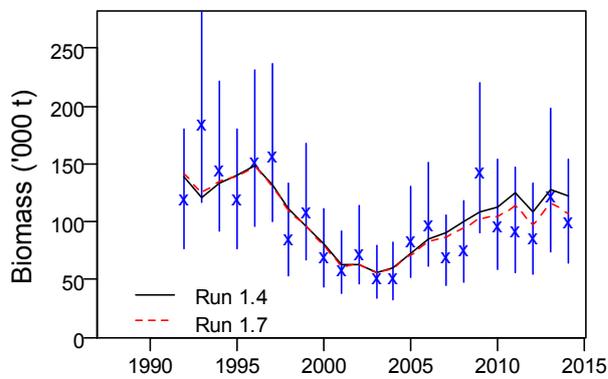
Current biomasses for east and west stocks are summarised for all model runs in Table 21.

**Table 18: Goodness of fit to biomass indices as measured by SDNR (standard deviation of the normalised residuals) for two 2014 model runs. For this table the normalised residuals were calculated using the original CVs (i.e. ignoring changes in CVs. for upweighting trawl biomass data sets).**

| run | CRsumbio | SAsumbio | SAautbio | CSacous | WCacous |
|-----|----------|----------|----------|---------|---------|
| 1.4 | 0.87     | 1.37     | 0.67     | 0.94    | 0.90    |
| 1.7 | 0.80     | 1.10     | 0.68     | 0.97    | 0.96    |



**Figure 30: Fit to biomass indices for 2014 runs 1.4 and 1.7 showing observed ('x') and expected values (lines). In model run 1.4 the trawl survey indices are not upweighted, for 1.7 they are.**



**Figure 31: Fits to CRsumbio for 2014 runs 1.4 and 1.7, showing observed ('x', with vertical lines showing 95% confidence intervals) and expected values (lines). Plotted years are as in the model (so the last survey is plotted at 2014). The trawl survey indices are not upweighted (solid lines) or upweighted (dashed lines).**

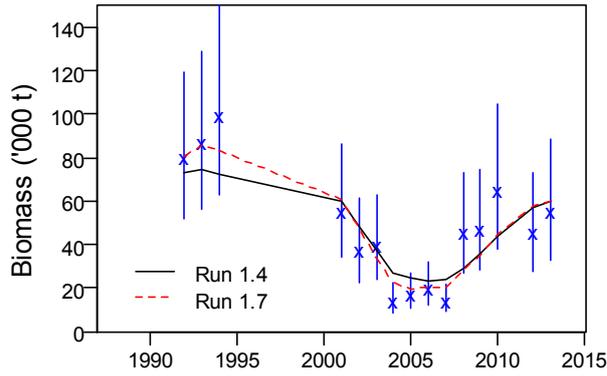


Figure 32: Fits to SAsumbio for 2014 runs 1.4 and 1.7, showing observed ('x', with vertical lines showing 95% confidence intervals) and expected values (lines). Plotted years are as in the model (so the last survey is plotted at 2013). The trawl survey indices are not upweighted (solid lines), and upweighted (dashed lines).

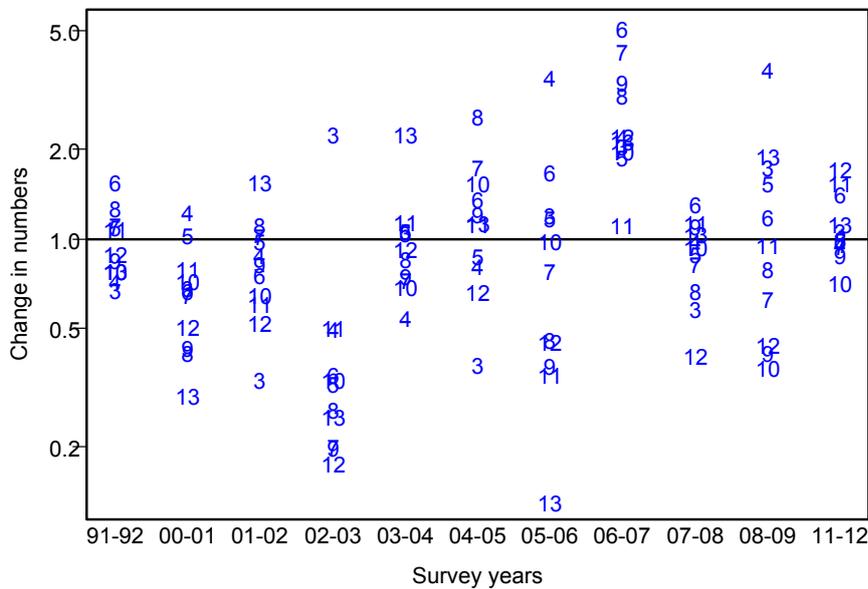
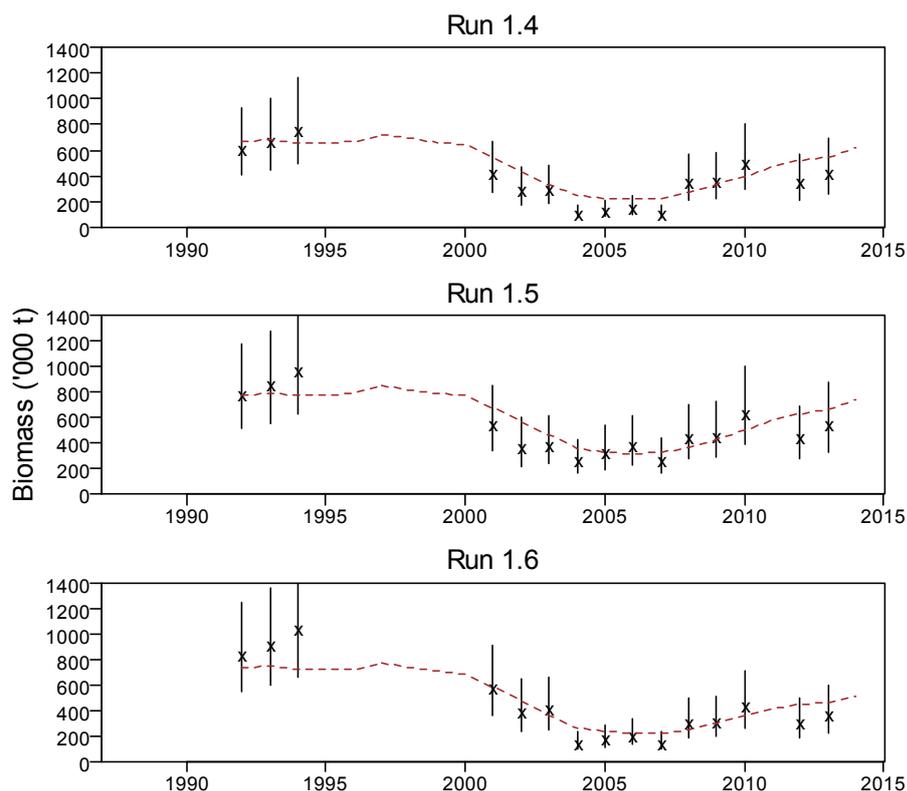


Figure 33: Changes, between surveys one year apart in the Southern Plateau summer series, in estimated numbers of selected cohorts. Each plotted point indicates how the estimated number in a cohort changed between the two surveys; the plotting symbol is the age of the cohort in the earlier survey. For example, for the 06-07 survey years, the estimated number in the cohort that was aged 6 in the 2006 survey increased by a factor of about five in the 2007 survey. Note that the 2006 Southern Plateau summer survey year is in the 2007 fishing year.



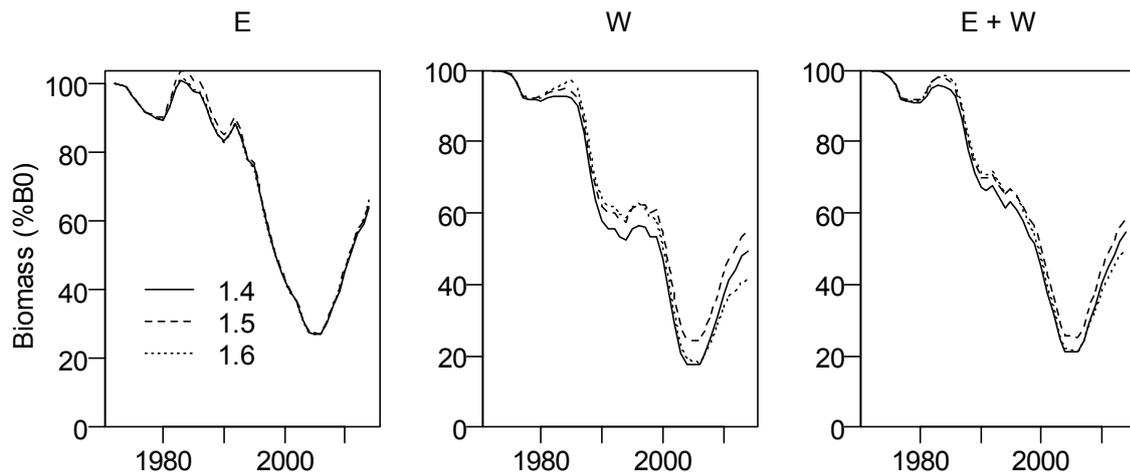
**Figure 34: Fits to SAsumbio for runs 1.4, 1.5, and 1.6 showing observed scaled to biomass by dividing by catchability ('x', with vertical lines showing 95% confidence intervals) and expected values (dashed lines). Plotted years are as in the model (so the last survey is plotted at 2014). The trawl survey indices are not upweighted for any runs. In run 1.5 the years 2004–2007 inclusive have a separate catchability from other years; for run 1.6 the years 2008–2013 inclusive have a separate catchability from other years.**

**Table 19: Objective function values for selected model runs.**

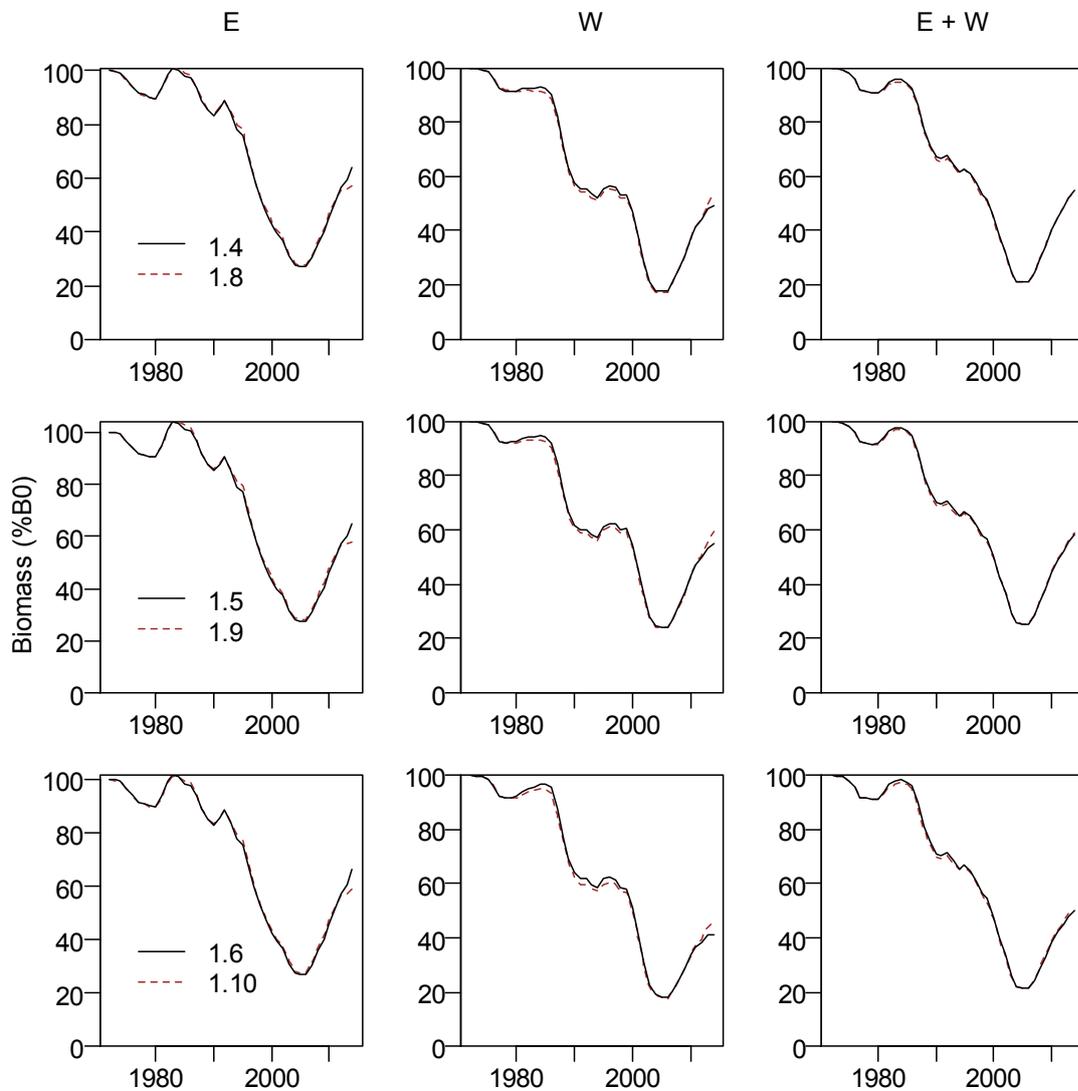
| Run | Trawl surveys<br>upweighted? | Objective function |       |         |
|-----|------------------------------|--------------------|-------|---------|
|     |                              | SAsumbio           | Total |         |
| 1.4 | single $q$                   | N                  | -8.7  | 2 635.0 |
| 1.5 | 04–07 $q$ different          | N                  | -16.0 | 2 623.6 |
| 1.6 | 08–13 $q$ different          | N                  | -12.7 | 2 629.5 |

**Table 20: Estimated catchability for the model runs.**

| Run | Catchability |         |         |
|-----|--------------|---------|---------|
|     | 1992–2003    | 2004–07 | 2008–13 |
| 1.4 | 0.11         | 0.11    | 0.11    |
| 1.5 | 0.10         | 0.05    | 0.10    |
| 1.6 | 0.10         | 0.10    | 0.15    |



**Figure 35: Comparison of biomass trajectories from different runs: E stock (left column), W stock (middle column), and E + W stocks combined (right column).**



**Figure 36: Comparison of biomass trajectories from different runs: E stock (left column), W stock (middle column), and E + W stocks combined (right column). Excluding Espage for 2011, 2012, and 2013 (solid line) or including it (dashed line). For an explanation of the model runs see Table 16.**

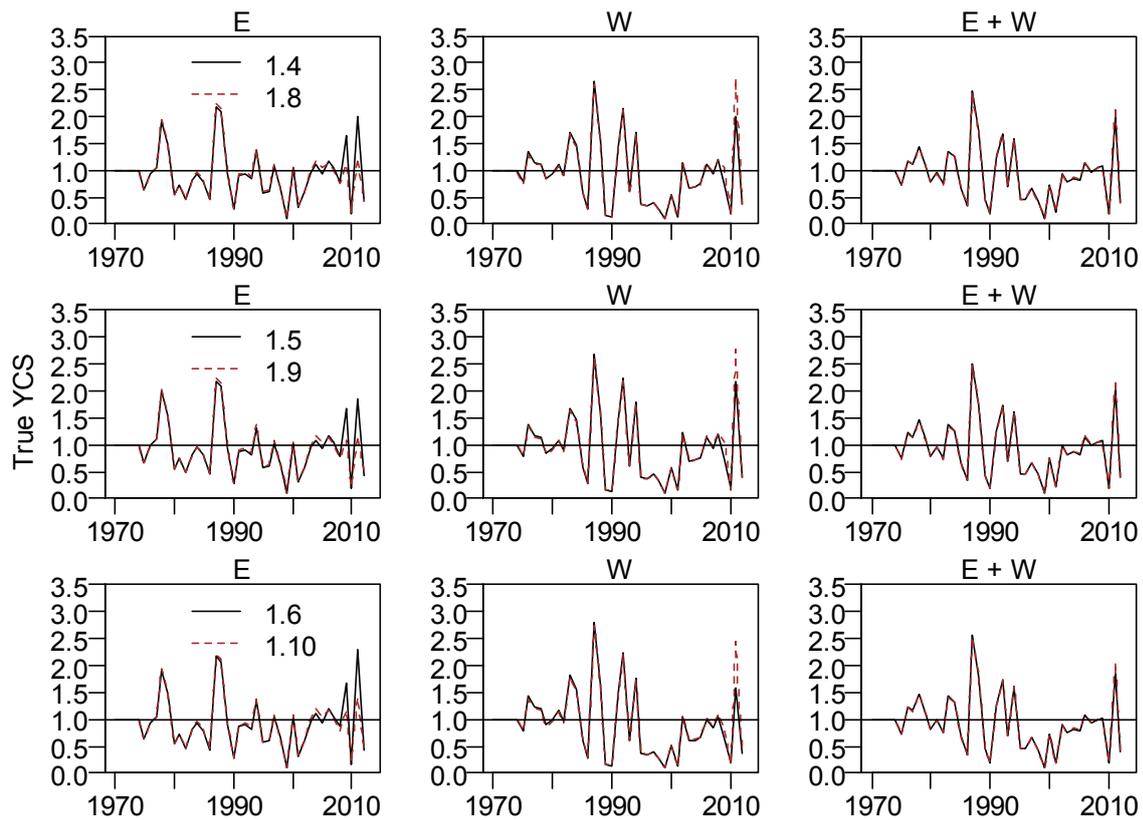


Figure 37: True YCS estimates excluding Espage for 2011, 2012, and 2013 (solid line) or including it (dashed line). For an explanation of the model runs see Table 16.

