A 2-Stock Hypothesis for South African Sardine: Two Discrete Stocks

Carryn L de Moor* **and Douglas S Butterworth**

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

Background

A 2-stock, 2-area hypothesis for the South African sardine resource is being developed, with the following boundaries:

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

As previously discussed (de Moor 2009) two separate scenarios are to be considered for this 2-stock hypothesis:

i) No mixing between these stocks.

ii) Movement of 1-year-olds from the "western" stock to the "eastern" stock and movement of 2+-year-olds from the "eastern" stock to the "western" stock. Recruitment to the "western" stock will be dependent on the SSB of both the "western" and "eastern" stocks. Recruitment to the "eastern" stock will be dependent on the SSB of the "eastern" stock only.

This document gives the results of fitting the assessment model to data under the first of these scenarios: two discrete "western" and "eastern" stocks of the South African sardine resource.

Data

The estimates of November 1+ biomass from the hydroacoustic surveys have been split at Cape Agulhas (Figure 1, Table 1). The estimates of May recruitment from the hydroacoustic surveys have also been split at Cape Agulhas (Figure 2), but it was decided at the Pelagic Working Group on 6th May that the recruits observed between Cape Agulhas and Cape Infanta should be attributed to the "western" stock (Table 2). Direct estimates (e.g. from surveys) of recruitment to the "eastern" stock are therefore not available at this time.

The estimated mean weights-at-age from the November survey are given in Table 3. These area-disaggregated weights differ quite substantially from those estimated for the full survey area. Note that ALKs from the full survey area were used in deriving these mean weights-at-age. It is hoped that area-disaggregated ALKs will soon be available to update these data.

The catch tonnage has been split west and east of Cape Agulhas (Figure 3). The juvenile catch prior to the survey has also been split west and east of Cape Agulhas (Table 4). Note that the sum of the juvenile catches

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

from these two areas does not always equal the juvenile catch prior to the survey for the full area used in the single stock assessment. This is because when the data are separated, some landings are assigned length frequencies from different sets.

Assessment Model

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 assumptions were made:

1) Juvenile catch prior to the surveys in 1985 and 1986 was from west of Cape Agulhas.
2) Juvenile and adult natural mortality is the same for both stocks.
3) The November survey bias (k_N) is the same for both stocks. No similar assumption was made regarding the survey bias for the May survey (k_R) since that is taken to represent the "western" stock only.
4) The additional November survey variance over and above survey sampling CVs (λ_N^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). The additional May survey variance, which applies only to the "western" stock, was fixed at zero, as in the single stock assessment.
5) Maximum recruitment parameters for the Hockey stick stock recruitment curve were estimated separately for the "western" and "eastern" stocks. Thus four maximum recruitment parameters are estimated: for each stock a maximum recruitment parameter during "peak" and "non-peak" periods. 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.
6) The variance about the stock recruitment curves ($\left(\sigma_r^S\right)^2$ and $\left(\sigma_{r,peak}^S\right)^2$) is the same for both stocks.
7) 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.]
8) 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.

Alternatives to 3, 6 and 8 could be investigated as sensitivity tests.

Two alternatives for the stock recruitment residuals were investigated:

9a) The annual stock recruitment residuals (ε_y^R) were the same for both stocks, implying that good/poor recruitment occurs in the "western" and "eastern" stocks in the same years, e.g. due to the same environmental factors affecting both stocks.

9b) Separate annual stock recruitment residuals were estimated for each stock e.g. due to their independent stock status.

Although the latter may seem more realistic, the lack of recruitment data for the "eastern" stock may result in over-parameterisation of the model.

In order to progressively test the model and hypothesis, the model parameters were estimated using the following sets of data:

a) November 1+ biomass and May recruitment numbers west of Cape Agulhas, assumed to be "western" stock. In this case the "eastern" stock was still modeled, but results from this stock were superfluous given that no "eastern" stock data were used.
b) In addition to a), November 1+ biomass east of Cape Agulhas, assumed to relate to the "eastern" stock.
c) In addition to b), May recruitment numbers west of Cape Infanta, assumed to relate to the "western" stock.

<u>Results and Discussion</u>

The fit of the model to the November 1+ biomass estimates is shown in Figure 4 when the same recruitment residuals are estimated for both stocks, and in Figure 5 when different recruitment residuals are estimated for the two stocks. When the model is fitted to all three sets of data (c) above), the model fits the November 1+ biomass estimates east and west of Cape Agulhas appears somewhat better (lower value of the negative log of the modal posterior probability density) under the scenario of estimating separate recruitment residuals for the "western" and "eastern" stocks. Note that Table 5 reflects improved likelihoods for fits to the data for separate recruitment residuals; however as this is a Bayesian rather than a frequentist estimation, a criterion such as AIC cannot be used to indicate whether the improvement is sufficient to justify the additional parameters.

