# Initial results from fitting the revised sardine two-mixing-stock model to data from 1984-2014, including consideration of parasite prevalence-by-length sampled from November surveys 2010-2014

**C.L. de Moor* and D.S. Butterworth***

Correspondence email: *carryn.demoor@uct.ac.za*

## Introduction

The operating model for the South African sardine resource is being updated from the last assessment (de Moor and Butterworth 2015a) to take account of data collected between 2012 and 2014. Both a single and two-mixing-stock hypothesis will be considered again, although revisions to the two-mixing-stock hypothesis are also being considered. New data on the differences in infection of sardine on the west and south coasts by a digenean 'tetracotyle-type' metacercarian endoparasite are to be included in the model with the aim of obtaining improved estimates of sardine movement for the two stock hypothesis.

This document presents some initial results from the revised two mixing stock hypothesis only.

## Available Data

de Moor et al. (2015a) detail all the data used in this assessment. Key changes from the data used by de Moor and Butterworth (2015a), and how they are utilised in the model, include the incorporation of three more year's survey data from November 2012 to 2014. These initial results include a comparison to parasite prevalence-by-length from samples from November surveys from 2010 to 2014, without their inclusion in the likelihood as yet.

## Population Dynamics Model

The operating model used for the South African sardine resource is detailed in de Moor and Butterworth (2015b), with all the parameters being defined in Tables A.1 and A.2 of de Moor and Butterworth (2015b). Key changes in the population dynamics model from de Moor and Butterworth (2015a) include the following.

i) The assumption is made that the November survey estimate of biomass is an estimate of total (0+) biomass, i.e. all sardine of lengths ≥2.5 cm, rather than only 1+ biomass.

ii) A logistic trawl survey selectivity-at-length is used, to reflect the lower selectivity of smaller sardine in the trawls used to capture survey length-frequency data. Given the survey design, uniform trawl selectivity is assumed for all lengths ≥7cm.

iii) Instead of assuming all 2+ sardine are mature, spawner biomass is calculated from 1+ sardine after taking a maturity-at-length relationship into account. This relationship is allowed to vary

* MARAM (Marine Resource Assessment and Management Group), Department of Mathematics and Applied Mathematics, University of Cape Town, Rondebosch, 7701, South Africa.

over time (van der Lingen et al. 2006). Future work may also include differences in maturity by stock, and perhaps the incorporation of a density-dependent maturity-at-length relationship.

iv) Weight-at-length, rather than weight-at-age, is now used, being more appropriate for this model formulation.

v) Immediately after the recruits are modelled to become one year olds, they are allowed to move from the west stock to the south stock in November in the two-mixing-stock hypothesis. Movement of 2+ sardine is assumed to comprise a time- and age-invariant proportion ($\phi$) of that estimated annually for age-1 sardine ($move_{y,1}$).

vi) A time- and age-invariant proportion of west stock sardine are assumed to become infected by the parasite each November in the two-mixing-stock hypothesis.

During initial testing of this model, the parasite prevalence data have not yet been included in the likelihood, i.e. the model is not yet fit to these data. However, plots are shown of model predicted prevalence-by-length compared to that sampled from the November surveys to inform on the choice of appropriate model assumptions. Four alternative models are presented here:

Model a): Only age-1 sardine move and 20% of uninfected west stock sardine are infected with the endoparasite annually ($\phi = 0$ and $I_y = 0.2$).

Model b): Only age-1 sardine move and 40% of uninfected west stock sardine are infected with the endoparasite annually ($\phi = 0$ and $I_y = 0.4$).

Model c): Age 1+ sardine move, with the proportion moving being the same for ages 2 to 5+ and a smaller proportion of that estimated for age-1, and 20% of uninfected west stock sardine are infected with the endoparasite annually (estimate $\phi$ and $I_y = 0.2$).

Model d): Age 1+ sardine move, with the proportion moving being the same for ages 2 to 5+ and a smaller proportion of that estimated for age-1, and 40% of uninfected west stock sardine are infected with the endoparasite annually (estimate $\phi$ and $I_y = 0.4$).

**Results and Discussion**

It is important to note that the results presented here have not yet converged to the joint posterior mode[1], and the authors are still wary of the apparent inability of the current version of the model to estimate some parameter values. It is hoped some of these model fits can be further improved. Some comments on the current results are provided nevertheless.

[1] The Hessian is non positive-definite.

The model fits to the November and May survey indices of abundance are reasonable and similar across all hypotheses (Figures 1 and 2). The model estimated hockey-stick stock-recruitment relationships are shown in Figure 3. There is little difference between the four models tested. The maximum recruitment for the west stock is estimated to be around nine times higher than that for the south stock. Although this continues to indicate that the west stock is more productive than the south stock, the difference between the two is substantially less than that estimated by de Moor and Butterworth (2015a). In addition, the variability about the west stock stock-recruitment curve (~0.7) is substantially larger from the 0.16 estimated by de Moor and Butterworth (2015a).

The proportions of age-1 west stock sardine modelled to move to the south stock between 1994 and 2014 are shown in Figure 4. These initial results correspond to a model estimated proportion of 2+ sardine moving to be 25% of that of age-1 sardine in models c) and d). There is some difference in the age-1 proportions estimated in 2002, 2003, 2008, 2009, 2012, but this is not substantial. There is a lack of information to estimate annual movement prior to 1994 (see Figure 2), and thus this model has for the moment assumed zero movement prior to 1994 given the small sardine abundances observed on the south coast during this time period (Figure 1). An alternative approach might be to assume the median estimated 1994-2014 proportion moves from 1984-1993.

The model estimated survey trawl selectivity-at-length is shown in Figure 5 and the average model fit to the survey length frequencies are shown in Figure 6. The under-prediction of proportions in the lower length classes for the south stock is interesting in the light of the hypothesised south stock winter recruitment. The higher proportions observed in length classes ≤10cm on the south coast compared to the west coast may be indicative of winter spawned south-stock recruits, and the difference between model predicted and observed is greatest between 2004 and 2008 (Figure 7). An alternative model assuming two co-horts of south stock recruitment is planned to be considered (de Moor et al. 2015b)

The model estimated commercial selectivity-at-length is shown in Figure 8 and the average model fit to the commercial length frequencies are shown in Figure 9. Commercial selectivity is assumed to be the same for all quarters of the year. There is some difference in the curves estimated, and the model fit for the models that assume only age 1 fish move (models a) and b)) and models that assume age 1 to 5+ fish move (models c) and d)). The plots in Figure 8 are shown averaged over all quarters and separately by quarter. It is unclear at this stage whether the differences in observed proportions-at-length between the quarters are primarily a reflection of differences in fish availability (particularly considering recruits enter the fishery from April onwards), or whether they are a reflection of differences in commercial selectivity over the year. Figure 10 shows the standardised residuals from the model fits to commercial proportions-at-length.

Figure 11 shows the model estimated growth curves and Figure 12 the length distributions for each age class.

