Assessment of the South African sardine resource using data from 1984-2011: initial results for a two stock hypothesis

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

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

Introduction

As part of the process of updating the assessment of the South African sardine resource, a sardine two mixing-stock hypothesis is to be tested. This 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 as recruits age to 1 year olds.

Population Dynamics Model

The updated operating model for the South African sardine resource is detailed in Appendix A of de Moor and Butterworth (2012) and the data used in this assessment are listed in de Moor *et al*. (2012). All key changes to the model described in de Moor and Butterworth (2012) also apply to the model used for this two stock hypothesis. The particular difference when fitting the two-stock model to the data 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. A glossary of terms used in this model is repeated from de Moor and Butterworth (2012) in the Appendix of this document for ease of reference.

The median juvenile, $\overline{M}_j^S = 1.0$, and adult, $\overline{M}_{ad}^S = 0.8$, natural mortality values and the Hockey Stick stock recruitment relationship are assumed in line with choices for the base case single stock hypotheses. Alternative natural mortality and stock-recruitment relationships will be tested at a later stage. As for the single stock hypothesis, natural mortality is assumed to be time-invariant for the base case hypothesis, called S^2_{HS} in this document.

Results and Discussion

The population model fits to the time series of abundance estimates of November 1+ biomass are reasonable, though there is consistent under-prediction of the peak in the "south" stock in the early 2000s (Figure 1). The corresponding model fits to the time series of May recruitments are plotted in Figure 2. The residual for the "south" stock in 2001 is large (-6.8), but a larger than observed recruitment is required by the model as a non-negligible 0-year-old catch occurred to the east of Cape Agulhas before

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

November 2001. As was the case for the single stock hypothesis, the model under-predicts recruitment to the "west" stock in May 2010 as it is unable to reconcile the conflicting data of an above average recruitment estimate in May 2010 with almost no increase in the November 1+ biomass estimate from 2009 to 2010. The bias associated with the hydroacoustic survey is estimated to be similar to that estimated by the single stock assessment (0.75 compared to 0.72), while the coverage of the May recruit survey in comparison to that of the November survey is estimated to be 61% (compared to 54% estimated for the single stock assessment). The coverage of the recruits to the "south" stock relative to that for the "west" stock is estimated to be 76%. This results in a bias associated with the May survey estimate of recruitment of 0.46 for the "west" stock and 0.35 for the "south" stock; both low values, yet both near that estimated for the single stock hypothesis.

More than 50% of the "west" stock recruits are modelled to move to the "south" stock in 9 out of 28 years, with the greatest movement between stocks in biomass terms occurring from the late 1990's to the early 2000s (Figure 3), corresponding closely to the years of peak biomass in the "south" stock. The model currently estimates movement of recruits from the "west" stock to the "south" stock for all years. However, as hydroacoustic estimates of recruitment are available for the "south" stock from 1993 onwards only, there is little information estimate the south-east movement of recruits in November precisely prior to 1994. Alternatives which have previously been considered include setting the movement to zero prior to 1994 and setting the annual movement from 1984 to 1993 constant and equal to the average of the years from 1994 to 2011 (de Moor and Butterworth 2011)

The model estimated stock recruitment relationships are plotted in Figure 4. The "west" stock is estimated to be more productive than the "south" stock, with a maximum recruitment of 76 billion compared to 2 billion (Table 1). The model estimates 1+ biomass to be 277 thousand tons for the "west" stock and 913 thousand tons for the "south" stock in November 2011. This means that median recruitment to the "south" stock is currently at a maximum, while median recruitment to the "west" stock is currently only about half its maximum. Variability about these stock recruitment curves is estimated at the lower bound of the prior distribution (Table 1).

The model estimated survey selectivities-at-length, which are restricted to vary from 1 only for lengths contributing to the minus and plus length classes (see Appendix A of de Moor and Butterworth (2012) for details), are shown in Figure 5. The residuals from the model fits to the survey proportions-at-length are given in Figure 6. Figure 7 shows the average (over all years) model predicted November survey proportions-at-length. Considering the restriction of survey selectivity to be 1 for all length classes other than the minus and plus length classes, the comparison of the model predicted to observed averages is relatively good for the "west" stock. The model over-predicts the proportion-at-length in the plus group for the "south" stock, with the selectivity being as low as the prior will allow (0.9; Figure 5).

The model estimated commercial selectivities-at-length are shown in Figure 8, with a higher selectivity about the lower lengths for the "west" stock than the "south" stock. Some trends in the residuals from the model fit to the commercial proportion-at-length data are evident (Figure 9), but given the assumption of constant selectivity over time, these are considered to be acceptable. The average (over all years and quarters) model predicted commercial proportions-at-length matches the general pattern of that observed, although the peak about the higher lengths is under-predicted for both stocks (Figure 10).

A key factor in the model fits to the proportion-at-length data is the model estimated growth curves (Figure 11) and variability about this curve (Figure 12).

Summary

This document has given initial results for a two stock hypothesis for the South African sardine resource. A Hockey stick stock recruitment relationship is assumed. These results indicate the "west" stock resource abundance was around 277 million tons and the "south" stock resource abundance is 913 million tons in November 2011. This "west" stock abundance is well below its long-term average, while the "east" stock abundance is above its long-term average. Seven out of the last eight years have resulted in below average recruitment for the "west" stock, while the "south" stock has experienced above average recruitment since 2002.

The results presented in this document are for the current best fit for a proposed base case two stock hypothesis. However, according to the program used to run this assessment, ADMB, these results may not yet have fully converged (i.e. a positive definite Hessian has not been obtained). Without such a Hessian, the simulation of full posterior distributions for this hypothesis will be very difficult. It may be that the model is over-parameterised and some simplification or fixing "unimportant" parameters at their values near the mode may help. Work in this area is continuing.

If using this hypothesis is to be used in simulation testing OMP-13, future migration from the "west" to "south" stocks will need to be modelled. This would be relatively simple if a strong relationship between "west" or "south" stock 1+ biomass or recruitment was found. Initial results suggested this was not the case (de Moor and Butterworth, 2011), and Figure 13 for the updated analysis confirms this.

References

de Moor, C.L., and Butterworth, D.S. 2011. Assessment of the South African sardine resource using data from 1984-2010: results at the posterior mode for a two stock hypothesis. MARAM International Stock Assessment Workshop MARAM IWS/DEC11/P/OMP/P9. 26pp.

de Moor, C.L., and Butterworth, D.S. 2012. Assessment of the South African sardine resource using data from 1984-2011, with some results for a single stock hypothesis. DAFF: Branch Fisheries Document FISHERIES/2012/SEP/SWG-PEL/48. 36pp.

de Moor, C.L., Coetzee, J., Durholtz D.,Merkle, D., and van der Westhuizen, J.J., 2012. A final record of the generation of data used in the 2011 sardine and anchovy assessments. DAFF: Branch Fisheries Document FISHEREIS/2012/AUG/SWG-PEL/41. 29pp.

