Assessment of the South African sardine resource using data from 1984-2015: initial results for a two mixing-stock hypothesis

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

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

Introduction

The assessment of the South African sardine resource is in the process of being revised and updated using data available up to November 2015. Two primary hypotheses regarding the sardine stock structure have been agreed for investigation. The first considers sardine distributed off the west and south coasts of South Africa to form a single stock or population. The second considers the sardine to consist of a western stock and southern stock with some mixing between the stocks. This document presents initial results for this two mixing-stock hypothesis only.

The two mixing-stock hypothesis postulates a "west" stock distributed west of Cape Agulhas and a "south" stock distributed south-east of Cape Agulhas, with movement from the "west" to the "south" stock in November. de Moor and Butterworth (2015) considered the only mixing to be that of annually-varying west stock recruits to move to the south stock as they become 1 year old each November. In addition, de Moor and Butterworth (2015) assumed no mixing prior to 1994 when there are no recruit survey data for the south coast. This document extends that previous hypothesis by allowing for older west stock fish to move to the south stock and by estimating mixing for all years modelled.

This document also includes new data on the proportion of sardine-by-length infected by a digenean 'tetracotyle-type' metacercarian endoparasite. Accordingly, the working hypothesis assumed in this document is that only sardine distributed to the west of Cape Agulhas, i.e. west stock sardine, are infected with this parasite based on the assumption that the parasite host is only found west of Cape Agulhas (van der Lingen et al. 2015). Under this working hypothesis, infection of sardine on the south coast can result only from west-to-south mixing.

Population Dynamics Model

The generalised operating model for the South African sardine resource can apply to either the single or two mixing-stock hypotheses, and the data used in this assessment are listed in de Moor *et al*. (2016). The particular difference when fitting the two mixing-stock hypothesis to the data compared to the single-stock hypothesis is that both abundance index and proportions-at-length data are divided west and south of Cape Agulhas, and the negative log likelihoods include terms for each of these spatially separate components. In addition, the parasite data are used only in the likelihood for the two mixing-stock hypothesis.

Key features of this model include:

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

- The model is age-structured with a plus group of age 5. A distribution of length-at-age is used to model the length-structure of the population at fixed times during the year.
- Recruitment to each stock is dependent on the spawner biomass of that stock only (though the equations are generalised to allow for alternative assumptions in robustness testing). This document assumes a hockey-stick stock recruitment relationship for both stocks.
- In the two mixing-stock hypothesis, permanent west-to-south movement is modelled, but no south-to-west movement is permitted.

Key differences in the model used to calculate the results presented in this document compared to those of de Moor and Butterworth (2015) are as follows:

- Spawner biomass is calculated assuming a maturity-at-length ogive which changes over time, rather than assuming all sardine mature at age 2, and weight-at-length rather than weight-at-age.
- The trawl survey selectivity-at-length is assumed to be logistic (allowing for some escapement of small fish); escapement of large fish is no longer modelled.
- The estimated stock-specific commercial selectivity-at-length curve is described by a double-normal distribution at higher lengths rather than an inverted lognormal distribution.
- Instead of assuming small (<14cm) sardine bycatch is measured without error, a small error is allowed and a fishing mortality is estimated for this bycatch to assist with model convergence.
- The informative prior distribution for the bias associated with the acoustic survey has been recalculated assuming a lognormal rather than normal shape.
- To aid parameter estimation, the stock-specific lengths at ages 1 and 3 are estimated instead of the von-Bertalanffy growth curve parameters themselves. As this does not allow for realistic extrapolation of the von-Bertanaffy growth curve below age 1, a straight line to the origin is assumed.
- In the two mixing-stock hypothesis, movement of age 2+ sardine is assumed to be non-zero and is a time-invariant proportion of the proportion of age-1 sardine moving each year.
- In the two mixing-stock hypothesis, infection of sardine by the parasite is modelled to occur in an annual pulse on 1st November and the proportion of sardine infected is age-invariant (but excludes recruits age 0 on 1st November). Infection by the parasite is assumed to result in no change to growth, maturity, natural or fishing mortality.

In addition, a number of other prior distributions have been modified and/or parameters have been re-parameterised to assist with model convergence.

Results and Discussion

These results should be considered preliminary as the 2015 parasite data have only recently become available and insufficient time was available to fully test model alternatives previously tested on 2010-2014 data only. For this reason, little written commentary is given on some possible mis-fits to the data as the model fits may improve with further testing. However, discussion of these initial results at the SWG-PEL is encouraged.

The model fits to the November total biomass and May recruit surveys are shown in Figures 1 and 2. The bias in the surveys is estimated to be 0.76 for the November acoustic survey and 0.55 for the May recruit survey, and the model assumes the coverage of the south stock recruits by the May survey is the same as that of the west stock recruits. The estimated stock-recruitment relationships are shown in Figure 3. Note that to ensure convergence of these initial results, the inflection point of the stock-recruitment relationship has needed to be fixed.

The model estimated annual proportions of age 1 and age 2+ sardine moving from the west to south stock are shown in Figure 4. The proportion of 2+ sardine moving is estimated to be half of that of the 1 year olds. This proportion is (currently) assumed to be time- and age-independent.

The model estimated survey trawl selectivity is shown in Figure 5 with the residuals from the fit to the November survey length frequency data given in Figure 6. There are some systematic patterms of residuals for the south stock, also noticeable when the average model predicted proportions-at-length are compared with those from the survey (Figure 7). This may be indicative of the hypothesised south coast winter spawning, but further analyses to investigate this have yet to be carried out.

The model estimated commercial selectivity is shown in Figure 8. There are systematic residual patterns in the model fit to the data (Figures 9 and 10) which may indicate that some change in commercial selectivity over the years may need to be modelled. The differences in average proportions-at-length between quarters may also indicate that the quarterly distribution of length in the catch is not only informed by changes in availability during the year, but also by changes in commercial selectivity within a year.

The estimated von Bertalanffy growth curve is very similar for both stocks (Figure 11), with high variability about this growth curve estimated for age 0 (Figure 12).

