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

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Introduction

As part of the process of updating the assessment of the South African sardine resource, a model of the sardine two mixing-stock hypothesis is being developed. 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. de Moor and Butterworth (2012a) presented some initial results for a two mixing-stock model, but cautioned that those results may not yet have fully converged and that the lack of a Hessian prevented MCMC simulation to estimate posterior distributions for key model parameters.

Work has continued on this model to try to ascertain in which areas the model may be over-parameterised and which "unimportant" parameters can be fixed at their estimated values without influencing results. In this document further results for the model of a two sardine mixing-stock hypothesis are presented. The current fit is improved from that of de Moor and Butterworth (2012a) and a Hessian is estimated by ADMB. The main changes to the model are detailed below. Some ideas for further work are also listed.

Population Dynamics Model

The operating model for the South African sardine resource is detailed in Appendix A of de Moor and Butterworth (2012b) and the data used in this assessment are listed in de Moor *et al*. (2012). The particular difference when fitting the two-stock model to the data compared to the single-stock model of de Moor and Butterworth (2012b) 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 (2012b) in the Appendix of this document for ease of reference.

Key differences in the model used to calculate the results presented in this document compared to those of de Moor and Butterworth (2012a) are as follows:

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i) No stock-recruitment curve is estimated for the west stock within the model, and thus variation about this curve is also not estimated. Annual November recruitment is estimated with a U(0,100 billion) prior distribution.

ii) The slope of the south stock stock-recruitment curve is fixed by fixing the b_2^S / K_2^S ratio at 0.2. (The intention is to add an alternative with $b_2^S / K_2^S = 0.4$ to the list of robustness tests.)

iii) The additional variance parameters, $(\lambda_{j,N/r}^S)^2$, are fixed = 0. (This has little impact on the results.)

iv) Annual movement is estimated from 1994 to 2011 only and set equal to zero in earlier years.

v) Initial numbers at ages 0, 1 and 2 are fixed at formerly estimated values. (The fishing mortality parameter to calculate initial numbers at ages 3, 4 and 5+ is estimated.)

vi) The two variance parameters in the commercial selectivity-at-length function are set the same for both stocks

vii) The age at which the length of sardine of is zero, $t_{0,j}$, is set the same for both stocks and the product of the maximum length and annual growth rate of the stocks, $\kappa_j L_{j,\infty}$, are the same for both stocks.

viii) To assist with testing, the annual November stock weight-at-age has been fixed at most recent estimates, rather than estimated using equation (A.6) of de Moor and Butterworth (2012b).

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 for the south stock are assumed in line with choices for the current base case single stock hypotheses. Alternative natural mortality and stock-recruitment relationships will be tested at a later stage for both hypotheses. As for the single stock hypothesis, natural mortality is assumed to be time-invariant for the base case hypothesis.

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. These model fits to the time series of recruitment are an improvement from those presented by de Moor and Butterworth (2012a), with a slightly worse fit to the time series of 1+ biomass. 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 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 (0.78 compared to 0.72), while the coverage of the May recruit survey in comparison to that of the November survey is estimated to be 76% (compared to 54% estimated for the single stock hypothesis).

The coverage of the recruits to the "south" stock relative to that for the "west" stock is estimated to be just 26%, a large decrease from the 76% estimated by de Moor and Butterworth (2012a). The bias associated with the May survey estimate of recruitment is thus 0.60 for the "west" stock and 0.16 for the "south" stock, compared to 0.39 estimated for the single stock hypothesis.

More than 50% of the "west" stock recruits are modelled to move to the "south" stock in 8 out of 18 years, with the greatest movement between stocks in biomass terms occurring from the late 1990's to the early 2000s, and then again at the end of the time series (Figure 3), the former 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 only for years from which hydroacoustic estimates of recruitment are first available for the "south" stock, as there is little information to estimate the south-east movement of recruits in November precisely prior to 1994.

The model estimated November recruitment is plotted in Figure 4 against Spawning Stock Biomass. The estimated stock recruitment relationship for the "south" stock is also shown. Although a stock recruitment relationship has not been directly estimated by the model for the "west" stock, it is clear that this stock is estimated to be far more productive than the "south" stock, which has a maximum median recruitment of 5.4 billion recruits at the joint posterior mode (Table 1). Variability about the "south" stock recruitment curves is estimated at the lower bound of the prior distribution (Table 1). Most notably, the three highest years of survey estimated recruitment to the "south" stock are substantially under-predicted by this lognormal likelihood model (Figure 2).

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, though the model over-predicts the proportion-at-length in the minus group for the "west" stock, with the selectivity being as low as the prior will allow (0.6; 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 and Further Work

This document has given further results for a two stock hypothesis for the South African sardine resource. A Hockey Stick stock recruitment relationship is assumed for the "south" stock only, while the "west" stock recruitment was estimated independently each year. These results indicate the "west" stock resource abundance was around 298 thousand tons and the "south" stock resource abundance is 1 million tons in November 2011. This "west" stock abundance is well below its long-term average, while the "south" stock abundance is above its long-term average. Seven out of the last eight years have resulted in below average May recruitment for the "west" stock, while the "south" stock has experienced above average recruitment in all years except two since 1994.

Although the current results do not indicate a simple stock recruitment relationship for the "west" stock, it is clear that the "west" stock is substantially more productive than the "south" stock, and the model indicates that movement of recruits from the "west" to the "south" stock has a greater impact on the "south" stock biomass than does good "south" stock recruitment.