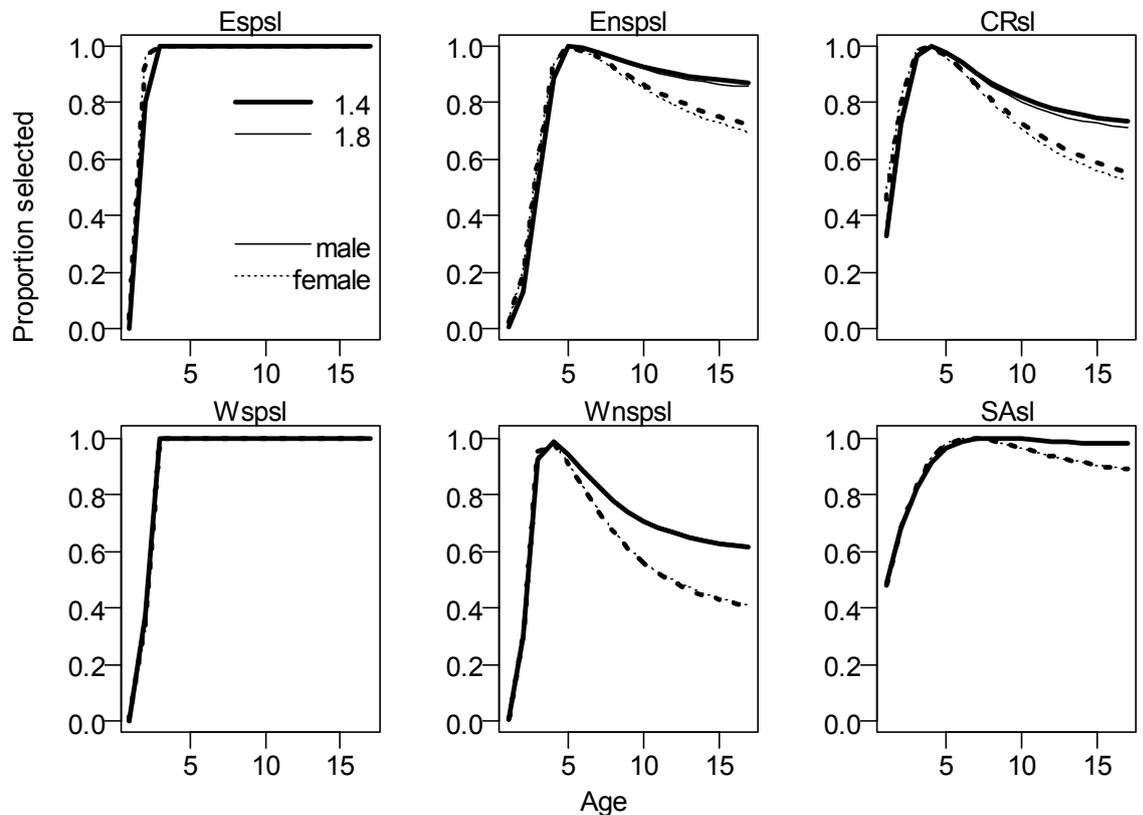


Figure 38: Estimated selectivities: excluding Espage for 2011, 2012, and 2013 (heavy line) or including them (light line). Males are shown by a solid line, females by a dotted line.

**Table 21: Estimates of current biomass for MPD runs.**

| Run  | $B_{\text{current}}(\%B_0)$ |    |
|------|-----------------------------|----|
|      | E                           | W  |
| 1.4  | 64                          | 49 |
| 1.5  | 65                          | 55 |
| 1.6  | 66                          | 41 |
| 1.7  | 58                          | 38 |
| 1.8  | 57                          | 53 |
| 1.9  | 58                          | 59 |
| 1.10 | 59                          | 46 |

## 5. FINAL MODEL ASSESSMENT RESULTS

It was decided by the Deepwater Working Group to take nine runs, 1.11 to 1.19, through to the MCMC stage (Table 22).

The base model 1.11 uses a single catchability for the Southern Plateau trawl survey (SAsumbio). The alternative model runs 1.12 and 1.13 use two catchabilities for the Southern Plateau summer trawl survey.

Run 1.13 (2008–13 two- $q$ ) gives the lowest estimates of western biomass of the three model runs 1.11, 1.12, and 1.13; consequently, sensitivities are conducted on it (Table 22). In the first, natal fidelity isn't assumed (1.14). In model run 1.15 a domed spawning selectivity is used instead of an age-varying natural mortality (with  $M$  estimated as a constant). For model 1.16 the Haist parameterisation is retained, but uniform priors (instead of lognormal) are used for the YCSs.

Model run 1.17 is considered a continuity run with the 2013 assessment in which the Francis parameterisation of YCSs is used with a lognormal prior (as was used for all final model runs of the 2013 assessment).

Year class strengths are estimated for the east and west stocks up to the 2012 fishing year. In run 1.18 the uncertainty in the split of the year class strengths is investigated by setting the east and west year class strength equal for 2011 and 2012; this run was taken through into projections where recent year class strengths are influential.

In model runs 1.11 to 1.18 the catchability parameters are estimated as “nuisance” parameters, i.e., they are calculated analytically as part of the estimation process (Bull et al. 2012, p. 83). This approach is potentially helpful for MPD fits, but arguably not appropriate when sampling from the posterior in an MCMC (except asymptotically). Because of this a sensitivity run 1.19 is done in which the catchability parameters are estimated as “free” instead of “nuisance”.

For model runs 1.11 to 1.18 the at-age data is reweighted, with this being done for each model run. For model run 1.19 the same at-age data weightings are used as in run 1.13, for which it is intended as a direct sensitivity with no changes to the data weightings. Trawl surveys are not upweighted in any runs, as was the case for the previous assessment. In all of the runs, except for one sensitivity, the Haist parameterisation is used for YCSs with lognormal priors, instead of the Francis parameterisation used in the previous assessment (see Section 3 for an explanation why).

**Table 22: Comparison of final model runs for the 2014 hoki stock assessment, including sensitivities to run 1.13 (2008–13 two- $q$ ).**

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

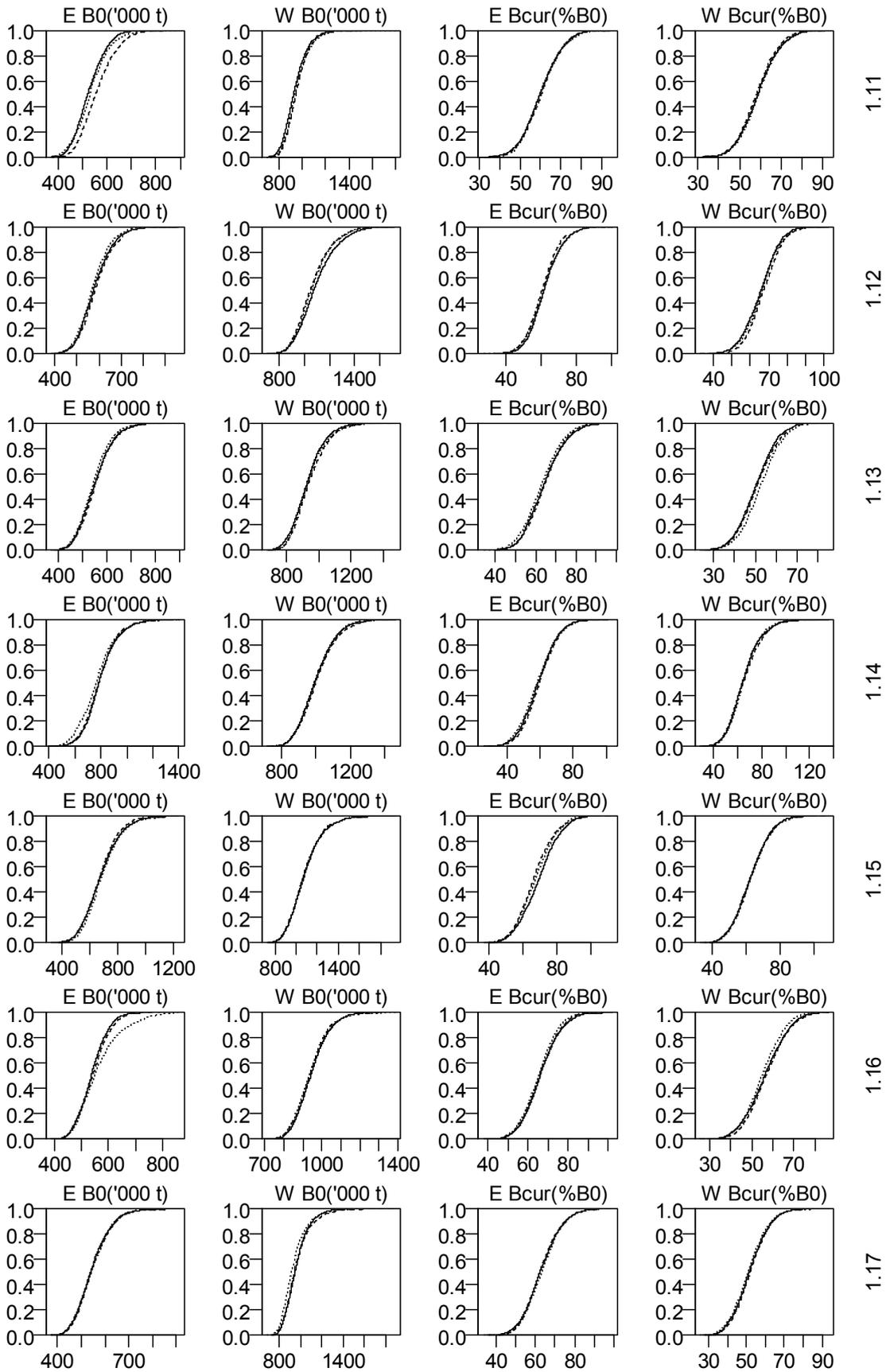
Three MCMC chains of length 2 million samples were created, each chain having a different starting point, which was generated by stepping randomly away from the MPD. As in the previous assessment, those migration or selectivity parameters that were found to be at a bound in the MPD run were fixed for the MCMC runs in order to improve convergence (Table 23). Fixed parameters are similar to those in the previous assessment, and most of them probably have minor impact, although those for the position of the peak of the selectivities may warrant further investigation (i.e. the Chatham Rise and Southern Plateau trawl surveys).

Diagnostic plots comparing the three chains for each run suggest good convergence for the runs, although for 1.11 (single catchability) and 1.16 (Haist with uniform) the eastern virgin biomass for one of the chains differs somewhat from the other two (Figure 39–40). Estimating catchabilities as free parameters instead of nuisance parameters gives chains that don’t converge as well, but are still acceptable (Figure 41).

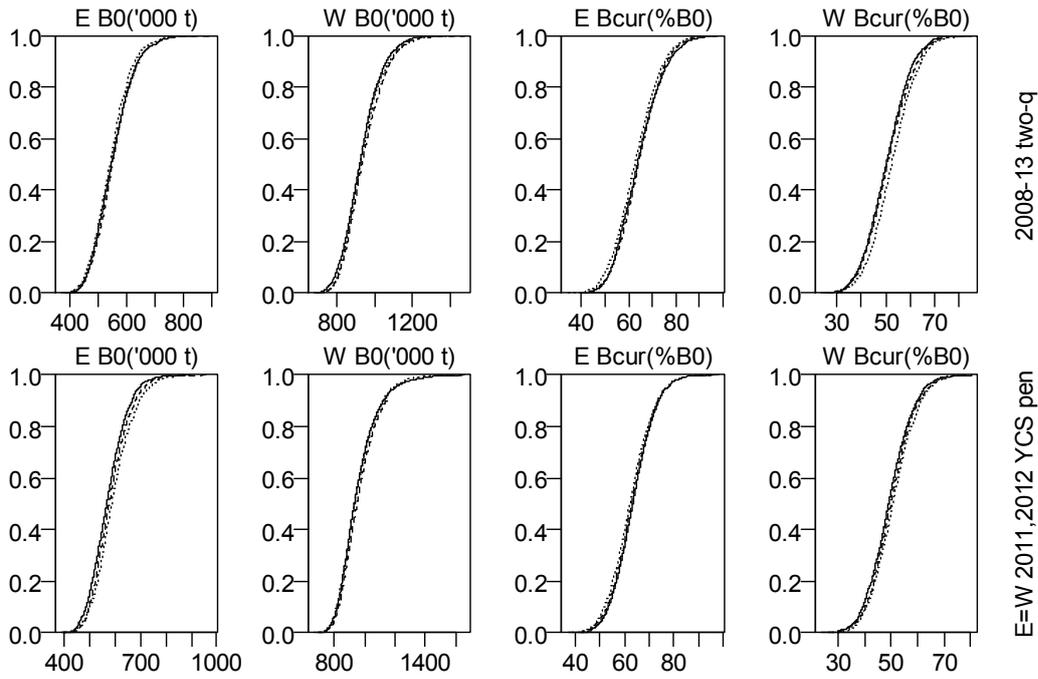
For all subsequent results, the first quarter of each chain was discarded, the three chains for each run were concatenated, and the resulting chain was thinned to produce a posterior sample of length 1000.

**Table 23: Migration and selectivity parameters held fixed in the MCMC base run 1.11 (one- $q$ ) and the MCMC run 1.13 (2008–13 two- $q$ ) for which the sensitivities were conducted (with fixed values in parentheses). Similar parameters were fixed for the sensitivities. The notation M1 refers to a male of age 1, and similarly F8 refers to a female of age 8. The parameters a1, sL, sR define the parameters of a double normal selectivity (Bull et al. 2012). For the meanings of the other abbreviations, refer to Table 1.**  
Parameters (fixed values)

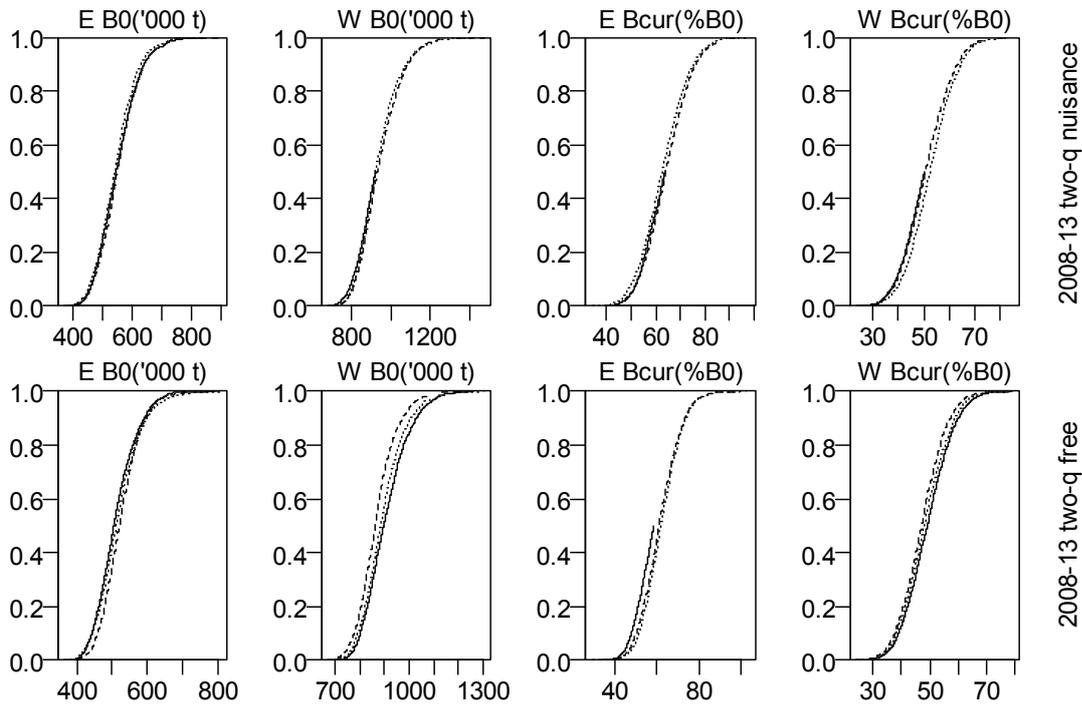
Whome7(1), EspmgF1(0), EspmgF8(0), WspmF8(0.6), WnspL.a1(64), EspL.sL(4), CRsl.a1(64), SAsl.a1(84), SAsl.sL(44), SAsl.sR(44).



**Figure 39: Diagnostics for MCMC chains for the seven runs: 1.11 to 1.17. Each panel contains cumulative probability distributions, for  $B_0$  or  $B_{current}$ , for three chains from the same model run.**



**Figure 40: Diagnostics for MCMC chains for the run 1.13 (2008-13 two- $q$ ) and the sensitivity where the E and W 2011 and 2012 YCSs are set equal in run 1.18 (E=W 2011, 2012 YCS pen). Each panel contains cumulative probability distributions, for  $B_0$  or  $B_{\text{current}}$ , for three chains from the same model run.**



**Figure 41: Diagnostics for MCMC chains for the run 1.13 (2008-13 two- $q$  nuisance) and the sensitivity 1.19 where the catchability parameters are estimated as free parameters (2008-13 two- $q$  free). Each panel contains cumulative probability distributions, for  $B_0$  or  $B_{\text{current}}$ , for three chains from the same model run.**

The MCMC results for all runs show that the western spawning stock was originally larger than the eastern spawning stock (Table 24, Figures 42–45). The models estimate the current spawning biomass for the eastern stock to be at 59–67%  $B_0$ , and for the western stock 48–66%  $B_0$  (values are ranges for medians).

Relative to the 2008–13 two- $q$  model (1.13), not assuming natal fidelity gives an E biomass that is about the same (% $B_0$ ) and a W biomass that is greater (Figure 43). Using a domed spawning selectivity gives a current biomass (% $B_0$ ) that is more for both E and W stocks (Figure 43).

Relative to the 2008–13 two- $q$  model (1.13) for which the Haist parameterisation is used with lognormal priors, using the Francis parameterisation with lognormal priors gives very similar results, while the Haist with uniform priors gives a greater biomass for the W stock (% $B_0$ ) (Figure 44).

Estimating catchabilities as free instead of nuisance parameters reduces the estimates of current biomass (Figure 45). However, changes in median values (% $B_0$ ) are small with the E stock reducing from 62 to 60 and the W stock from 50 to 48 (Table 24).

For estimated biomass in 2013, the estimated values from the 2014 assessment are similar to those from last year (Figure 46).

