A Two Discrete Stock Hypothesis for South African Sardine Resource

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The two discrete stock hypothesis for South African sardine has been extended. An improved fit to the data has been obtained. These results show that the hypothesis of two discrete stocks of sardine in South African waters can fit the observed data well. The implications of this are that the "western" stock increased from a reduced state earlier than the "eastern" stock, but that the "eastern" stock had previously been more heavily reduced than the "western" stock. The biomass of the both stocks are modelled to have decreased again, the "western" stock falling earlier than the "eastern" one.

Introduction

A two-stock, two-area hypothesis for the South African sardine resource was put forward in de Moor and Butterworth (2009). Their model was unable to fit the observed data well. Following the provision of a time series of estimates of recruitment for the "eastern" stock, and further testing of model assumptions, an improved fit to the data has been obtained. This document presents a revised two-stock, two-area hypothesis for the South African sardine resource.

The boundaries of the two stocks remain unchanged:

i) A "western" stock distributed throughout the "western area", defined as the area west of Cape Agulhas

ii) An "eastern" stock distributed throughout the "eastern area", defined as the area east of Cape Agulhas

This discrete stock hypothesis assumes the two stocks are independent and no mixing between the stocks occurs. The assumptions made regarding the two discrete stock model are listed in the Appendix.

Model Assumptions and Methods

The data used are listed in Tables 1 to 4 and Figure 1. The model used was based on the single stock assessment, excluding catch-at-length data (Cunningham and Butterworth 2007). The selectivities-at-age were therefore treated as fixed inputs to the model (constant over areas/stocks), corresponding to those used by the single stock assessment.

The following changes have been made to the model presented by de Moor and Butterworth (2009):

1) A time series of May recruitment from surveys covering the area from Cape Infanta to Cape St Francis, assumed to reflect recruitment to the "eastern" stock has been included (Table 2).

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2) Assumption 4: Previously only one multiplicative bias parameter was estimated for the May recruit survey bias, as this was taken to reflect recruitment to the "western" stock only. Two time series of recruit surveys are now available (for the "western" and "eastern" stocks). As the survey estimates for the "eastern" stock cover the area from Cape Infanta to Cape St Francis only, it is certainly conceivable that this could represent a lower proportion of the recruitment to this stock than that which is estimated by the survey for the "western" stock. Thus a separate multiplicative bias parameter is estimated for the May recruit survey for each stock.
3) Assumption 7: The variance about the stock recruitment curves was previously estimated to differ between the "peak" (i.e. 2000 to 2004) and "non-peak" years, but to be the same for both stocks. Further model testing has indicated that improved fits to the model are obtained if the variance is estimated separately for the two stocks, but that only one variance applies to the full period for each. This is also in line with further testing of the model (see below) which has indicated that separate stock-recruitment curves need no longer be used for "peak" and "non-peak" years.
4) Assumption 10: Given the inclusion of a time series for recruitment to the "eastern" stock, annual recruitment residuals can now be estimated for both stocks separately without over-parameterising the model.

Three key comparisons in model / data assumptions are shown in this document:

i) The full time series of May recruit data for the "eastern" stock is used and recruitment during the "peak" (2000-2004) years is assumed to fluctuate about a constant curve, while recruitment during "non-peak" years is assumed to fluctuate about a hockey stick stock recruitment curve. Average November weights-at-age differ for the "peak" and "non-peak" years (Table 3).
ii) The full time series of May recruit data for the "eastern" stock is used and recruitment is assumed to fluctuate about a hockey stick stock recruitment curve in all years.
iii) The survey estimate of recruitment in May 2001 is considered an outlier and excluded from the time series of May recruit data for the "eastern" stock. Such a very low estimate is very influential in the log likelihood and can thereby potentially bias the model fit to the remaining data series. Recruitment is assumed to fluctuate about a Hockey stick stock recruitment curve in all years.

Results and Discussion

The model fits to the November 1+ biomass data for are shown in Figure 2 and to the May recruit data are shown in Figure 3. The influence of the May 2001 "eastern" stock recruitment data point can be clearly seen in these figures. When excluded, model iii) clearly provides the best overall fit to the data and priors (Table 5), though the individual contributions to the likelihood of the four data sets are not a maximum for model iii). The greatest gain for model iii) in terms of the objective function is in the prior distribution for the recruitment residuals (Table 5). This can be seen in Figure 4 which also indicates the "outlier" status of the May 2001 data point. The variance about the stock recruitment relationship decreased substantially once this "outlier" data point was excluded (Table 5).