The fit of the model to the May recruit numbers is shown in Figure 6 when the same recruitment residuals are estimated for both stocks and in Figure 7 when different recruitment residuals are estimated for the two stocks. The model fits the time series of recruit estimates west of Cape Infanta best when the same recruitment residuals are estimated for both stocks (Table 5). The model predicted recruitment for the "eastern" stock is also shown in Figures 6 and 7. A large peak in both the "western" and "eastern" stock recruitment is estimated for 2000, regardless of whether separate recruitment residuals are estimated for both stocks or not. This above average recruitment can also be seen when considering the recruitment residuals estimated by the model.

In the second scenario where separate recruitment residuals are estimated for the "western" and "eastern" stocks, there are some differences in the estimated recruitment residuals for the two stocks which suggests a preference for this approach. This might, however, simply reflect poor information content in respect of recruitment of the data available (the time series of November 1+ biomass observations only) for the eastern stock. As a result, the majority of residuals are estimated to be around 0, the mean of the prior distribution. This indicates that the model is over-parameterised. The residuals were estimated to be positive from 1998 to 2001 and negative from 2002 to 2004 to enable a closer fit to the sharp increase and decrease observed in 1+ biomass, respectively.

Summary

Neither of these scenarios produce particularly good fits to the November 1+ data, although the "western" recruitment data can be adequately replicated. This is not unexpected, and confirms discussions within the Pelagic Working Group which have indicated a strong possibility of some mixing between the hypothesised "western" and "eastern" stocks. This two discrete stock hypothesis is, however, useful as a building block in the development and exploration of a 2-stock hypothesis for the South African sardine resource.

Further alternatives to some of the assumptions made in this model could be tested. In addition, the inclusion of new data, such as refined weights-at-age and the availability of recruitment data for the "eastern" stock (i.e. from the area east of Cape Infanta) in some years may prove useful. The latter may not be straightforward, due to differing survey area coverage between years. However, we feel it would be most productive to begin development of the two mixing stock hypothesis and rather explore further sensitivity tests and the inclusion of new data for the separate-stocks hypothesis.

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 (2009) Progress on the sardine 2-stock hypothesis. Unpublished MCM Document MCM/2009/SWG-PEL/13. 3pp.

Table 1. *Sardine 1+ biomass (in tons) west and east (up to Port Alfred) of Cape Agulhas 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

Table 2. *Sardine recruitment (in billions) west of Cape Agulhas and Cape Infanta 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. Both sets of data are assumed to correspond to recruitment of the "Western" stock in this document. The recruitment numbers and CV up to Cape Infanta correspond to that used in the one stock model.*

	West of Cape Agulhas		**West of Cape Infanta**	
Year	**Recruit Numbers**	**CV**	**Recruit Numbers**	**CV**
1985	3.585	0.64	3.603	0.596
1986	3.710	0.594	3.708	0.594
1987	8.060	0.598	8.062	0.598
1988	0.440	0.402	0.436	0.402
1989	2.250	0.616	2.254	0.616
1990	2.500	0.907	2.496	0.907
1991	1.898	0.281	1.904	0.276
1992	5.571	0.328	5.590	0.325
1993	15.396	0.364	15.434	0.358
1994	2.687	0.315	2.699	0.311
1995	26.036	0.346	26.042	0.345
1996	3.530	0.37	3.530	0.370
1997	40.539	0.42	40.539	0.420
1998	10.616	0.361	10.716	0.354
1999	7.298	0.465	10.378	0.378
2000	20.002	0.359	20.002	0.359
2001	60.065	0.285	60.065	0.285
2002	45.786	0.203	49.153	0.183
2003	33.406	0.232	36.448	0.217
2004	4.074	0.333	4.089	0.324
2005	2.679	0.392	2.874	0.303
2006	9.521	0.383	9.564	0.379

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.*

	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 (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[1]	15.5	195160000	0	194929000
1989	08-Jun[2]	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

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

[2] 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 negative log of the posterior density function at its mode , and the individual contributions to this posterior mode, for the sardine 2-stock model. The model was progressively fit to the November and May recruitment data west of Cape Agulhas (Now_w, Rec_w), the November data east of Cape Agulhas (Nov_e) and the May recruitment data west of Cape Infanta (Rec_tot). **Bolded** values reflect the best fits to the data in question.*