All runs suggest that the W and E stocks are increasing (Figures 47–52), and estimate a high YCS in 2011 followed by a low YCS in 2012 (Figure 53–57).

The estimated selectivities are very similar for the three base models (Figure 58). Migration ogives and age-varying natural mortality are similar between runs, except that without natal fidelity natural mortality is estimated to be higher for younger fish (Figures 59–60). The values estimated for natural mortality can be quite low, e.g., for the base case 1.11 (one- $q$ ) the minimum value is 0.215 for males and 0.098 for females.

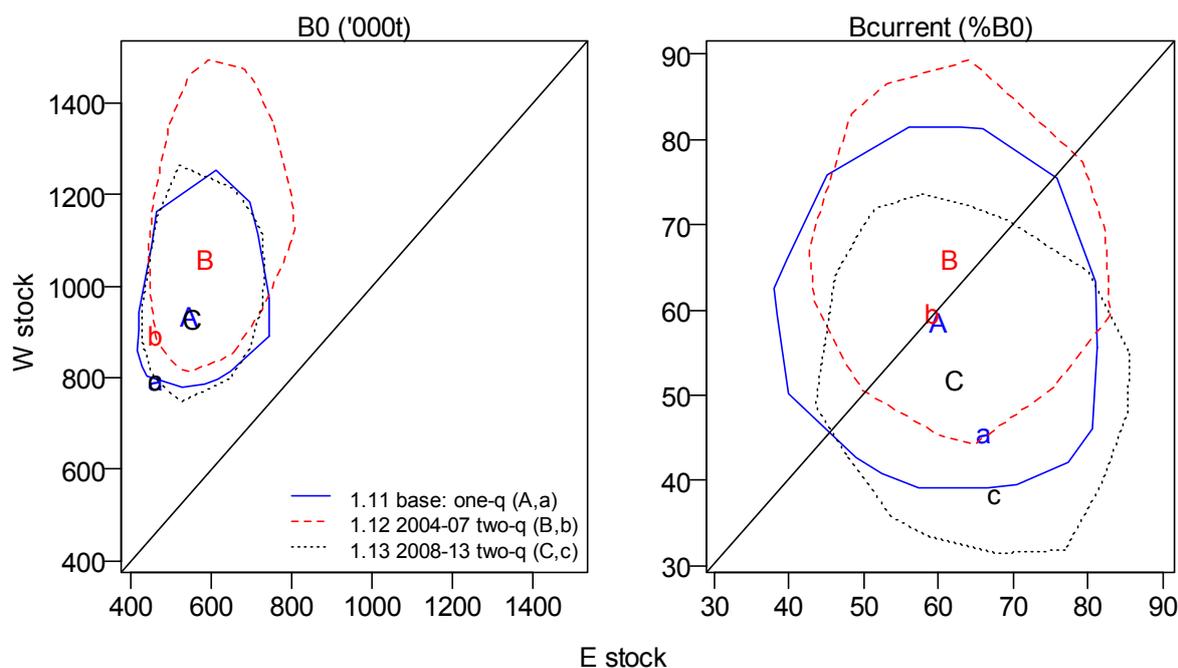
The biggest difference between priors and posteriors occurs for the estimate of the Southern Plateau catchability for 2004–07 (Figures 61–63). When more than one catchability is estimated for the Southern Plateau trawl survey, the value for 2004–07 is about half that for other years, or the value for 2008–13 is about 50% more than other years (Table 25, Figures 64–65).

Without a separate 2004–07 catchability estimated for the Southern Plateau trawl survey, a pattern of three or four low residuals is observed for these years (Figures 66–68). However, for a series of the length of the Southern Plateau trawl survey this is not unexpected statistically (Patrick Cordue, pers. comm.).

The posterior distributions for the catchabilities retain the same shape when estimated as free, but are shifted to the right (Figure 69, Table 26).

**Table 24: Estimates of spawning biomass (medians of marginal posterior, with 95% confidence intervals in parentheses) for the five runs. B<sub>current</sub> is the biomass in mid-season 2014.**

| Run  | B <sub>0</sub> ('000 t) |                | B <sub>current</sub> ('000 t) |               | B <sub>current</sub> (%B <sub>0</sub> ) |            |            |
|------|-------------------------|----------------|-------------------------------|---------------|---|------------|------------|
|      | E                       | W              | E                             | W             | E                                       | W          | E+W        |
| 1.11 | 542(430,698)            | 938(787,1179)  | 324(205,496)                  | 547(344,894)  | 60(43,79)                               | 59(42,78)  | 60(48,74)  |
| 1.12 | 581(460,754)            | 1064(853,1420) | 357(239,531)                  | 707(438,1113) | 61(45,78)                               | 66(49,84)  | 65(53,78)  |
| 1.13 | 540(434,729)            | 918(780,1177)  | 336(226,519)                  | 464(274,746)  | 62(47,81)                               | 50(34,67)  | 55(44,68)  |
| 1.14 | 772(549,1097)           | 992(825,1224)  | 459(256,751)                  | 632(381,1030) | 59(41,81)                               | 64(43,92)  | 62(50,78)  |
| 1.15 | 673(472,980)            | 1066(837,1456) | 447(272,728)                  | 677(419,1065) | 67(47,91)                               | 63(45,85)  | 65(53,78)  |
| 1.16 | 543(448,712)            | 945(815,1124)  | 358(235,537)                  | 542(344,793)  | 65(48,83)                               | 57(40,75)  | 60(49,73)  |
| 1.17 | 544(428,700)            | 939(782,1236)  | 344(217,516)                  | 484(290,821)  | 63(46,83)                               | 51(36,71)  | 56(45,69)  |
| 1.18 | 570 (453,750)           | 937 (778,1283) | 358(238,542)                  | 464 (279,795) | 63 (48,79)                              | 49 (34,67) | 55 (43,68) |
| 1.19 | 516 (419,651)           | 884 (760,1095) | 312(204,466)                  | 423 (265,651) | 60 (43,81)                              | 48 (34,64) | 53 (42,64) |



**Figure 42: Estimates and approximate 95% confidence intervals for virgin (B<sub>0</sub>) and current (B<sub>current</sub> as %B<sub>0</sub>) biomass by stock for the three runs 1.11, 1.12, and 1.13. In each panel the points 'A', 'B', 'C' indicate best estimates (median of the posterior distribution) for these three runs, 'a', 'b', 'c' are the MPD estimates, and the polygons (with solid, broken and dotted lines, respectively) enclose approximate 95% confidence intervals. Diagonal lines indicate equality (y = x).**

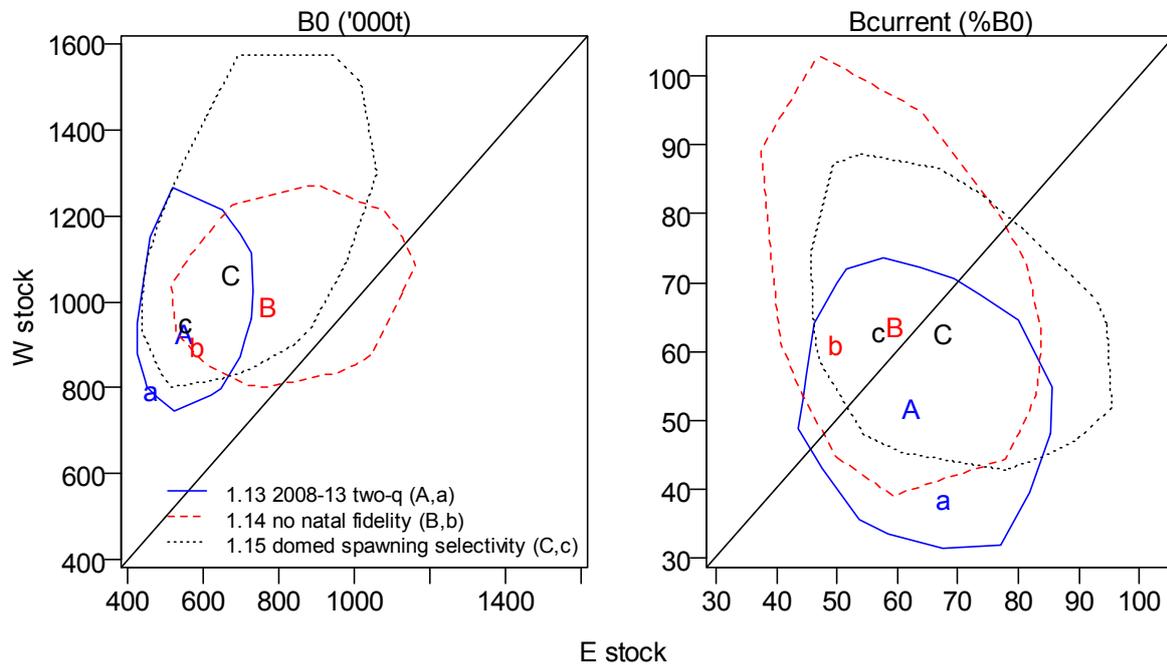


Figure 43: As for Figure 42 but for the run 1.13 (2008–13 two- $q$ ), and the two sensitivities 1.14 (no natal fidelity) and 1.15 (domed spawning selectivity).

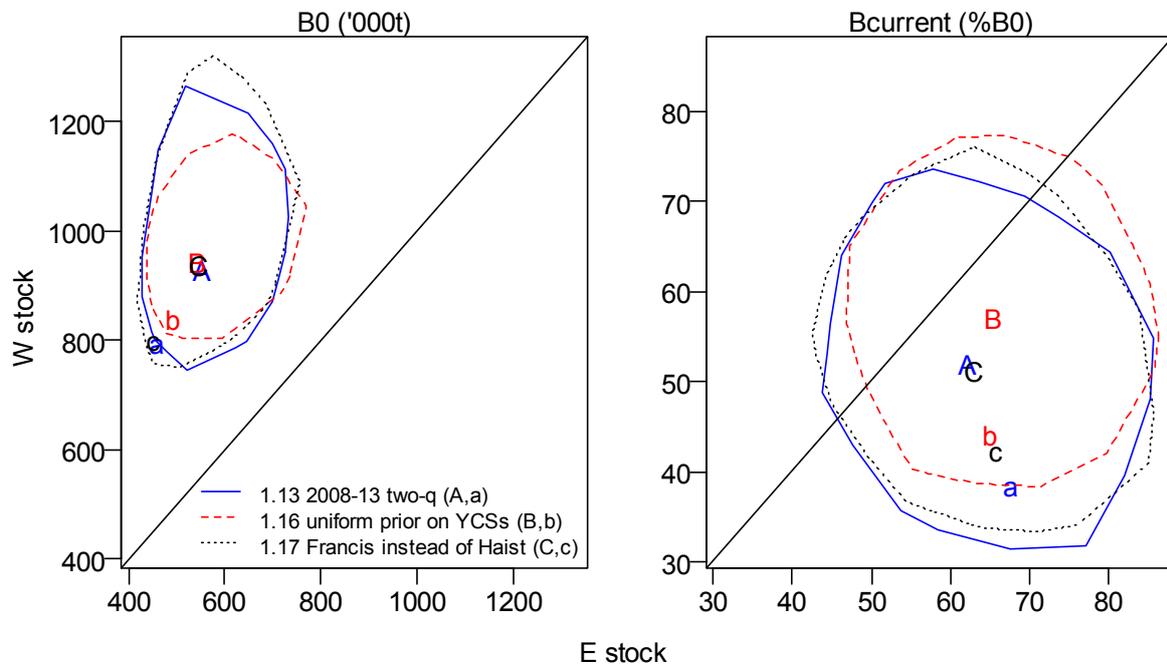


Figure 44: As for Figure 42 but for the run 1.13 (2008–13 two- $q$ ), and the two sensitivities 1.16 (Haist with uniform prior on YCSs) and 1.17 (Francis instead of Haist parameterisation).

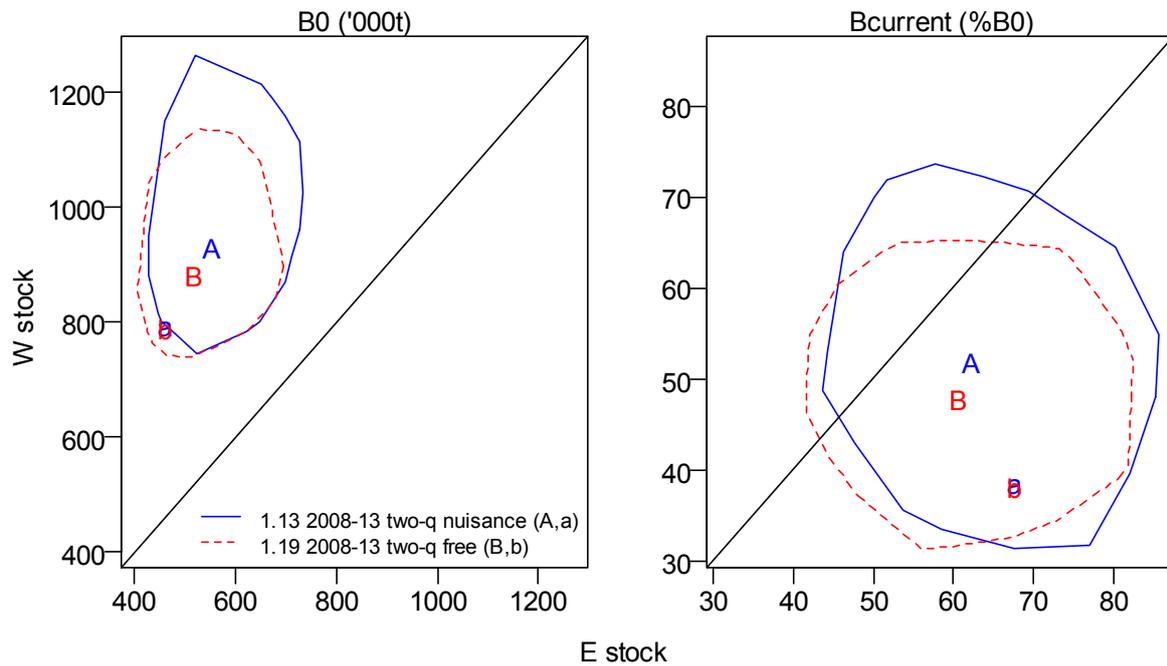


Figure 45: As for Figure 42 but for the run 1.13 (2008–13 two- $q$ ), and the sensitivity 1.19 (estimate catchabilities as free instead of nuisance).