As parasite prevalence-at-length data are only available from 2010 onwards, the infection rate is estimated from 2008 onwards and fixed at an arbitrary rate prior to 2008. The estimated rates of infection of west stock sardine by the parasite are estimated to vary substantially between years (Figure 13). The model is able to trace the observed prevalence-at-length from November surveys sufficiently well for the west stock, with some good fits (e.g. 2015) to the south stock data too (Figure 14).

Figure 15 shows the model estimated harvest rates.

Summary

This document has demonstrated further progress towards a new two mixing-stock hypothesis for South African sardine. The model is able to estimate a time and age-invariant proportion parameter allowing for age 2+ sardine to also permanently move from the west to the south stocks. In addition, this in the first time results are being shown following the inclusion of the parasite prevalence-at-length data from the November surveys between 2010 and 2015 and the model is able to reasonably match the trends in these data.

Further work is still required, both in terms of testing some key alternative assumptions and in terms of further checking appropriate parameterisation to aid MCMC convergence. Some key alternatives still to be considered include:

i) Two co-horts of recruitment to the south stock, one on 1st November and one on 1st May.
ii) A change in commercial selectivity over time (within a year and at selected points over time).
iii) Sensitivity to alternative rates of natural motality
iv) Estimating the inflection point of the stock-recruitment relationships and sensitivity to alterative stock-recruitment relationships.

References

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

de Moor CL, Coetzee J, Merkle D, van der Westhuizen JJ and van der Lingen C. 2016. A record of the generation of data used in the 2016 sardine and anchovy assessments. DAFF: Branch Fisheries Document FISHEREIS/2016/APR/SWG-PEL/13. 27pp.

van der Lingen CD, Weston LF, Ssempa NN, Reed CC. 2015. Incorporating parasite data in population structure studies of South African sardine *Sardinops sagax*. *Parasitology* 142:156-167.

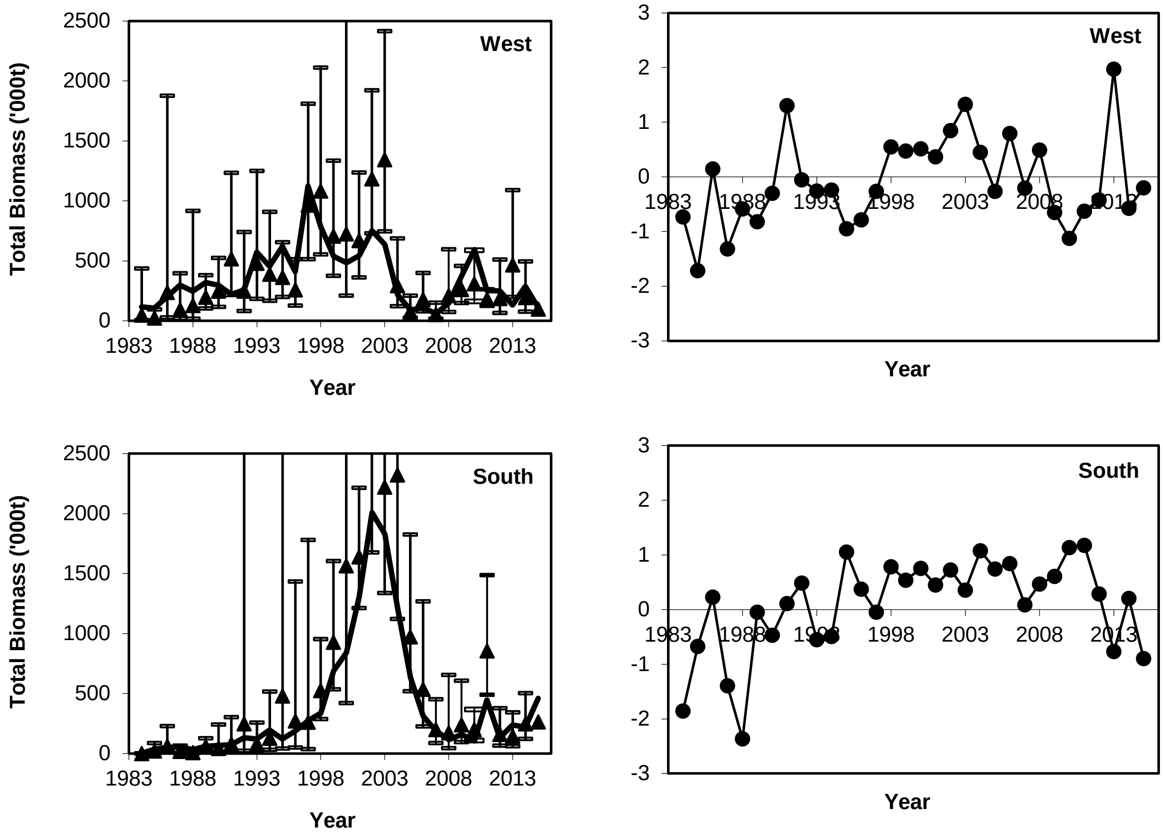

Figure 1. Acoustic survey estimated and model predicted November sardine 1+ biomass from 1984 to 2015. The observed indices are shown with 95% confidence intervals. The standardised residuals (i.e. the residual divided by the corresponding standard deviation, including additional variance where appropriate) from the fits are given in the right hand plots.