Table 1. Key model parameter values and model outputs estimated at the joint posterior mode. Values fixed on input are given in **bold**. Numbers are reported in billions and biomass in thousands of tonnes. $j=1$ denotes the "west" stock and $j=2$ denotes the "south" stock.

Parameter	S^2_{HS}	Parameter	S^2_{HS}
$-\ln(posterior)$	691.2	$a^S_{j=1}$	76.2
$-\ln L^{Nov}$	44.3	$a^S_{j=2}$	2.4
$-\ln L^{rec}$	68.0	$b^S_{j=1}$	523
$-\ln L^{coml\ propl}$	507.5	$b^S_{j=2}$	100
$-\ln L^{sur\ propl\ \min}$	5.5	$K^S_{j=1}$	2758
$-\ln L^{surl\ propl}$	51.5	$K^S_{j=2}$	100
$-\ln(priors)$	14.4	$\sigma^S_{j=1,r}$	0.40
$\overline{M}^S_j$	**1.0**	$\sigma^S_{j=2,r}$	0.40
$\overline{M}^S_{ad}$	**0.8**	$\overline{B}^S_{j=1,Nov}$ [1]	381
$k^S_{j=1,N}=k^S_{ac}$	0.75	$\overline{B}^S_{j=2,Nov}$	170
$k^S_{j=2,N}=k^S_{ac}$	0.75	$\eta^S_{j=1,2009}$	-0.19
k^S_{cov}	0.61	$\eta^S_{j=2,2009}$	-0.02
$k^S_{\mathrm{cov}\,E}$	0.76	$s^S_{j=1,cor}$	0.21
$k^S_{j=1,r}$	0.46	$s^S_{j=2,cor}$	-0.26
$k^S_{j=2,r}$	0.35	$L_{j=1,\infty}$	**19.5**
$k^S_{j=1,r}/k^S_{j=1,N}$	0.61	$L_{j=1,\infty}$	**20.6**
$k^S_{j=2,r}/k^S_{j=2,N}$	0.46	$\kappa_{j=1}$	1.08
$(\lambda^S_{j=1,N})^2$	**0.00**	$\kappa_{j=2}$	1.02
$(\lambda^S_{j=2,N})^2$	**0.00**	t_0	0.033.0
$(\lambda^S_{j=1,r})^2$	**0.00**	ϑ_0	2.6
$(\lambda^S_{j=2,r})^2$	**0.00**	ϑ_1	1.7
$N^S_{j=1,1983,0}$	5.73	ϑ_2	1.7
$N^S_{j=1,1983,1}$	2.68	ϑ_3	1.7
$N^S_{j=1,1983,2}$	<0.001	ϑ_4	1.7
$N^S_{j=2,1983,0}$	<0.001	ϑ_{5+}	1.7
$N^S_{j=2,1983,1}$	<0.001	*Finit*	0.99
$N^S_{j=2,1983,2}$	<0.001		

[1] This average it taken over 1991 to 1994. OMP-04 and OMP-08 were developed using Risk defined as "the probability that 1+ sardine biomass falls below the average 1+ sardine biomass between November 1991 and November 1994 at least once during the projection period of 20 years".

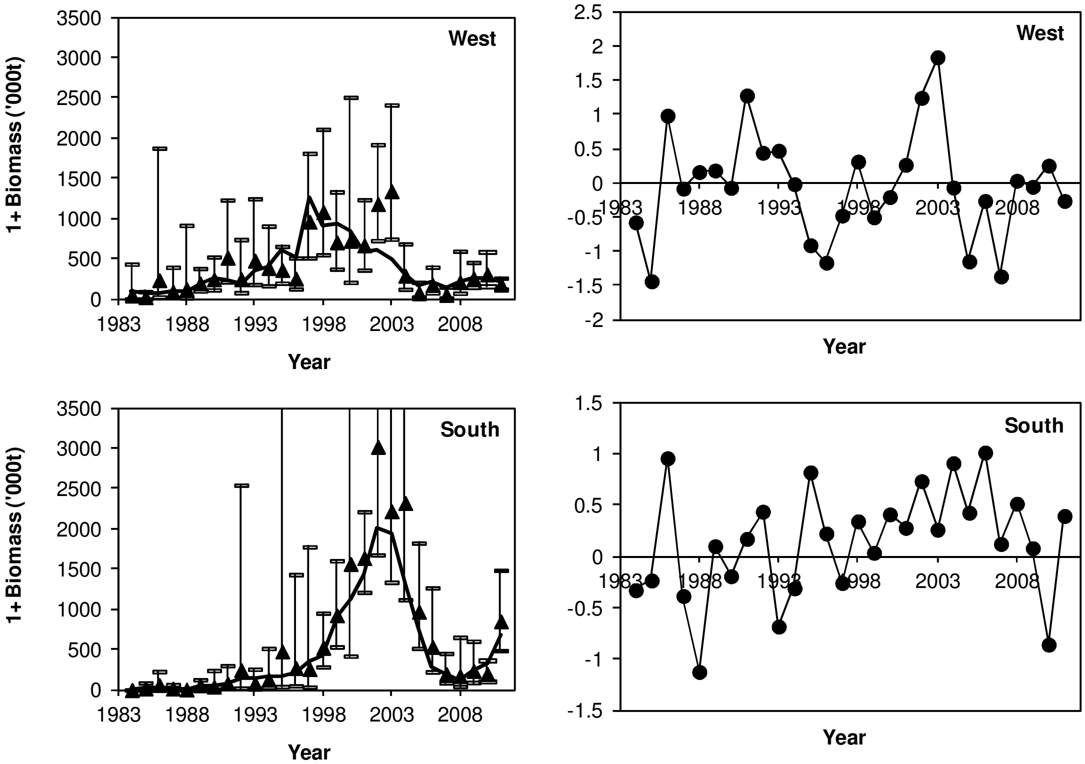

Figure 1. Acoustic survey estimated and model predicted November sardine 1+ biomass from 1984 to 2011 for S^2_{HS}. The observed indices are shown with 95% confidence intervals. The standardised residuals (i.e. the residual divided by the corresponding standard deviation, including additional variance where appropriate, as indicated in equation (A.26) of de Moor and Butterworth 2012) from the fits are given in the right hand plot.