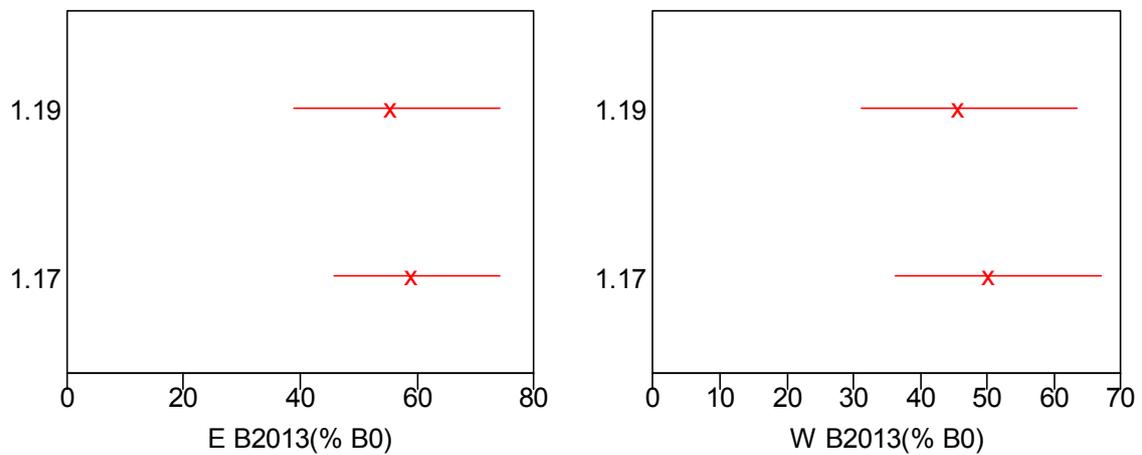
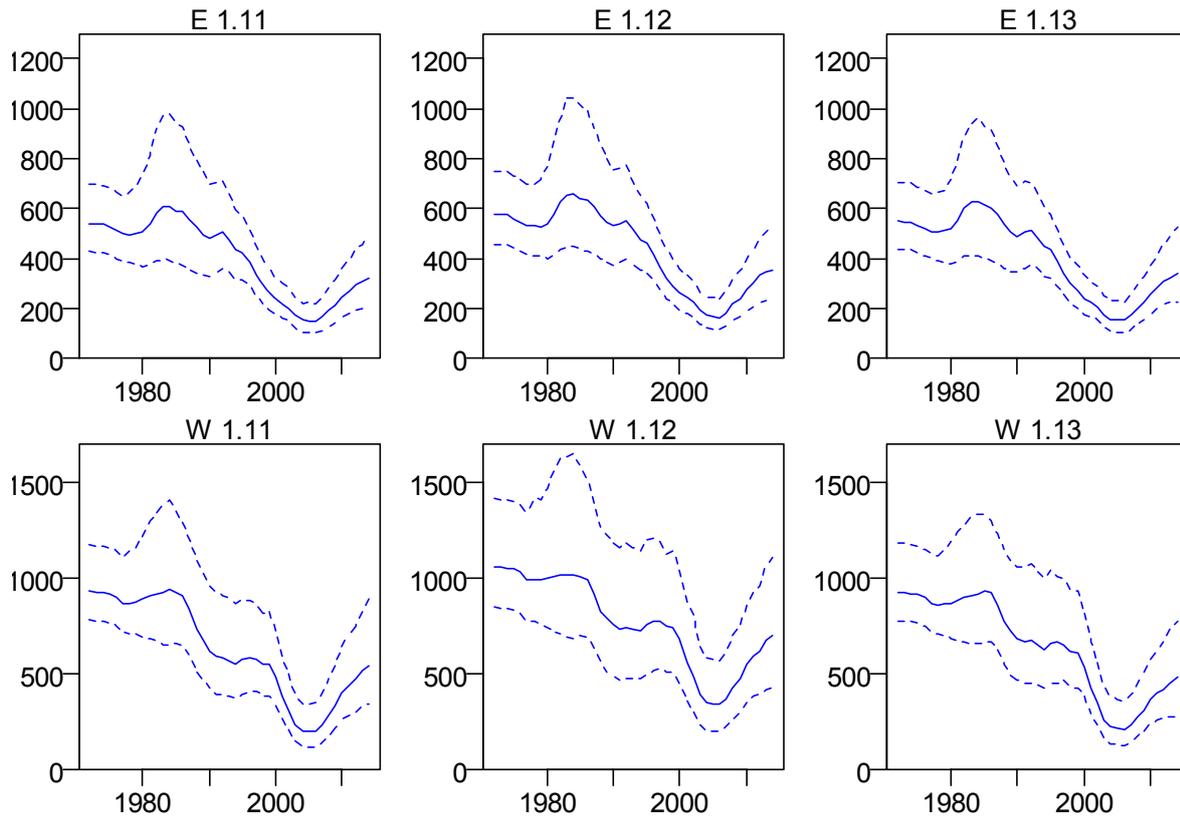
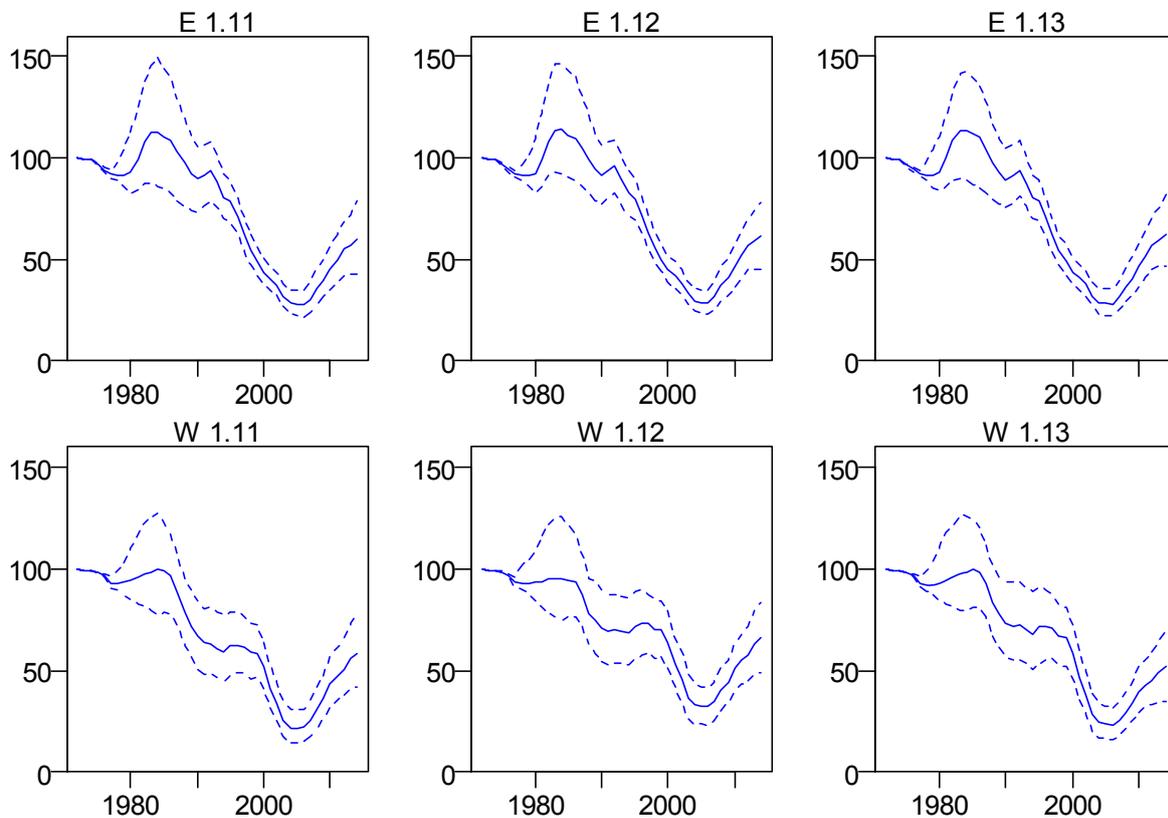


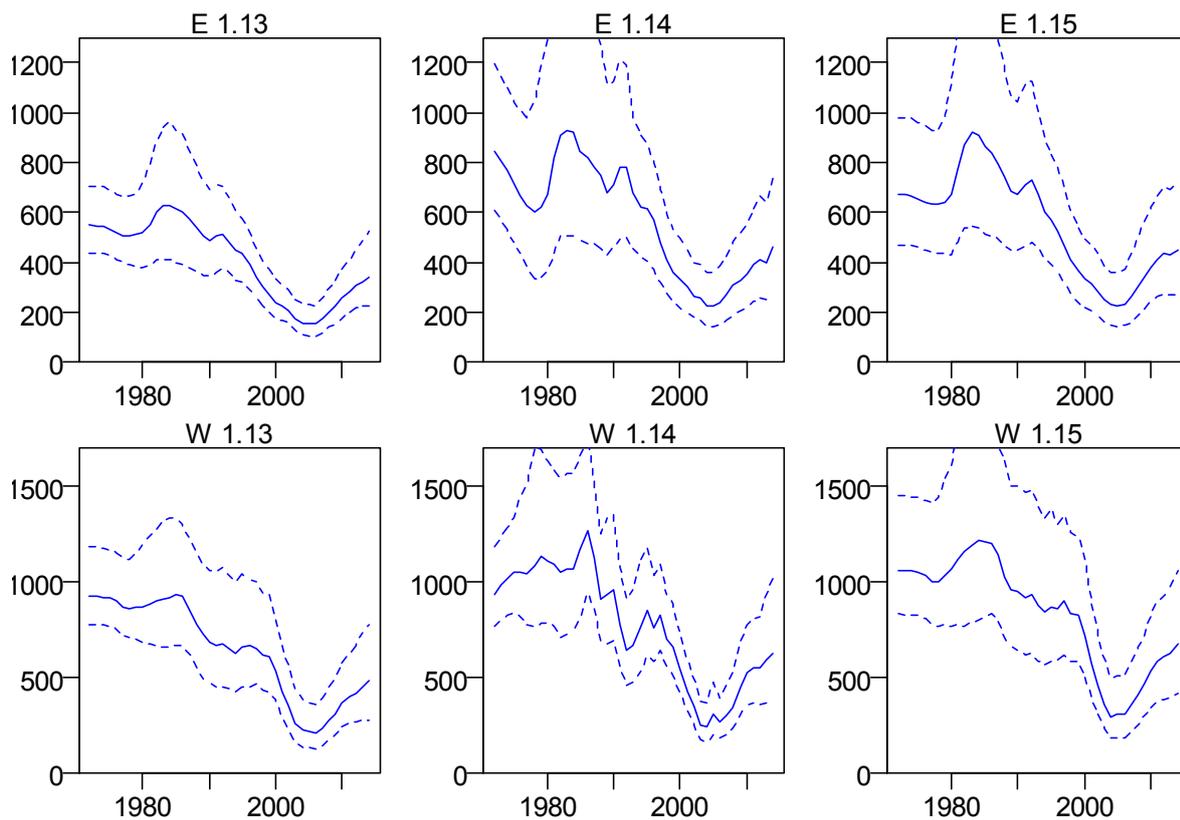
Figure 46: Comparison of 2014 continuity run 1.17 (2008–13 two- $q$  and Francis parameterisation with lognormal priors) with the comparable run 1.19 from 2013 (see Table 14): estimates of stock status in 2013 ( $B_{2013}$  as % $B_0$ ), with 95% confidence intervals shown as horizontal lines.



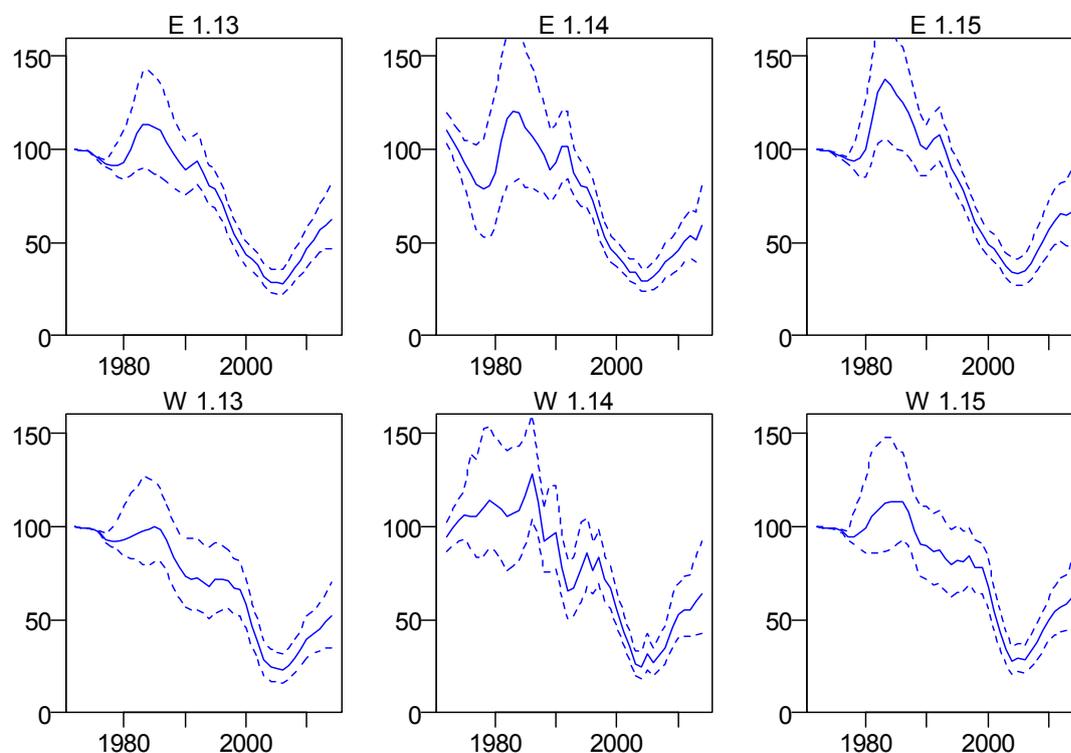
**Figure 47: Estimated spawning biomass trajectories from the MCMC runs, showing medians (solid lines) and 95% confidence intervals (broken lines) by run for E (upper panels) and W (lower panels).**



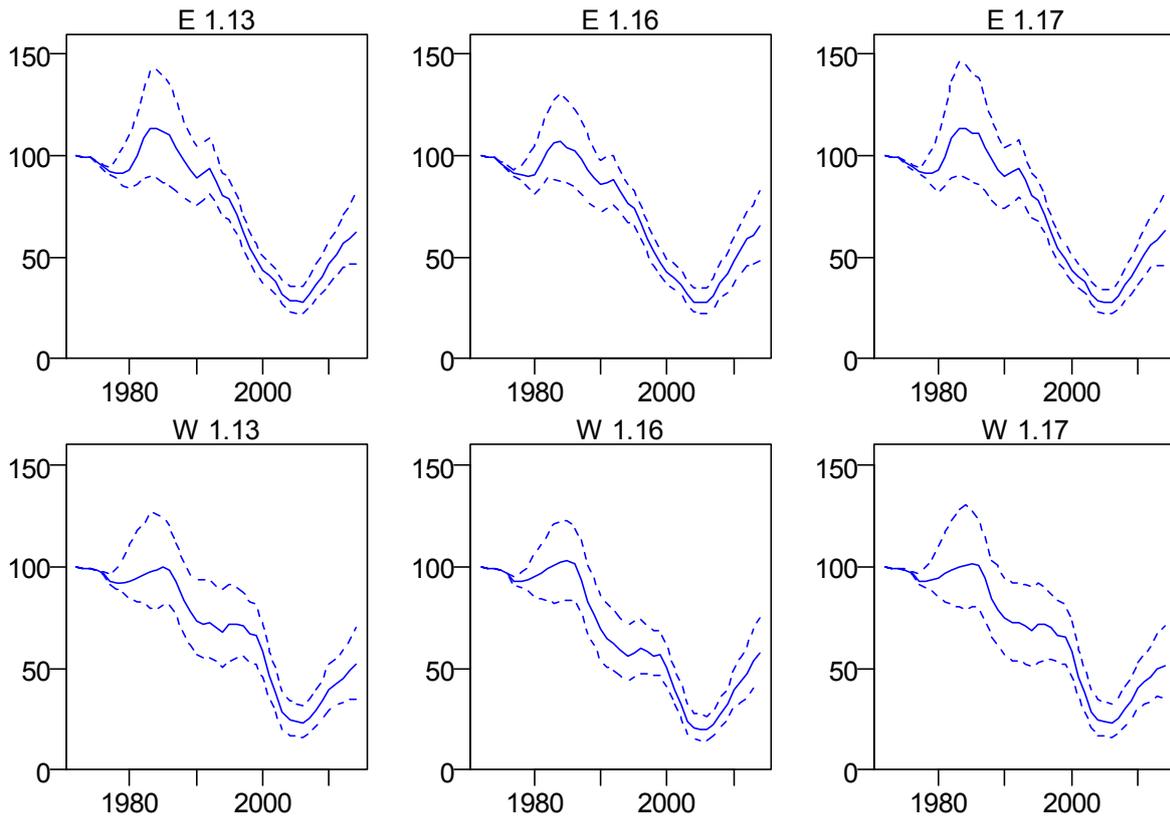
**Figure 48: As for Figure 47, but plotted as %B<sub>0</sub>.**



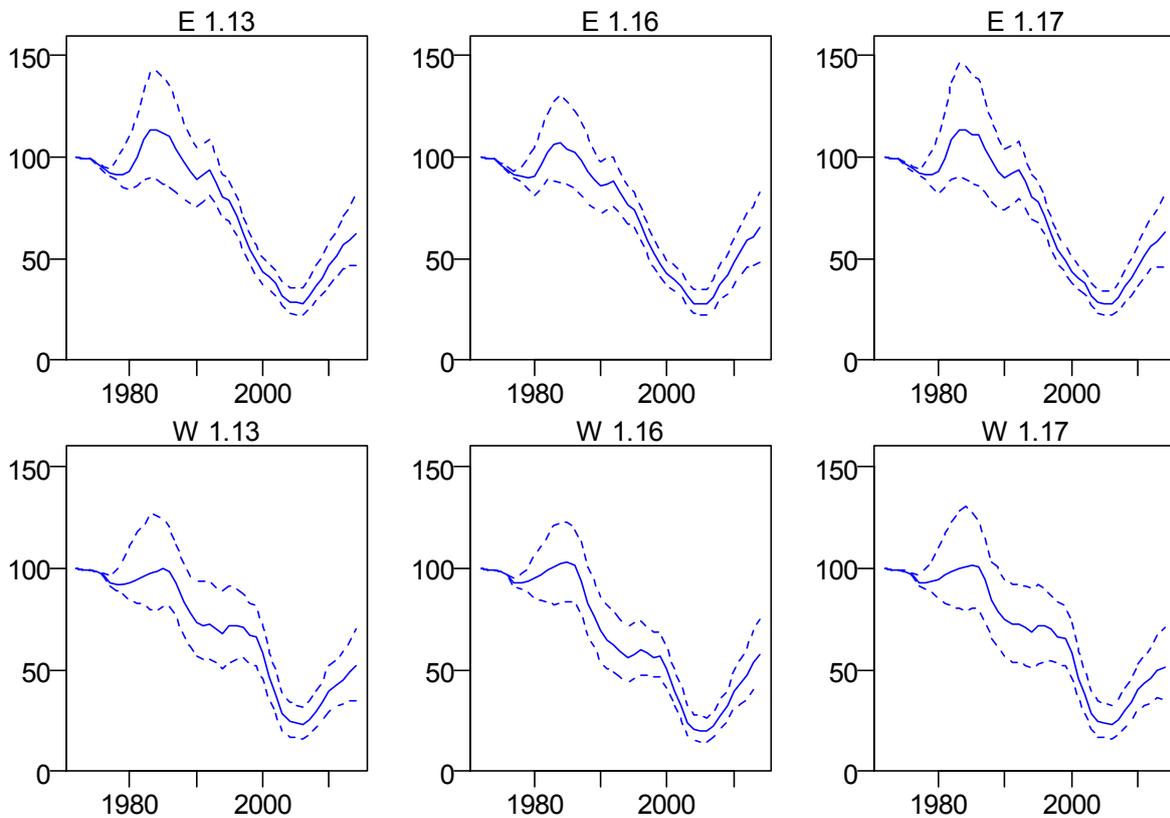
**Figure 49: Estimated spawning biomass trajectories from the MCMC runs, showing medians (solid lines) and 95% confidence intervals (broken lines) by run for E (upper panels) and W (lower panels).**