Figure 13 compares the model predicted parasite prevalence-at-length to the observed prevalence-at-length from the November surveys. These initial comparisons were produced to consider what a realistic range of annual proportions of sardine infected with the parasite should be – initial results suggest 40% may be too high – and what the impact of assuming movement of older (2+) sardine could have on the model's ability to mimic the observed prevalence-by-length. These initial results show little difference in the model predicted prevalence-at-length for west stock fish between assuming only age-1 or age 1 to 5+ sardine move. However, assuming age 2+ fish move in addition to age-1 fish results in a (slight) increase in prevalence of south stock fish for higher length classes. Deviating from the assumption of a constant annual infection rate is constrained by the limitation of having five years of data only.

**References**

de Moor CL and Butterworth DS. 2015a. Assessing the South African sardine resource: two stocks rather than one? African Journal of Marine Science 27:41-51.

de Moor CL and Butterworth DS. 2015b. The stock assessment model for South African sardine. MARAM International Fisheries Stock Assessment Workshop Report No MARAM IWS/DEC15/Sardine/P1. 17pp.

de Moor CL, Butterworth DS, Coetzee JC and van der Lingen CD. 2015b. Progress report on recommendations from the international review panel report for the 2013 and 2014 International Fisheries Stock Assessment Workshop: sardine two-stock hypothesis. MARAM International Fisheries Stock Assessment Workshop Report No. MARAM IWS/DEC15/Sardine/BG2. 9pp.

de Moor CL, Coetzee J, Merkle D, van der Westhuizen JJ, can der Lingen C. 2015. A record of the generation of data used in the 2015 sardine and anchovy assessments. Department of Agriculture, Forestry and Fisheries Report No FISHERIES/2015/NOV/SWG-PEL/42. 25pp.

van der Lingen CD, Fréon P, Fairweather TP, van der Westhuizen JJ. 2006. Density-dependent changes in reproductive parameters and condition of southern Benguela sardine *Sardinops sagax*. African Journal of Marine Science 28:625-636.

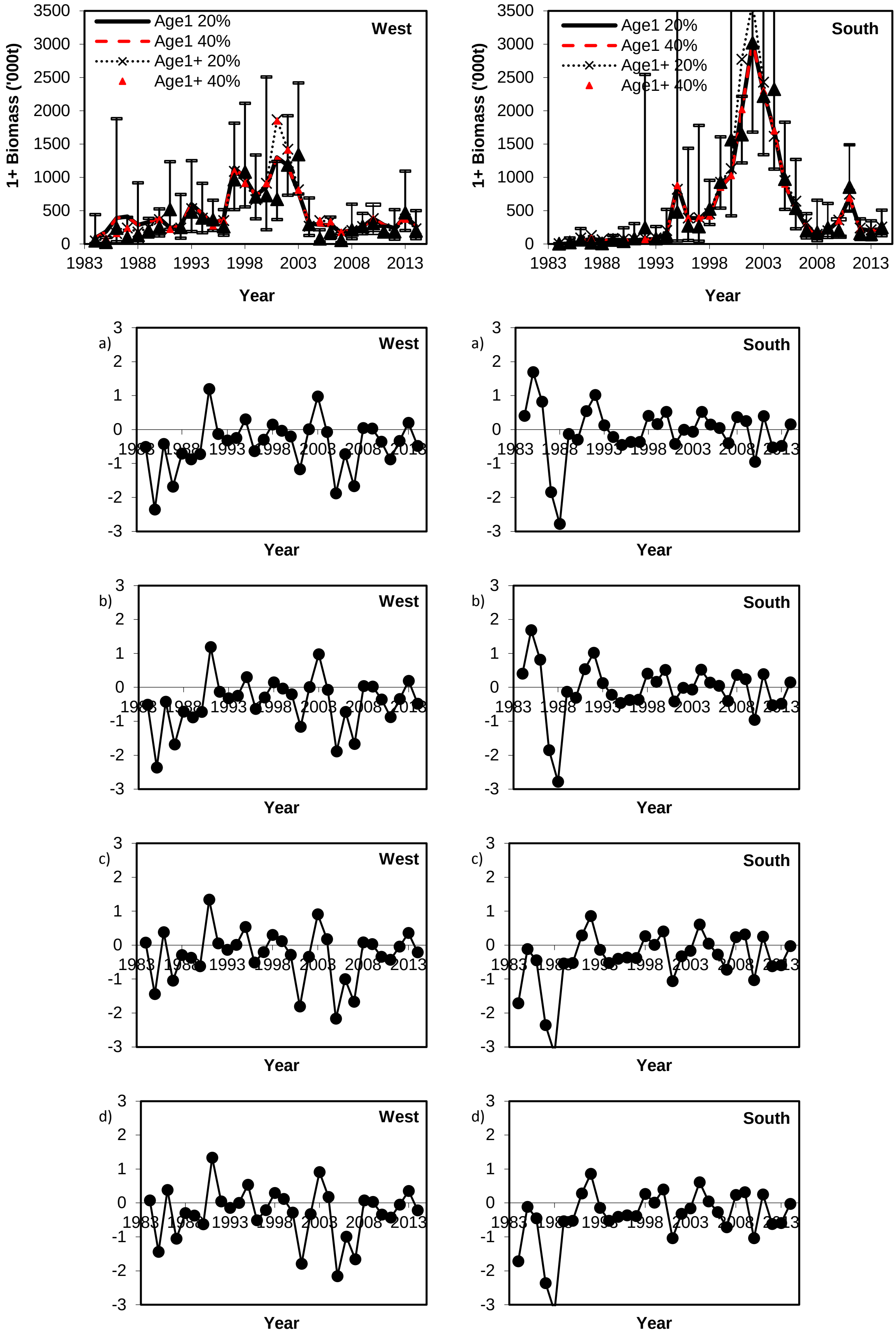


**Figure 1.** Acoustic survey results and model estimates for November sardine total biomass from 1984 to 2014, for west and south of Cape Agulhas, corresponding to the west and south stocks. The survey indices are shown with 95% confidence intervals reflecting survey inter-transect variance. The standardised residuals are given in the lower plots. Results are shown assuming models a) – d).