The results presented in this document are for the current best fit for a proposed base case two stock hypothesis. Although ADMB diagnostics indicate this model to have satisfactorily converged at the joint posterior mode (thus allowing MCMC to be run), some further work on the model is desired before finalising a base case assessment. The proposed priority of such further work is as follows:

a) Improvement in the fit to commercial selectivity-at-length for the "south" stock (possibly through estimation of further separate "west"/"south" stock parameters).
b) Testing the impact of estimating all growth parameters separately for both stocks.
c) A stock-recruitment curve for the "west" stock is required for future projection and OMP-13 simulation testing. Initially this will be explored separately to this assessment. If possible, a stock-recruitment curve for the "west" stock will be estimated within the model once again.
d) If 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. Figure 13 shows no indication for a strong relationship, but ideas on how to model future movement are being explored.

e) Alternative fixed values for initial numbers at ages 0, 1 and 2, or estimation of these parameters.
f) Further alternatives / estimation of the slope of the "south" stock stock-recruitment curve, b_2^S / K_2^S.
g) To assist with testing, the annual November stock weight-at-age has been fixed at most recent estimates. This needs to be re-estimated following equation (A.6) of de Moor and Butterworth (2012b) for a final base case assessment.

References

de Moor, C.L., and Butterworth, D.S. 2012a. Assessment of the South African sardine resource using data from 1984-2011: initial results for a two stock hypothesis. DAFF: Branch Fisheries Document FISHERIES/2012/SEP/SWG-PEL/49. 19pp.

de Moor, C.L., and Butterworth, D.S. 2012b. 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}
$-\ln(posterior)$	678.5	$a^S_{j=2}$	5.4
$-\ln L^{Nov}$	50.6	$b^S_{j=2}$	43
$-\ln L^{rec}$	59.0	$K^S_{j=2}$	216
$-\ln L^{coml\ propl}$	506.6	$\sigma^S_{j=2,r}$	0.40
$-\ln L^{sur\ propl\ \min}$	5.4	$\overline{B}^S_{j=1,Nov}$ [1]	427
$-\ln L^{surl\ propl}$	49.2	$\overline{B}^S_{j=2,Nov}$	158
$-\ln(priors)$	7.7	$\eta^S_{j=2,2009}$	-0.05
$\overline{M}^S_j$	**1.0**	$s^S_{j=2,cor}$	-0.19
$\overline{M}^S_{ad}$	**0.8**	$L_{j=1,\infty}$	19.0
$k^S_{j=1,N}=k^S_{ac}$	0.79	$L_{j=2,\infty}$	19.6
$k^S_{j=2,N}=k^S_{ac}$	0.79	$\kappa_{j=1}$	1.20
k^S_{cov}	0.76	$\kappa_{j=2}$	1.17
$k^S_{\mathrm{cov}\,E}$	0.26	t_0	0.12
$k^S_{j=1,r}$	0.60	ϑ_0	3.0
$k^S_{j=2,r}$	0.16	ϑ_1	2.5
$k^S_{j=1,r}/k^S_{j=1,N}$	0.76	ϑ_2	1.8
$k^S_{j=2,r}/k^S_{j=2,N}$	0.20	ϑ_3	1.8
$(\lambda^S_{j=1,N})^2$	**0.00**	ϑ_4	1.8
$(\lambda^S_{j=2,N})^2$	**0.00**	ϑ_{5+}	1.8
$(\lambda^S_{j=1,r})^2$	**0.00**	*Finit*	<0.001
$(\lambda^S_{j=2,r})^2$	**0.00**		
$N^S_{j=1,1983,0}$	**5.00**		
$N^S_{j=1,1983,1}$	**2.60**		
$N^S_{j=1,1983,2}$	**<0.001**		
$N^S_{j=2,1983,0}$	**0.001**		
$N^S_{j=2,1983,1}$	**0.022**		
$N^S_{j=2,1983,2}$	**0.012**		

[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".