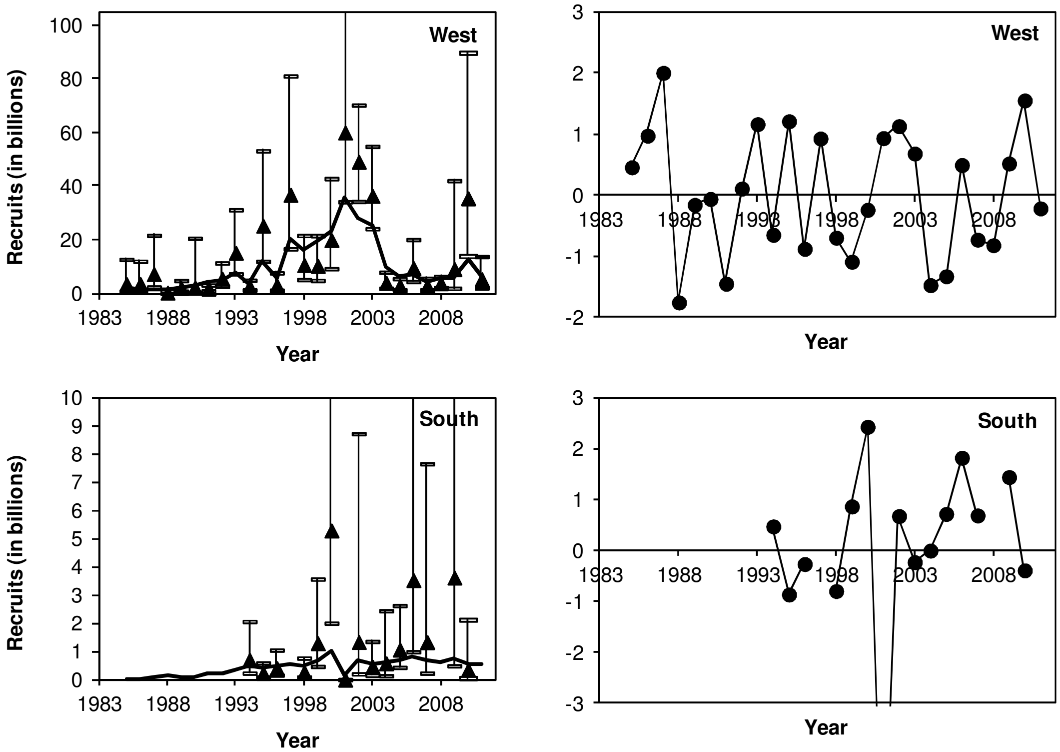

Figure 2. Acoustic survey estimated and model predicted sardine recruitment numbers from May 1985 to May 2011 for S^2_{HS}.The survey indices are shown with 95% confidence intervals. The standardised residuals from the fit are given in the right hand plot.

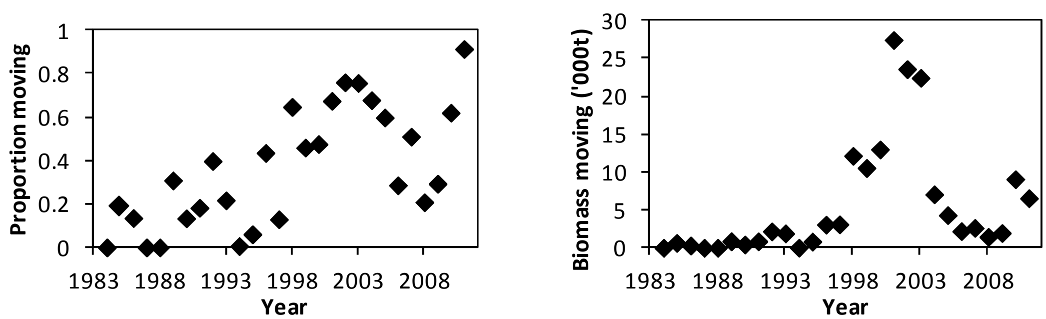

Figure 3. Model estimated proportion of recruits which move from the "west" stock to the "south" stock in November as they reach age 1 for S^2_{HS}. The right hand plots shows rough[2] estimates of the biomass of recruits which move.