Figure 5 shows the stock recruitment relationships estimated by the models. The constant line about which recruitment is estimated to fluctuate during the "peak" years of 2000 to 2004 is estimated to be lower than the maximum of the stock recruitment curve in model i) (Table 5, Figure 5a). This is contrary to the assumption of a period of "peak" recruitment! Models ii) and iii) assume a single stock recruitment relationship over all years, thereby allowing for the observed peak in abundance to be explained primarily through an increase in the "eastern" stock. The large "eastern" stock recruitment predicted in November 1999 (corresponding to May 2000) for models i) and ii) is necessary to sustain the observed increase in 1+ biomass in November 2000 AND 2001, while fitting a very low May recruitment observation in May 2001. Once this "outlier" data point is excluded, the model predicted recruitment in November 1999 is much lower (Figure 5c).

A realistic range for the ratio between the multiplicative bias estimated for the May recruit survey and that for the November survey is generally assumed to [0.5,1]. This stems from the assumption that the recruit survey is not able to survey all the recruitment, while the November survey does survey all the 1+ biomass. In all three models presented in this document $k_R^{west} : k_N > 1$ (though not by large amounts), while $k_R^{east} : k_N < 0.1$. Since this ratio has been used in the past to exclude some fixed natural mortality combinations, this may indicate that the fixed values of 1.0 for juvenile natural mortality and 0.8 for adult natural mortality may need to be reconsidered for a two discrete stock hypothesis.

Note, however, that the results presented in this document do not represent fits to the model which have fully converged on the posterior mode. Further investigation is being carried out to attempt to determine the parameter(s) for which there may not be sufficient information to estimate reliably.

<u>Summary</u>

In summary, the results presented in this document have the following implications:

i) The observed data can be reasonably explained by a two discrete stock hypothesis.

ii) The observed "peak" in abundance during the early 2000's is explained by a larger increase in the "eastern" stock than the "western" stock.

iii) The "western" stock 1+ biomass increased appreciably from its long-term reduced state in 1997, and decreased again in 2004.

iv) The "eastern" stock 1+ biomass increased appreciably from its long-term reduced state in 1999/2000, and decreased in 2006.

v) The November survey is assumed to estimate about 64% (model iii)) of the true 1+ biomass. The median of the prior distribution on the multiplicative bias for the November survey is 0.72. This prior distribution was calculated taking a number of different errors into account (see Cunningham and Butterworth 2007). The fact that this model pulls the estimate lower still suggests that these data are informative and claim that the November survey is either also not covering the full 1+ biomass distribution, or that further errors are adding bias to the survey estimate. The splitting of the catch data into that caught in the west and east may be a possible cause, e.g. if catches in one area are now large relative to the observed biomass, the model will want to increase the true biomass above that observed (and hence decrease k_N)

vi) The May recruit survey is assumed to estimate about 65% of the true “western” stock recruitment and only 3% of the true “eastern” stock recruitment (model iii)). This very low bias for the “eastern” stock may be a reflection of the lesser area covered (Cape Infanta to Cape St Francis), i.e. recruitment may still occur east of Cape St Francis, or that the recruit survey is not adequately timed with the availability of recruits on the south coast. A further explanation may be that there is mixing between the two stocks and that recruits from the “western” stock contribute to the 1+ biomass of the “eastern” stock.

References

Cunningham CL, Butterworth DS (2007) Base Case Assessment of the South African Sardine Resource. Unpublished MCM Document MCM/2007/SEP/SWG-PEL/06. 30pp.

de Moor CL, Butterworth DS (2009) A 2-Stock Hypothesis for South African Sardine: Two Discrete Stocks. Unpublished MCM Document MCM/2009/SWG-PEL/23. 16pp.

Table 1. Sardine 1+ biomass (in tons) west of Cape Agulhas, assumed to be "western" stock sardine, and from Cape Agulhas to Port Alfred[1], assumed to be "eastern" stock sardine, and associated CVs estimated from the November hydroacoustic surveys. The total survey sardine 1+ biomass up to Port Alfred and associated CV, as used in the one stock model, is given for comparison.

	West of Cape Agulhas		**East of Cape Agulhas**		**Full Survey**	
Year	**1+ Biomass (t)**	**CV**	**1+ Biomass (t)**	**CV**	**1+ Biomass (t)**	**CV**
1984	48009	1.127	369	0.644	48378	1.118
1985	25457	0.680	19556	0.767	45013	0.509
1986	238230	1.054	61566	0.672	299797	0.848
1987	94165	0.734	17120	0.693	111285	0.630
1988	128043	1.005	6319	0.525	134362	0.957
1989	198328	0.334	58327	0.397	256655	0.274
1990	248855	0.382	41020	0.905	289876	0.352
1991	517180	0.444	80678	0.675	597858	0.395
1992	247756	0.560	246401	1.191	494157	0.658
1993	480822	0.488	79198	0.603	560019	0.427
1994	389730	0.432	128624	0.709	518354	0.370
1995	363542	0.302	480402	1.229	843944	0.713
1996	257763	0.352	271693	0.849	529456	0.471
1997	964835	0.322	259797	0.982	1224632	0.329
1998	1082547	0.341	524781	0.305	1607328	0.251
1999	708029	0.324	927381	0.280	1635410	0.212
2000	726230	0.633	1566150	0.670	2292380	0.500
2001	669617	0.313	1639983	0.154	2309600	0.142
2002	1184713	0.247	3021538	0.300	4206250	0.227
2003	1343118	0.300	2221053	0.258	3564171	0.197
2004	292522	0.437	2323193	0.372	2615715	0.334
2005	75604	0.524	973386	0.321	1048991	0.300
2006	177885	0.414	534667	0.441	712553	0.346