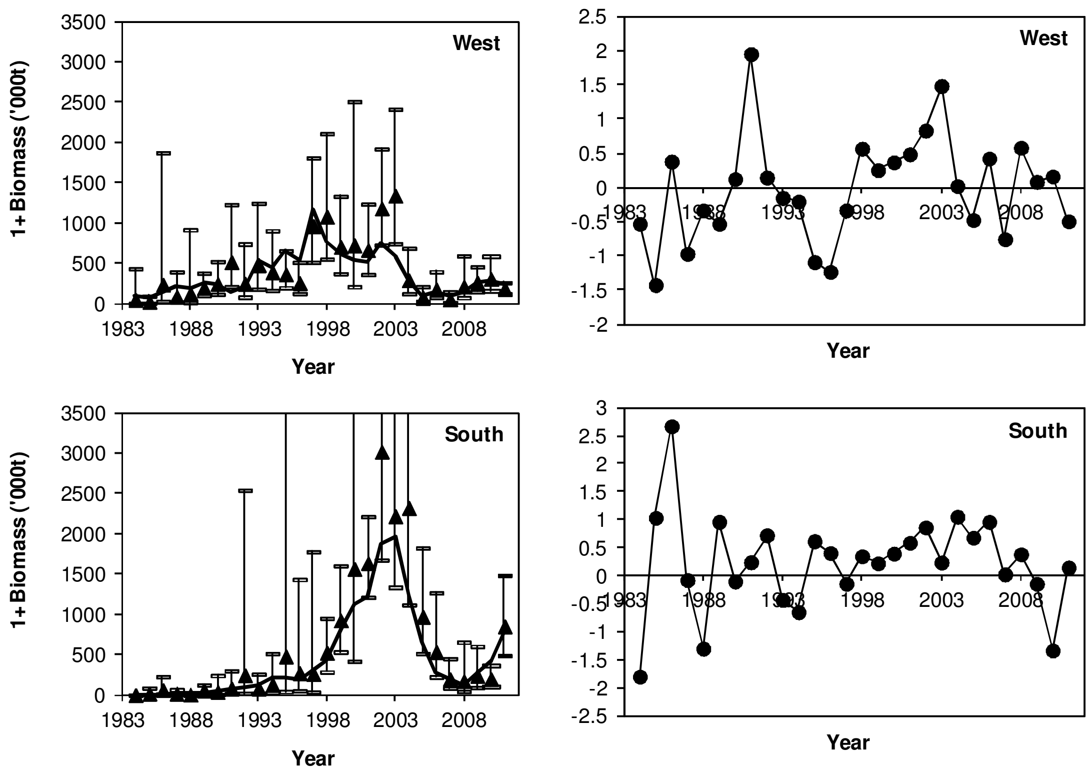

Figure 1. Acoustic survey estimated and model predicted November sardine 1+ biomass from 1984 to 2011. The observed indices are shown with 95% confidence intervals. The standardised residuals (i.e. the residual divided by the corresponding standard deviation, including additional variance where appropriate,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

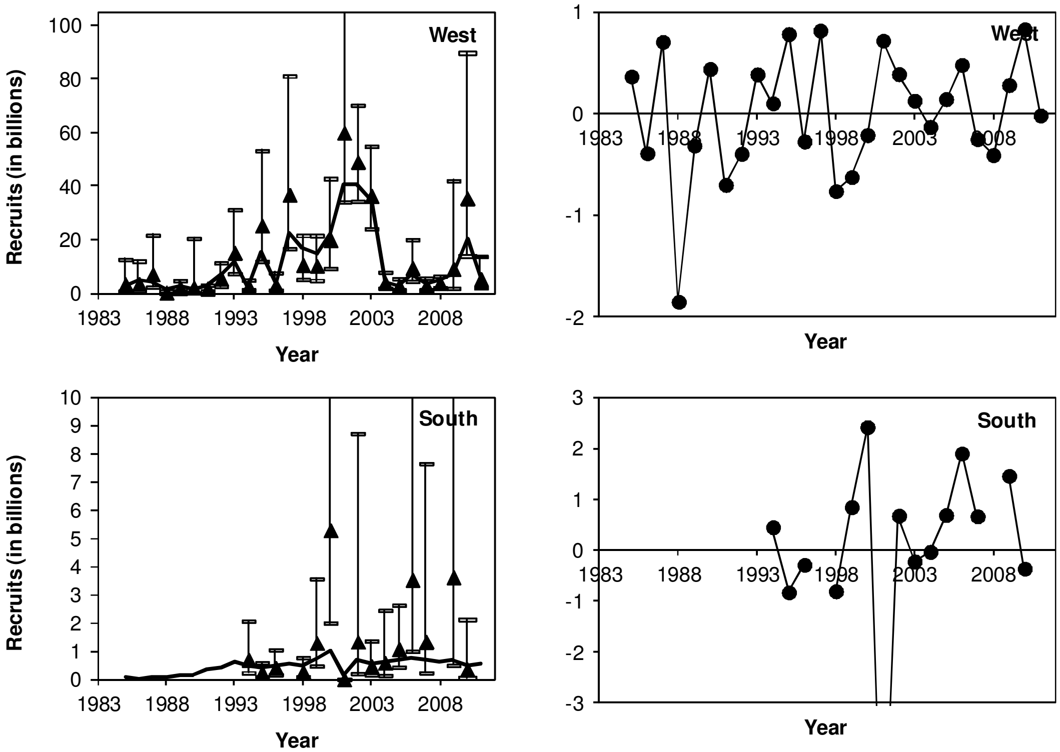

Figure 2. Acoustic survey estimated and model predicted sardine recruitment numbers from May 1985 to May 2011.The survey indices are shown with 95% confidence intervals. The standardised residuals from the fit are given in the right hand plot.

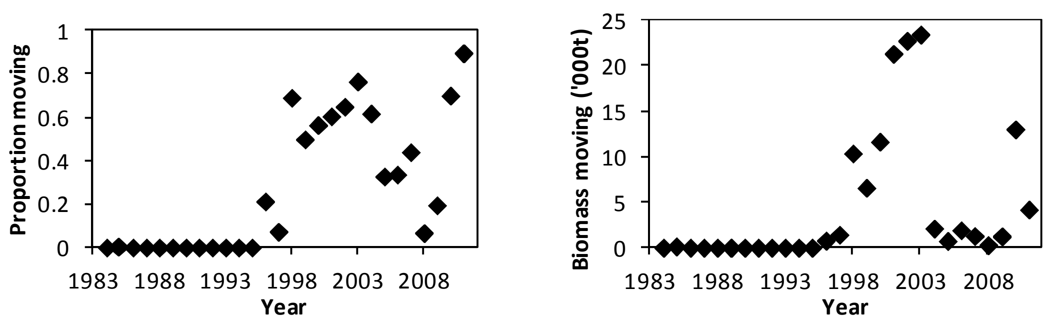

Figure 3. Model estimated proportion of recruits which move from the “west” stock to the “south” stock in November as they reach age 1. The right hand plots shows rough[2] estimates of the biomass of recruits which move.