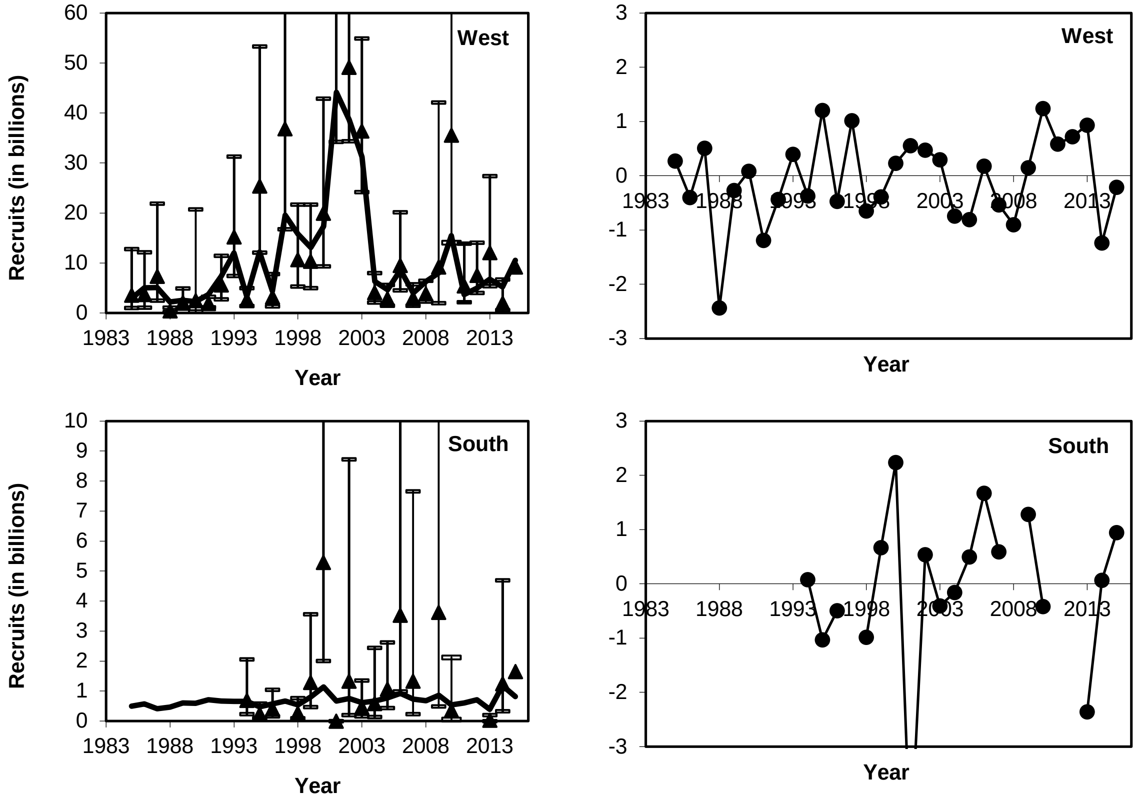

Figure 2. Acoustic survey estimated and model predicted sardine recruitment numbers from May 1985 to May 2015. The survey indices are shown with 95% confidence intervals. The standardised residuals from the fit are given in the right hand plots.

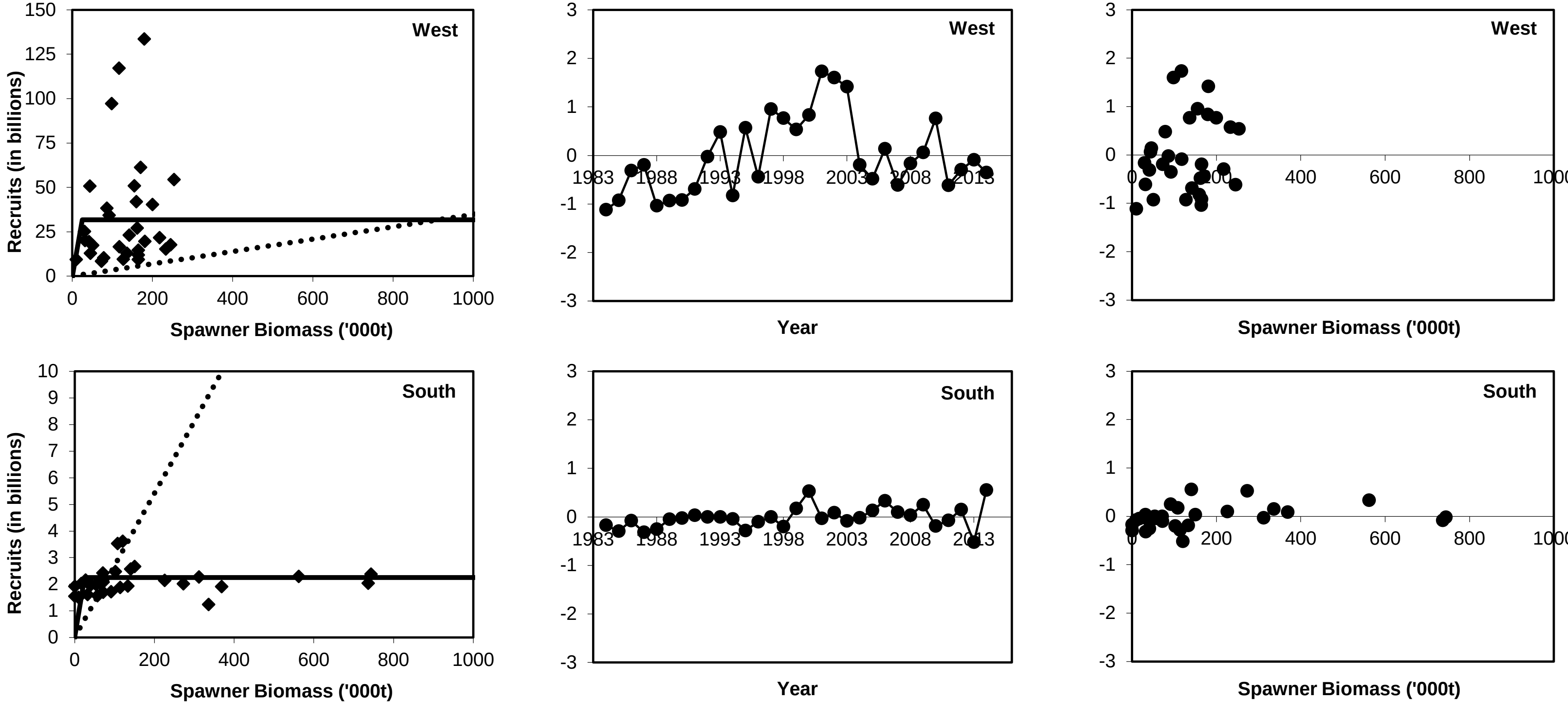

Figure 3. Model predicted sardine recruitment (in November) plotted against spawner biomass from November 1984 to November 2014 with the estimated Hockey stick stock recruitment relationships are shown in the left side plots. The dotted line indicates the replacement line. The standardised residuals for the fits are given in the centre and right side plots, against year and against spawner biomass respectively.