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

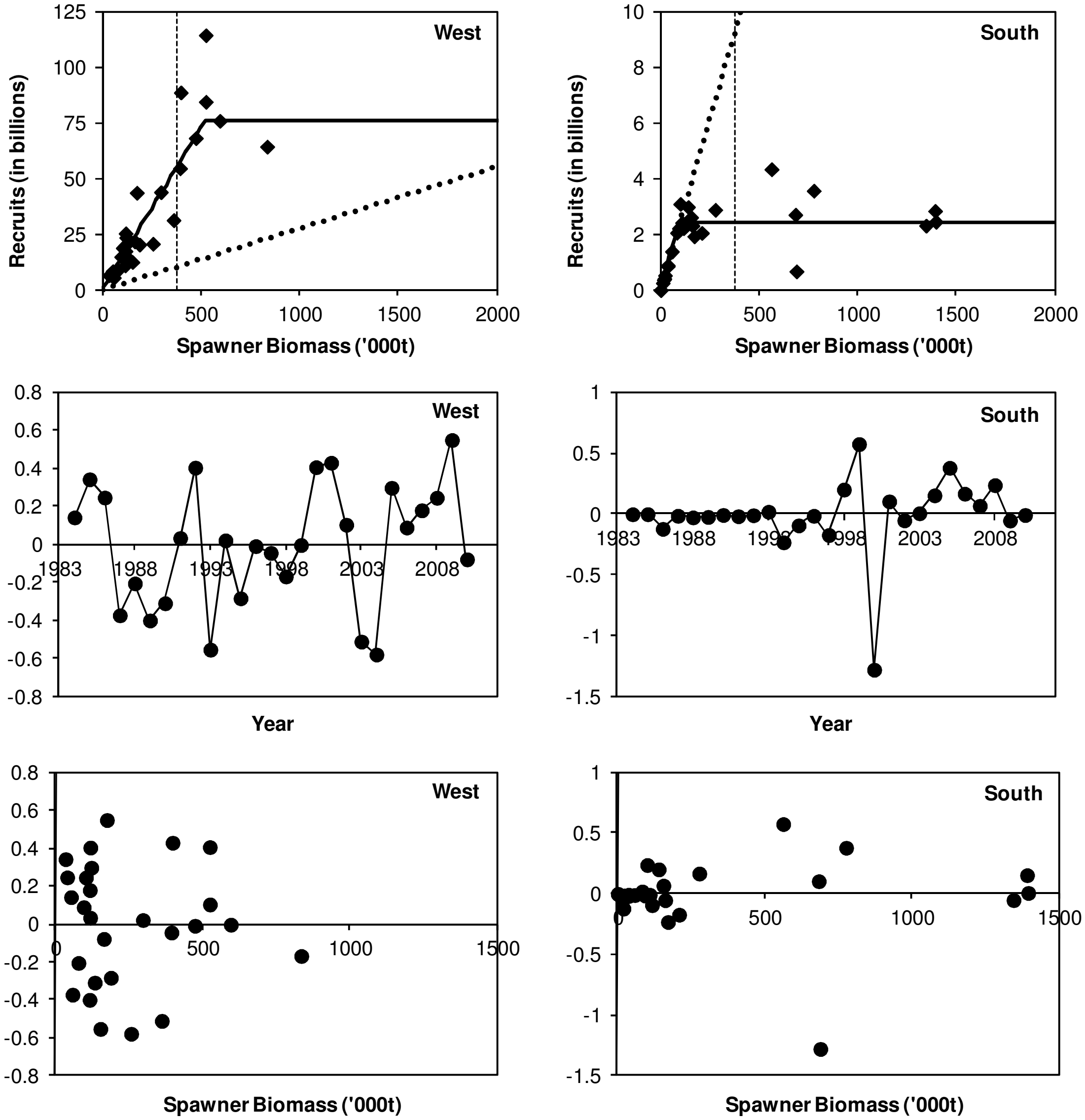

Figure 4. Model predicted anchovy recruitment (in November) plotted against spawner biomass from November 1984 to November 2010 for S_{HS} with the Hockey stick stock recruitment relationship. The vertical thin dashed line indicates the average 1991 to 1994 spawner biomass (used in the definition of risk in OMP-04 and OMP-08). The dotted line indicates the replacement line. The standardised residuals from the fit are given in the lower plots, against year and against spawner biomass.

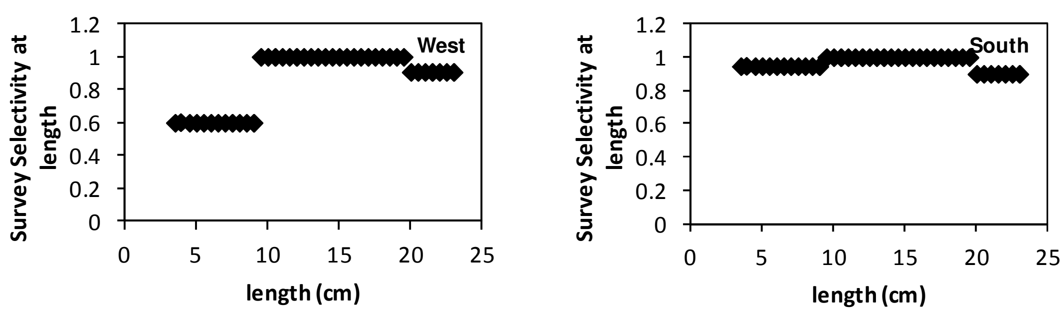

Figure 5. The model estimated November survey selectivity at length for S^2_{HS}.

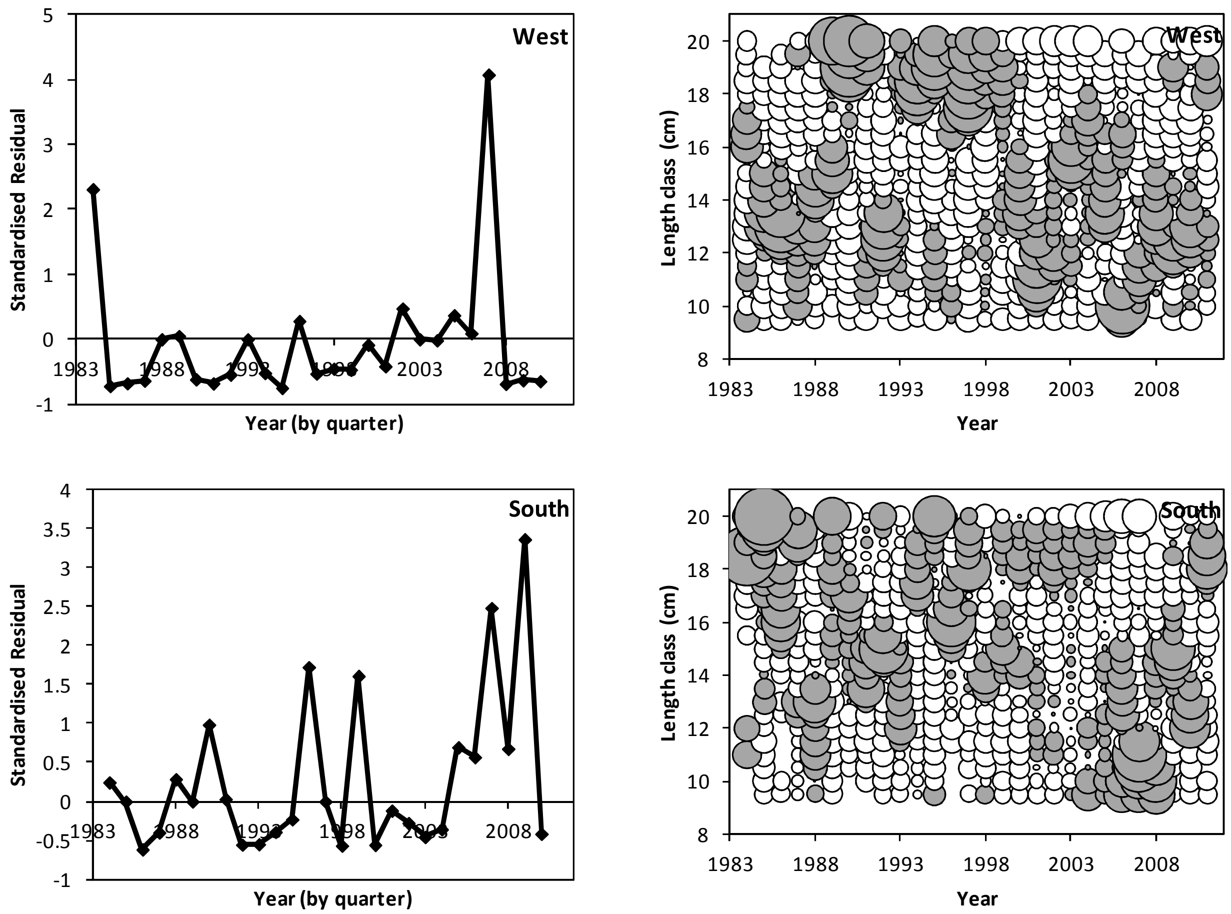

Figure 6. Residuals from the fit of the model predicted proportions-at-length in the November survey to the hydroacoustic survey estimated proportions for S^2_{HS}. The left panels show the residuals for the minus length class (9cm) and the right panels show the residuals for the remaining length classes.