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

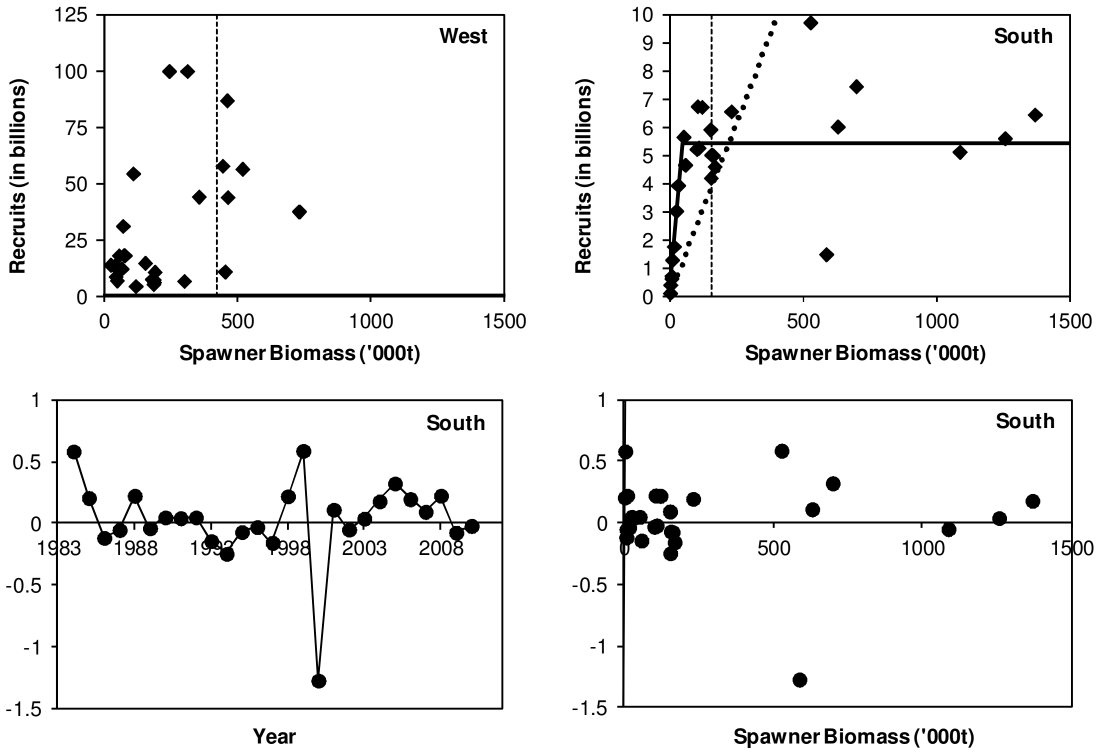

Figure 4. Model predicted sardine recruitment (in November) plotted against spawner biomass from November 1984 to November 2010 with the Hockey stick stock recruitment relationship estimated for the "south" stock. The vertical thin dashed line indicates the average 1991 to 1994 1+ biomass (used in the definition of risk in OMP-04 and OMP-08 for a single sardine stock). 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.

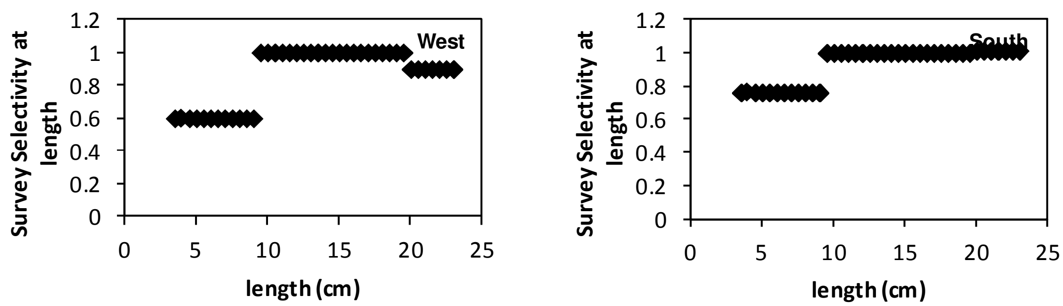

Figure 5. The model estimated November survey selectivity at length.