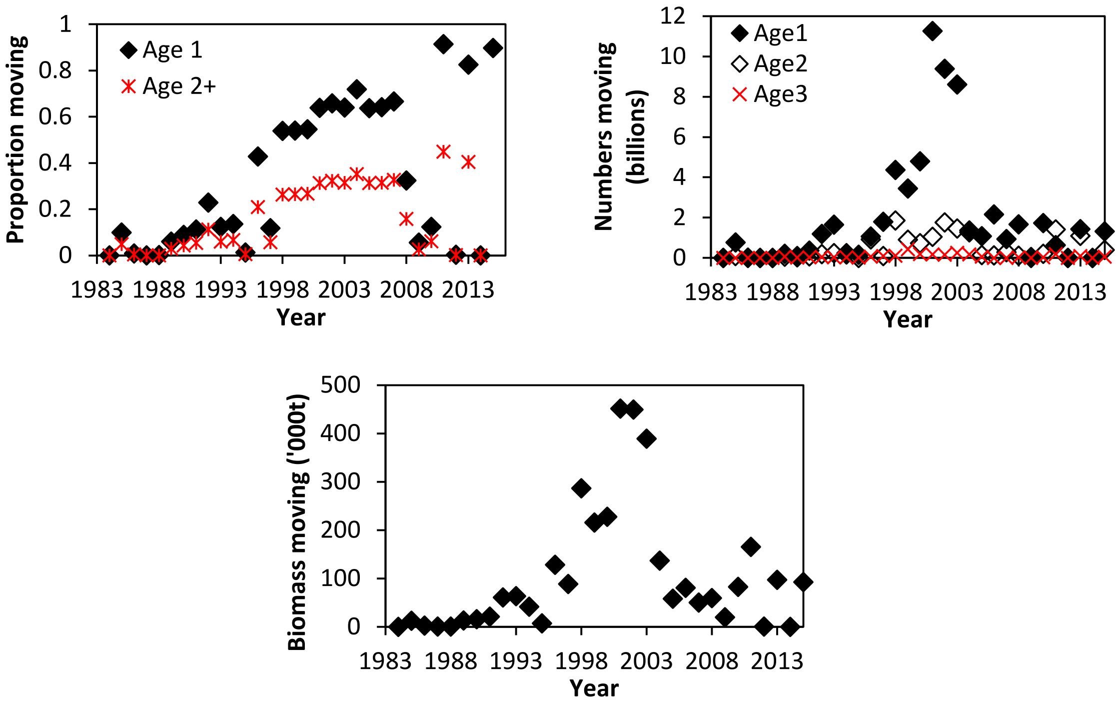

Figure 4. Model estimated proportion of 1-year-olds and 2+-year-olds which move from the "west" stock to the "south" stock in November. The right hand plot shows the numbers of 1-, 2- and 3-year olds moving while the lower plot shows rough[1] estimates of the annual biomass moving from the west to south stock.

[1] Calculated using the average of "west" and "south" stock weights-at-age 1.

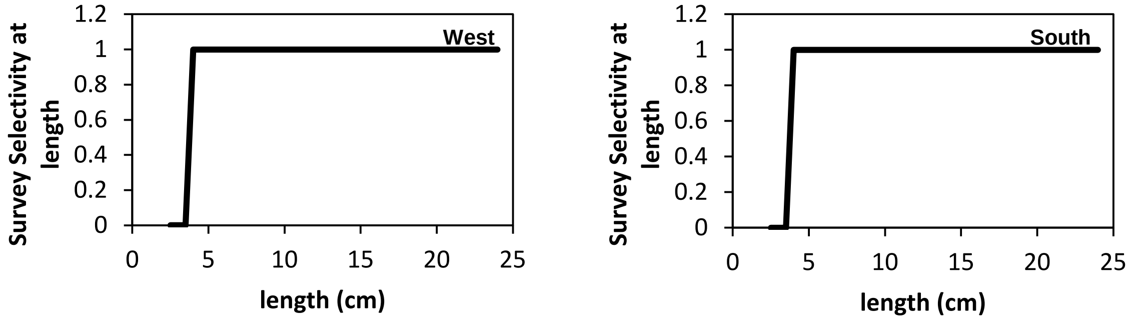

Figure 5. The model estimated November survey selectivity at length.

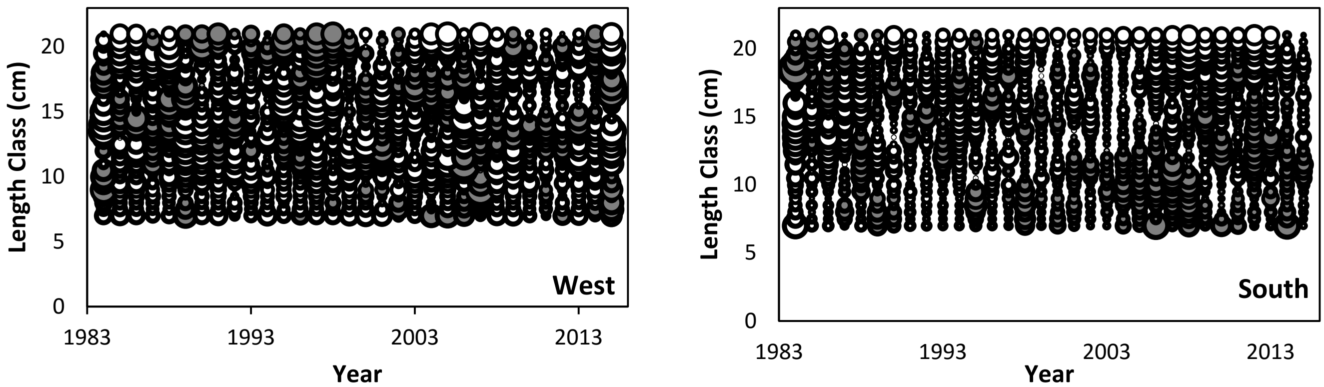

Figure 6. Residuals from the fit of the model predicted proportions-at-length in the November survey to the hydroacoustic survey estimated proportions. The left panels show the residuals for the minus length class (9cm) and the right panels show the residuals for the remaining length classes.