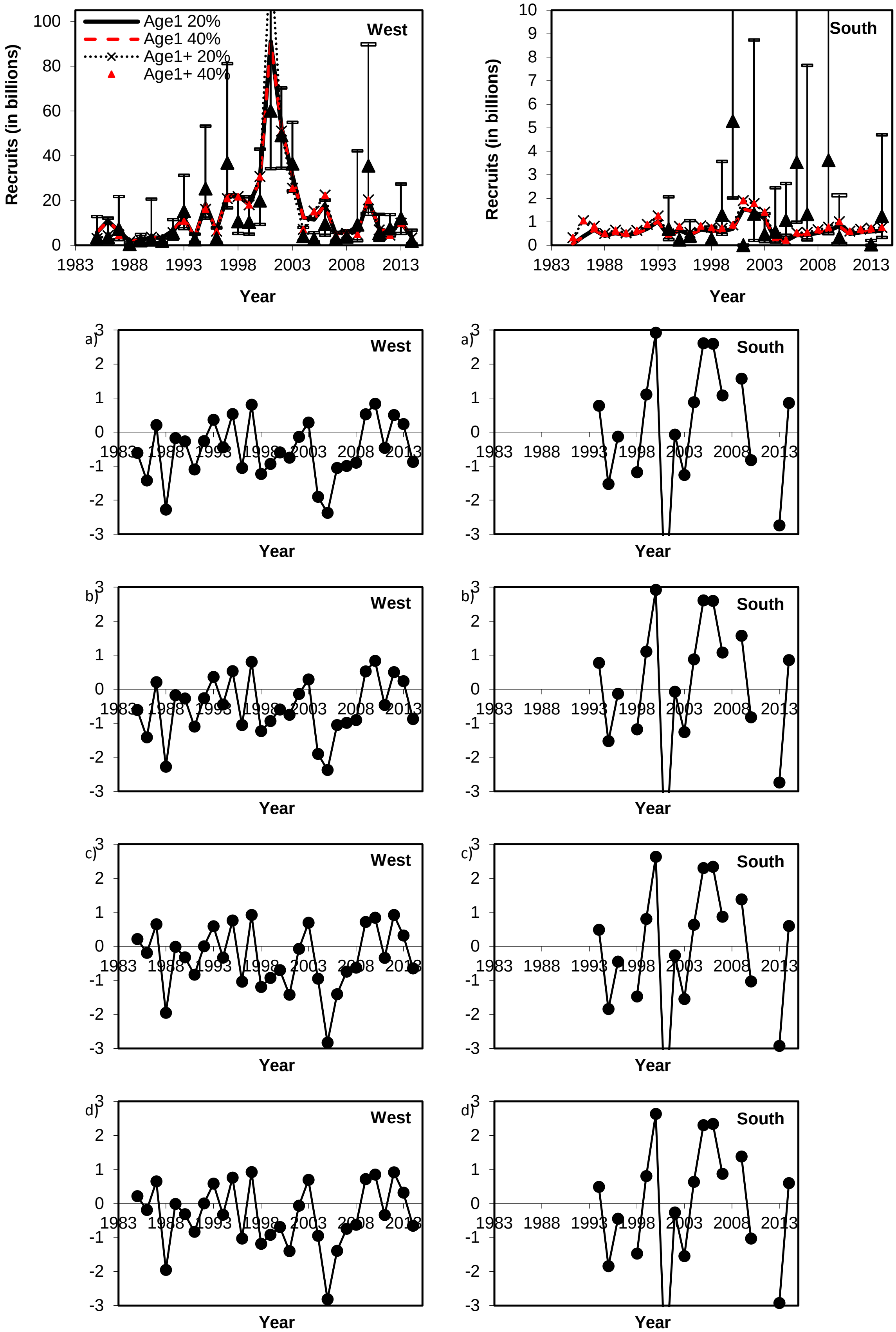


**Figure 2.** Acoustic survey results and model estimates for sardine recruitment numbers from May 1985 to May 2014, for west and south of Cape Infanta, corresponding to the west and south stocks. The survey indices are shown with 95% confidence intervals reflecting survey inter-transect variance. The standardised residuals are given in the lower plots. Results are shown assuming models a) – d).

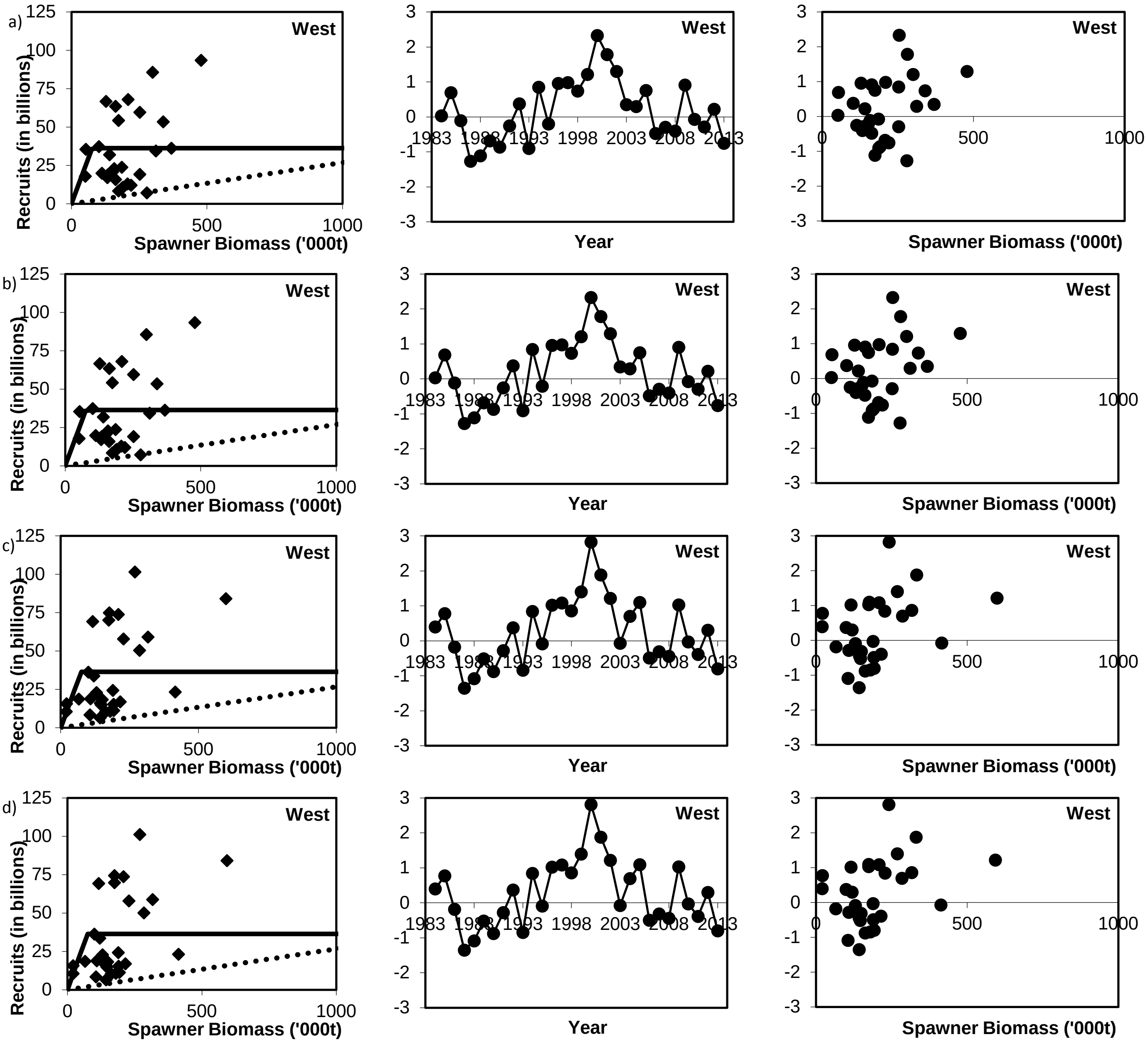


**Figure 3a.** Model predicted sardine recruitment (in November) plotted against spawner biomass from November 1984 to November 2013 for the **west stock**, with the Hockey Stick stock recruitment relationship. The dotted line indicates the replacement line. The standardised residuals from the fit are given in the right hand plots, against year and against spawner biomass. Results are shown assuming models a) – d).