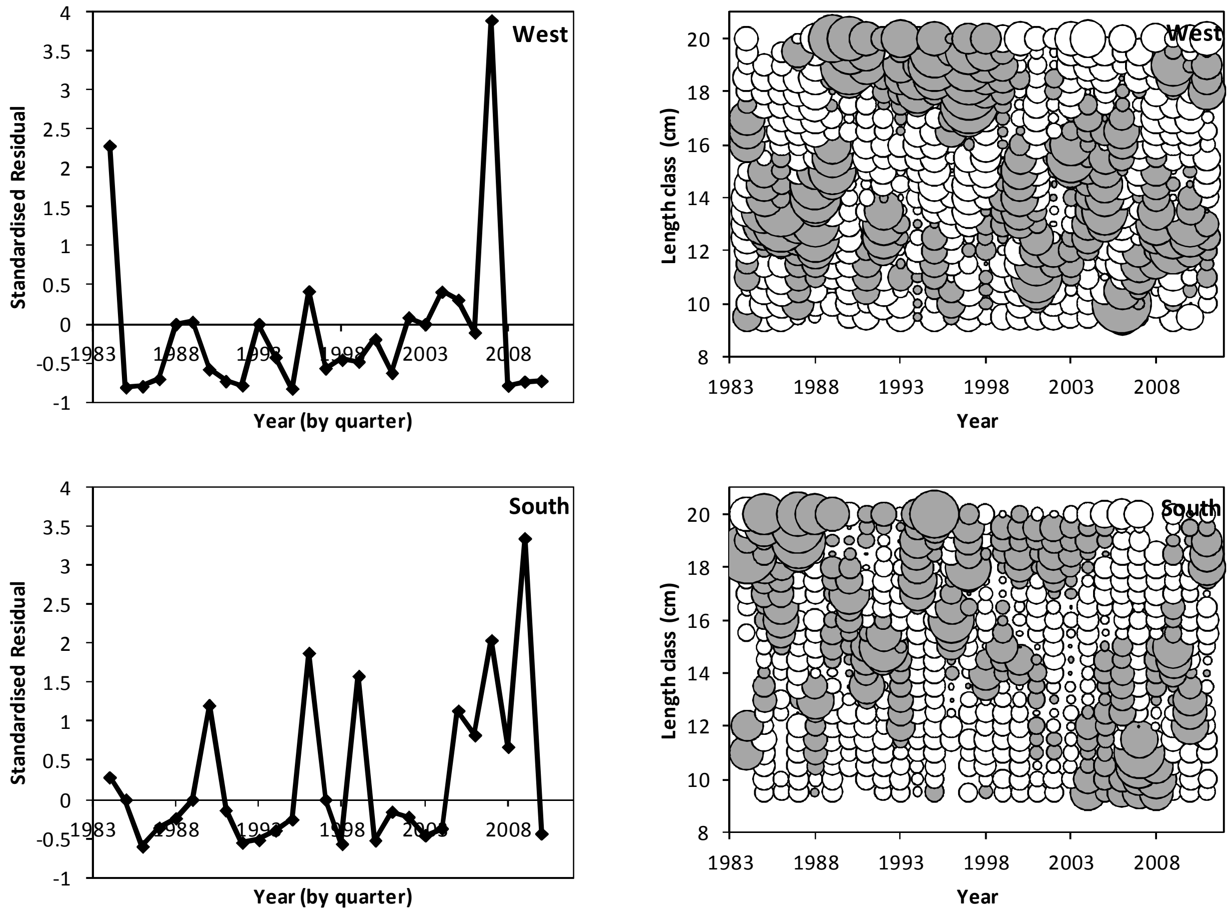

Figure 6. Residuals from the fit of the model predicted proportions-at-length in the November survey to the hydroacoustic survey estimated proportions. The left panels show the residuals for the minus length class (9cm) and the right panels show the residuals for the remaining length classes.

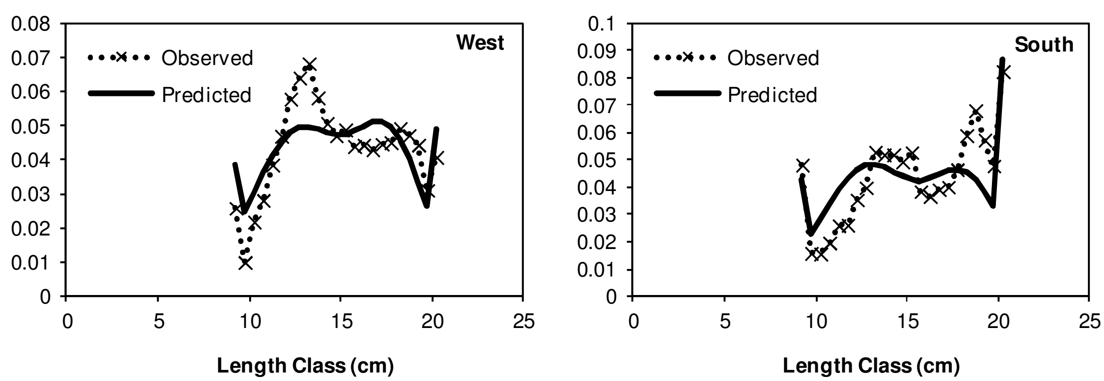

Figure 7. Average (over all years) model predicted and observed proportion-at-length in the November survey.

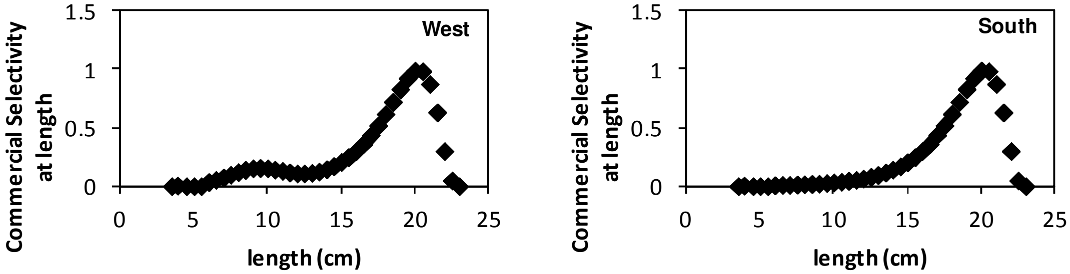

Figure 8. The model estimated commercial selectivity at age.