[1] From 1984 to 1994 the survey extended to Cape St Francis or Port Elizabeth. During this period few sardine were located on the south coast, with most of the biomass being on the western Agulhas bank. Sardine were seldom found between Cape St Francis and Port Elizabeth. Thus we assume that very few sardine were present between the end point of the survey and Port Alfred, and therefore these data points are consistent with those from surveys which extended up to Port Alfred. In 1994 sardine were present in moderate densities between Cape St Francis and Port Elizabeth. From 1995 to 2006 the survey has extended to at least Port Alfred and sardine biomass east of Cape St Francis has increased.

Table 2. Sardine recruitment (in billions) west of Cape Infanta, assumed to be "western" stock sardine, and from Cape Infanta to Port Alfred, assumed to be "eastern" stock sardine, and associated CVs estimated from the May recruitment hydroacoustic surveys. Note that the CV is calculated using the surveyed recruitment biomass, but taken to apply the recruitment numbers. The 2001 estimate of recruitment for the "eastern" stock is given in brackets as it is excluded from the proposed two discrete stock hypothesis (see main text). The recruitment numbers and CV up to Cape Infanta correspond closely though not exactly to those used in the one stock model.

	West of Cape Infanta		East of Cape Infanta	
Year	**Recruit Numbers**	**CV**	**Recruit Numbers**	**CV**
1985	3.6	0.596		
1986	3.71	0.594		
1987	8.06	0.598		
1988	0.44	0.402		
1989	2.25	0.616		
1990	2.5	0.907		
1991	1.90	0.276		
1992	5.57	0.325		
1993	15.40	0.358		
1994	2.57	0.311	1.15	0.562
1995	18.85	0.345	0.40	0.417
1996	5.51	0.370	[2]	
1997	40.54	0.420		
1998	11.14	0.354	0.31	0.541
1999	9.16	0.378	0.73	0.585
2000	20.00	0.359	5.29	0.503
2001	60.07	0.285	(0.0005)	(0.767)
2002	48.21	0.183	1.28	0.960
2003	36.45	0.217	0.46	0.512
2004	4.09	0.324	0.58	0.794
2005	2.87	0.337	1.07	0.593
2006	9.56	0.379	3.53	0.579

[2] Survey only extended as far east as Wilderness

Table 3. Sardine mean weights-at-age (in grams) in the November survey, calculated using data west and east of Cape Agulhas. The mean weights-at-age used in the one stock model are given for comparison. Note that ALKs from the full survey area were used in deriving these mean weights-at-age. Once area-disaggregated ALKs are available, these mean weights-at-age will be updated.

	West of Cape Agulhas					East of Cape Agulhas					Full Survey Area				
Year	**Age 1**	**Age 2**	**Age 3**	**Age 4**	**Age 5**	**Age 1**	**Age 2**	**Age 3**	**Age 4**	**Age 5**	**Age 1**	**Age 2**	**Age 3**	**Age 4**	**Age 5**
1993	25.294	41.785	74.520	77.679	110.642	26.101	34.823	72.470	77.655	107.900	25.483	39.937	74.304	77.632	110.329
1994	41.211	59.759	80.357	87.221	93.200	49.727	68.631	87.168	96.529	104.085	42.281	61.340	81.786	89.778	96.285
1996	17.262	52.961	67.569	77.225	87.310	78.741	102.255	140.929	169.192	207.848	31.515	67.920	92.792	108.538	124.788
2001	26.126	36.328	58.139	67.351	85.618	25.789	48.538	83.378	91.208	101.661	19.896	29.992	72.327	82.142	95.360
2002	18.177	24.572	64.288	68.081	92.547	20.603	33.101	75.963	87.132	97.123	22.750	33.187	66.103	77.252	88.508
2003	25.471	33.346	52.634	63.669	77.670	19.708	30.885	74.050	81.165	91.180	38.804	53.252	81.420	93.045	105.959
2004	32.100	42.442	55.167	67.222	90.244	44.097	66.835	99.493	108.101	121.404	20.408	57.433	80.811	86.814	96.115
2006	28.755	44.954	60.466	70.432	82.011	18.749	63.331	84.005	88.433	96.936	30.232	65.055	85.564	94.835	103.858
Average	27.037	44.849	65.365	73.159	89.417	36.099	58.462	90.802	100.935	116.654	28.921	51.014	79.388	88.754	102.650
Average (93,94,96,06)	27.949	53.369	72.59	78.967	93.217	46.409	68.385	98.226	110.662	131.647	32.378	58.563	83.612	92.696	108.815
Average (01-04)	26.126	36.328	58.139	67.351	85.618	25.789	48.538	83.378	91.208	101.661	25.464	43.466	75.165	84.813	96.486