	Same Recruitment Residuals			Different Recruitment Residuals
Nov_w, Rec_w	√	√	√	√
Rec_w		√	√	√
Nov_e	√	√		
Rec_tot			√	√
-ln(posterior)	41.57	102.77	102.41	91.28
-lnL(Nov_w)	**16.54**	20.04	20.47	19.31
-lnL(Nov_e)		50.76	50.17	**37.30**
-lnL(Rec_w)	**4.66**	6.17	5.19	7.18
-lnprior(kN)	-1.37	3.36	3.89	-1.57
-lnprior(rec_residuals)	21.74	22.44	22.69	(not comparable) 29.07

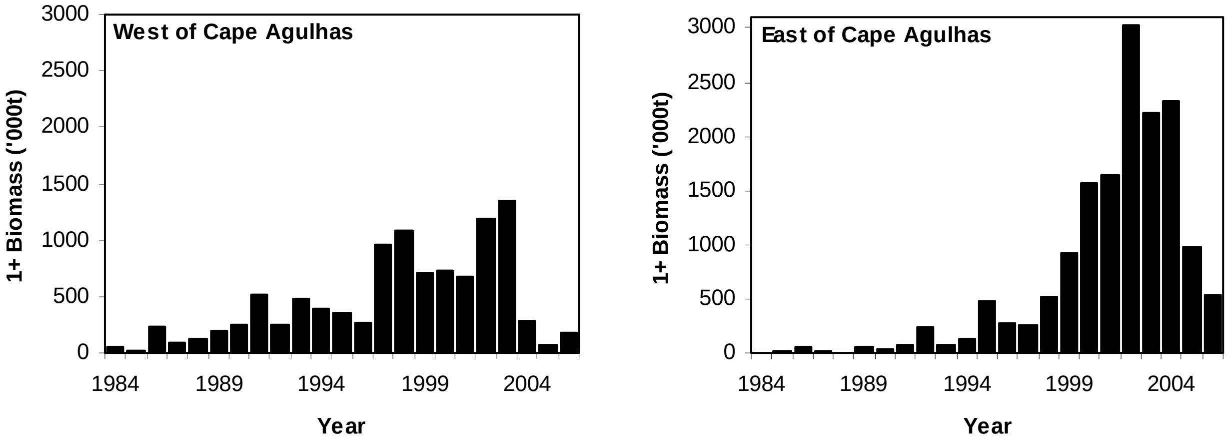

Figure 1. *The sardine 1+ biomass observed during the November acoustic survey, split east and west of Cape Agulhas.*

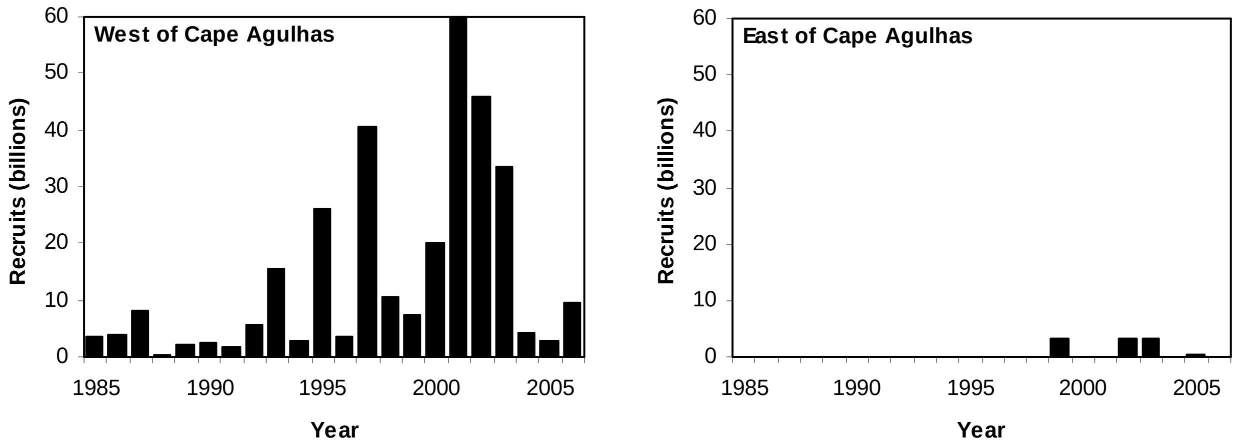

Figure 2. *The sardine recruitment observed during the May acoustic survey up to Cape Infanta, split east and west of Cape Agulhas.*