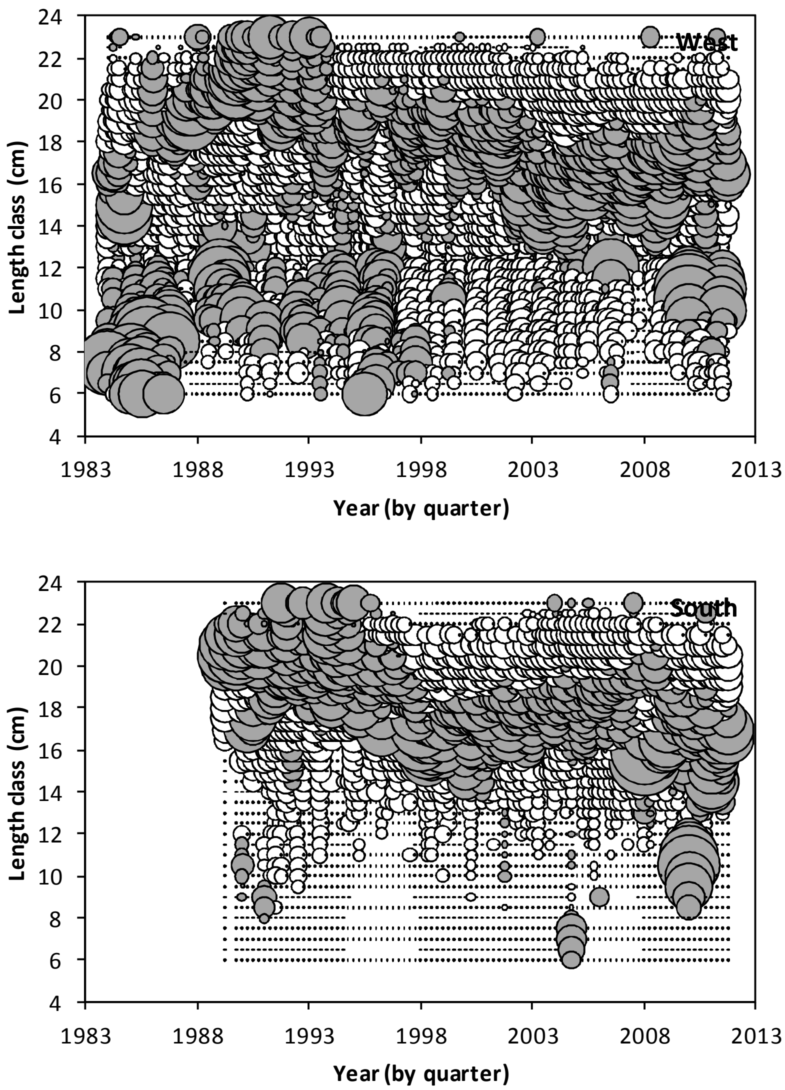

Figure 9. Residuals from the fit of the model predicted proportions-at-length in the commercial catch to the observed proportions.

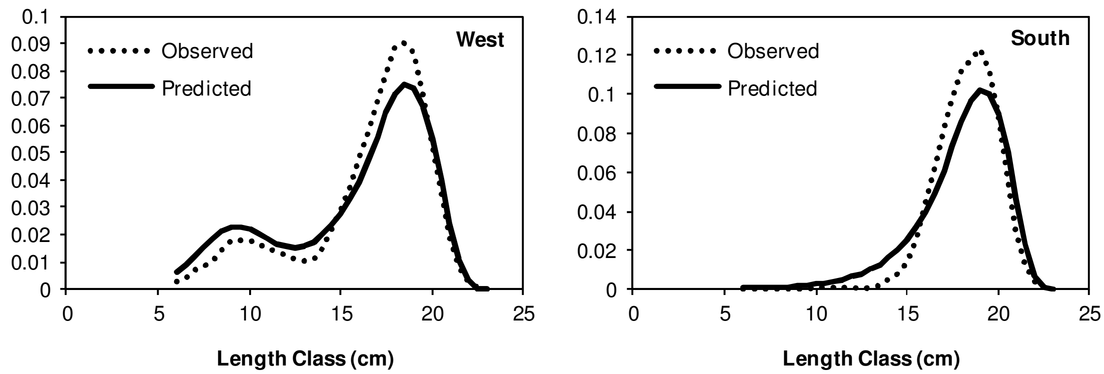

Figure 10. Average (over all quarters and years) model predicted and observed proportion-at-length in the commercial catch.

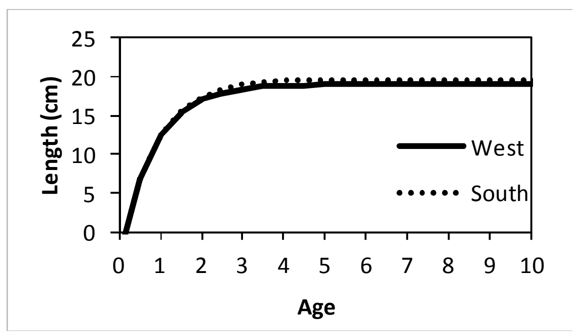

Figure 11. The von Bertalanffy growth curves estimated.