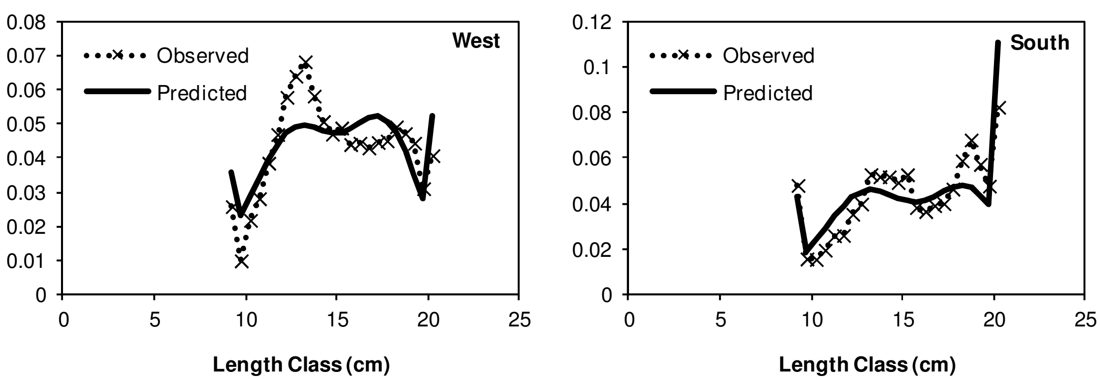

Figure 7. Average (over all years) model predicted and observed proportion-at-length in the November survey for S^2_{HS}..

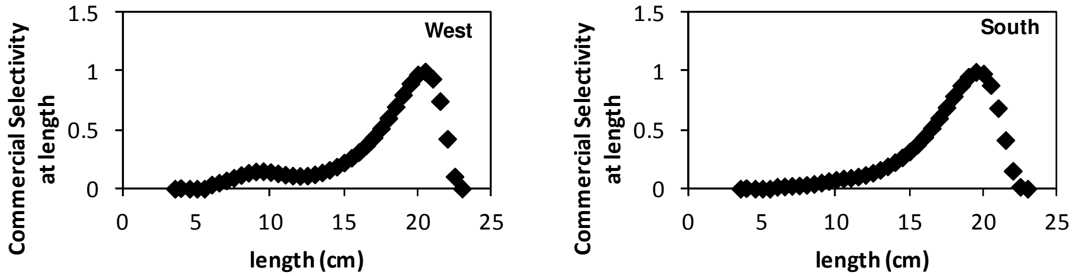

Figure 8. The model estimated commercial selectivity at age for S^2_{HS}.

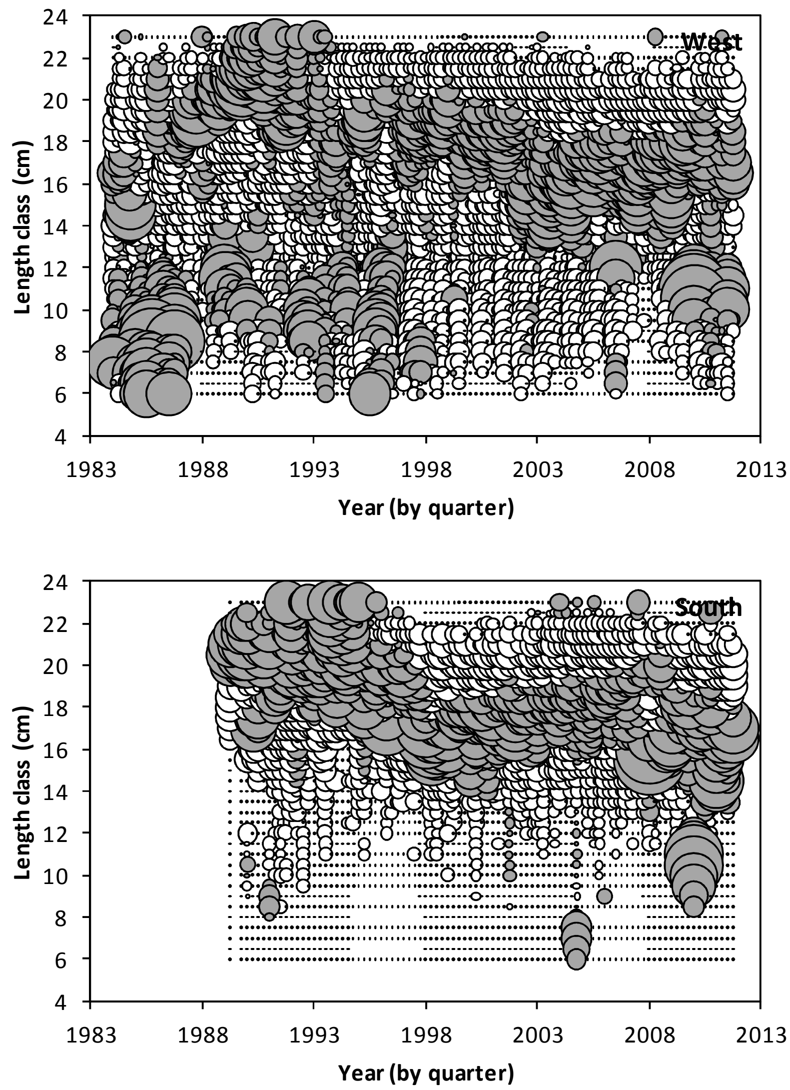

Figure 9. Residuals from the fit of the model predicted proportions-at-length in the commercial catch to the observed proportions for S^2_{HS}.

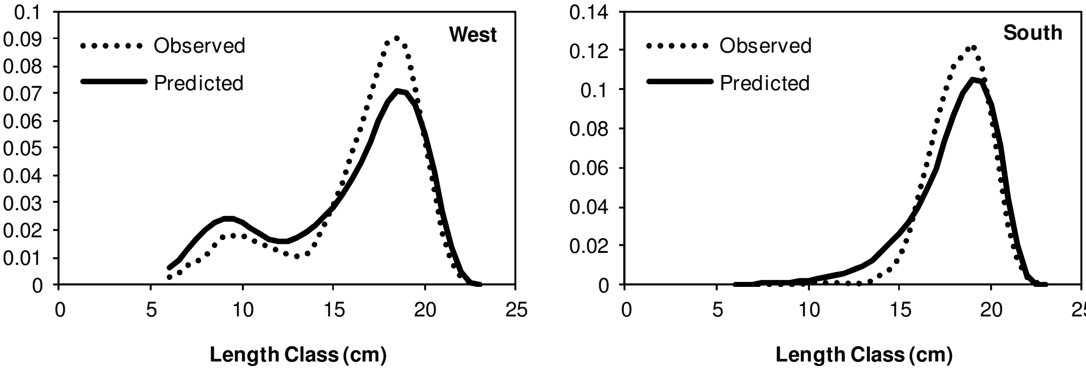

Figure 10. Average (over all quarters and years) model predicted and observed proportion-at-length in the commercial catch for S^2_{HS}.