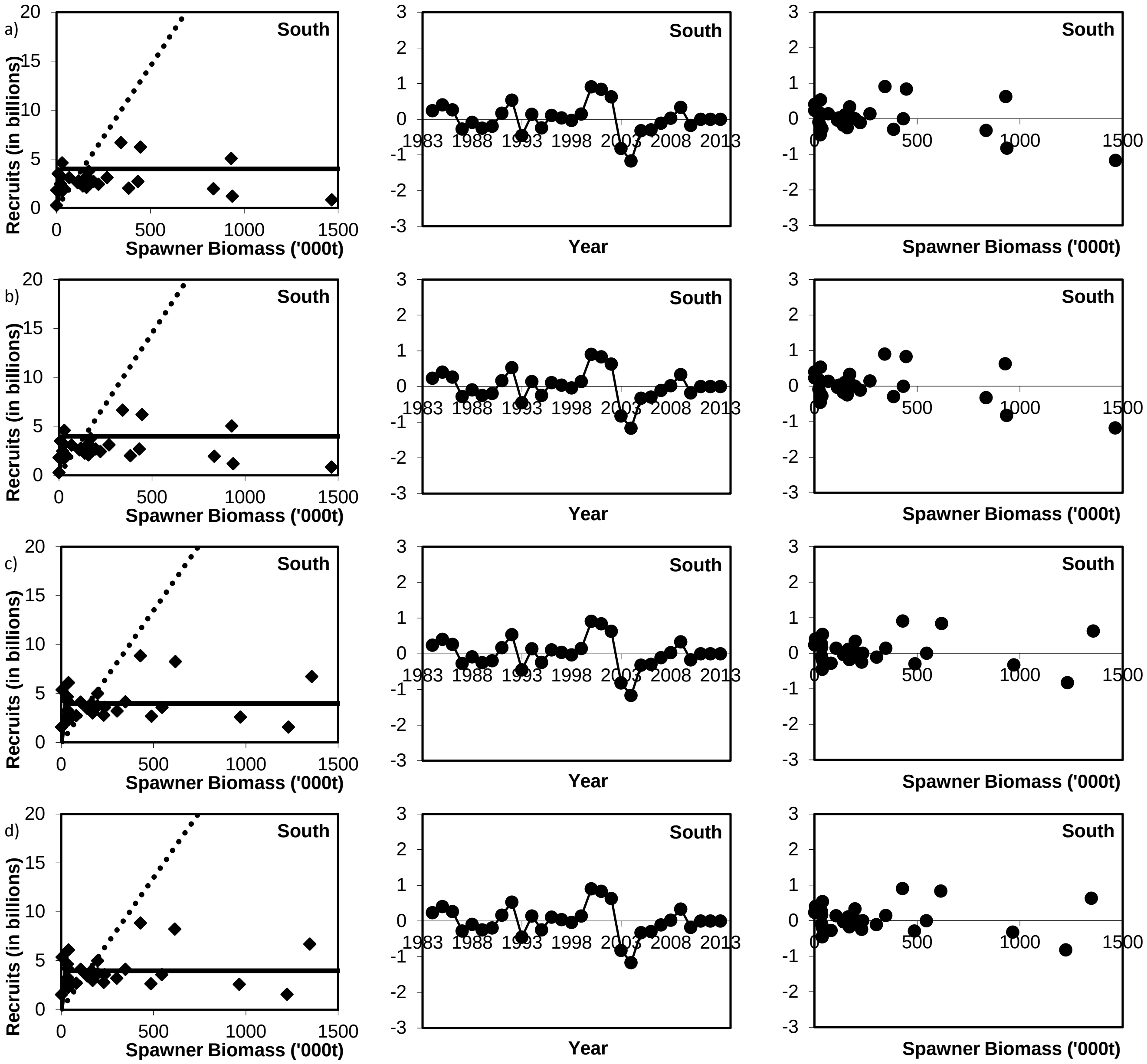


**Figure 3b.** Model predicted sardine recruitment (in November) plotted against spawner biomass from November 1984 to November 2013 for the **south stock**, with the Hockey Stick stock recruitment relationship. The dotted line indicates the replacement line. The standardised residuals from the fit are given in the right hand plots, against year and against spawner biomass. Results are shown assuming models a) – d).

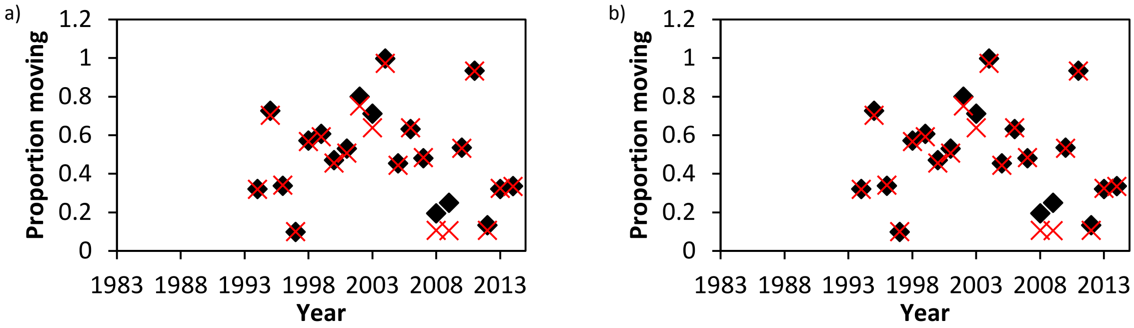


**Figure 4.** Model estimated proportion of age-1 sardine moving from the west to south stock annually. Results are shown for a) models a) and c) which assume 20% of west stock sardine are infected with the parasite annually, and b) models b) and d) which assume 40% of west stock sardine are infected with the parasite annually. The solid diamonds show the estimated proportions assuming only age-1 sardine move, while the red crosses show the estimated proportions assuming age 1 to 5+ sardine move.

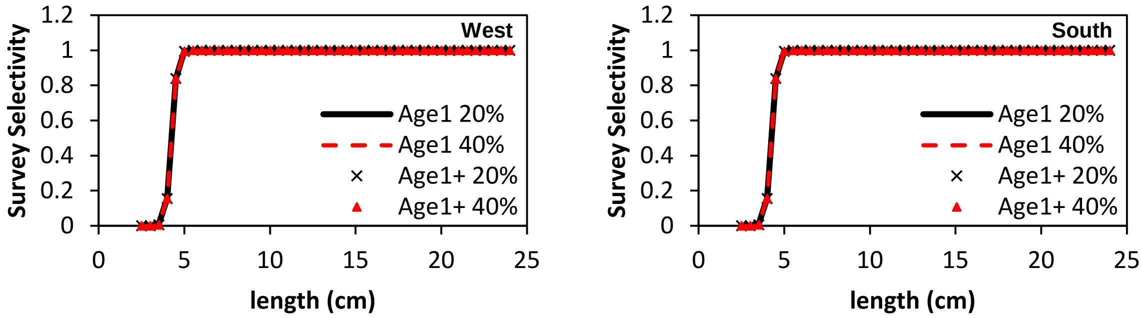


**Figure 5.** Model estimated trawl survey selectivity at length for west and south of Cape Agulhas, corresponding to the west and south stocks. Results are shown for models a) to d).