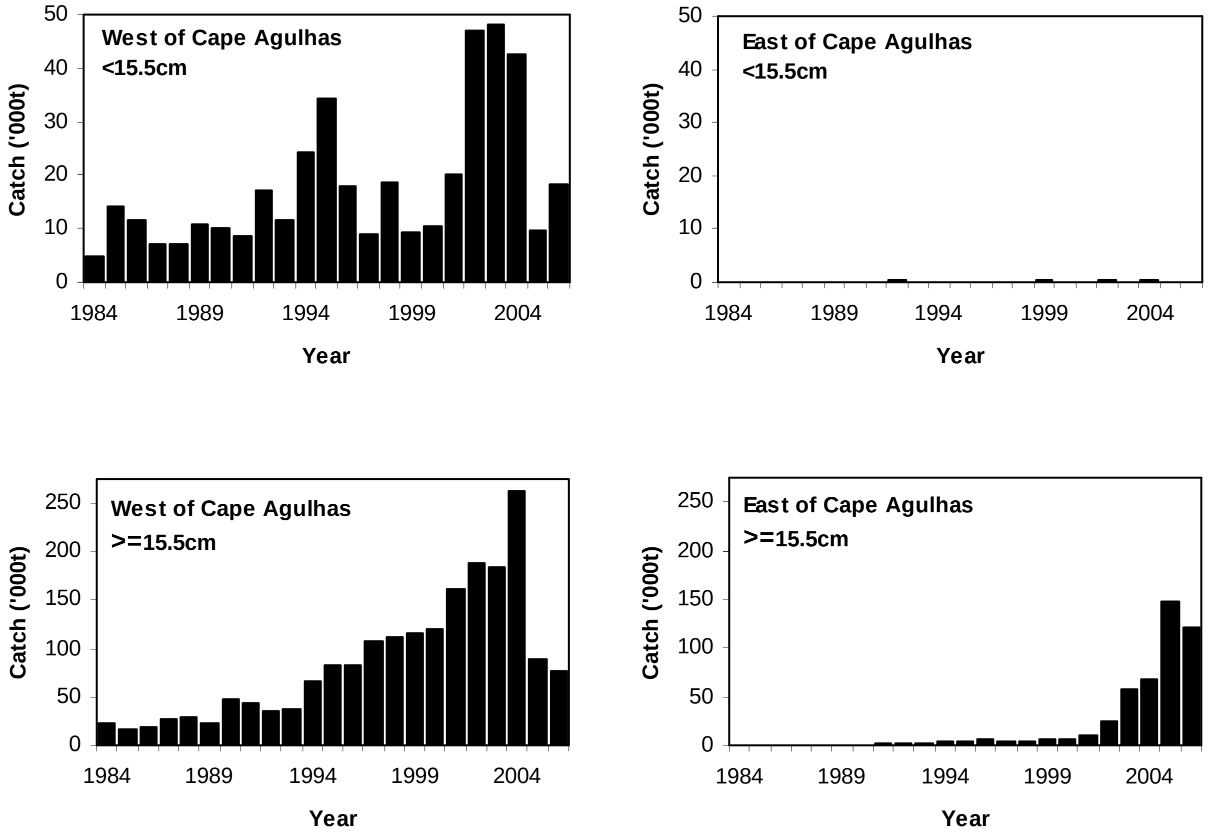

Figure 3. *The sardine catch tonnage split east and west of Cape Agulhas and separated for 0-year-olds (assumed to be <15.5cm, upper plots) and 1-year-olds (lower plots).*