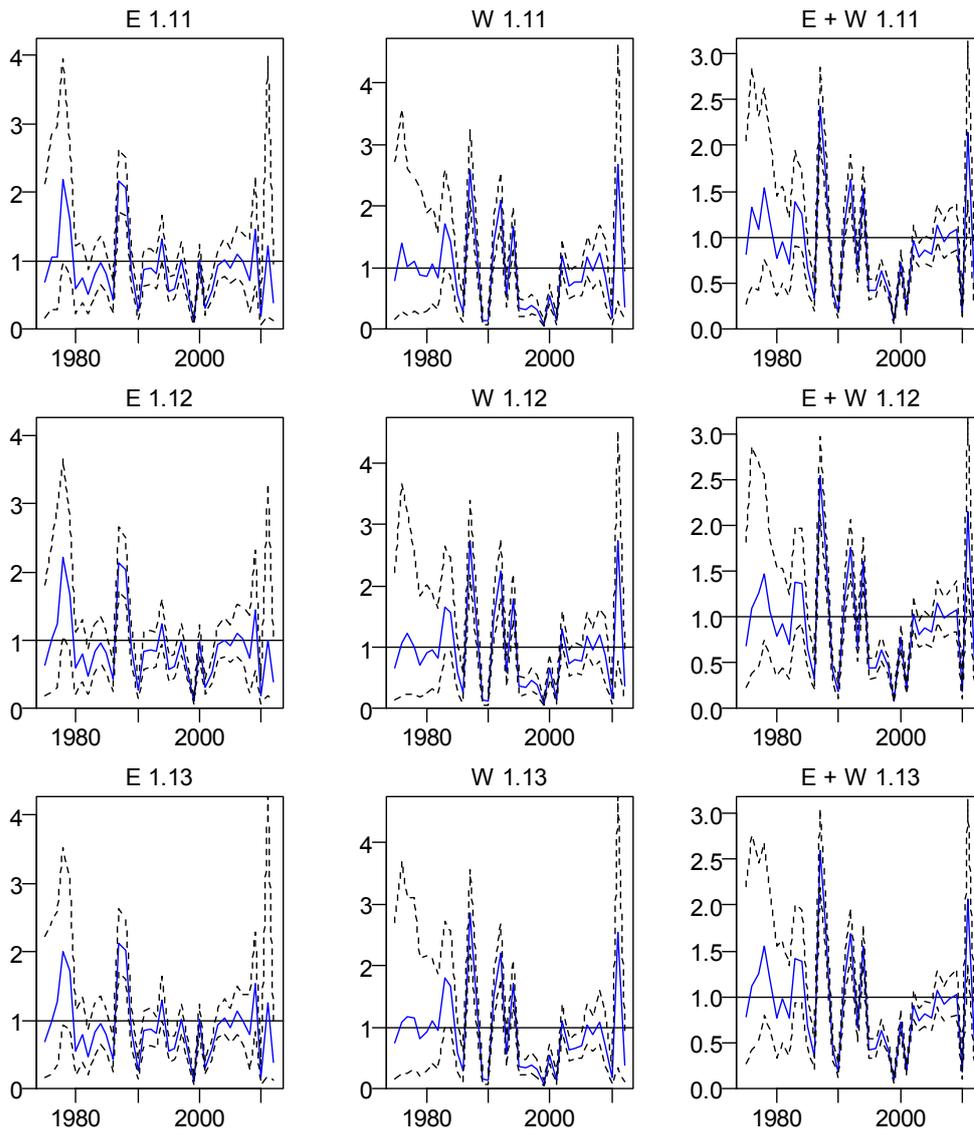
**Figure 50: As for Figure 49, but plotted as %B<sub>0</sub>.**



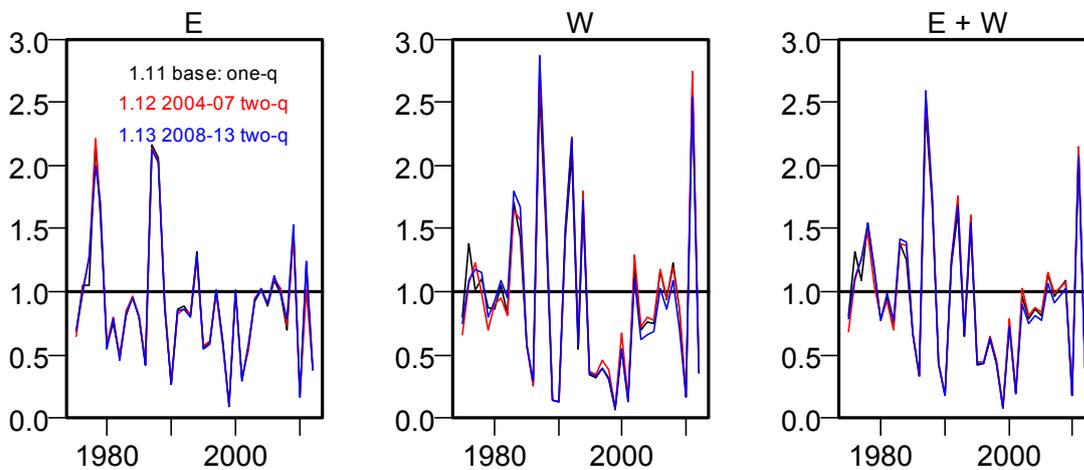
**Figure 51: Estimated spawning biomass trajectories from the MCMC runs, showing medians (solid lines) and 95% confidence intervals (broken lines) by run for E (upper panels) and W (lower panels).**



**Figure 52: As for Figure 51, but plotted as %B<sub>0</sub>.**



**Figure 53: Estimated year-class strengths (YCSs) from the runs 1.11 (base: one- $q$ ), 1.12 (2004-07 two- $q$ ), and 1.13 (2008-13 two- $q$ ) showing medians (solid lines) and 95% confidence intervals (broken lines) by run for E (left panels), W (middle panels) and E + W (right panels).**



**Figure 54: As in Figure 53 but showing just the medians.**

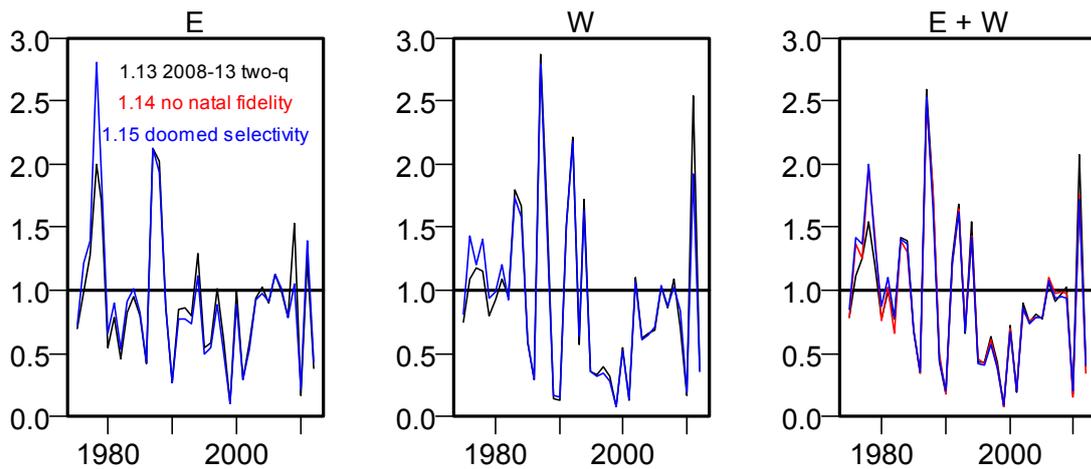


Figure 55: As in Figure 54, but for the sensitivities 1.14 (no natal fidelity) and 1.15 (domed spawning selectivity).

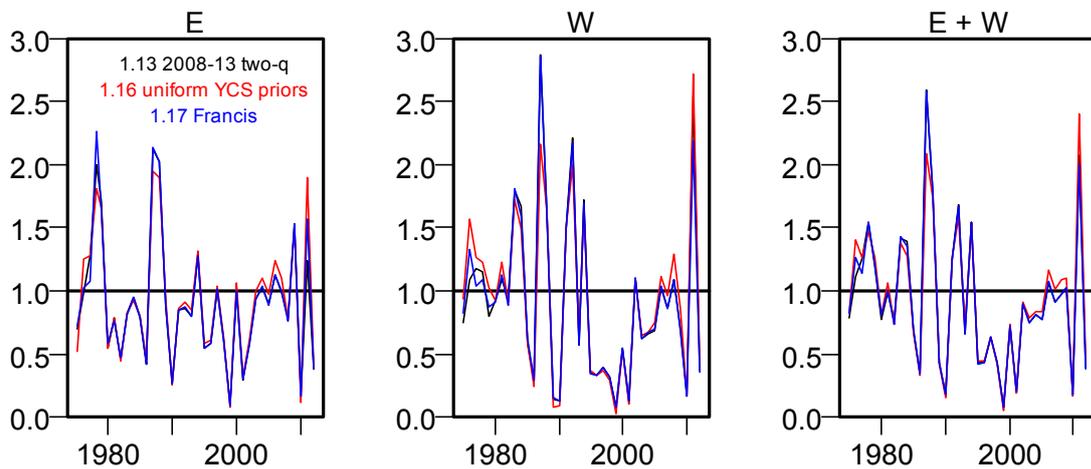


Figure 56: As in Figure 54, but for the sensitivities 1.16 (uniform prior on YCSs) and 1.17 (Francis parameterisation of YCSs instead of Haist).

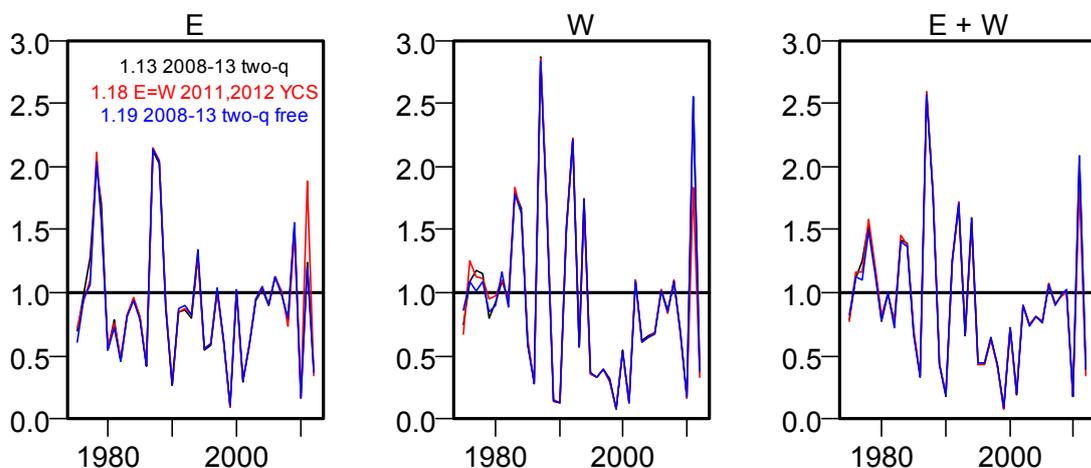
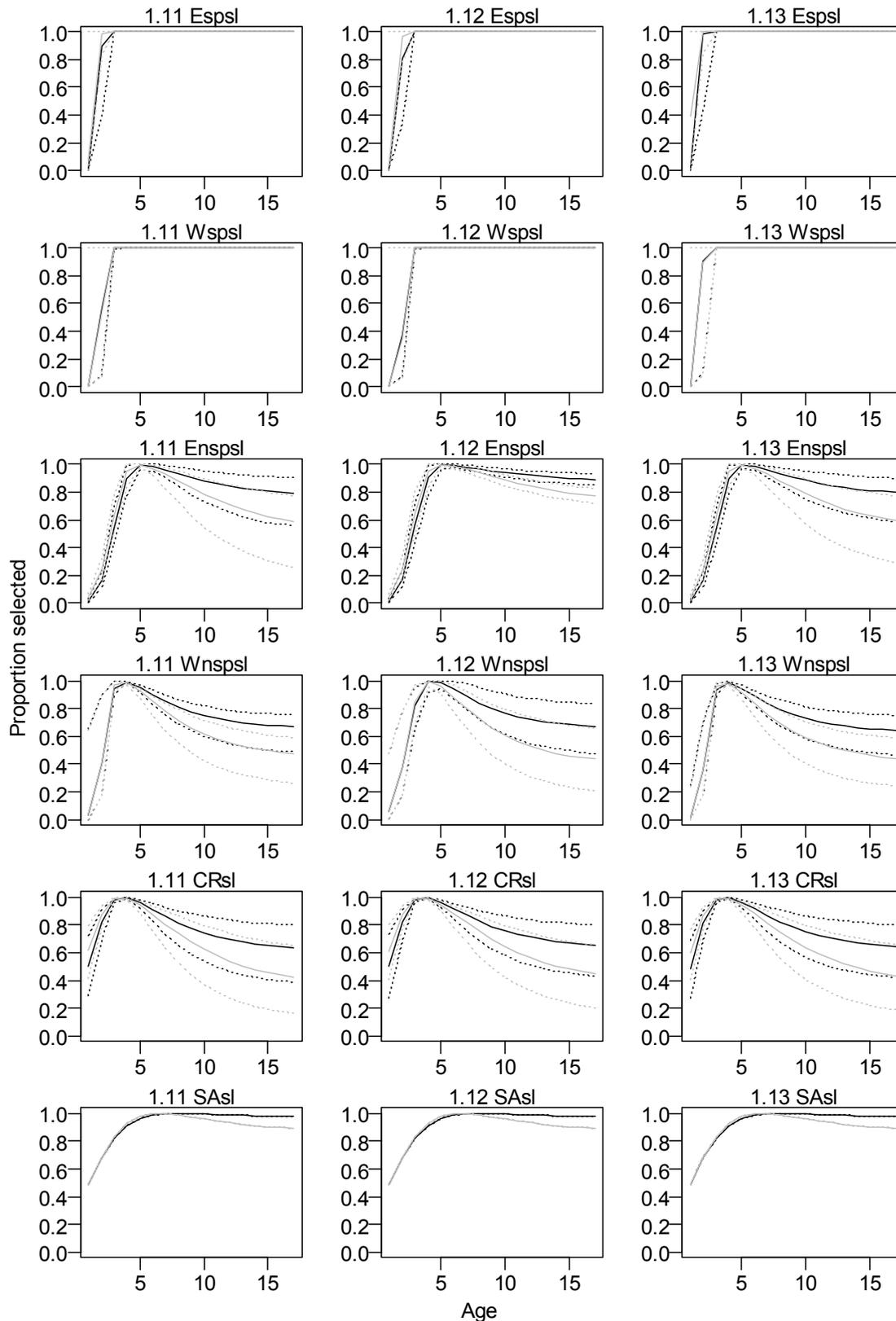
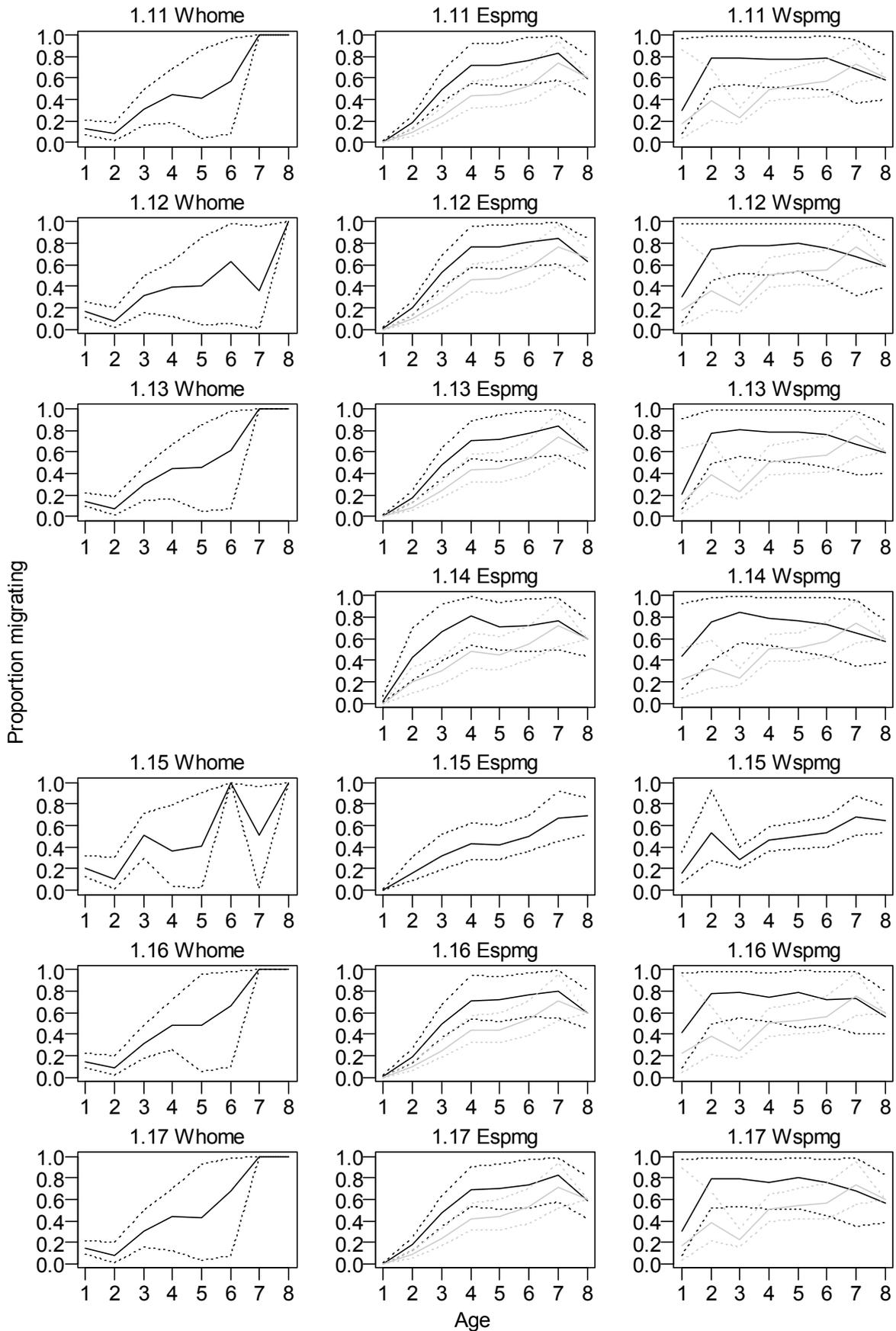