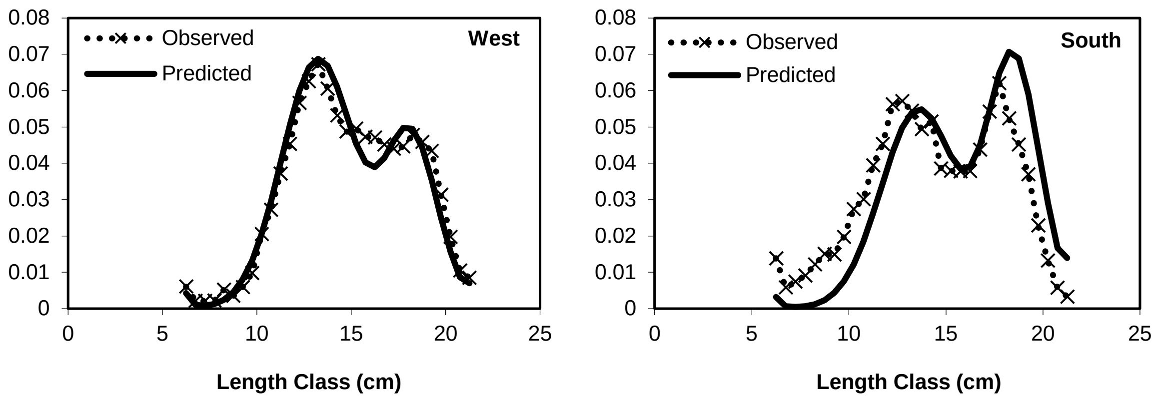

Figure 7. Average (over all years) model predicted and observed proportion-at-length in the November survey.

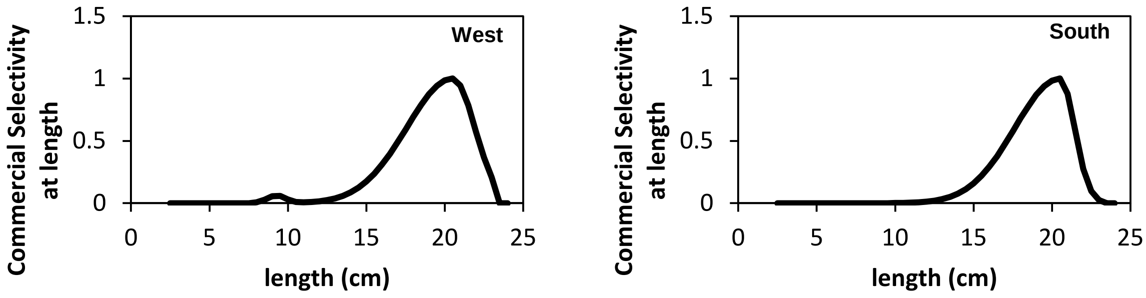

Figure 8. The model estimated commercial selectivity at length.

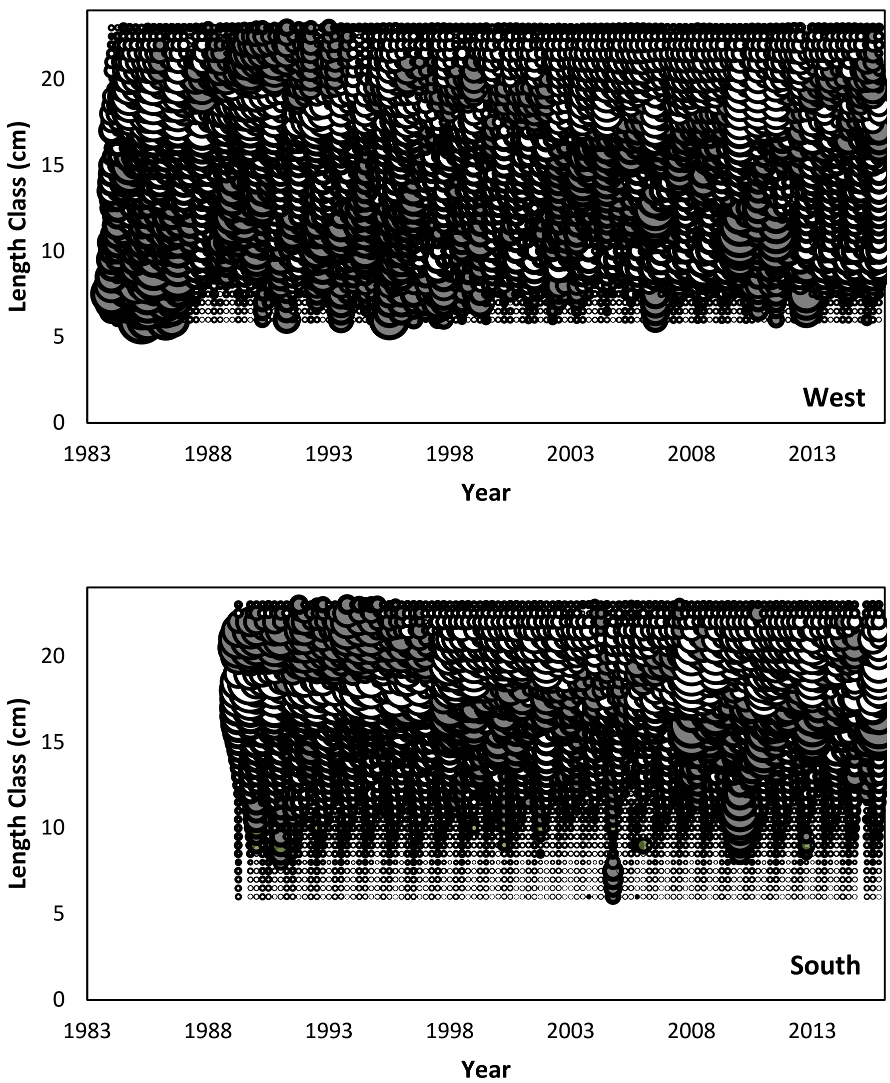

Figure 9. Residuals from the fit of the model predicted proportions-at-length in the quarterly commercial catch to the observed proportions.