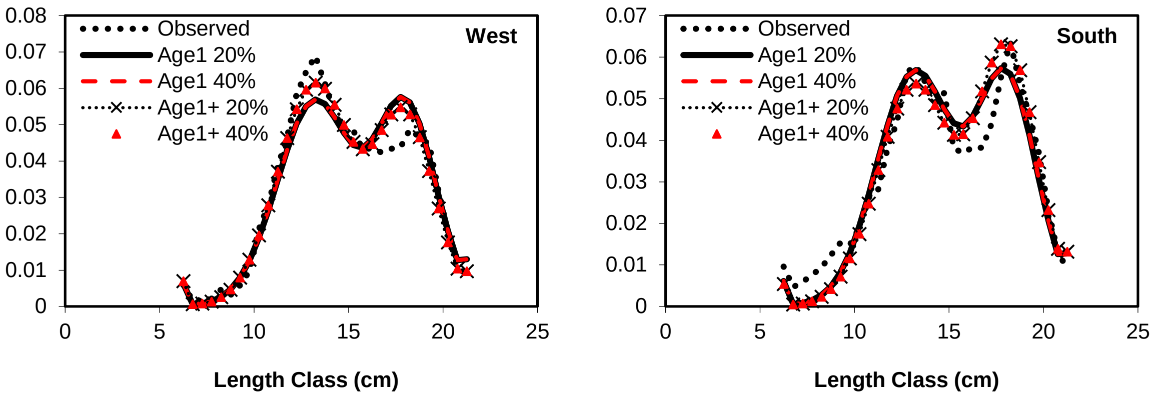


**Figure 6.** Average (over all years) model predicted and observed proportions-at-length in the November survey trawls for west and south of Cape Agulhas, corresponding to the west and south stocks. Results are shown for models a) to d).

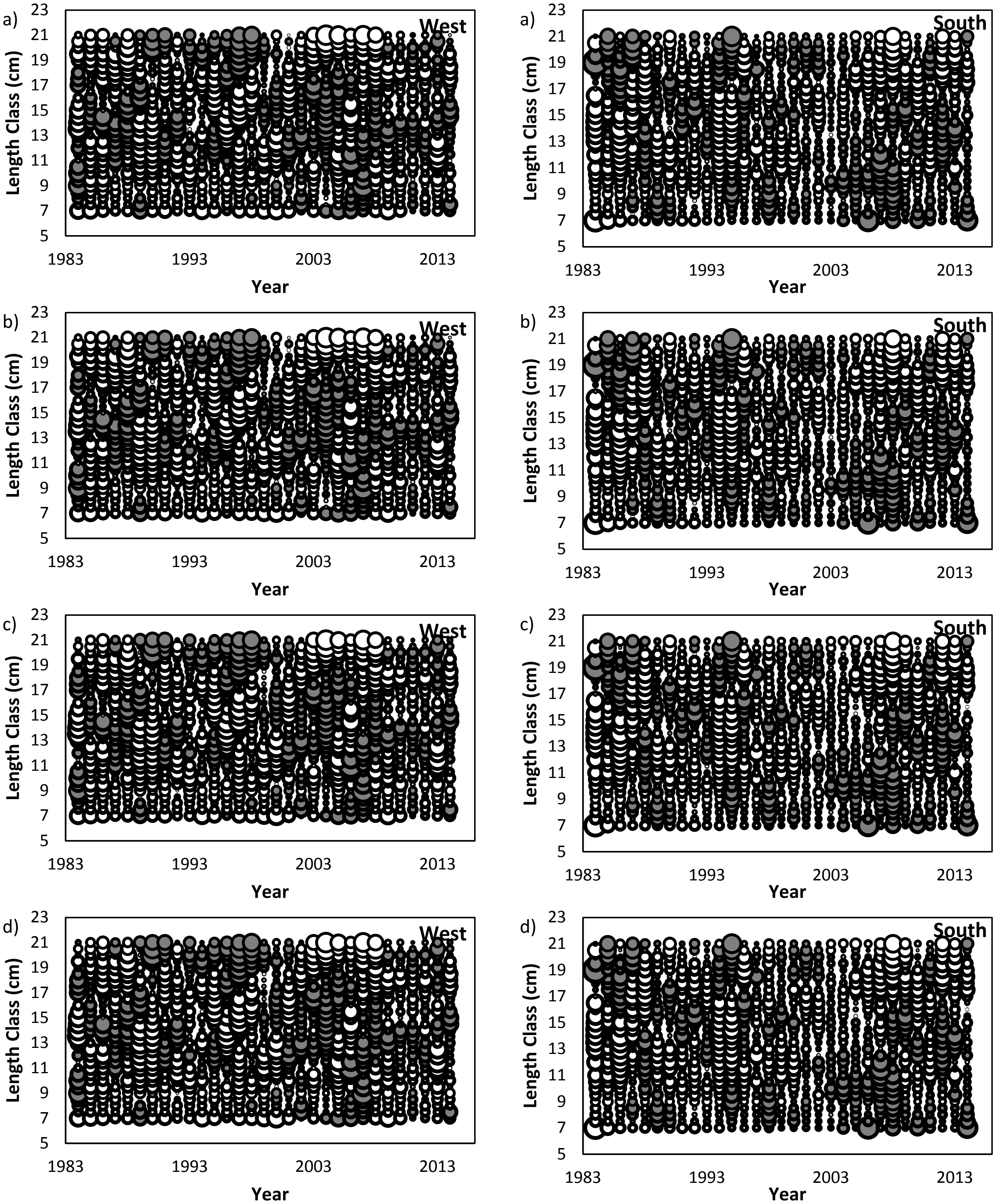


**Figure 7.** Standardised residuals for proportions-at-length in the November survey trawls for models a) to d). The size of the bubbles are proportional to the absolute value of the residuals, while the shaded bubbles show positive and the unshaded bubbles show negative residuals

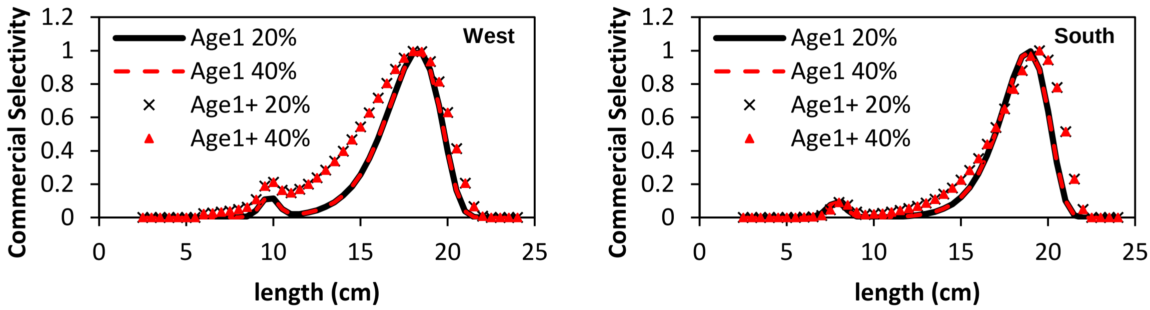


**Figure 8.** Model estimated quarterly commercial survey selectivity at length for the west and south stocks. Results are shown for models a) to d).