Table 4. The date in year *y* of the commencement of the annual recruit survey and juvenile sardine catch (in numbers) west and east of Cape Agulhas from 1 November (of year *y*-1) to the day before the annual recruit survey. The recruit catch calculated for the full area used in the one stock model is given for comparison. (Note that the recruit catch for the full area does not always equal the sum of the recruit catches from the areas west and east of Cape Agulhas. This is because when considering the data from the two areas separately, different length frequencies may be assigned to landings.)

Year	Date of commence-ment of survey	Cut-off length (cm) for sardine juvenile catch	Juvenile catch before the survey		
			West of Cape Agulhas	East of Cape Agulhas	Full Area
1985	20-May	15.0	7318000	0	7318000
1986	10-Jun	15.0	8971000	0	8971000
1987	20-Jul	15.0	59446000	0	63464000
1988	27-Jun[3]	15.5	195160000	0	194929000
1989	08-Jun[4]	15.5	45493000	0	45282000
1990	22-Jun	15.5	402543000	21000	10499000
1991	07-May	15.5	7975000	9000	8518000
1992	13-May	15.5	36603000	0	29171000
1993	21-May	15.5	47511000	952000	45048000
1994	05-May	15.5	61532000	205000	72884000
1995	10-Jun	15.5	195335000	3000	161119000
1996	05-Jun	15.5	79096000	0	81362000
1997	17-May	13.5	36188000	0	35419000
1998	20-May	13.5	424333000	0	424298000
1999	10-May	16.5	23625000	70000	25231000
2000	15-May	16.5	99425000	63000	86717000
2001	05-May	11.5	330000	0	330000
2002	05-May	15.5	19738000	1749000	36846000
2003	14-May	15.5	73885000	648000	87499000
2004	08-May	13.5	35365000	0	35994000
2005	13-May	13.0	88757000	6000	100522000
2006	19-May	14.5	36551000	78000	37312000

[3] The first station was on 27th June 1988, although the first acoustic interval was only logged after midnight, i.e. on 28th June 1988.

[4] The first station was on 8th June 1989, although the first acoustic interval was only logged after midnight, i.e. on 9th June 1989.

Table 5. The values of the maximised log posterior mode (objective function) for the three models considered, and the individual contributions to the joint posterior. The best individual contributions to the joint posterior are given in **bold**. Estimated parameter values are also listed.

		Model i)	Model ii)	Model iii)
SR relationship		Peak and Non-Peak	Same for all years	Same for all years
May 2001 data point		Included	Included	Excluded
ln(Posterior)		-131.77	-132.82	**-105.50**
ln(L_Nov_w)		-15.95	**-14.84**	-17.19
ln(L_Nov_e)		-36.00	**-34.77**	-38.49
ln(L_Rec_w)		**-3.01**	-3.63	-3.51
ln(L_Rec_e)		-15.14	**-9.26**	-11.51
ln(Prior_kN)		**1.63**	1.42	1.07
ln(Prior_residuals)		-63.30	-71.74	**-35.87**
k_N	November survey bias	0.72	0.77	0.64
k_R^{west}	"Western" May survey bias	0.76	0.84	0.65
k_R^{east}	"Eastern" May survey bias	0.04	0.04	0.03
a_{west}^S	Maximum recruitment	37	28	43
a_{east}^S		125	44	83
b_{west}^S	Threshold above which recruitment should not be impaired	279	130	430
b_{east}^S		1557	650	860
c_{west}^S	Median recruitment during "peak" years	35	N/A	N/A
c_{east}^S		13	N/A	N/A
$\sigma_{r,west}^S$	Standard deviation about the stock recruitment relationship	0.77	0.97	0.81
$\sigma_{r,east}^S$		0.94	1.64	0.40
$K_{normal,west}^S$	Carrying capacity	1493	1223	1640
$K_{normal,east}^S$		8345	6095	3276
$K_{peak,west}^S$	Carrying capacity in "peak" years	1144	N/A	N/A
$K_{peak,east}^S$		608	N/A	N/A