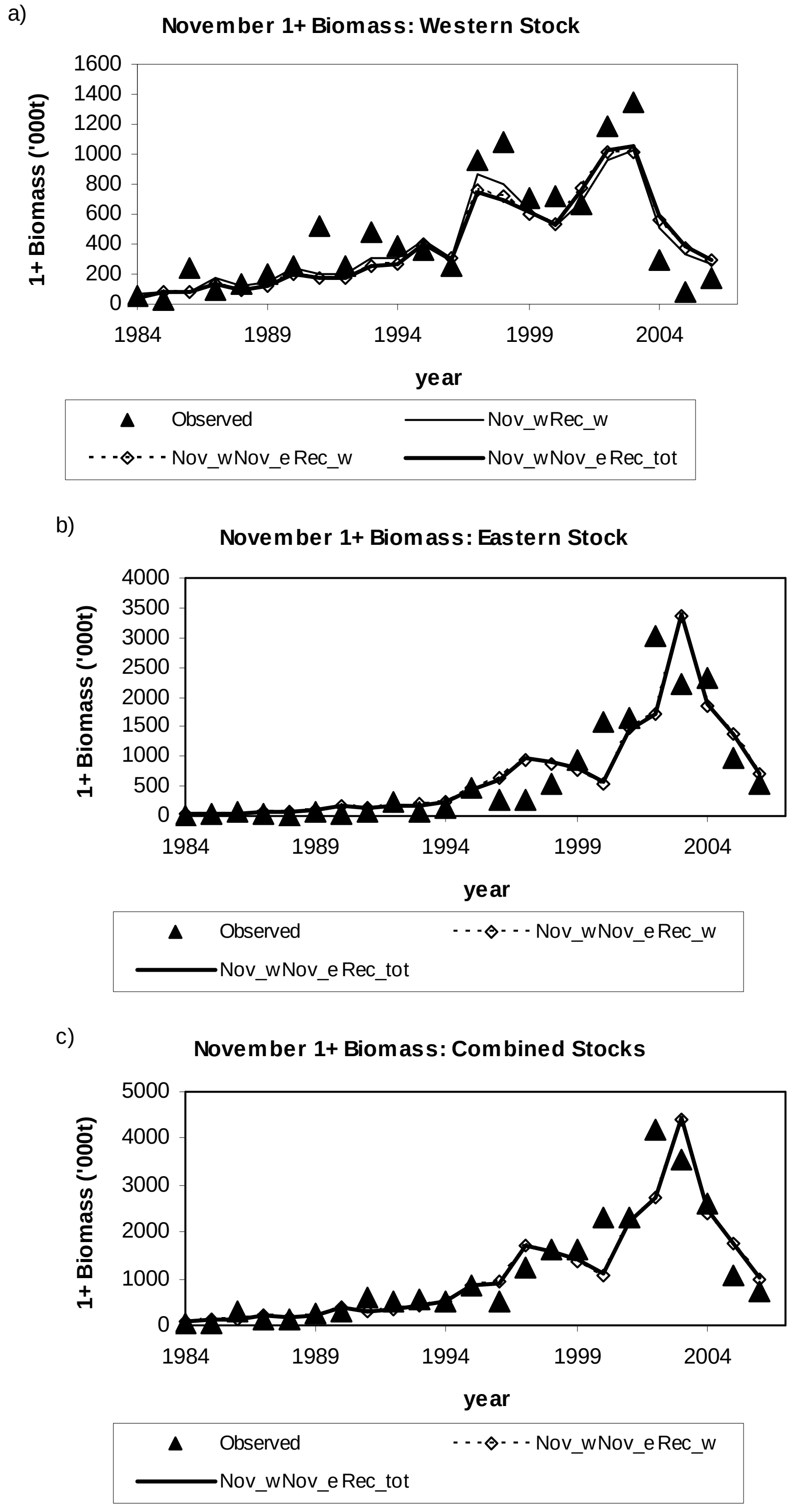

***Figure 4**. The observed and model predicted November sardine 1+ biomass a) west of Cape Agulhas, b) east of Cape Agulhas and c) for the full survey area up to Port Alfred, assuming the same recruitment residuals for both the "western" and "eastern" stocks. The model was progressively fit to the November and May recruitment data west of Cape Agulhas (Nov_w, Rec_w), the November data east of Cape Agulhas (Nov_e) and the May recruitment data west of Cape Infanta (Rec_tot). Note that scales on the vertical axes differ amongst the plots.*