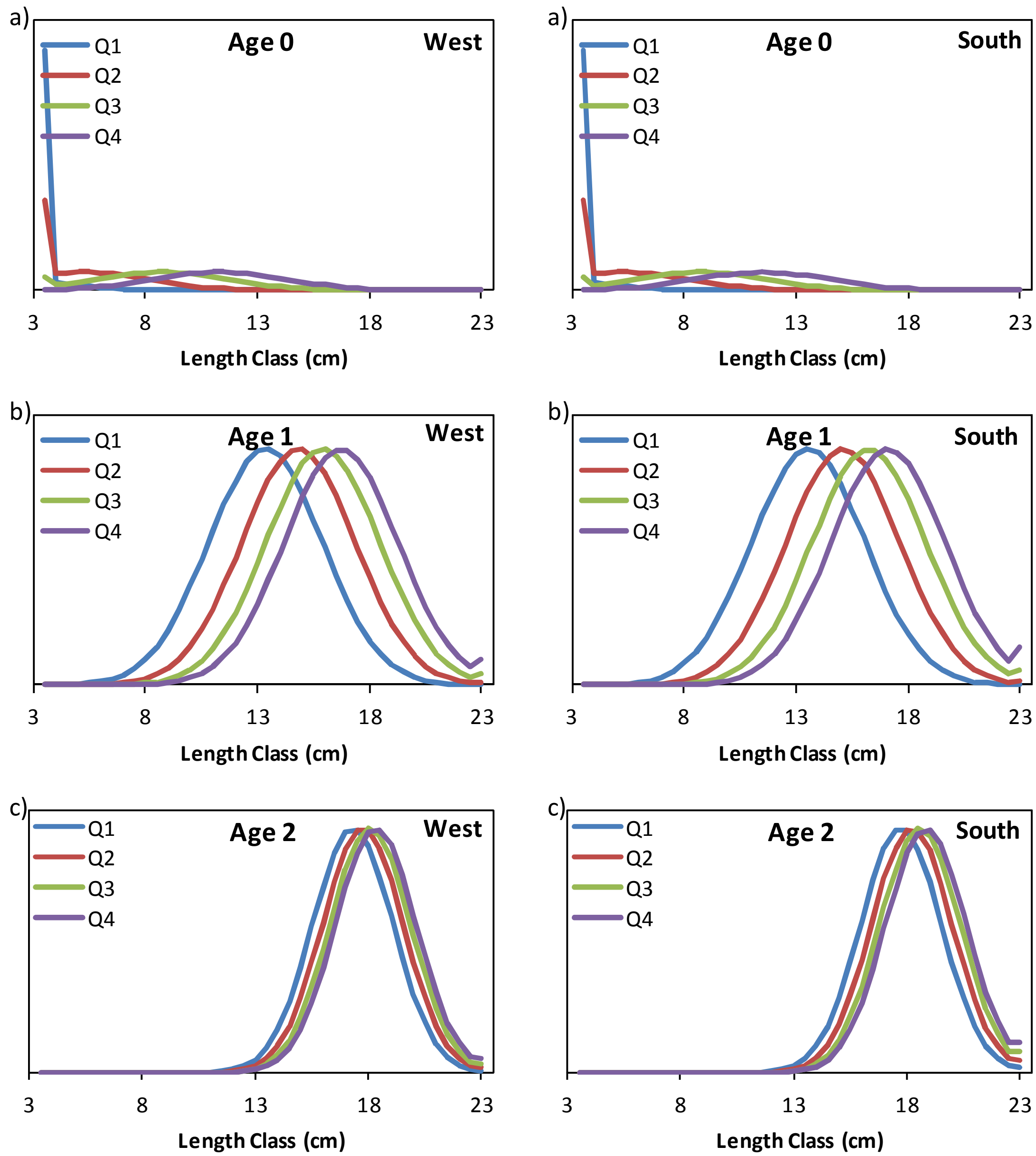

Figure 12. The model estimated distributions of proportions-at-length for each age, given at the middle of each quarter of the year (corresponding to the times commercial catch is modelled to be taken). The lowest plot compares the distributions for all ages at the middle of quarter 1.