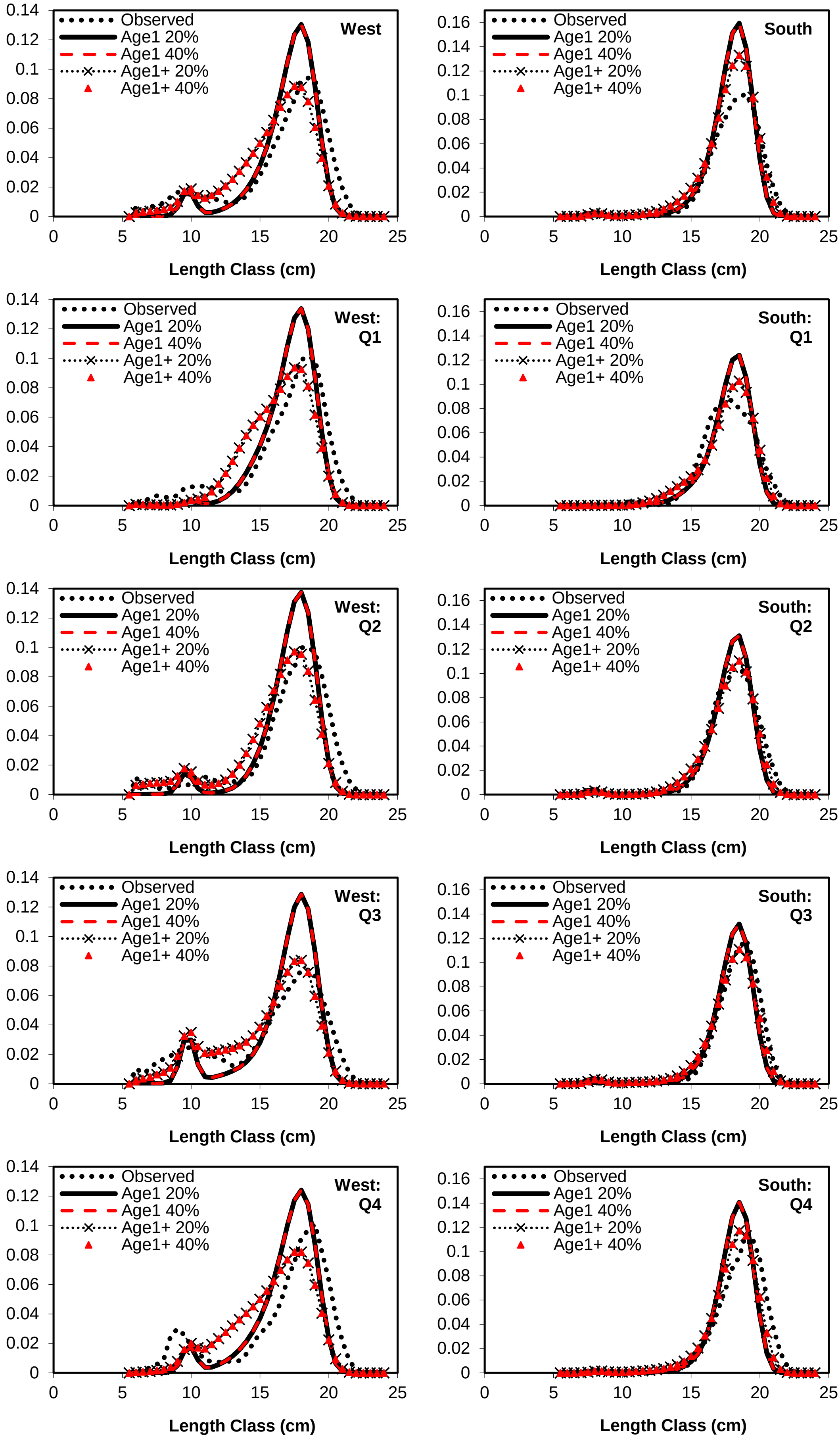


**Figure 9.** Average (over all years) model predicted and observed proportions-at-length in the quarterly commercial catch for the west and south stocks. Results are shown for models a) to d).

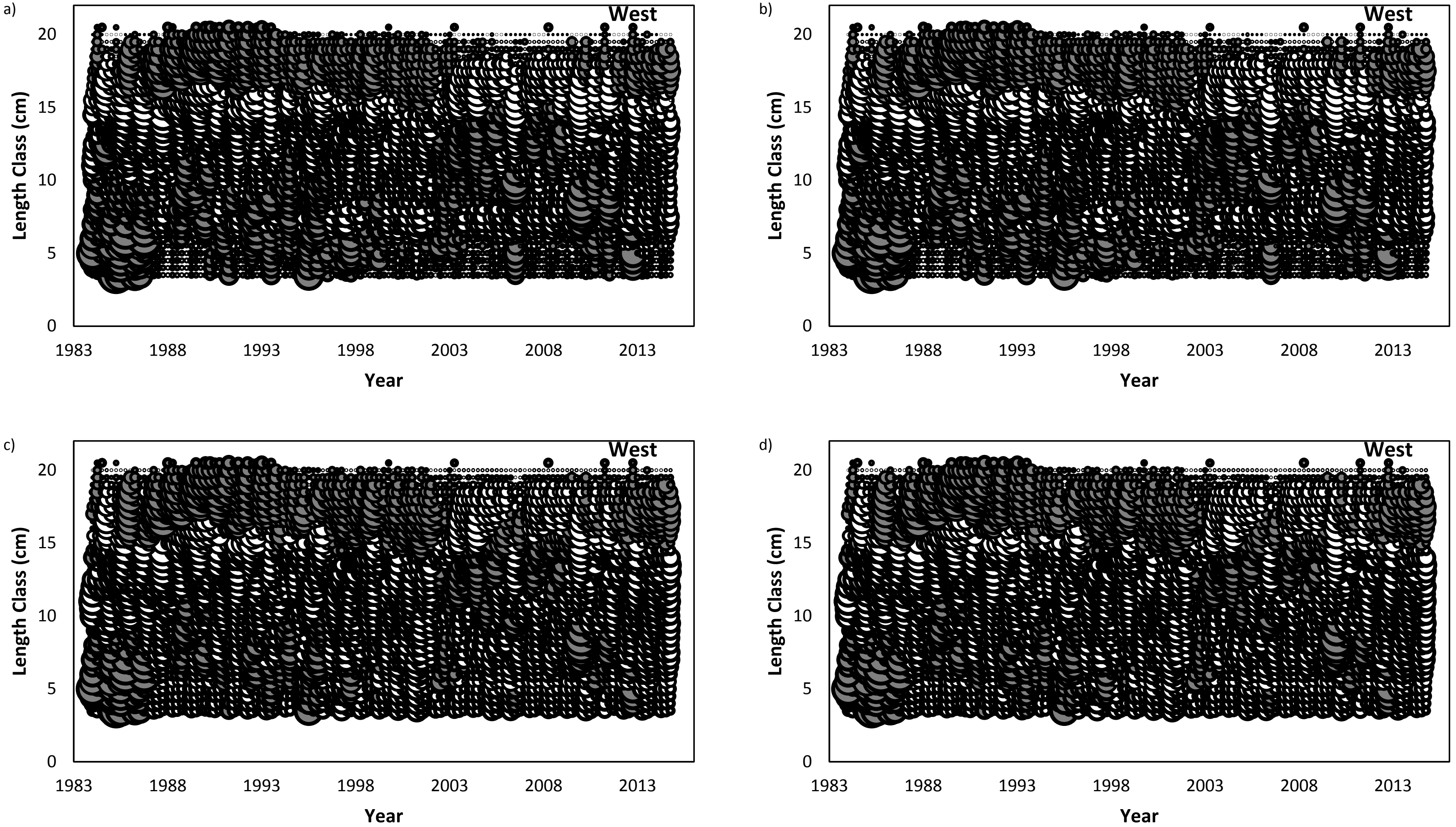


**Figure 10.** Standardised residuals for proportions-at-length in the commercial catch for models a) to d). The size of the bubbles are proportional to the absolute value of the residuals, while the shaded bubbles show positive and the unshaded bubbles show negative residuals