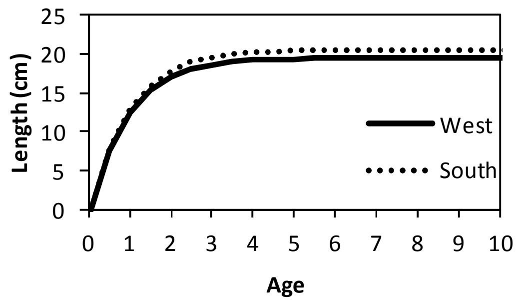

Figure 11. The von Bertalanffy growth curves estimated for S^2_{HS}.

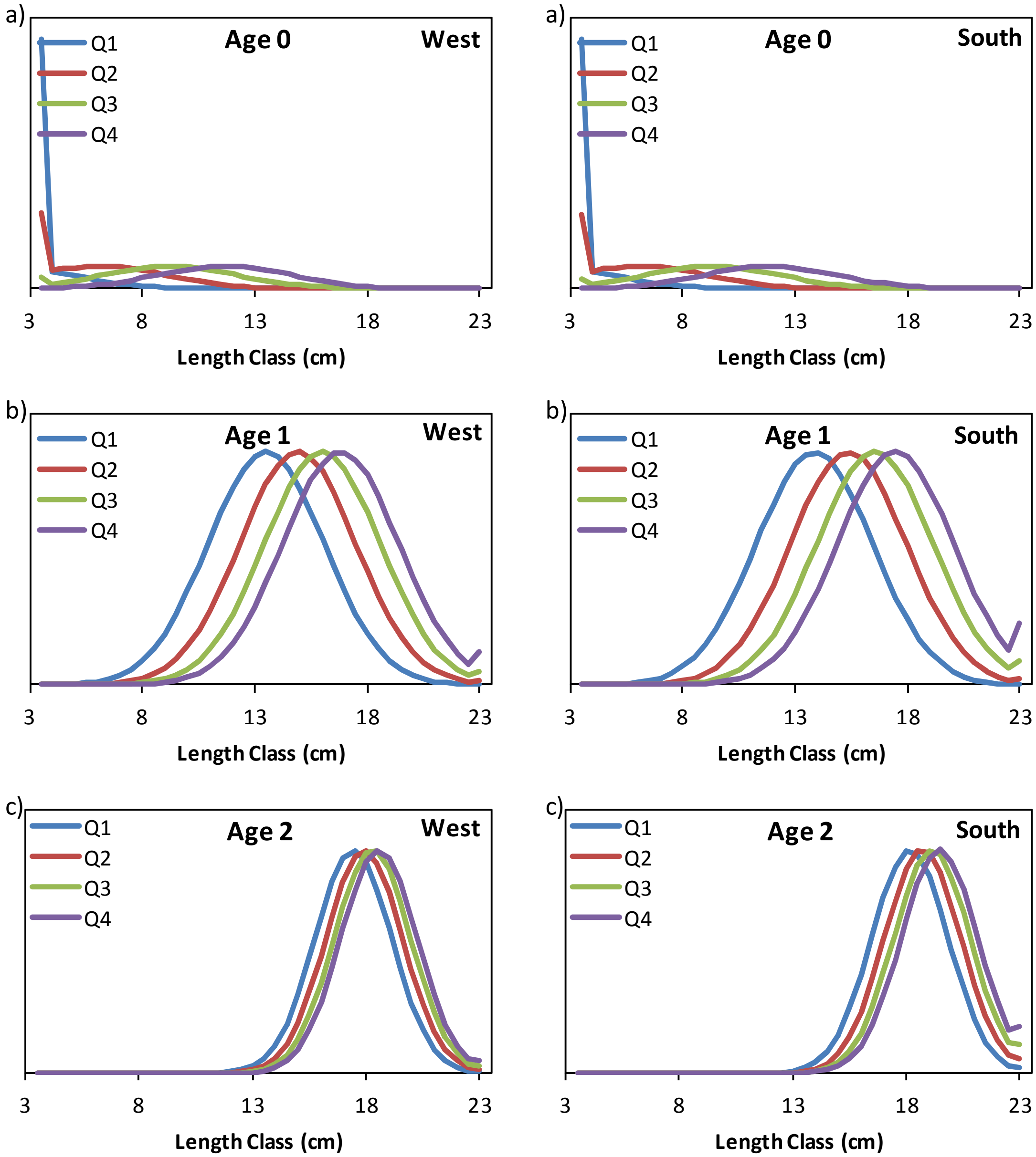

Figure 12. The model estimated distributions of proportions-at-length for each age, given at the middle of each quarter of the year (corresponding to the times commercial catch is modelled to be taken). The lowest plot compares the distributions for all ages at the middle of quarter 1.