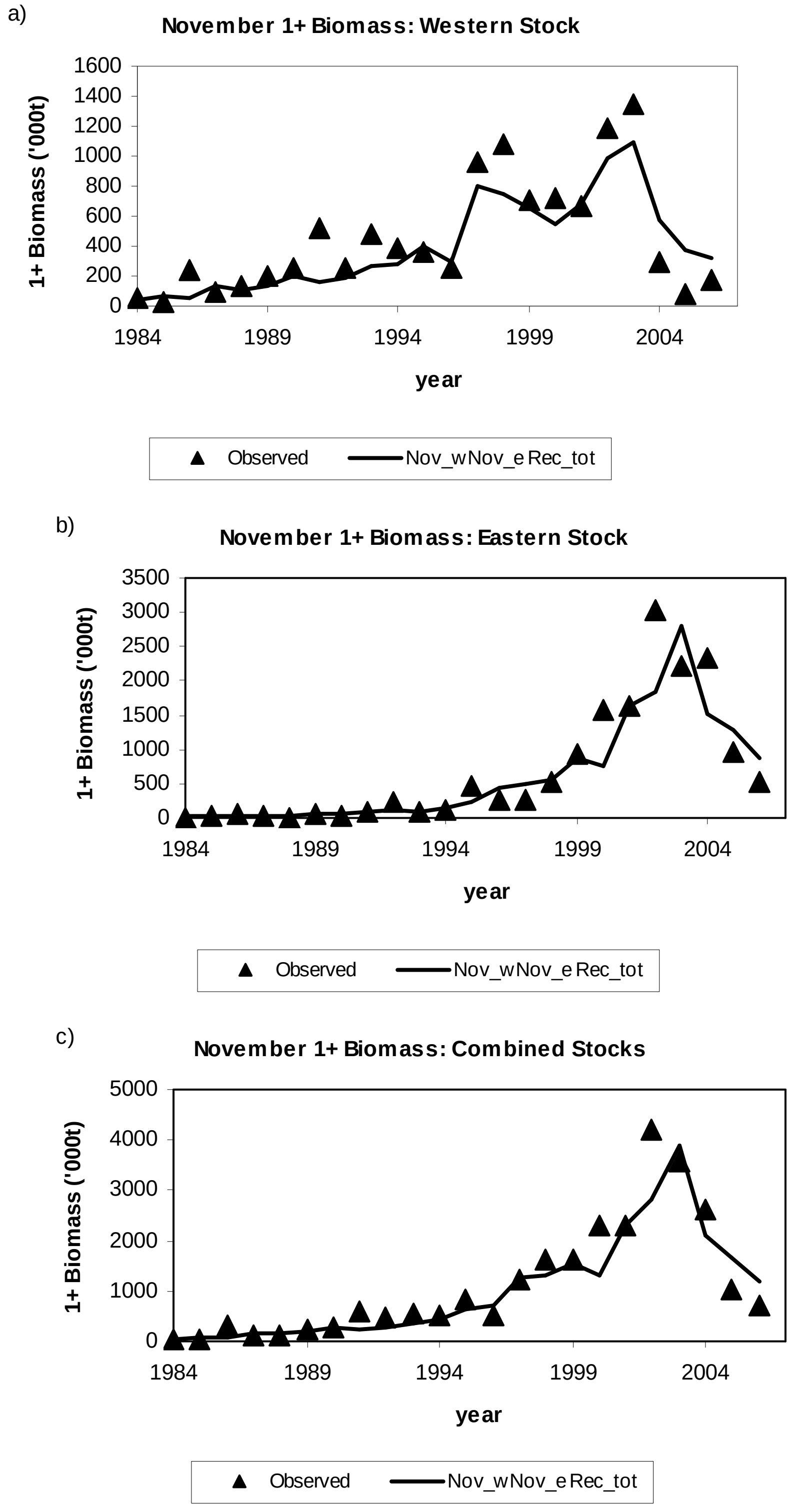

Figure 5. *The observed and model predicted November sardine 1+ biomass a) west of Cape Agulhas, b) east of Cape Agulhas and c) for the full survey area up to Port Alfred, estimating separate recruitment residuals for the "western" and "eastern" stocks. Model predicted results are shown only for fits to all the data.*