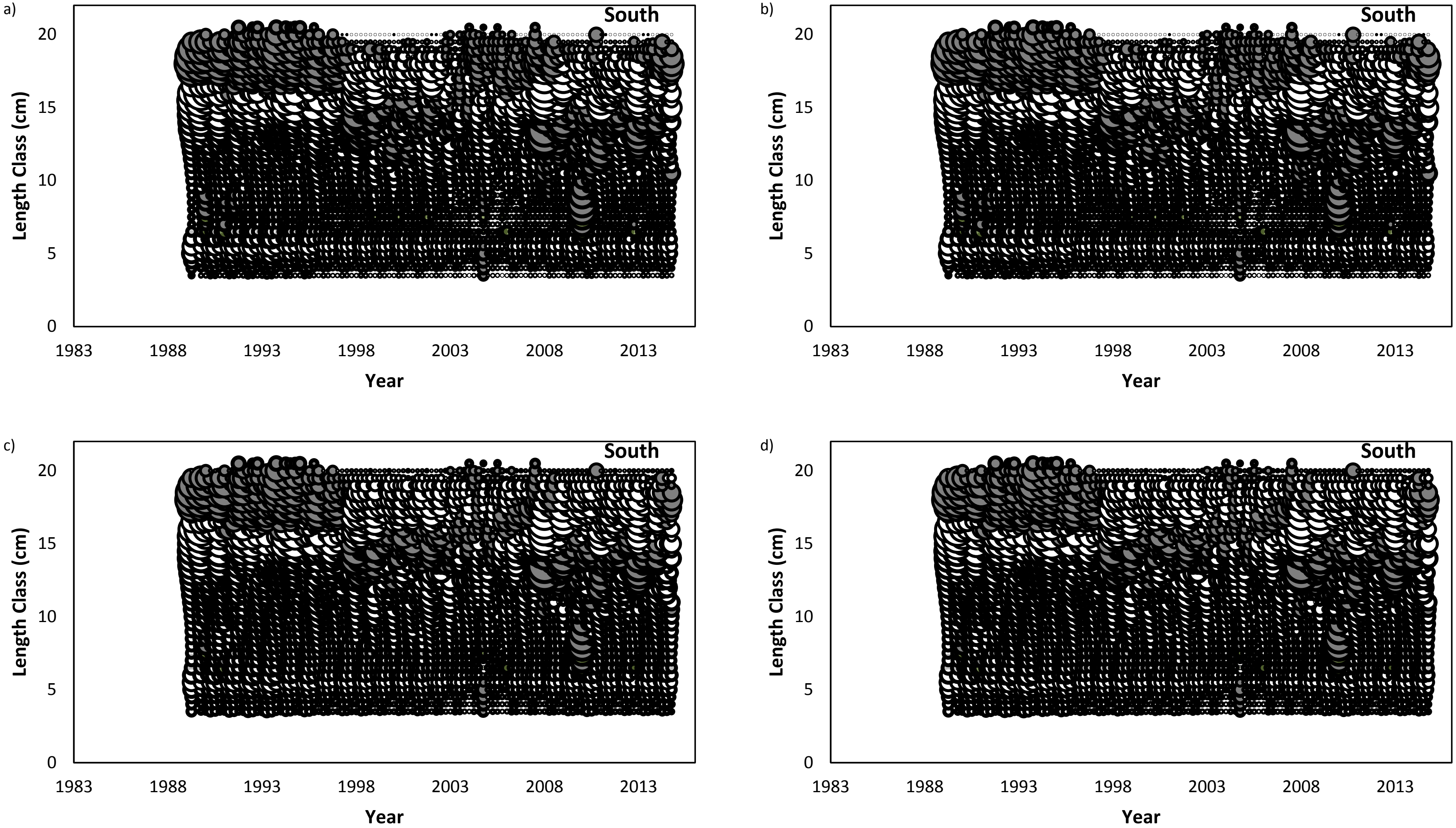


**Figure 10 (continued).**

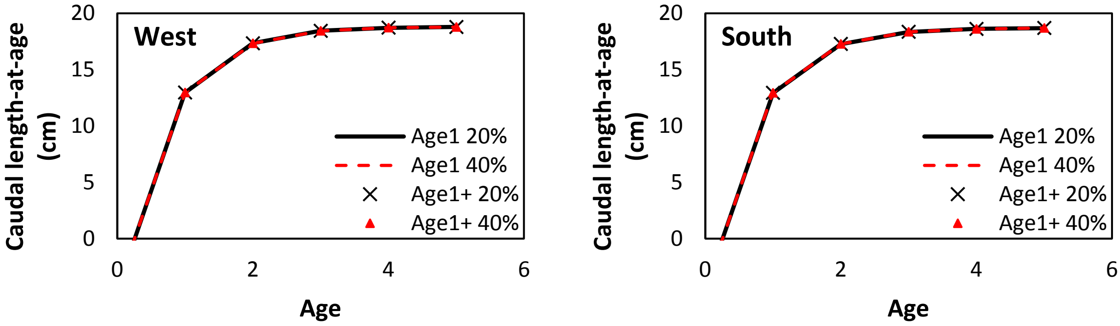


**Figure 11.** The model estimated von Bertalanffy growth curve, where integer ages are taken to correspond to November each year. Results are shown for models a) to d).