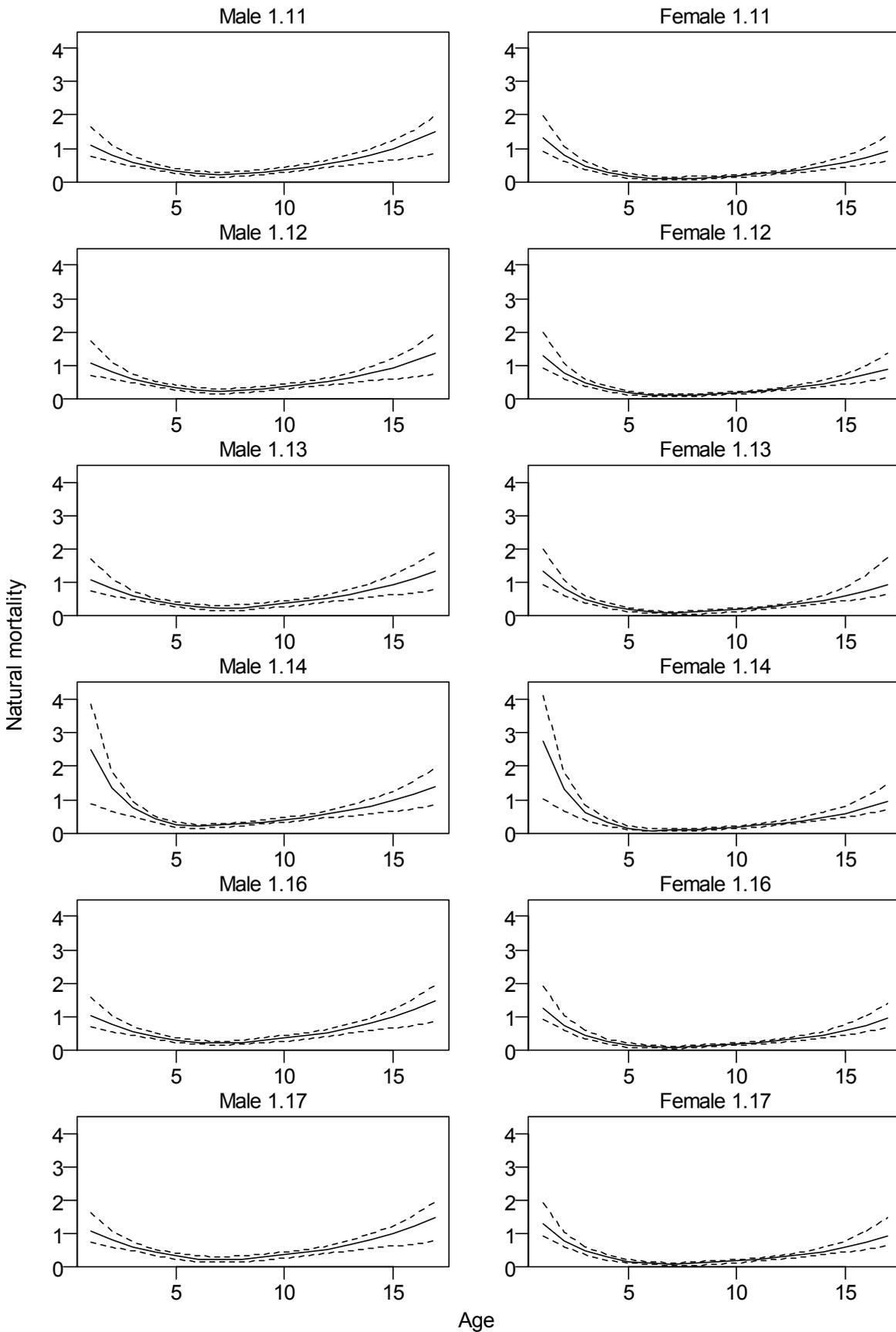
Figure 57: As in Figure 54, but for the sensitivities 1.18 (E=W 2011, 2012 YCSs) and 1.19 (2008–13 two- $q$  free).



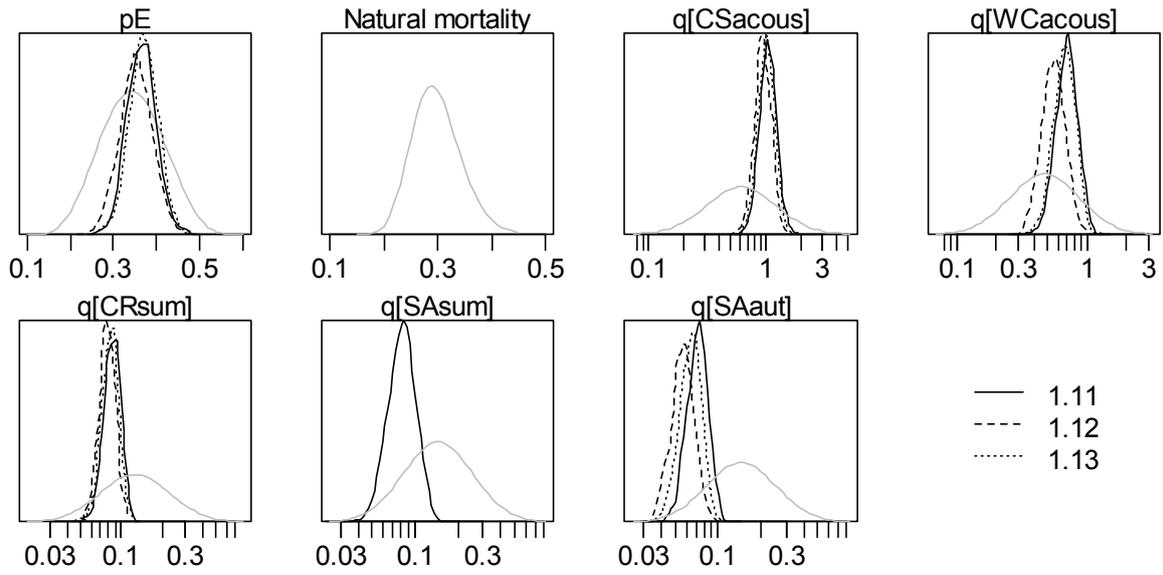
**Figure 58: Posterior estimates of selectivity ogives for each for the three MCMC runs 1.11 (base: one- $q$ ), 1.12 (2004–07 two- $q$ ), and 1.13 (2008–13 two- $q$ ). Solid lines are medians; broken lines show 95% confidence intervals. Where ogives differ by sex they are plotted as black for males and grey for females. Where they differ by stock or time step the plotted curves are for one selected combination (E step 2 for Enspsl and CRsl, W step 2 for Wnspsl and SAsl).**



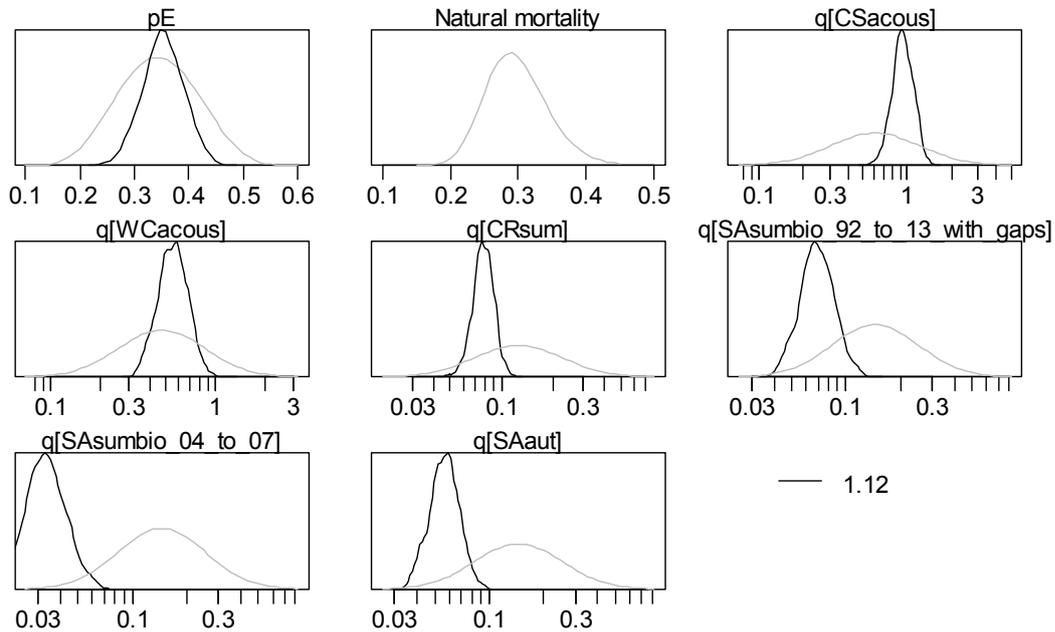
**Figure 59: Migration ogives estimated in seven of the main MCMC runs. Solid lines are medians, broken lines show 95% confidence intervals. Where ogives differ by sex they are plotted as black for males and grey for females.**



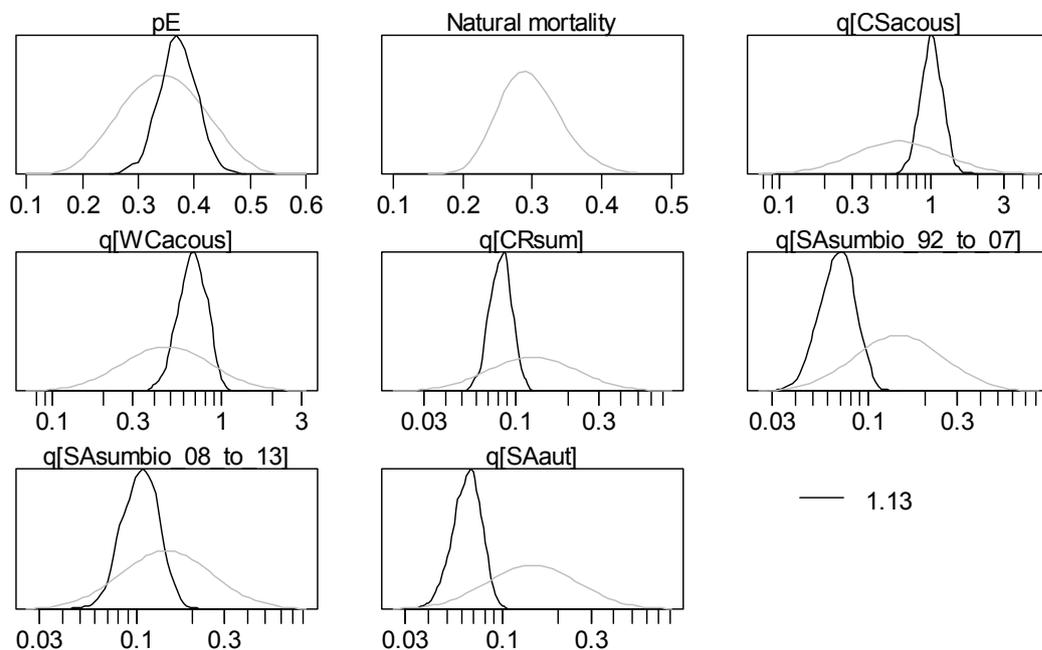
**Figure 60: 2014 assessment estimates of age-dependent natural mortality ogives showing median estimates (solid lines) and 95% confidence intervals (broken lines) for each sex.**



**Figure 61: 2014 assessment prior (grey lines) and estimated posterior (black lines) distributions for the following parameters: pE (proportion of  $B_0$  in E stock), natural mortality (independent of age runs only), and survey catchabilities (acoustic and trawl).**



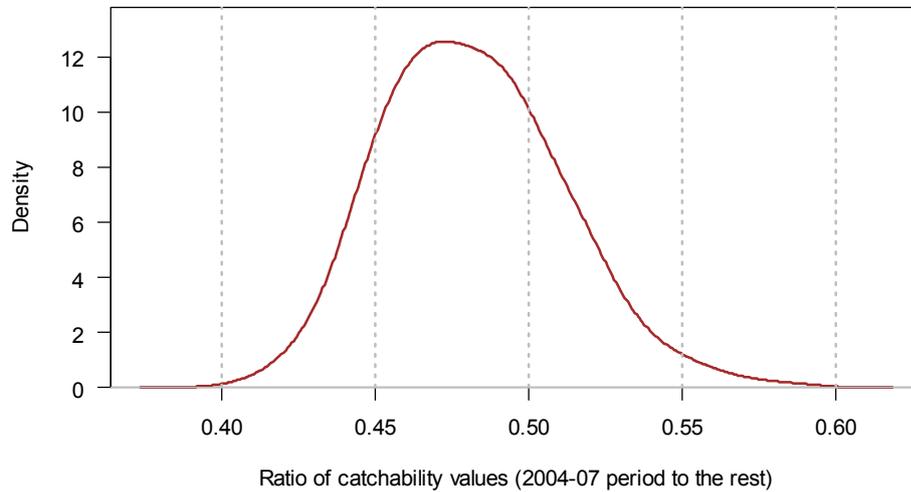
**Figure 62: 2014 assessment prior (grey lines) and estimated posterior (black lines) distributions for the following parameters: pE (proportion of B<sub>0</sub> in E stock), natural mortality (independent of age run 1.15 only) and survey catchabilities (acoustic and trawl). The catchability q[SAsumbio\_04\_07] refers to the years 2004–07, while q[SAsumbio\_92\_13\_with\_gaps] the other years. In both cases the catchability is bounded on [0.020, 0.51].**



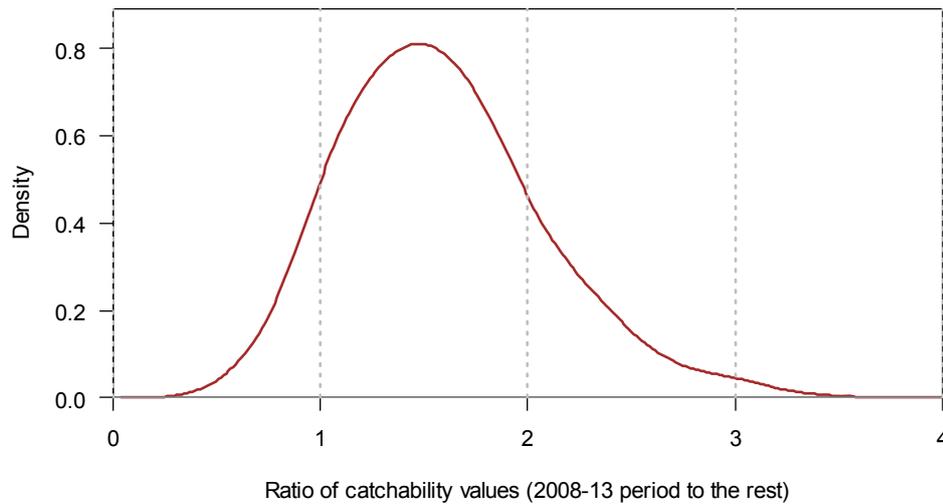
**Figure 63: 2014 assessment prior (grey lines) and estimated posterior (black lines) distributions for the following parameters: pE (proportion of B<sub>0</sub> in E stock), natural mortality (independent of age run 1.15 only), and survey catchabilities (acoustic and trawl). The catchability q[SAsumbio\_08\_13] refers to the years 2008–13, while q[SAsumbio\_92\_07\_with\_gaps] to the years 1992–2007.**

**Table 25: Estimated catchability for model runs. Medians from the MCMCs.**

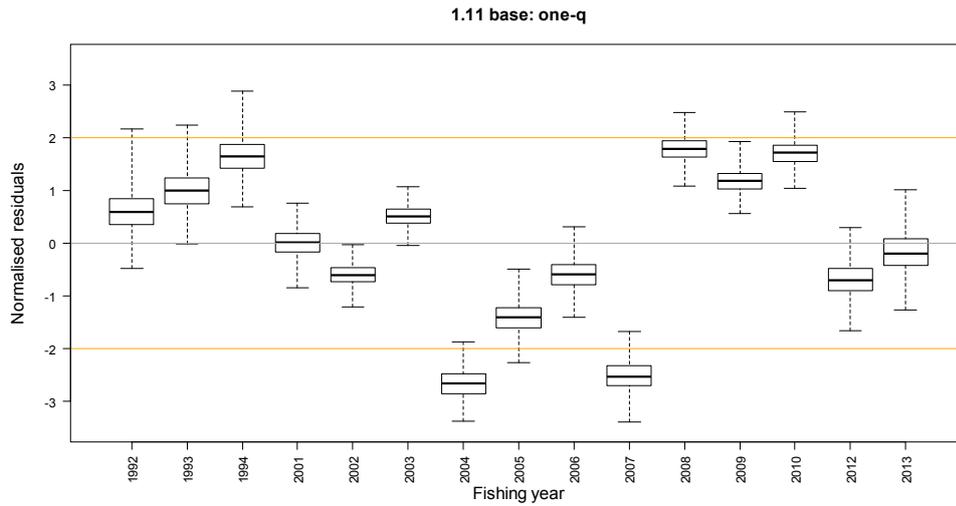
| Run  | Short description | 1992–2003 | 2004–2007 | 2008–2013 |
|------|-------------------|-----------|-----------|-----------|
| 1.11 | one- $q$          | 0.08      | 0.08      | 0.08      |
| 1.12 | 2004–07 two- $q$  | 0.07      | 0.03      | 0.07      |
| 1.13 | 2008–13 two- $q$  | 0.07      | 0.07      | 0.11      |



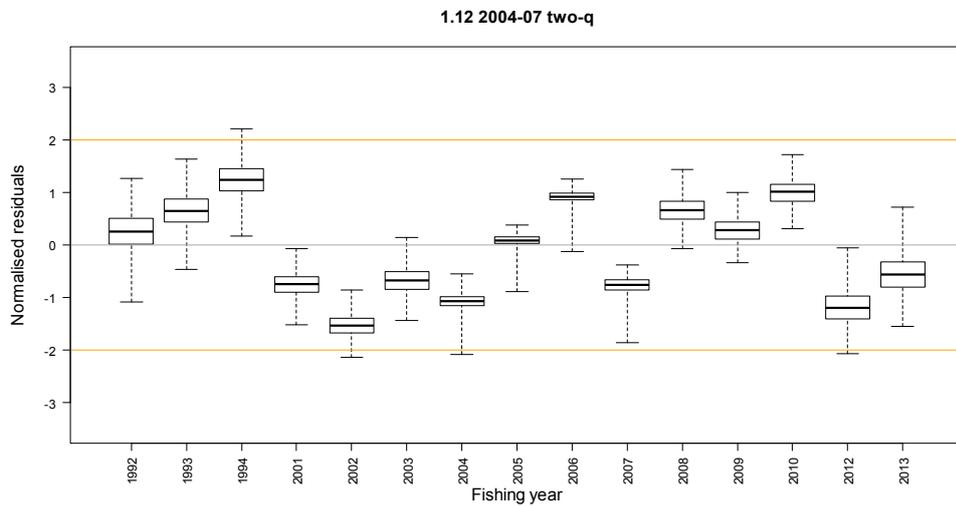
**Figure 64: Ratio of estimated catchability value in 2004–07 to the other years (2004–07 two- $q$  model). The median value is 0.48.**