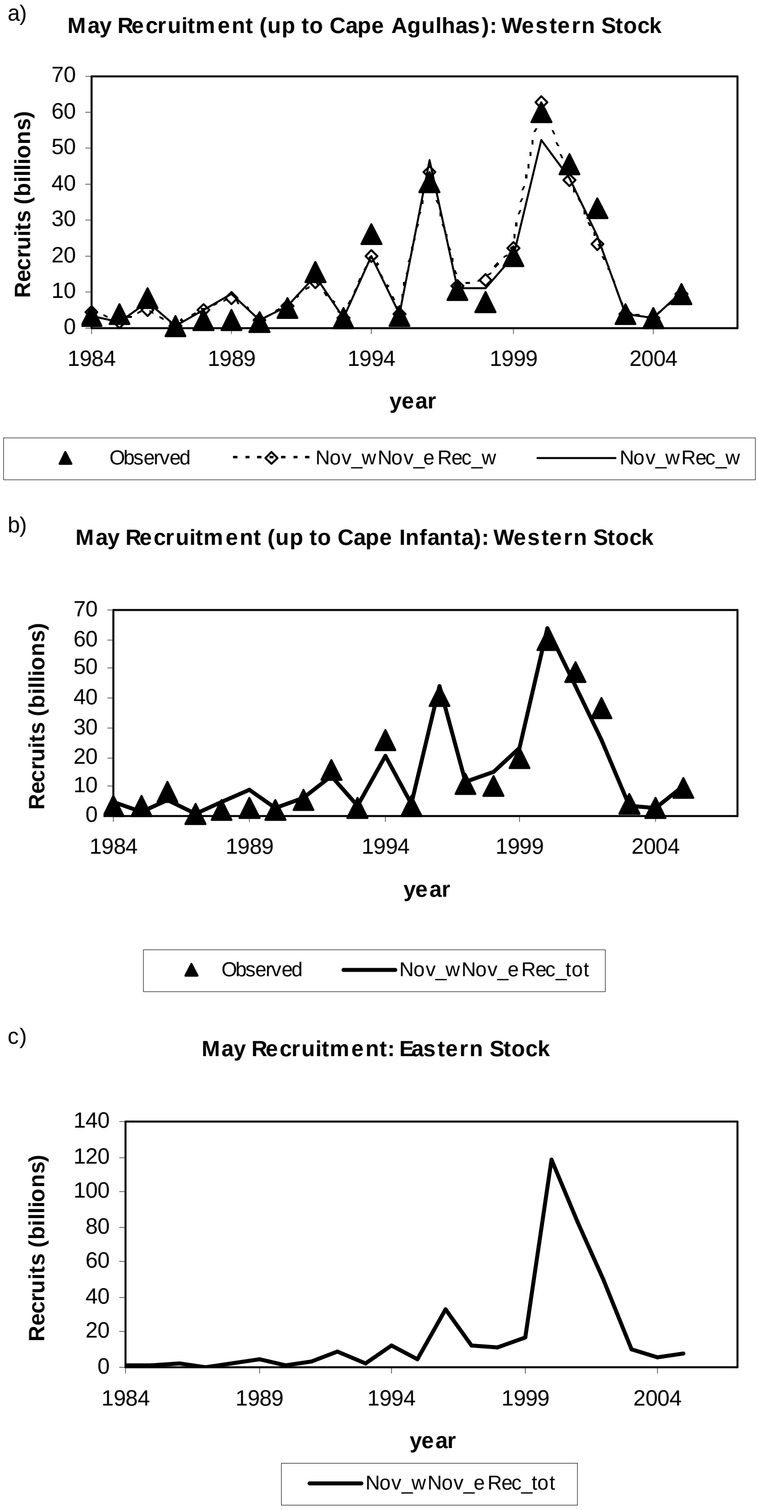

Figure 6. *The observed and model predicted sardine May recruitment numbers a) west of Cape Agulhas, b) west of Cape Infanta (assumed to be recruits to the "western" stock) and c) model predicted sardine May recruitment numbers for the "eastern" stock, assuming the same recruitment residuals for both the "western" and "eastern" stocks. The model was progressively fit to the November and May recruitment data west of Cape Agulhas (Nov_w, Rec_w), the November data east of Cape Agulhas (Nov_e) and the May recruitment data west of Cape Infanta (Rec_tot).*