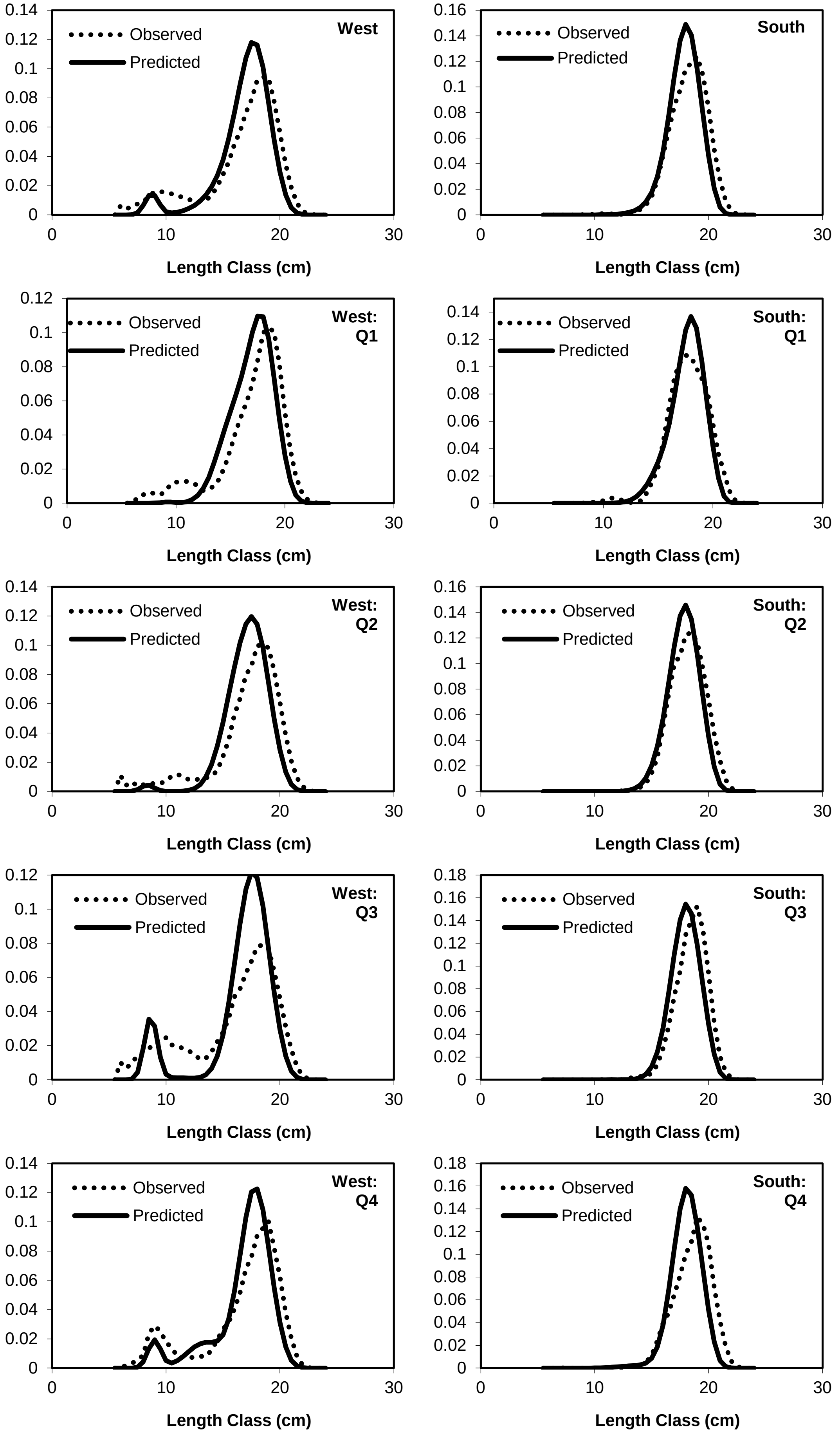

Figure 10. Average (over all quarters and years) model predicted and observed proportion-at-length in the commercial catch (top row), and average (over all years) quarterly model predicted and observed proportions-at-length in the commercial catch (subsequent rows).

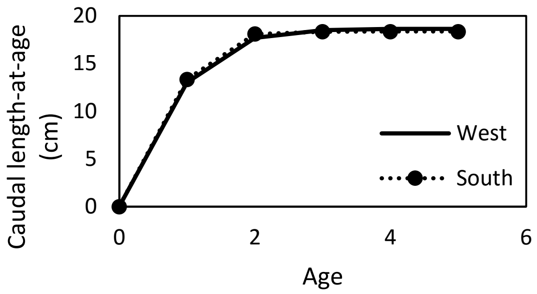

Figure 11. The von Bertalanffy growth curves estimated from ages 1+; a straight line to the origin is assumed below age 1.