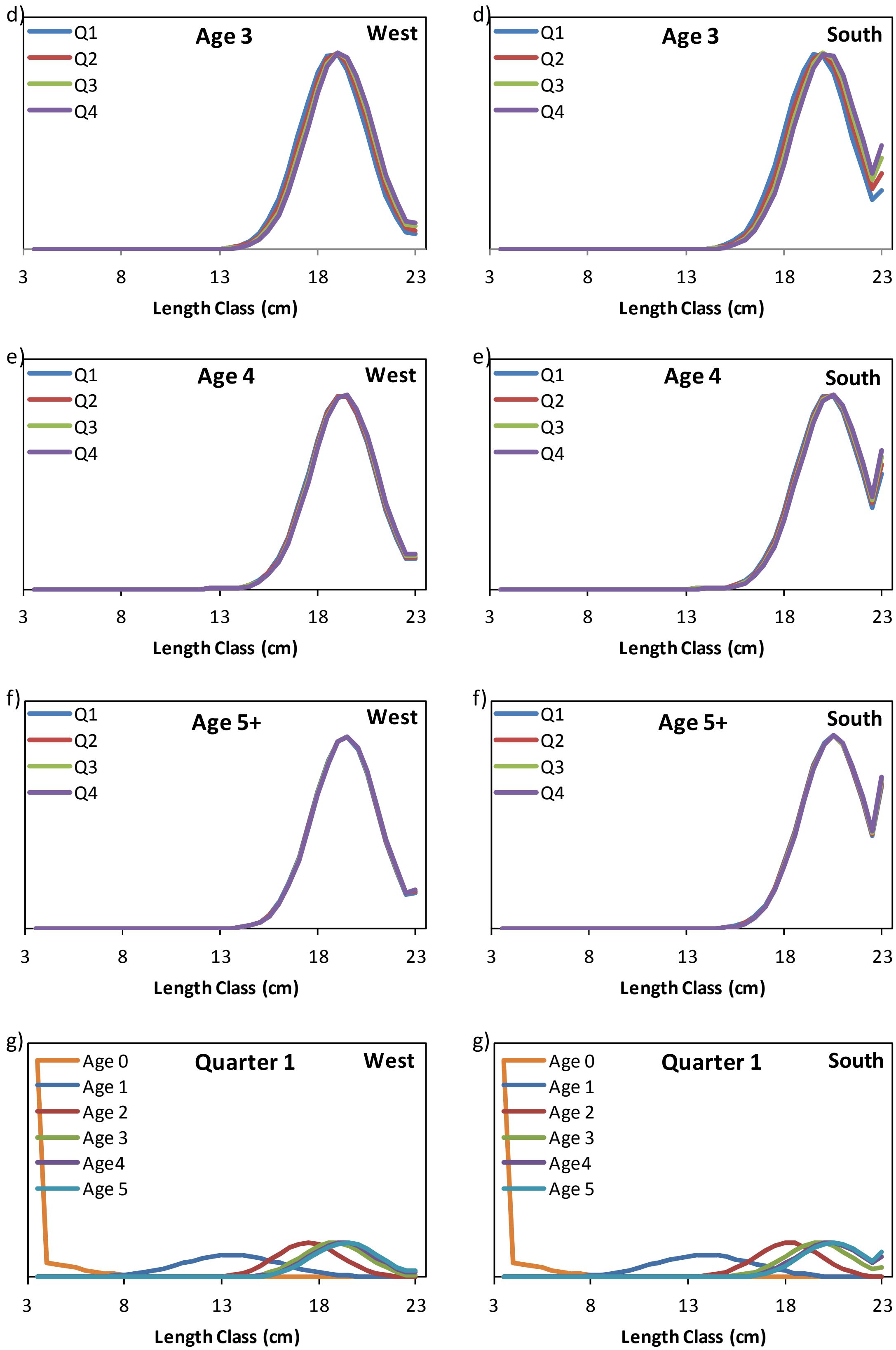

Figure 12 (continued).

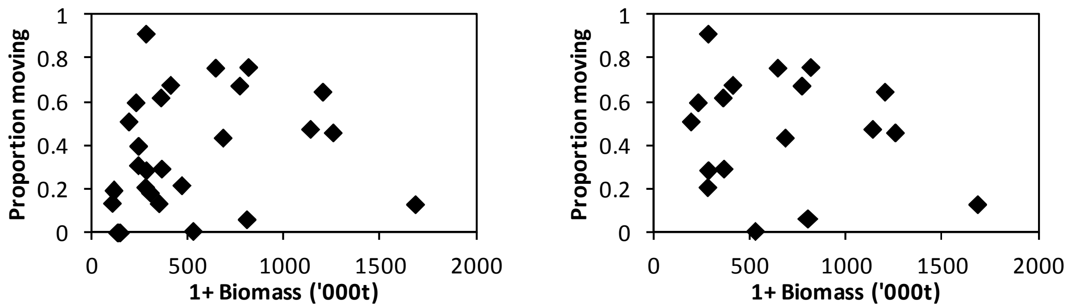

Figure 13. The model estimated proportion of recruits which move from the "west" stock to the "south" stock in November as they reach age 1 for S^2_{HS}, plotted against November 1+ biomass of the "west" stock of the same year. The plot on the right only includes proportions

Appendix: Glossary of parameters used in this document

Annual numbers and biomass:

$N^S_{j,y,a}$ - model predicted number (in billions) of sardine of age a at the beginning of November in year y of stock j

$B^S_{j,y}$ - model predicted biomass (in thousand tonnes) of adult sardine of stock j at the beginning of November in year y, associated with the November survey

$SSB^S_{j,y}$ - model predicted spawning stock biomass (in thousand tonnes) of stock j at the beginning of November in year y

$w^S_{j,y,a}$ - mean mass (in grams) of sardine of age a of stock j sampled during the November survey of year y

$w^{S1+}_{j,y}$ is the total (1+) mean mass (in grams) of sardine of stock j sampled during the November survey of year y

$\overline{\frac{w^S_{j,a}}{w^S_{j,1}}}$ is the average ratio of mean mass (in grams) of sardine of stock j aged a to age 1 obtained from the growth curve

$N^S_{j,y,r}$ - model predicted number (in billions) of juvenile sardine of stock j at the time of the recruit survey in year y

t^S_y - time lapsed (in months) between 1 May and the start of the recruit survey in year y

$move_y$ - proportion of west stock recruits which migrate to the east stock at the beginning of November of year y

Natural mortality:

$M^S_{a,y}$ - rate of natural mortality (in year^{-1}) of sardine of age a in year y

$\overline{M}^S_{ju}$ - median juvenile rate of natural mortality (in year^{-1})

$\overline{M}^S_{ad}$ - median adult rate of natural mortality (in year^{-1})

ε^{ad}_y - annual residuals about adult natural mortality

η^{ad}_y - normally distributed error used in calculating ε^{ad}_y

σ_{ad} - standard deviation in the annual residuals about adult natural mortality

σ_j - standard deviation in the annual residuals about juvenile natural mortality

p - annual autocorrelation coefficient in annual residuals about adult natural mortality

Commercial selectivity

$S_{j,y,l}$ - commercial selectivity at length l during year y of stock j

χ_j - denotes the height of the near-normal curve for stock j

l_{mid} - the midpoint (in cm) of length class l

$l_{\max} = 23.5cm$ - one length class above the maximum

$\bar{l}_{1,j}$ - the mean of the near-normal distribution for stock j

$\bar{l}_{2,j}$ - the median of the near-lognormal distribution for stock j

$\left(\sigma_{1,j}^{sel}\right)^2$ - the variance parameter of the near-normal distribution for stock j

$\left(\sigma_{2,j}^{sel}\right)^2$ - the variance parameter of the near-lognormal distribution for stock j