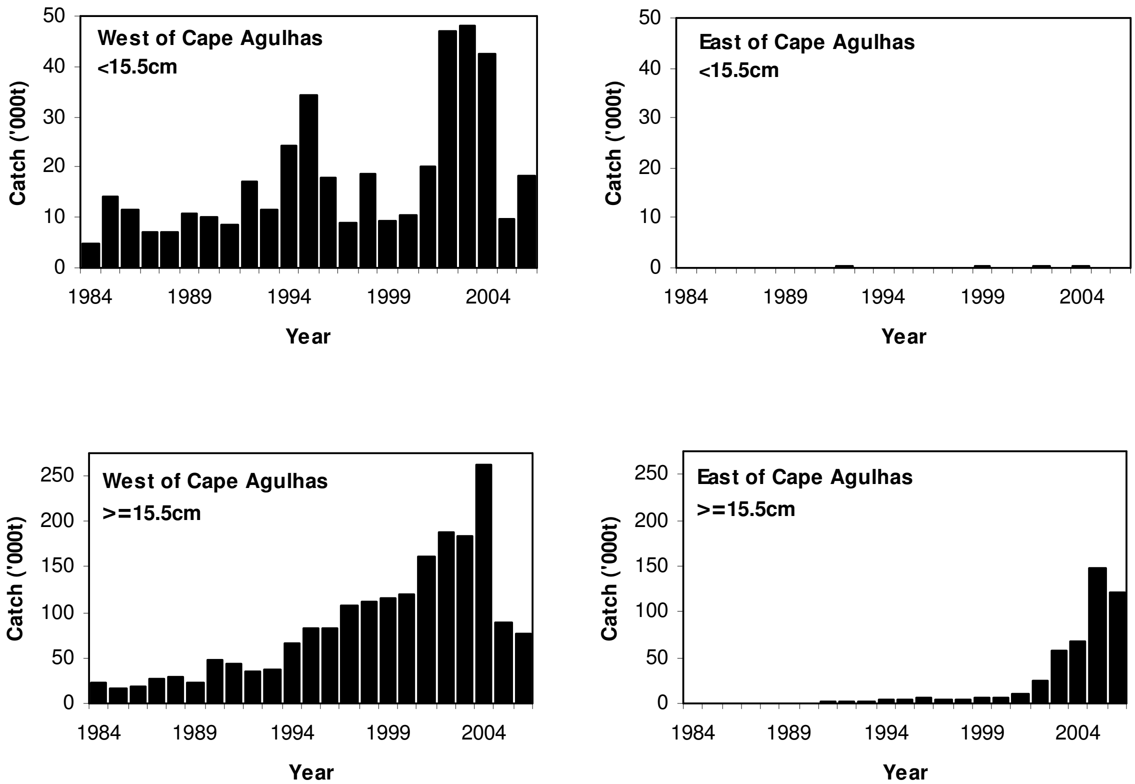

Figure 1. The sardine catch tonnage split east and west of Cape Agulhas and separated for 0-year-olds (assumed to be <15.5cm, upper plots) and 1+-year-olds (lower plots).

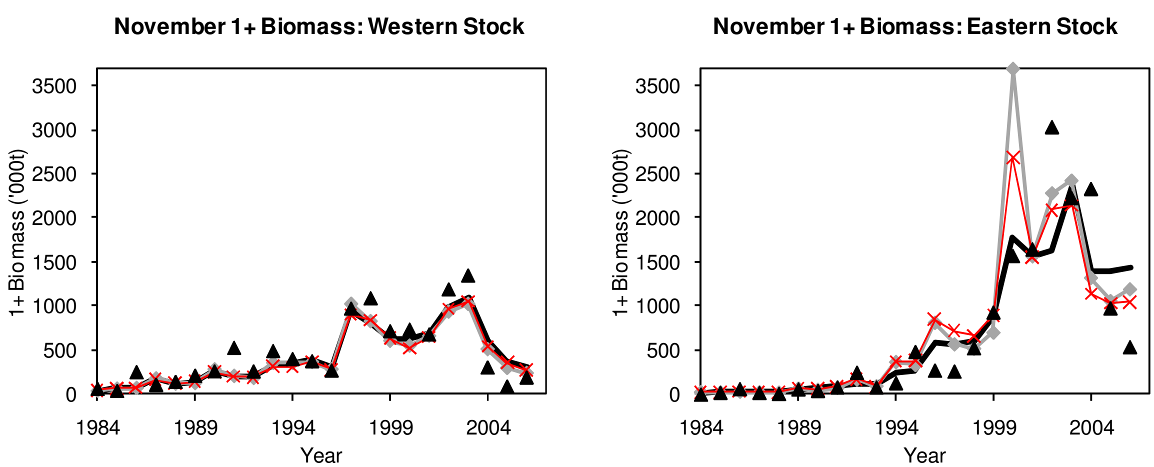

Figure 2. Observed and model predicted November 1+ biomass for the sardine two discrete stock model assuming i) separate "peak" stock recruitment dynamics (red line with crosses), ii) one stock recruitment relationship for each stock for all years (grey line with diamonds), and iii) one stock recruitment relationship for each stock for all years, and excluding the 2001 eastern stock recruitment data point (thick black line).