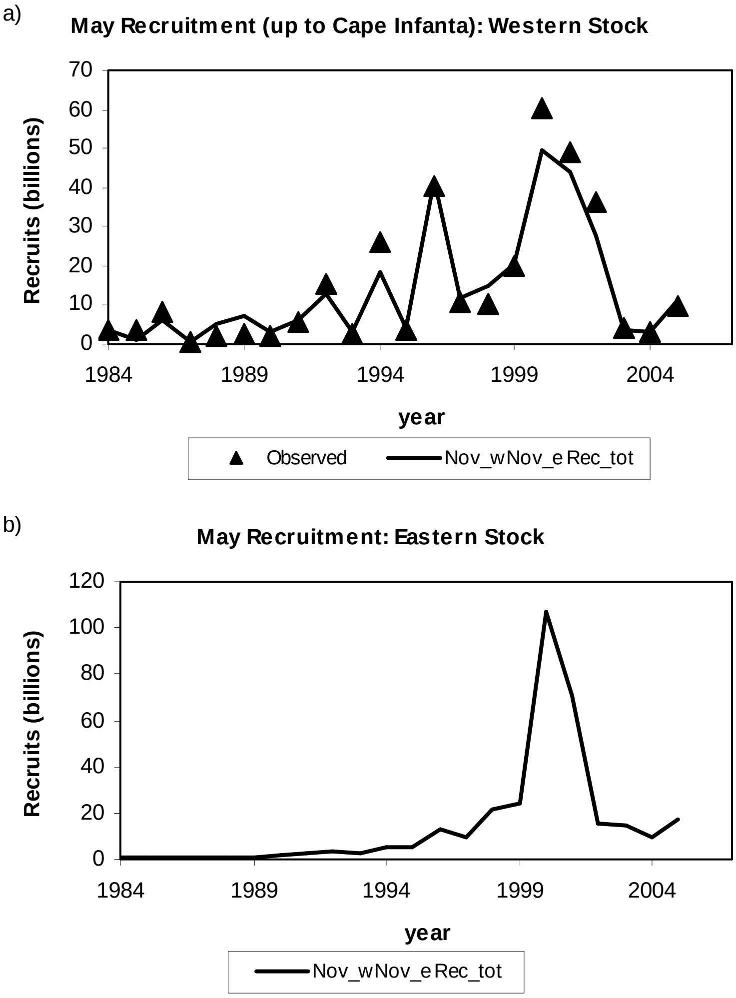

Figure 7. *The observed and model predicted sardine May recruitment numbers west of Cape Infanta (assumed to be recruits to the "western" stock) and model predicted sardine May recruitment numbers for the "eastern" stock, estimating separate recruitment residuals for the "western" and "eastern" stocks. Model predicted results are shown only for fits to all the data.*

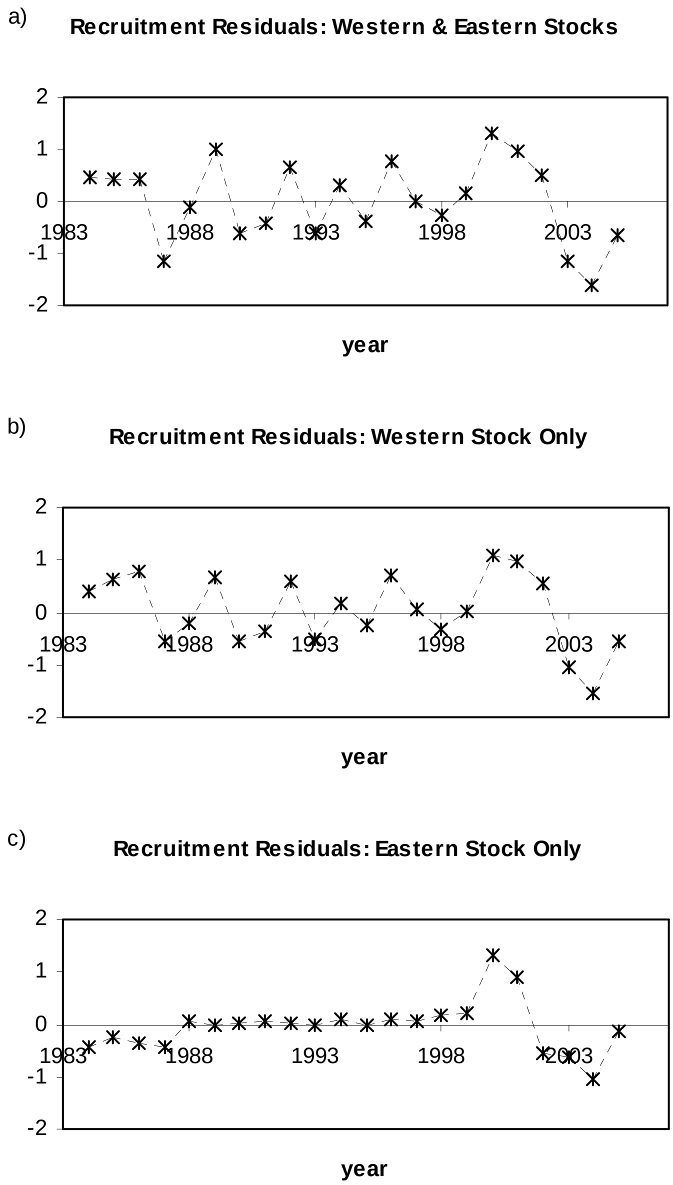

Figure 8*. The recruitment residuals for the case where the model is fit to the November 1+ biomass for the "Western" and "Eastern" stocks together with the "Western" stock May recruitment numbers from the area west of Cape Infanta. Residuals are shown for a) the case where the same recruitment residuals are assumed for both stocks, and the case where separate recruitment residuals are estimated for b) the "Western" stock and c) the "Eastern" stock.*