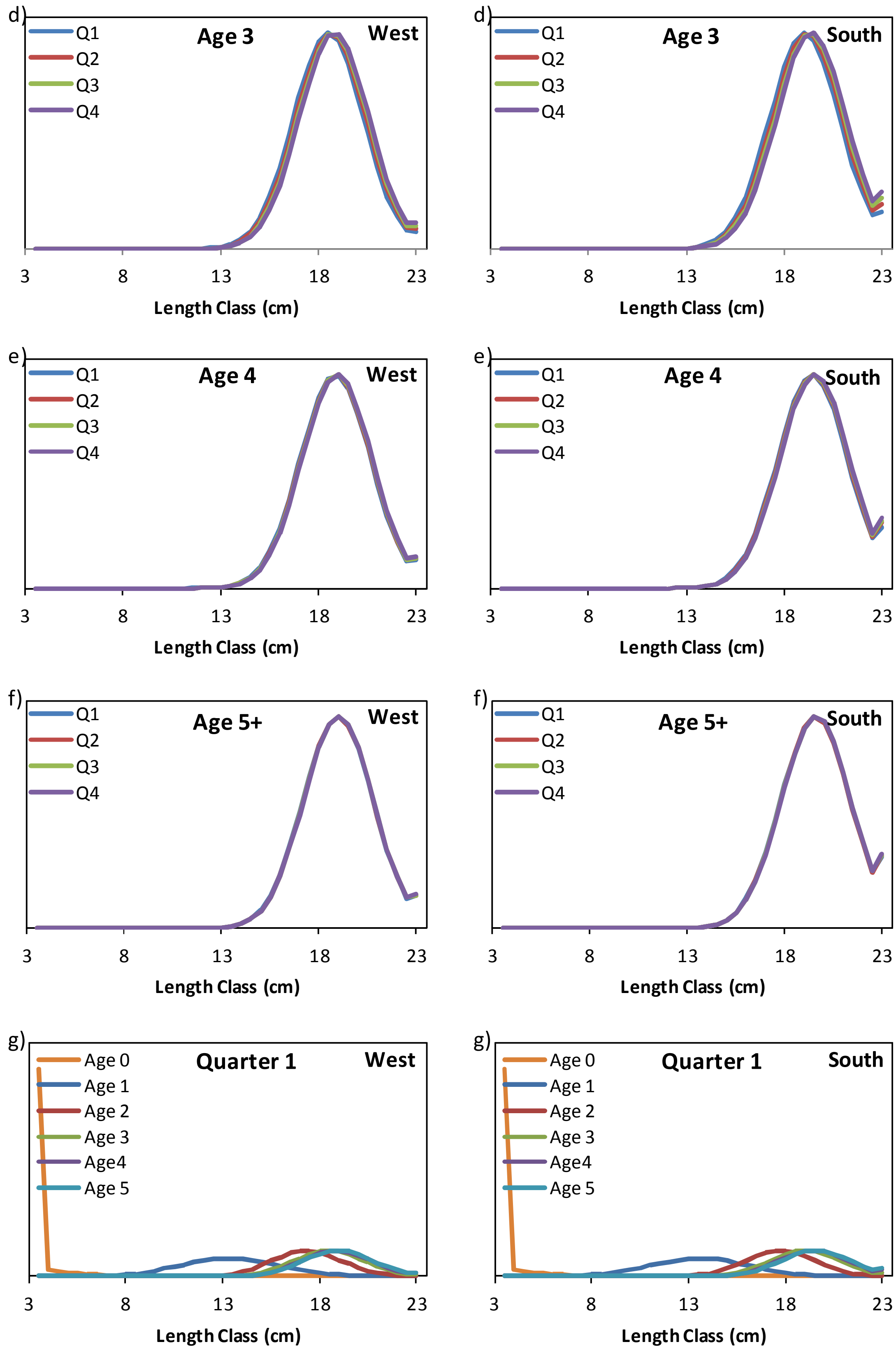

Figure 12 (continued).

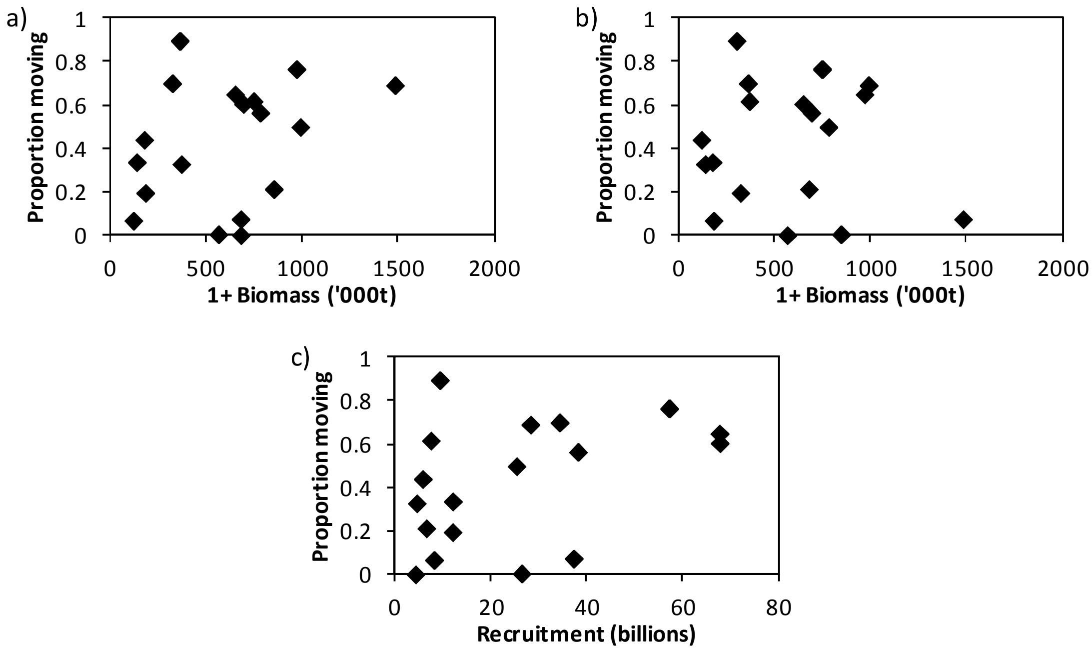

Figure 13. The model estimated proportion of recruits which move from the "west" stock to the "south" stock in November 1994 to 2011 as they reach age 1, plotted against a) "west" stock November 1+ biomass of the previous year, b) "west" stock November 1+ biomass of the current year and c) "west" stock May recruitment of the current year.

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

$\tilde{C}_{j,y,0bs}^{S}$ - 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).