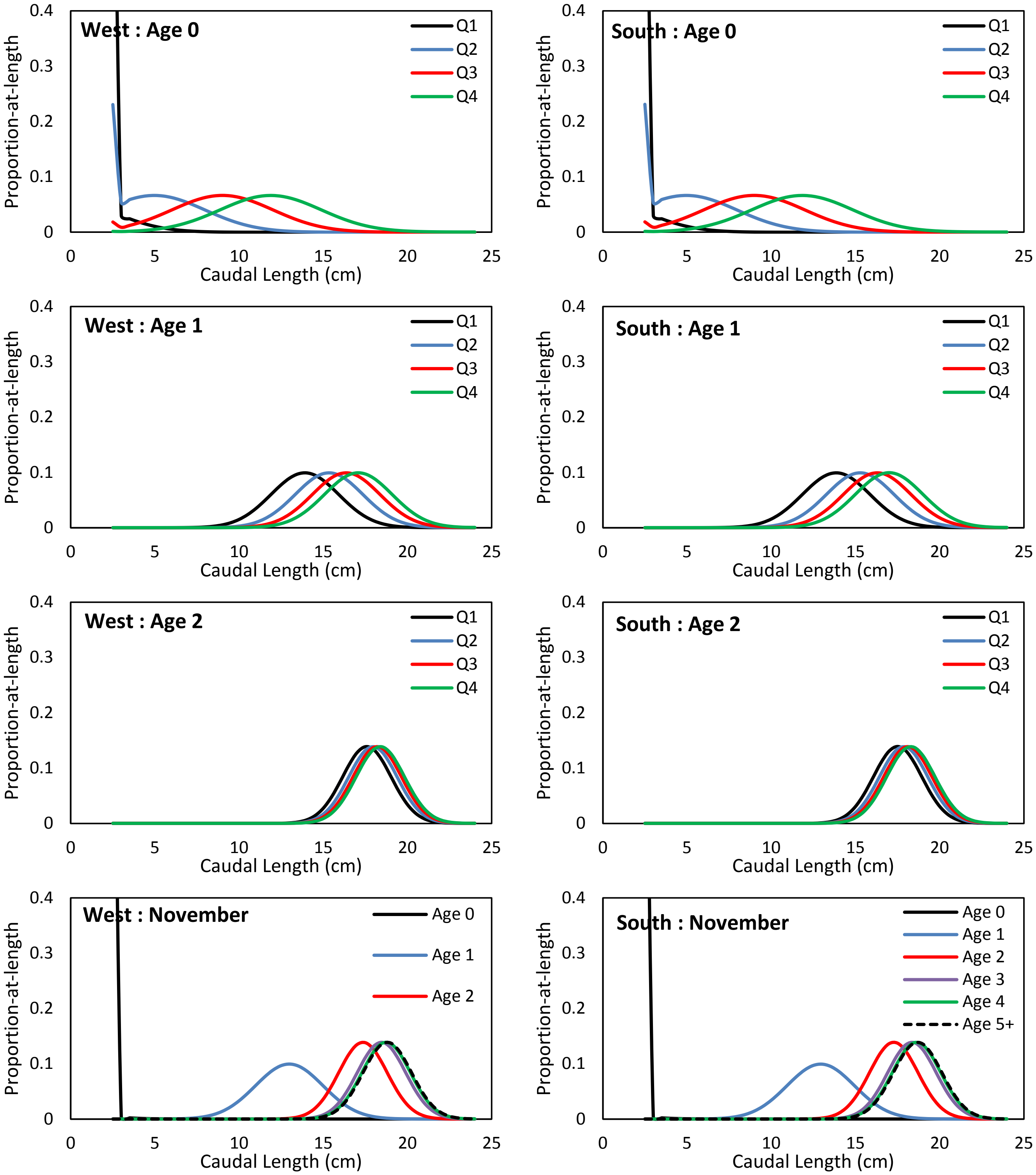


**Figure 12.** The model estimated distributions of proportions-at-length for ages 0, 1 and 2, given at the middle of each quarter of the year (corresponding to the times commercial catch is modelled to be taken). The last plot compares the distributions for all ages at 1 November. Given the similar growth curves for all models (Figure 11), only distributions for model a) are shown here.

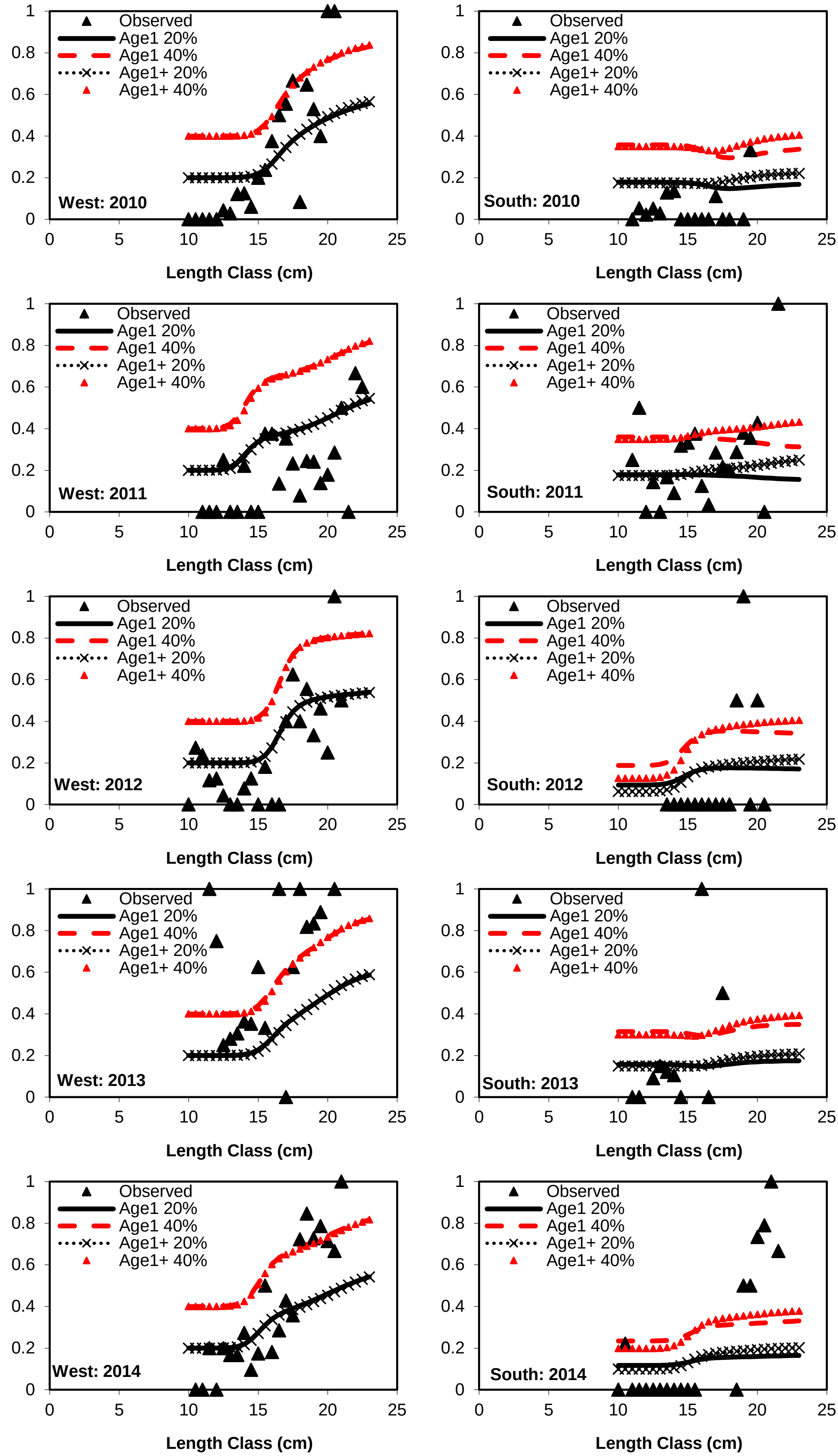


**Figure 13.** Model predicted and observed parasite prevalence-at-length in the November surveys for the west and south stocks. Results are shown for models a) to d). Note these data are not currently fit within the model.