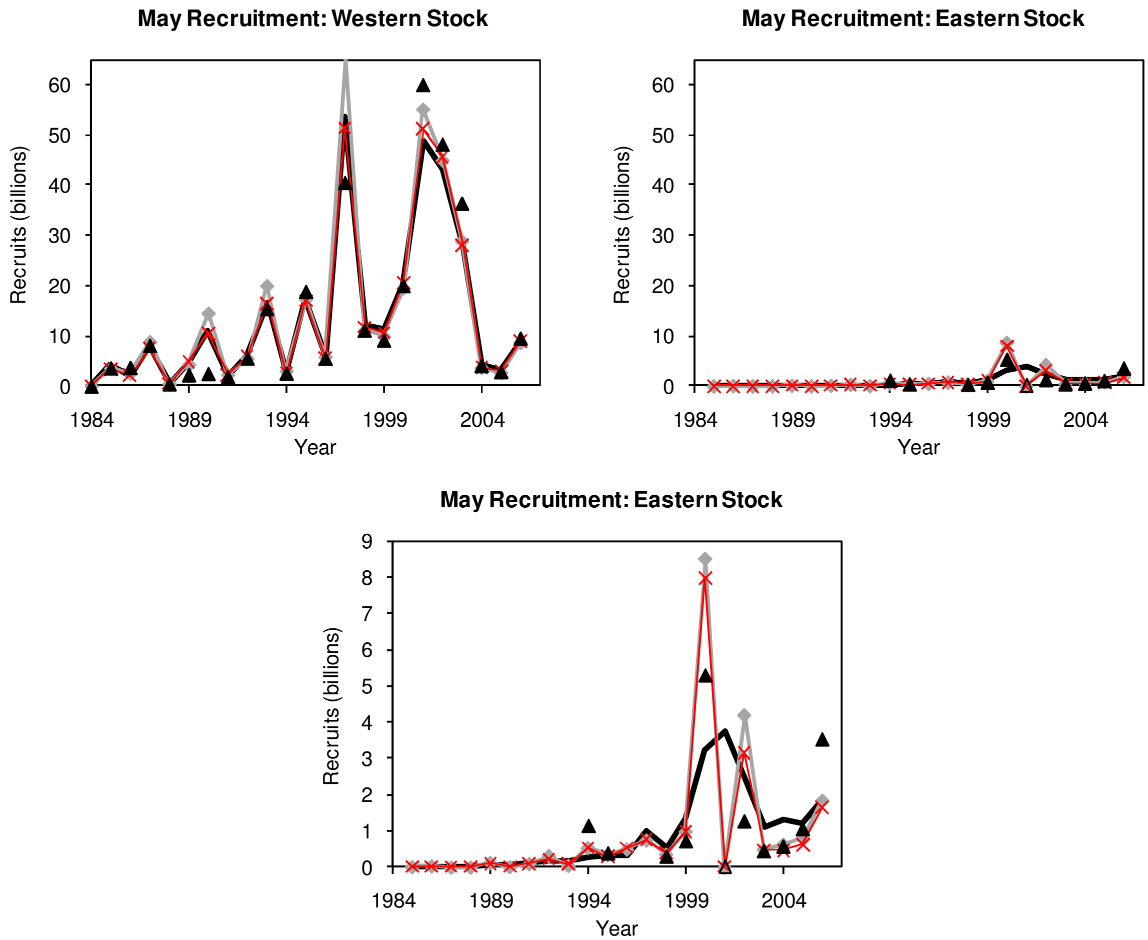

Figure 3. Observed and model predicted May recruitment for the sardine two discrete stock model assuming i) separate "peak" stock recruitment dynamics (red line with crosses), ii) one stock recruitment relationship for each stock for all years (grey line with diamonds), and iii) one stock recruitment relationship for each stock for all years, and excluding the 2001 eastern stock recruitment data point (thick black line). The lower panel repeats the model fits to the eastern stock data on a smaller vertical axis scale. The 2001 eastern stock recruitment data point is shown as an open triangle. Note that these plots compare recruit numbers available to the surveys; total recruitment is larger in each case, and much more so for the east for which the proportion not covered by the survey is estimated to be very high.