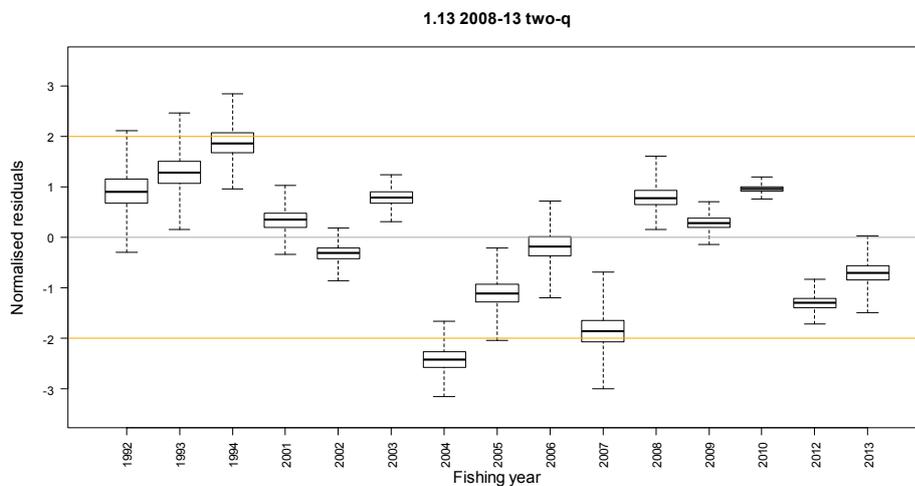
**Figure 65: Ratio of estimated catchability in the 2008–13 period to the other years (2008–13 two- $q$  model). The median value is 1.54.**



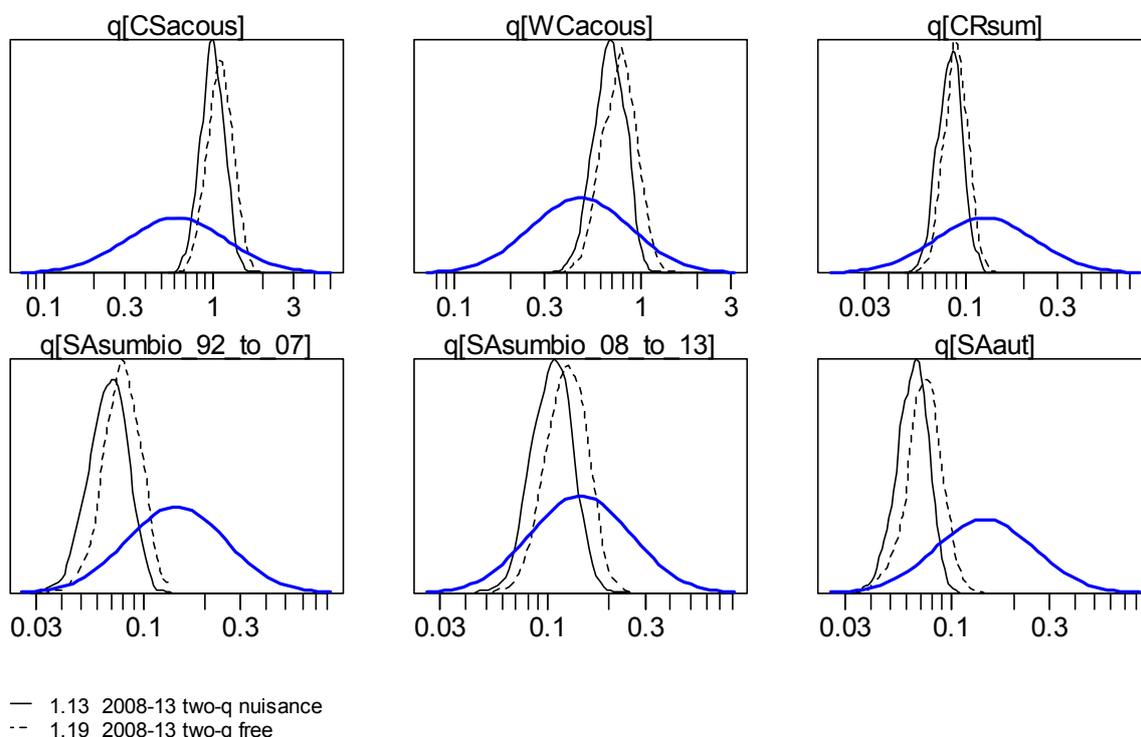
**Figure 66: Normalised residuals for the fit to the Southern Plateau trawl survey for model 1.11 (base one- $q$ ).**



**Figure 67: Normalised residuals for the fit to the Southern Plateau trawl survey for model 1.12 (2004–07 two- $q$ ).**



**Figure 68: Normalised residuals for the fit to the Southern Plateau trawl survey for model 1.13 (2008–13 two- $q$ ).**



**Figure 69:** Assessment prior (blue lines) and estimated posterior (black lines) distributions for the survey catchabilities (acoustic and trawl) for the run 1.13 (2008–13 two- $q$ , solid line) and the sensitivity 1.19 where the catchability parameters are estimated as free parameters (2008–13 two- $q$  free, dashed line).

**Table 26:** Estimated median catchability for the run 1.13 (2008–13 two- $q$ ) and the sensitivity 1.19 where the catchability parameters are estimated as free parameters (2008–13 two- $q$  free).

| Run                   | 1992–2003 | 2004–2007 | 2008–2013 |
|-----------------------|-----------|-----------|-----------|
| 2008–13 two- $q$      | 0.068     | 0.068     | 0.106     |
| 2008–13 two- $q$ free | 0.079     | 0.079     | 0.124     |

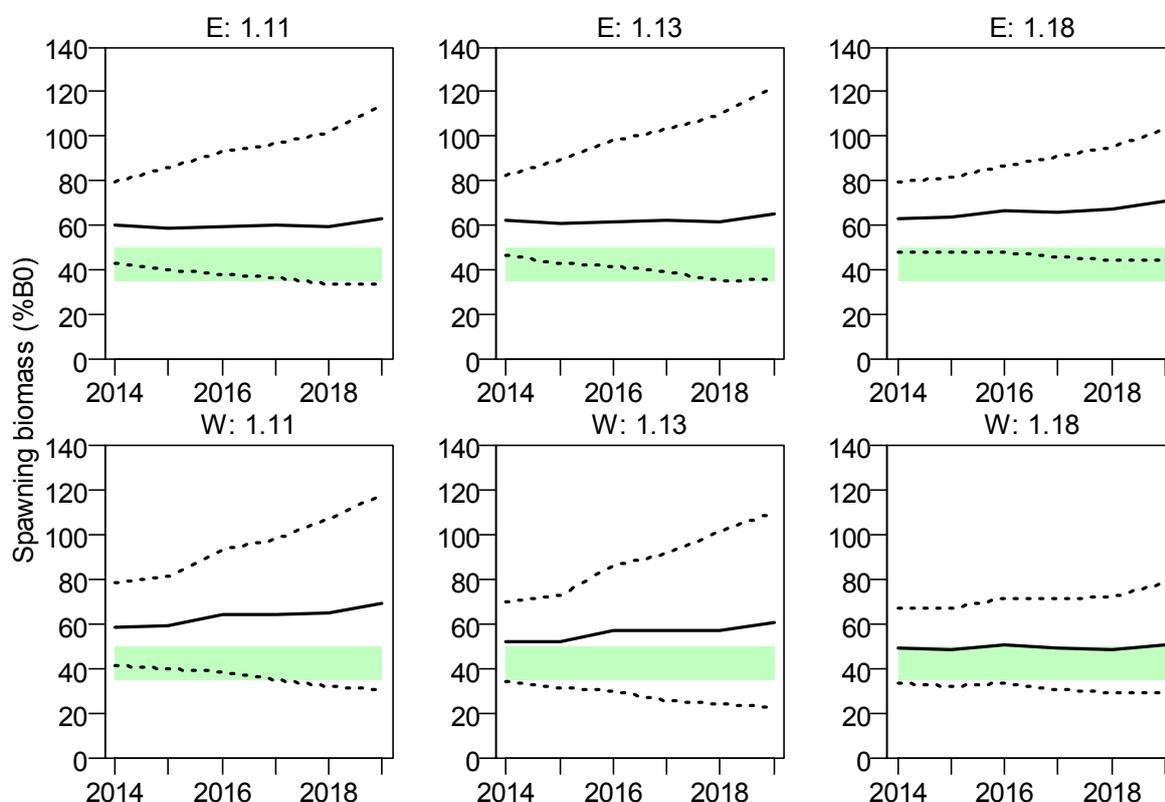
## 6. PROJECTIONS

Five-year projections were carried out for three models: the base model with a single catchability for the SAsumbio series (1.11), a second model where the catchability from 2008–13 for the SAsumbio series was estimated separately from other years (1.13), and a sensitivity to 1.13 where the E and W stock year class strengths are constrained to be equal in 2011 and 2012 (1.18). The last projection (1.18) investigates the impact of the uncertainty of the split of the 2011 and 2012 year class strengths between the E and W stocks, as the pattern of recent recruitment affects projections of stock status.

In all projections, future recruitments were selected at random from those estimated for 2003–2012, and the future catches in each fishery were assumed to be the same as for 2014 (i.e. as in the last line of Table 3). The projections indicate that with these assumed catches, the E and W biomasses are likely to remain flat or rise slightly over the next 5 years (Figure 70).

The probabilities of the current (2014) and projected spawning stock biomass being below the hard limit of 10%  $B_0$ , the soft limit of 20%  $B_0$ , and the lower and upper ends of the interim management

target range of 35–50%  $B_0$  are presented in Table 27 for the case where future catches remain at 2014 levels. The probability of either stock being less than either the soft or the hard limit over the five year projection period is negligible. Both stocks are projected to be within or above the 35–50%  $B_0$  target range at the end of the projection period.



**Figure 70: Projected spawning biomass (as % $B_0$ ): median (solid lines) and 95% confidence intervals (broken lines) for the base case and two sensitivities (Runs 1.11, 1.13 and 1.18). The shaded green region represents the target management range of 35–50%  $B_0$ .**

**Table 27: Probabilities (to two decimal places) associated with projections for SSB (% $B_0$ ) for the base case and two sensitivities (1.11, 1.13 and 1.18) for 2014 and 2019.**

|                    | 2014 |      |      | 2019 |      |      |
|--------------------|------|------|------|------|------|------|
|                    | 1.11 | 1.13 | 1.18 | 1.11 | 1.13 | 1.18 |
| <b>EAST</b>        |      |      |      |      |      |      |
| 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    | 0.04 | 0.02 | 0    |
| P (SSB<50% $B_0$ ) | 0.13 | 0.06 | 0.05 | 0.24 | 0.18 | 0.06 |
| <b>WEST</b>        |      |      |      |      |      |      |
| P (SSB<10% $B_0$ ) | 0    | 0    | 0    | 0    | 0    | 0    |
| P (SSB<20% $B_0$ ) | 0    | 0    | 0    | 0    | 0.02 | 0    |
| P (SSB<35% $B_0$ ) | 0    | 0.03 | 0.03 | 0.04 | 0.12 | 0.08 |
| P (SSB<50% $B_0$ ) | 0.15 | 0.41 | 0.52 | 0.17 | 0.32 | 0.45 |

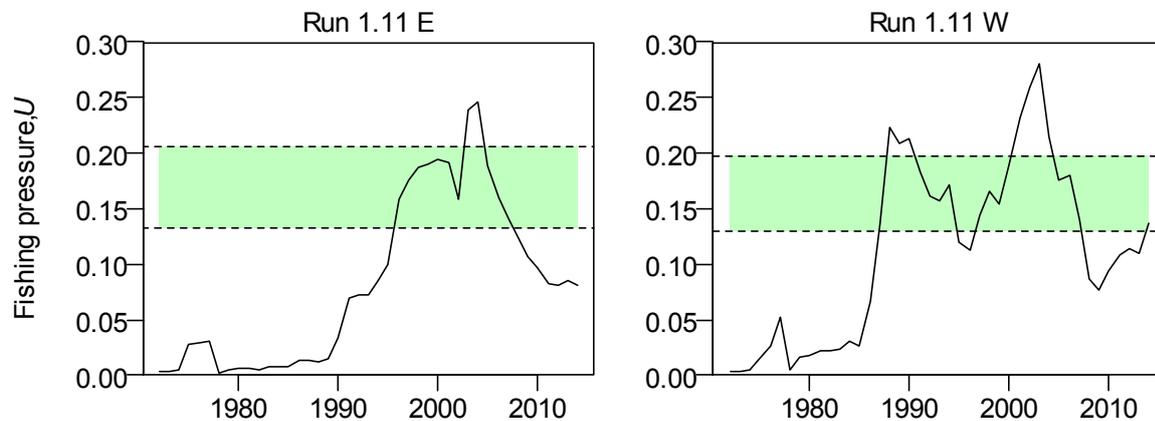
## 7. FISHING PRESSURE

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

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

For a given stock and run, the reference fishing pressures,  $U_{35\%}$  and  $U_{50\%}$ , are defined as the levels of  $U$  that would cause the spawning biomass for that stock to tend to 35% $B_0$  or 50% $B_0$ , respectively, assuming deterministic recruitment and individual fishery exploitation rates that are multiples of those in the current year. These reference pressures were calculated by simulating fishing using a harvest strategy in which the exploitation rate for fishery  $f$  was  $mU_{f,current}$ , where  $U_{f,current}$  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  $m_{x\%}U_{current}$ , where the multiplier,  $m_{x\%}$  (calculated by interpolation) was that which caused the equilibrium biomass of that stock to be  $x\%B_0$ .

Fishing intensity on both stocks was estimated to be at or near all-time highs in 2003 and is now substantially lower (Figure 71).



**Figure 71: Fishing intensity,  $U$  (from MPDs), plotted by run and stock. Also shown (as broken lines) are the reference levels  $U_{35\%B_0}$  (upper line) and  $U_{50\%B_0}$  (lower line), which are the fishing intensities that would cause the spawning biomass to tend to 35%  $B_0$  and 50%  $B_0$ , respectively.**

## 8. CALCULATION OF $B_{MSY}$

$B_{MSY}$  was calculated, for each stock, assuming a harvest strategy in which the exploitation rate for fishery  $f$  was  $mU_{f,2014}$ , where  $U_{f,2014}$  is the estimated 2014 exploitation rate for that fishery, and  $m$  is some multiplier (the same for all fisheries). For each of a series of values of  $m$ , simulations were carried out with this harvest strategy and deterministic recruitment, with each simulation continuing

until the population reached equilibrium. For each stock and run, the value of the multiplier,  $m$ , was found that maximised the equilibrium catch from that stock.  $B_{MSY}$  for that stock and run was then defined as the equilibrium biomass (expressed as % $B_0$ ) at that value of  $m$ .

For the base run 1.11 (one- $q$ ), estimates of  $B_{MSY}$  were 25% for the E stock, and 26% for the W stock.

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

## 9. DISCUSSION

Both the eastern and western hoki stocks are estimated to be increasing after reaching their lowest levels in about 2006. The western stock is estimated to be 48–66% $B_0$  and the eastern stock 59–67% $B_0$  (values are ranges for the medians of model runs). The western stock experienced an extended period of poor recruitment from 1995 to 2001 inclusive. However, recruitment has been near or above average since 2001, except for 2010 and 2012 where it was probably below average (although estimated with high uncertainty for both years). All projections indicate that continued fishing at current levels is likely to allow the eastern and western biomasses to remain flat or rise slightly over the next 5 years.

The uncertainty in this assessment is almost certainly greater than is implied by the confidence limits presented above. We may think of this uncertainty as having three types. The first is random error in the observations, which is reasonably well dealt with in the assessment by the CVs that are assigned to individual observations. The second arises from annual variability in population processes (e.g., growth and migration – but not recruitment, which is modelled explicitly) and fleet behaviour (which affects selectivities), and it is more problematic. We deal with this, rather simplistically, by adding process error. This assumes that the structure of our model is correct “on average”, but that the real world fluctuates about that average. The problem is that we cannot be at all sure about this assumption. This leads to the third type of uncertainty: we cannot be sure that our model assumptions are correct on average.

## 10. ACKNOWLEDGMENTS

I am grateful to Sira Ballara, Dan Fu, Richard O’Driscoll, and Darren Stevens for providing data, and to members of the Hoki Working Group for suggestions during the assessment process. This work was funded under Ministry for Primary Industries project DEE201002HOK. Thank you to Peter Horn and Kevin Sullivan for reviewing the manuscript, and for the sharp editorial eye of Marianne Vignaux.