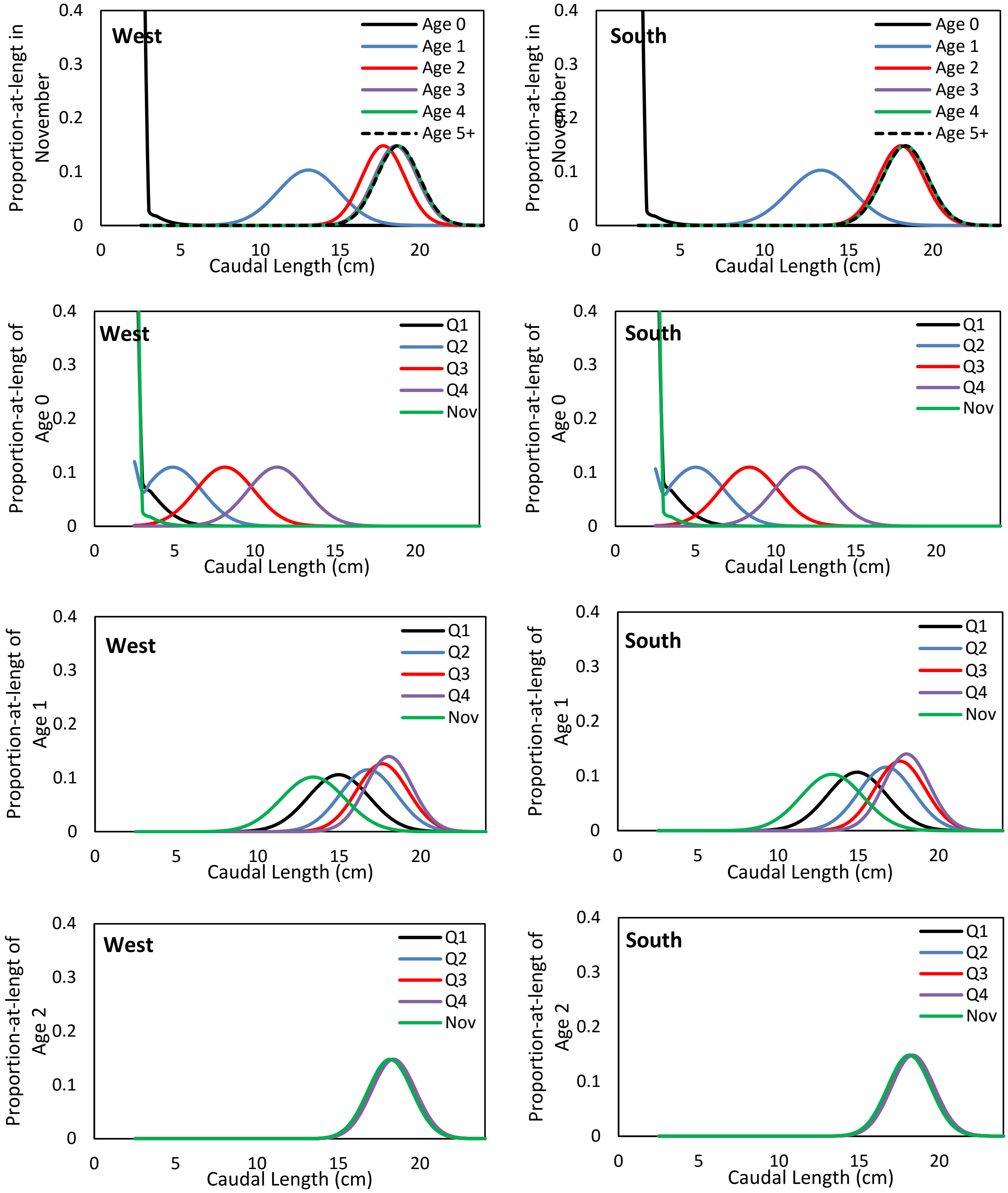

Figure 12. The model estimated distributions of proportions-at-length for each age, given at the time of the biomass survey (1 November, top row), and middle of each quarter of the year (corresponding to the times commercial catch is modelled to be taken) for age 0, 1 and 2 (subsequent rows).

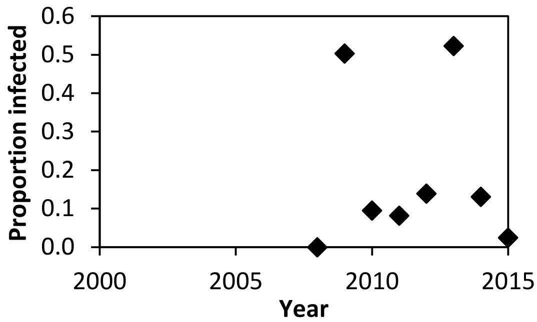

Figure 13. The model estimated proportion of west stock sardine infected with the parasite between 2008 and 2015. (Annual infection rate is arbitrarily assumed to be 0.2 prior to 2008.)