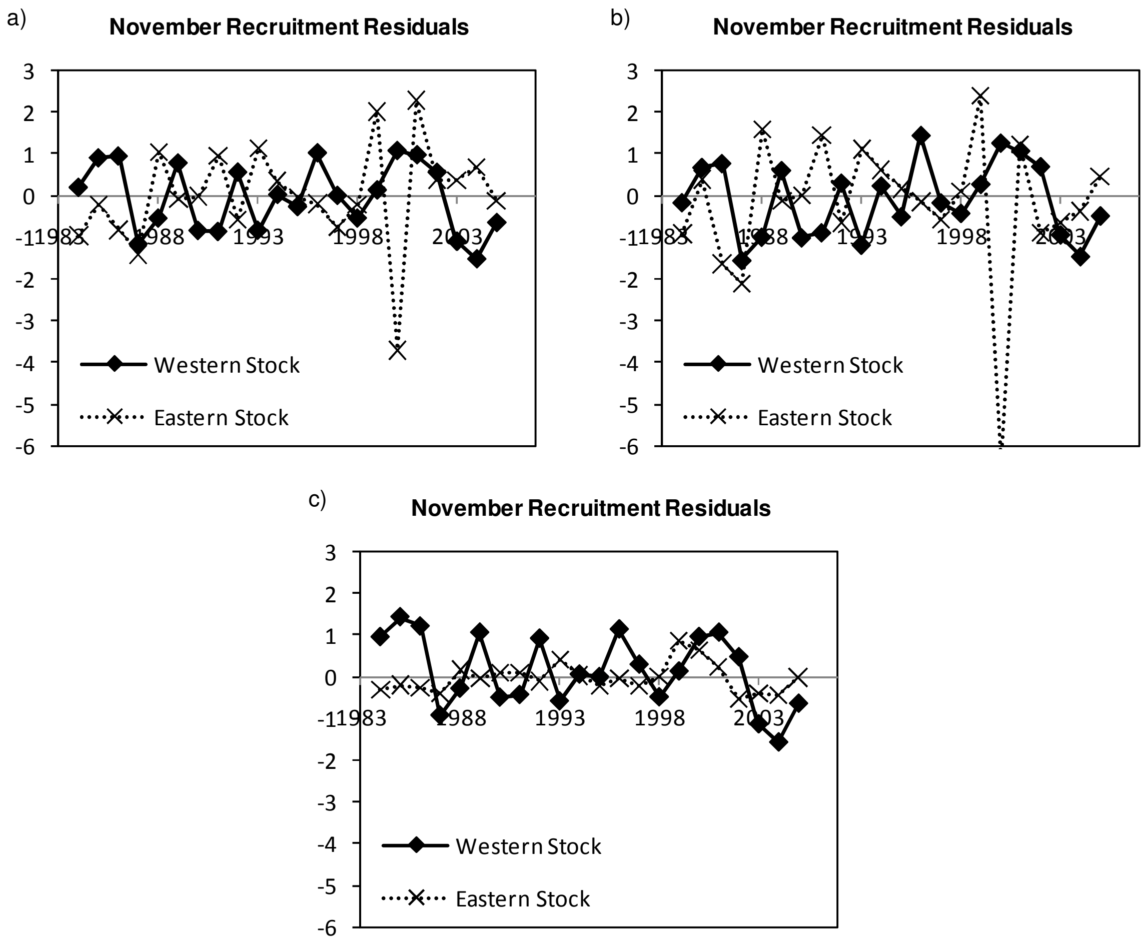

Figure 4. The estimated November recruitment residuals for the models assuming a) separate "peak" stock recruitment dynamics, b) one stock recruitment relationship for each stock for all years, and c) one stock recruitment relationship for each stock for all years, and excluding the 2001 eastern stock recruitment data point.