## 11. REFERENCES

- Bull, B.; Francis, R.I.C.C.; Dunn, A.; McKenzie, A.; Gilbert, D.J.; Smith, M.H.; Bian, R.; Fu, D. (2012). CASAL (C++ algorithmic stock assessment laboratory): CASAL user manual v2.30-2012/03/21. *NIWA Technical Report 135*. 279 p.
- Butterworth, D; Hillary, R; Ianelli, J (2014). Report on the review of the New Zealand hoki stock assessment model. Unpublished report to MPI 4th March 2014 18p.
- Cordue, P.L. (2001). MIAEL estimation of biomass and fishery indicators for the 2001 assessment of hoki stocks. *New Zealand Fisheries Assessment Report 2001/65*. 59 p.
- Cordue, P L (2006) Report on the 13 November 2006 M-prior HWG sub-group meeting. Unpublished report to the Hoki Working Group, dated 17 November 2006. WG-HOK-2007/11 (Unpublished report held by Ministry for Primary Industries, Wellington.)
- Francis, R.I.C.C. (2003). Analyses supporting the 2002 stock assessment of hoki. *New Zealand Fisheries Assessment Report 2003/5*. 34 p.
- Francis, R.I.C.C. (2004). Assessment of hoki (*Macruronus novaezelandiae*) in 2003. *New Zealand Fisheries Assessment Report 2004/15*. 95 p.
- Francis, R.I.C.C. (2005). Assessment of hoki (*Macruronus novaezelandiae*) in 2004. *New Zealand Fisheries Assessment Report 2005/35*. 97 p.
- Francis, R.I.C.C. (2006). Assessment of hoki (*Macruronus novaezelandiae*) in 2005. *New Zealand Fisheries Assessment Report 2006/3*. 96 p.
- Francis, R.I.C.C. (2007). Assessment of hoki (*Macruronus novaezelandiae*) in 2006. *New Zealand Fisheries Assessment Report 2007/15*. 99 p.
- Francis, R.I.C.C. (2008). Assessment of hoki (*Macruronus novaezelandiae*) in 2007. *New Zealand Fisheries Assessment Report 2008/4*. 109 p.
- Francis, R.I.C.C. (2009). Assessment of hoki (*Macruronus novaezelandiae*) in 2008. *New Zealand Fisheries Assessment Report 2009/7*. 80 p.
- Francis, R.I.C.C. (2011a). Data weighting in statistical fisheries stock assessment models. *Canadian Journal of Fisheries and Aquatic Sciences* 68: 1124–1138.
- Francis, R.I.C.C. (2011b). Weighting of at-age data sets in the hoki stock assessment. WG-HOK-2011/18. (Unpublished report held by Ministry for Primary Industries, Wellington.)
- Francis, R.I.C.C.; Haist, V.; Bull, B. (2003). Assessment of hoki (*Macruronus novaezelandiae*) in 2002 using a new model. *New Zealand Fisheries Assessment Report 2003/6*. 69 p.
- Francis, R.I.C.C.; Hurst, R.J.; Renwick, J.A. (2001). An evaluation of catchability assumptions in New Zealand stock assessments. *New Zealand Fisheries Assessment Report 2001/1*. 37 p.
- Hicks, A.C.; Cordue, P.L.; Bull, B. (2002). Estimating proportions-at-age and sex in the commercial catch of hoki (*Macruronus novaezelandiae*) using length frequency data. *New Zealand Fisheries Assessment Report 2002/43*. 51 p.
- Horn, P.L. (2011). Natal fidelity: a literature review in relation to the management of the New Zealand hoki (*Macruronus novaezelandiae*) stocks. *New Zealand Fisheries Assessment Report 2011/34*. 18 p.
- Horn, P.L.; Sullivan, K.J. (1996). Validated aging methodology using otoliths, and growth parameters for hoki (*Macruronus novaezelandiae*) in New Zealand waters. *New Zealand Journal of Marine and Freshwater Research* 30(2): 161–174.
- Livingston, M.E.; Stevens, D.W. (2002). Review of trawl survey data inputs to hoki stock assessment 2002. *New Zealand Fisheries Assessment Report 2002/48*. 69 p.
- McKenzie, A. (2009). Preliminary assessment results for hoki in 2009. WG-HOK-2009/10. (Unpublished report held by Ministry for Primary Industries, Wellington.)
- McKenzie, A. (2011a). Assessment of hoki (*Macruronus novaezelandiae*) in 2010. *New Zealand Fisheries Assessment Report 2011/06*. 44 p.
- McKenzie, A. (2011b). Assessment of hoki (*Macruronus novaezelandiae*) in 2011. *New Zealand Fisheries Assessment Report 2011/64*. 52 p.
- McKenzie, A. (2012). Further exploratory analyses of no natal fidelity runs. WG-HOK-2012/11. (Unpublished report held by Ministry for Primary Industries, Wellington.)
- McKenzie, A. (2013). Assessment of hoki (*Macruronus novaezelandiae*) in 2012. *New Zealand Fisheries Assessment Report 2013/27*. 65 p.

- McKenzie, A. (2015). Assessment of hoki (*Macruronus novaezelandiae*) in 2013. *New Zealand Fisheries Assessment Report 2015/8*. 73 p.
- McKenzie, A.; Francis, R.I.C.C. (2009). Assessment of hoki (*Macruronus novaezelandiae*) in 2009. *New Zealand Fisheries Assessment Report 2009/63*. 54 p.
- Ministry of Fisheries (2010). Report from the Fisheries Assessment Plenary, May 2010: stock assessments and yield estimates. 1086 p. Ministry of Fisheries, Wellington, New Zealand.
- O'Driscoll, R.L. (2002). Review of acoustic data inputs for the 2002 hoki stock assessment. *New Zealand Fisheries Assessment Report 2002/36*. 66 p.
- O'Driscoll, R.L.; Bagley, N.W.; Ballara, S.L.; Ladroit, Y. (2015a). Trawl and acoustic survey of hoki and middle depth fish abundance on the west coast South Island, July–August 2013 (TAN1308). *New Zealand Fisheries Assessment Report No 2015/XX*. 105 p.
- O'Driscoll, R.L.; Ladroit, Y.; Dunford, A.J.; MacGibbon, D.J. (2015b). Acoustic survey of spawning hoki in Cook Strait and Pegasus Canyon during winter 2013. *New Zealand Fisheries Assessment Report 2015/4*. 51 p.
- O'Driscoll, R.L.; Hurst, R.J.; Livingston, M.E.; Cordue, P.L.; Starr, P. (2002). Report of hoki working group technical meeting 8 March 2002. WG-HOK-2002/27 (Unpublished report held by Ministry for Primary Industries, Wellington.)
- Smith, M.H. (2003). Fitting a prior for the proportion of  $B_0$  in the eastern stock. WG-HOK-2003/22 2 p. (Unpublished report held by Ministry for Primary Industries, Wellington.)
- Smith, M.H. (2004). Fitting priors for natural mortality and proportion of virgin hoki biomass in eastern stock. WG-HOK-2004/14. 7 p. (Unpublished report held by Ministry for Primary Industries, Wellington.)
- Stevens, D.W.; O'Driscoll, R.L.; Oeffner, J.; Ballara, S.L.; Horn, P.L. (2015). Trawl survey of hoki and middle depth species on the Chatham Rise, January 2014 (TAN1401). *New Zealand Fisheries Assessment Report 2015/XX*. .

## Appendix 1: Files defining the final runs

Each of the final model runs is completely defined, in the context provided by the CASAL manual (Bull et al. 2012), by two input files — population.csl and estimation.csl — and, for runs with an age varying natural mortality, a user.prior\_penalty.cpp file. These files may be obtained as a pdf, from the Science Officer at Ministry for Primary Industries ([science.officer@mpi.govt.nz](mailto: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 | <ul style="list-style-type: none"> <li>Changed timing of spawning migrations from the middle to the end of the non-spawning fisheries (and after the autumn SA surveys)</li> <li>Earliest estimated YCS changed to 1977 from 1980</li> <li>Assumed Beverton-Holt stock-recruit relationship</li> <li>Disallowed annual variation in selectivities for Wnsp fishery</li> <li>Allowed for ageing error (expected to reduce bias in estimates of YCSs)</li> <li>Process errors for at-age data sets estimated within the model</li> <li>Non-uniform prior on pE</li> <li>Max. age of otolith-based at-age data increased from 10 (plus group) to 12 (no plus group)</li> <li>First use of otolith-based at-age data for non-spawning fisheries (Enspage &amp; Wnspage)</li> <li>Forced equality of recent W and E YCSs extended from 2 y to 3 y</li> <li>Improvements in methods of converting ogives from size-based to age-based and implementing annual variation in selectivities</li> </ul> |

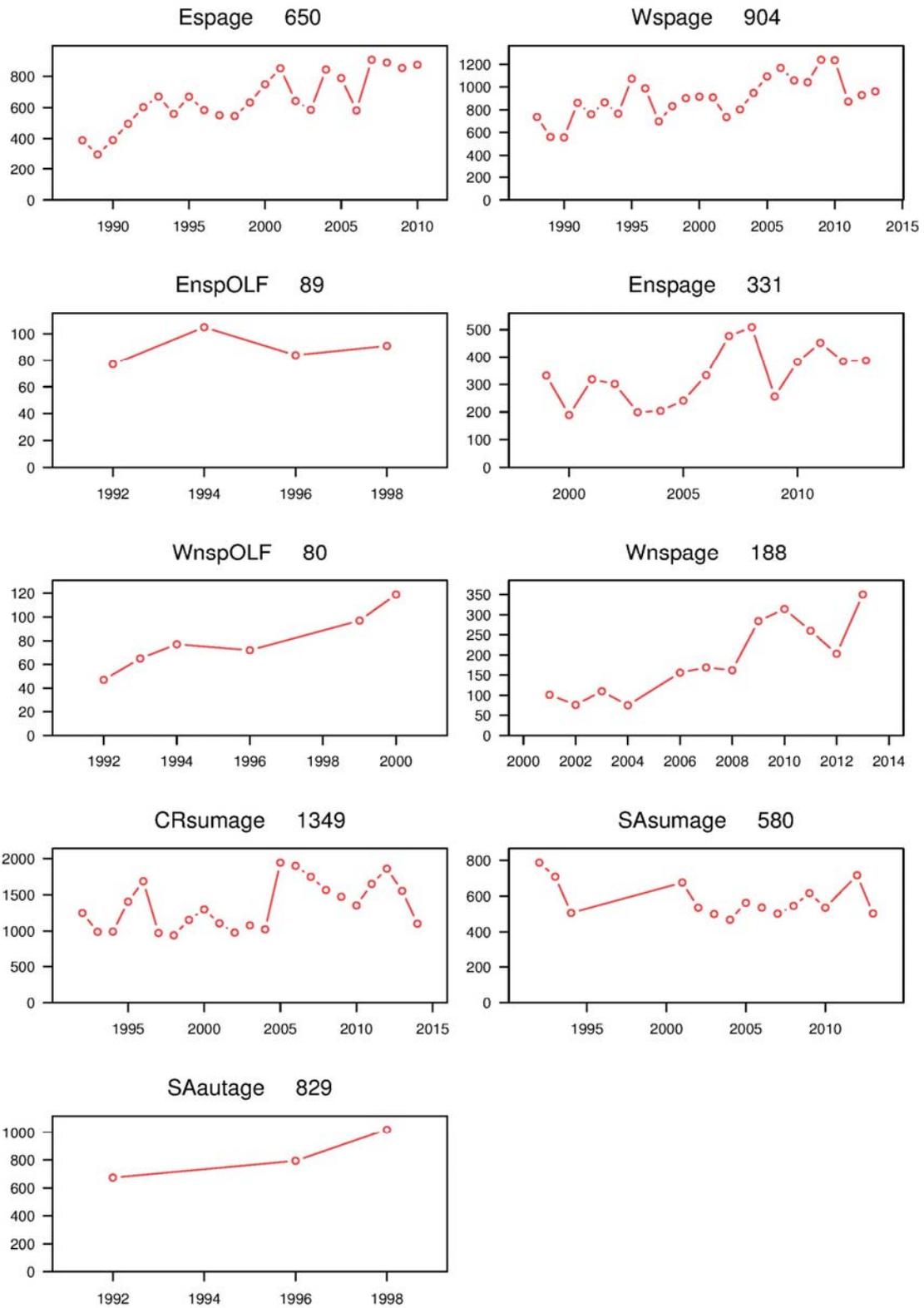
|      |   |
|------|---|
| 2004 | First use of age-dependent natural mortality and domed spawning selectivities to cope with lack of old fish<br>Maximum age in partition increased from 13 y to 17 y<br>New parameterisation for YCSs<br>Earliest estimated YCS changed to 1975 from 1977<br>Change in priors for CSacous catchability and pE<br>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<br>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<br>Forced equality of recent W and E YCSs reduced from 3 y to 1 y<br>Added smoothing penalty for age-dependent natural mortality<br>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<br>Stock recruitment steepness reduced from 0.90 to 0.75<br>1998 proportions spawning data re-analysed   |
| 2009 | Median catch day re-calculated using a new first year<br>1992 and 1993 proportions spawning data re-analysed  |
| 2010 | Allow two catchabilities for the Southern Plateau trawl survey in sensitivity model runs  |
| 2011 | Reduce to one base model (age-varying natural mortality) from two base models (for the other base model there were domed shaped fishing selectivities in the spawning fishery)  |
| 2012 | Re-weight the proportions-at-age data (the procedure giving them a substantial down-weighting)<br>Re-introduce a sensitivity model run without natal fidelity   |
| 2013 | Of the three final model runs, two have a time-varying catchability for the Southern Plateau trawl survey biomass series  |
| 2014 | Use the Haist year class strength parameterisation (instead of the Francis)   |

### Appendix 3: Reweighting the 2014 assessment at-age data

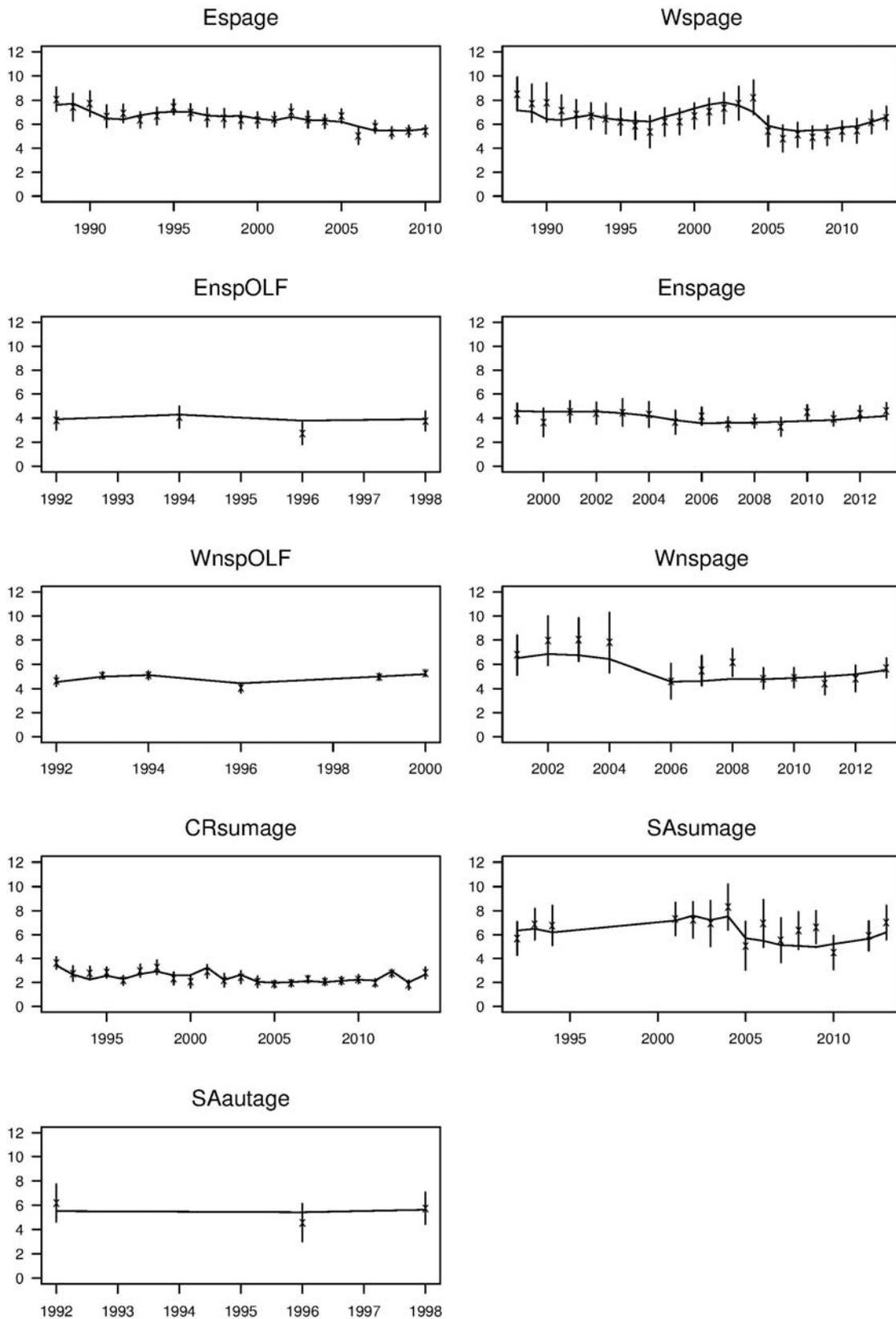
The same procedure as in McKenzie (2015) was used to reweight the at-age data for the model runs, with very similar resultant weightings across all the model runs. Summary results from the reweighting are shown for the base case 1.11 (one- $q$ ) in the tables and figures below: initial and final effective sample sizes (Table A2), initial effective sample sizes based on the observational error (Figure A1), and observed and expected ages after reweighting (Figure A2).

**Table A2: Model run 1.11. 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. Initial/Final values are rounded to the nearest integer.**

| Stage         | Espage | Wspage | EnspOLF | Enspage | WnspOLF | Wnspage | CRsumage | SAsumage | SAautage |
|---------------|--------|--------|---------|---------|---------|---------|----------|----------|----------|
| Initial       | 650    | 904    | 89      | 331     | 80      | 188     | 1349     | 580      | 829      |
| 2             | 57     | 33     | 13      | 32      | 101     | 21      | 92       | 12       | 23       |
| 3             | 63     | 26     | 12      | 33      | 59      | 17      | 79       | 12       | 15       |
| 4             | 68     | 24     | 12      | 33      | 54      | 16      | 75       | 13       | 15       |
| 5             | 71     | 23     | 12      | 32      | 54      | 16      | 73       | 13       | 14       |
| Final         | 72     | 23     | 12      | 32      | 53      | 16      | 72       | 13       | 14       |
| Initial/Final | 9      | 39     | 7       | 10      | 2       | 12      | 19       | 45       | 59       |



**Figure A1: Model 1.11. Equivalent multinomial N values for the observational error. The number above each panel is the mean value over the fishing years.**



**Figure A2: Model 1.11. Observed ('x', with 95% CIs as vertical lines) and expected (lines) for the at-age data sets after reweighting.**