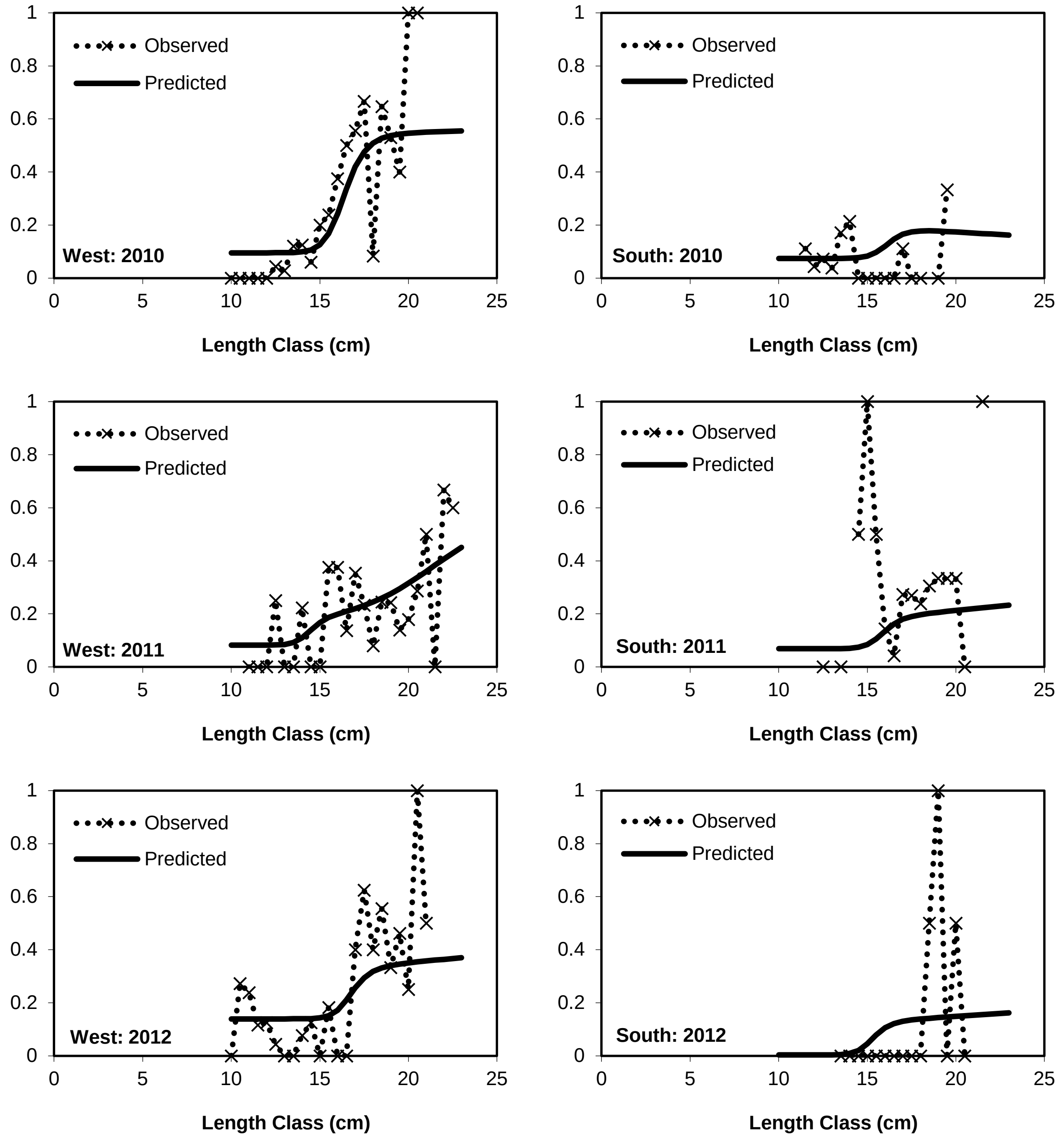

Figure 14. The model estimated proportions-at-length of west and south stock sardine infected with the parasite (i.e. parasite prevalence-by-length) between 2010 and 2015 together with the observed proportions-at-length.

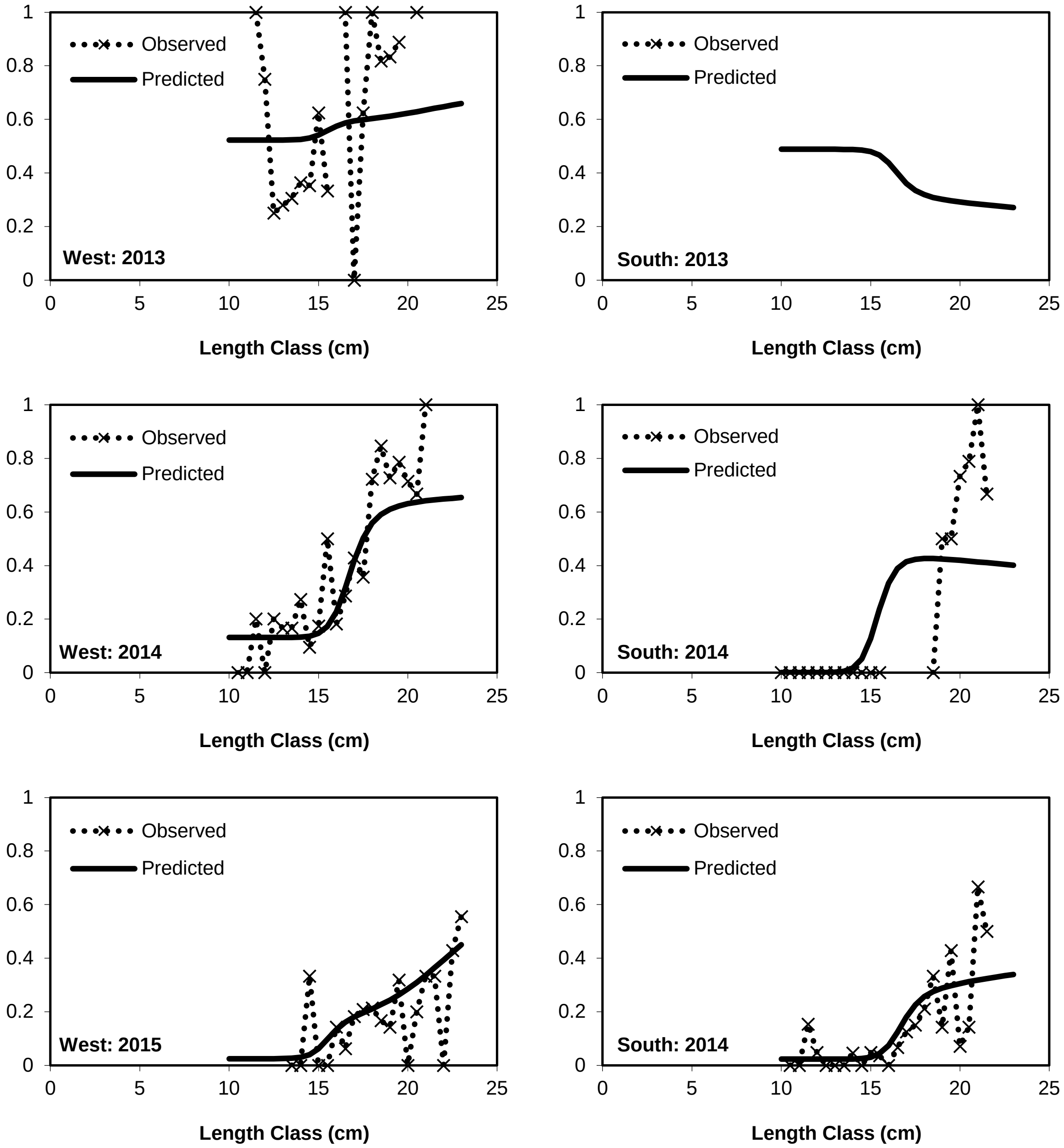

Figure 14 (continued).

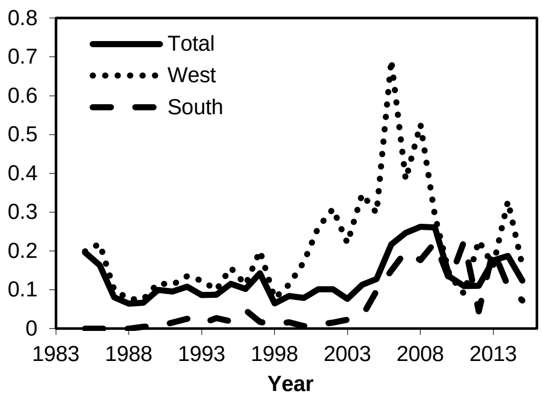

Figure 15. The harvest proportion (simply calculated as the observed annual (Nov-Oct) catch tonnage as a proportion of the model predicted total biomass) of the “west” and “south” stocks and the total population.