$S_{j,y,q,a}$ - commercial selectivity at age a during quarter q of year y of stock j

Catch:

$C_{j,y,a,q}^{S}$ - model predicted umber (in billions) of sardine of age a of stock j caught during quarter q of year y

$C_{j,y,m,l}^{RLF}$ - number of fish in length class l landed in month m of year y of stock j (the 'raised length frequency')

$lcut_{y,m}$ - cut off length for recruits in month m of year y

$C_{j,y,q,a}^{bycatch}$ - the number of fish of age $a \geq 1$ from the anchovy-directed fishery in quarter q of year y

$F_{j,y,q}$ - fished proportion in quarter q of year y for a fully selected age class a of stock j, by the directed and redeye bycatch fisheries

$\widetilde{C}_{j,y,0bs}^{S}$ - number (in billions) of juvenile sardine of stock j caught between 1 May and the day before the start of the recruit survey

Proportions at age:

$p_{j,y,a}^{S}$ - model predicted proportion-at-age a of stock j in the November survey of year y

$S_{j,a}^{survey}$ - survey selectivity at age a in the November survey for stock j

$p_{j,y,q,a}^{com,S}$ - model predicted proportion-at-age a of stock j in the directed and redeye bycatch commercial catch of quarter q of year y

Recruitment:

h_j^S - "steepness" of the stock-recruitment relationship for stock j

K_j^S - carrying capacity for stock j

K_{peak}^S - carrying capacity during peak years (only for single stock hypothesis)

a_j^S - maximum recruitment of stock j in the hockey stick model;

b_j^S - spawner biomass for stock j below which the expectation for recruitment is reduced below the maximum

c^S - constant recruitment (distribution median) during the "peak" years of 2000 to 2004 (only for single stock hypothesis)

$\varepsilon_{j,y}^S$ - annual lognormal deviation of sardine recruitment.

$\sigma_{j,r}^S$ - standard deviation in the residuals (lognormal deviation) about the stock recruitment curve of stock j

$\sigma_{r,peak}^S$ - standard deviation in the residuals (lognormal deviation) about the stock recruitment curve during peak years in the single stock hypothesis

Proportions at length and growth curve:

$p_{j,y,l}^S$ - model predicted proportion-at-length l of stock j associated with the November survey in year y

$A_{j,a,l}^{sur}$ - proportion of sardine of age a of stock j that fall in the length group l in November

$p_{j,y,q,l}^{coml,S}$ - model predicted proportion-at-length l of stock j in the directed and redeye bycatch commercial catch of quarter q of year y

$A_{j,q,a,l}^{com}$ - proportion of sardine of age a of stock j that fall in the length group l in quarter q

$L_{j,\infty}$ - maximum length of sardine of stock j

κ_j - annual growth rate of sardine of stock j

$t_{0,j}$ - age at which the length of sardine of stock j is zero

$\vartheta_{j,a}$ - standard deviation about the mean length for age a of sardine of stock j

Likelihoods:

$-\ln L^{Nov}$ - contribution to the negative log likelihood from the model fit to the November 1+ biomass data

$-\ln L^{rec}$ - contribution to the negative log likelihood from the model fit to the May recruit data

$-\ln L^{sur\ propl\ \min}$ - contribution to the negative log likelihood from the model fit to the November survey proportion-at-length data for the minus length class only

$-\ln L^{sur\ propl}$ - contribution to the negative log likelihood from the model fit to the November survey proportion-at-length data for the minus length class only

$-\ln L^{com\ propl}$ - contribution to the negative log likelihood from the model fit to the quarterly commercial proportion-at-length data for the remaining length classes

$\hat{B}_{j,y}^S$ - acoustic survey estimate (in thousands of tonnes) of adult sardine biomass of stock j from the November survey in year y

$\sigma_{j,y,Nov}^S$ - survey sampling CV associated with $\hat{B}_{j,y}^S$ that reflects survey inter-transect variance

$k_{j,N}^S$ - constant of proportionality (multiplicative bias) associated with the November survey of stock j

k_{ac}^{S} - multiplicative bias associated with the acoustic survey

$\hat{N}_{j,y,r}^{S}$ - acoustic survey estimate (in billions) of sardine recruitment numbers of stock j from the recruit survey in year y

$\sigma_{j,y,rec}^{S}$ - survey sampling CV associated with $\hat{N}_{j,y,r}^{S}$ that reflects survey inter-transect variance

$k_{j,r}^{S}$ - constant of proportionality (multiplicative bias) associated with the recruit survey of stock j

k_{cov}^{S} - multiplicative bias associated with the coverage of the recruits by the recruit survey in comparison to the 1+ biomass by the November survey

$k_{\text{cov}\,E}^{S}$ - multiplicative bias associated with the coverage of the east stock recruits by the recruit survey in comparison to the west stock recruits during the same survey

ϕ_{ac}^{S} - the CV associated with factors which cause bias in the acoustic survey estimates and which vary inter-annually;

$(\lambda_{j,N/r}^{S})^2$ - additional variance (over and above $\sigma_{y,Nov/rec}^{S}$ and ϕ_{ac}^{S}) associated with the November/recruit surveys of stock j;

$\hat{p}_{j,y,l}^{S}$ - observed proportion (by number) of sardine from stock j in length group l in the November survey of year y;

$w_{propl\,\min}^{sur}$ - weighting applied to the survey proportion at length data for the minus length class;

w_{propl}^{sur} - weighting applied to the remaining survey proportion at length data;

$\sigma_{j}^{S,surl\,\min}$ - variance-related parameter for the log-transformed survey proportion-at-length data for the minus length class;

$\sigma_{j}^{S,surl}$ - variance-related parameter for the log-transformed survey proportion-at-length data;

$\hat{p}_{j,y,q,l}^{S,coml}$ - observed proportion (by number) of the directed and redeye bycatch commercial catch in length group l of during quarter q of year y;

w_{propl}^{com} - weighting applied to the commercial proportion at length data

$\sigma_{j}^{S,coml}$ - variance-related parameter for the log-transformed commercial proportion-at-length data

<u>Other:</u>

F_{init} - rate of fishing mortality assumed in the initial year

$s_{j,cor}^{S}$ - recruitment serial correlation for stock j

$\eta_{j,2009}^{S}$ - standardised recruitment residual value for 2009 for stock j

$\overline{w}^{S}_{j,a}$ - mean mass (in grams) of sardine of age a from stock j sampled during each November survey, averaged over all years

$w^{catch}_{j,y,a}$ - mean mass (in grams) in the catch of sardine of age a from stock j in year y (from de Moor *et al*. 2012a).