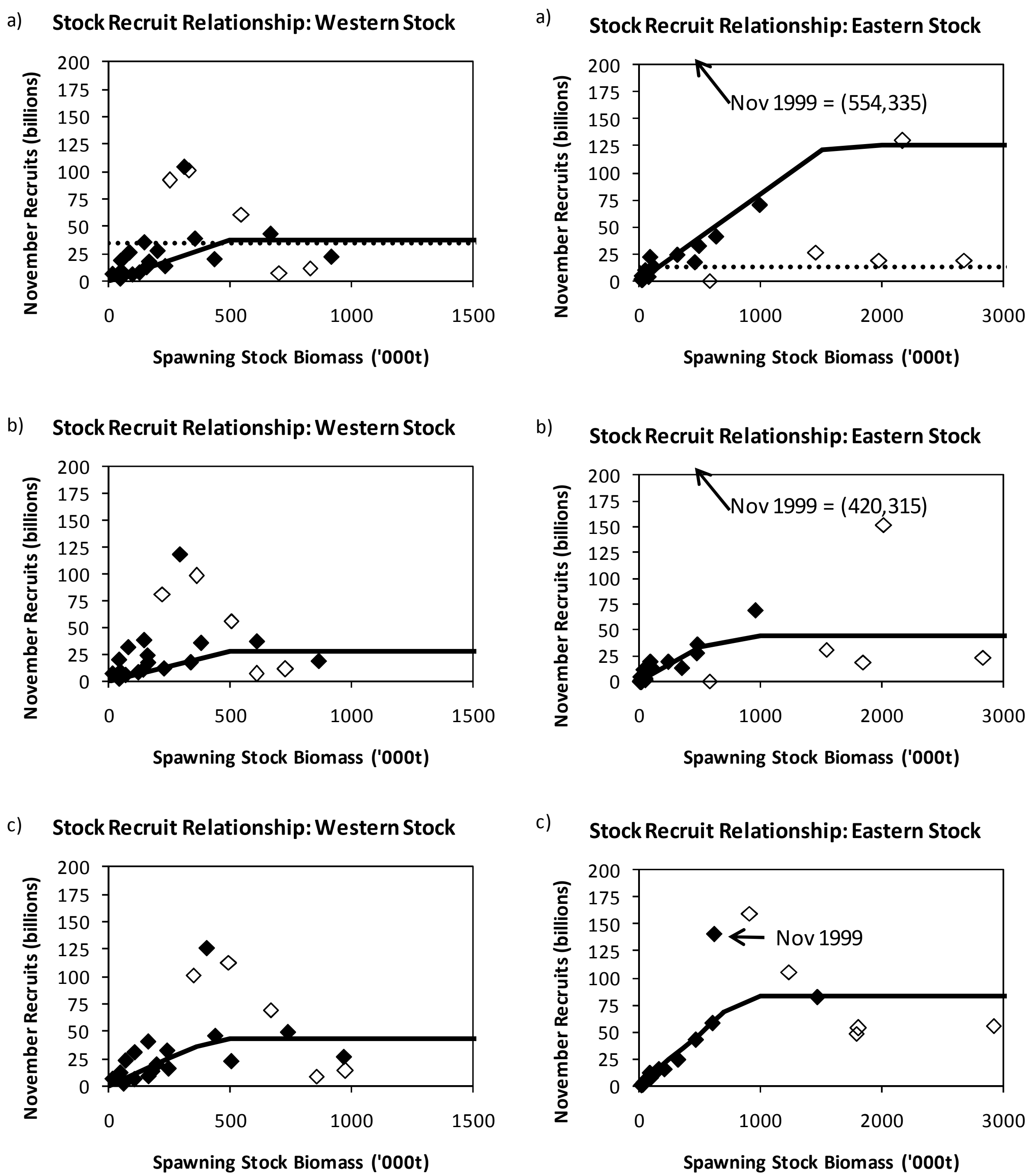

Figure 5. The model predicted annual November recruitment plotted against the spawning stock biomass, together with the estimated stock relationship, assuming a) separate "peak" stock recruitment dynamics, b) one stock recruitment relationship for each stock for all years, and c) one stock recruitment relationship for each stock for all years, and excluding the 2001 eastern stock recruitment data point. In plots a) the recruitment fluctuates about the constant (dotted line) during the peak (2000 to 2004) years, and around the solid hockey stick stock recruitment curve in all other years. In b) and c) the recruitment fluctuates around the solid hockey stick stock recruitment curve in all years. The 2000 to 2004 data points are indicated by open diamonds.

APPENDIX: MODEL ASSUMPTIONS OF THE TWO DISCRETE SARDINE STOCKS HYPOTHESIS

The following assumptions have been made when modeling two sardine stocks:

1) Juvenile catch prior to the surveys in 1985 and 1986 was from west of Cape Agulhas.
2) Juvenile and adult natural mortality are the same for both stocks.
3) The November survey bias (k_N) is the same for both stocks.[5]
4) The May recruit survey bias (k_R^{west} , k_R^{east}) is different for the "western" and "eastern" stocks. The survey estimates for the "eastern" stock cover the area from Cape Infanta to Cape St Francis only. It is certainly conceivable that this could represent a lower proportion of the recruitment to this stock than that which is estimated by the survey for the "western" stock.
5) The additional November and May recruit survey variance over and above survey sampling CVs (λ_N^2 and λ_R^2) was assumed to be the same for both stocks and set equal to zero (that estimated by the single stock model, and fixed for MCMC runs).
6) Maximum recruitment parameters for the Hockey stick stock recruitment curve were estimated separately for the "western" and "eastern" stocks. Thus the carrying capacities for the two stocks will differ. The same ratio between the inflection point on the hockey stick stock recruitment curve above which recruitment fluctuates around a maximum and the carrying capacity was assumed for both stocks. There is no difference in the stock recruitment relationship between "peak" and "non-peak" years.
7) The variance about the stock recruitment curves ($\left(\sigma_{r,west}^S\right)^2$, $\left(\sigma_{r,east}^S\right)^2$) is stock-dependent.
8) Selectivity-at-age 1 was fixed at 0.43, and selectivity-at-ages 2 to 5+ were fixed at that estimated from the assessment including catch-at-length data (as for the single stock assessment). [Selectivity-at-age 1 was estimated annually to be close to 0.43 in the single stock assessment, for which the prior range was between 0.43 and 1.]
9) The estimated total numbers-at-age in November 1983 were split with 80% assumed to be part of the "western" stock and 20% part of the "eastern" stock.
10) Two separate vectors of annual stock recruitment residuals ($\varepsilon_y^{R,west}$, $\varepsilon_y^{R,east}$) were estimated for each stock due to their independent stock status.

[5] Sensitivities to this assumption may still be tested.