An alternative method to estimate the contribution of south coast spawning to west coast sardine recruitment

C.L. de Moor*

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

Background

A small proportion of sardine eggs spawned on the south coast have been shown to be successfully transported in model simulations to a pre-defined west coast nursery area (Miller et al. 2006, Coetzee 2014). All analyses to date that consider this possible contribution of south coast spawning to west coast sardine recruitment, assume that the proportion informed by Miller *et al*. (2006) equates to the proportion of south coast spawner biomass (B^{sp}) that forms part of the west coast "effective spawner biomass", where stock-recruitment relationships assume recruitment is related to the effective B^{sp}. In contrast, this document considers the proportion informed by Miller *et al.* (2006) to equate to the proportion of recruitment resulting from south coast spawning that subsequently moves to and forms part of the west coast recruitment as observed by the time of the May recruit surveys.

Data

The data available for these analyses are model estimates at the joint posterior mode of the B^{sp} and recruitment for the west coast and south coast from the two mixing stock hypothesis for South African sardine that does not assume a stock-recruitment relationship within the model (de Moor 2016a).

It is important to consider these south coast "data" in the likelihood so as to avoid choices for the proportion moving, p, that result in an improved fit to the west coast "data", while ignoring the consequent resultant fit on the south coast. As a simple extreme example, some results in Figure A.3 of Butterworth (2016) suggest the best choice for p would be 1, when the consequent result of $p = 1$ would be that the south coast "data" are completely mis-fit as south coast recruitment could not be assumed to arise from a zero south coast effective B^{sp}.

While the model estimates B^{sp} and recruitment from November 1983 to 2014, the November recruitment should be best informed in years for which the model is provided with a hydroacoustic survey estimate of recruitment in the following May. The analyses in this document therefore consider recruitment from November 1984 to 2014 (31 years) for the west coast, and recruitment from November 1993 to 2014, with the exclusion of 1996, 2007, 2010 and 2011

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

(18 years) for the south coast. Sensitivity of these results to the exclusion of 1984 and/or 1985 west coast “data”, given these are initial years in the assessment model, has not (yet) been run.

Methods

The method outlined by Butterworth (2016) is used, but is adapted to estimate stock-recruitment relationships for both the west and south coasts, and to consider data from both coasts in the likelihood. Given time constraints, only the generalised model is considered here:

$$R_{s,y}^{mod} = \frac{\alpha_s B_{s,y}^{sp}}{1 + \frac{\alpha_s}{\beta_s}\left(B_{s,y}^{sp}\right)^{\gamma_s}}$$

where α_s, β_S, and γ_S are sub-stock dependent estimable parameters, and $B_{s,y}^{sp}$ denotes the model estimated spawner biomass from sub-stock s, during November of year y. Letting p denote the proportion of recruits from south coast spawning that contribute to west coast recruitment and assuming the residuals are log-normally distributed, the negative log-likelihood is given by:

$$-lnL = \sum_y \left(\begin{array}{l} ln\sigma_{west,y} + \dfrac{\left(lnR_{west,y}^{Assment} - ln\left(R_{west,y}^{mod} + pR_{south,y}^{mod}\right)\right)^2}{2\sigma_{west,y}^2} \\ +ln\sigma_{south,y} + \dfrac{\left(lnR_{south,y}^{Assment} - ln\left((1-p)R_{south,y}^{mod}\right)\right)^2}{2\sigma_{south,y}^2} \end{array} \right)$$

where $R_{west/south,y}^{Assessment}$ denotes the assessment model estimated recruitment west/south of Cape Agulhas, and:

$$\begin{array}{ll} \sigma_{west,y} & \begin{cases} \sigma_{1,peak} & if\ 2000 \le y \le 2004 \\ \sigma_1 & otherwise \end{cases} \\ \sigma_{south,y} & \qquad\qquad \sigma_2 \end{array} .$$

Closed form equations are available for the maximum likelihood estimates for the σ parameters as follows, with $Y = \{1984, \ldots, 1999, 2005, \ldots, 2015\}$:

$$\sigma_1 = \sqrt{\frac{1}{n}\sum_{y \in Y}\left(lnR_{west,y}^{Assment} - ln\left(R_{west,y}^{mod} + pR_{south,y}^{mod}\right)\right)^2}$$

$$\sigma_{1,peak} = \sqrt{\frac{1}{n}\sum_{00 \le y \le 04}\left(lnR_{west,y}^{Assment} - ln\left(R_{west,y}^{mod} + pR_{south,y}^{mod}\right)\right)^2}$$

$$\sigma_2 = \sqrt{\frac{1}{n}\sum_{y \in Y}\left(lnR_{south,y}^{Assment} - ln\left((1-p)R_{south,y}^{mod}\right)\right)^2}.$$

Results

Figure 1 shows the likelihood profile over alternative fixed values for p. Figure 2 shows the estimated stock-recruitment relationship for $p = 0$, $p = 0.5$, and $p = 0.85$. Finally using the Akaike weighting method of the Appendix in Butterworth (2016), Figure 3 shows the histogram for p, calculated using the 20 mid-points of the bins plotted for two illustrative prior distributions for p.

Discussion

The likelihood profile from this generalised model suggests a high (~85%) proportion of recruits spawned on the south coast contribute to west coast recruitment, while the extreme as $p \to 1$ is given a low weight. The stability of this method may need to be further considered in that γ_s needed to be restricted for higher p values to ensure "reasonable" shapes for the stock-recruitment functions.

Figure 2 (particularly the lower plots) clearly shows there is a high degree of variability about any stock recruitment relationship for sardine, with $\sigma_1 \sim 0.7$, $\sigma_{1,peak} \sim 2.0$ and $\sigma_2 \sim 1.4$ for the three alternatives plotted. This is typical of such small pelagic species. However, this "inability" for alternative stock-recruitment relationships to more closely reflect annual recruitment raises a question about how reliably these "data" can be used to *quantitatively* inform amongst alternative proportions p. This in contrast to, for example, using negative log likelihood values to quantitatively compare between model fits to survey data (e.g. Figure 4). In particular, how much weight should one afford such comparisons between alternative proportions p based on such "data", compared to methods external to assessment models which may be able to more directly estimate such proportions (e.g. Miller et al. 2006, van der Lingen et al. 2016)?

Miller et al. (2006) also demonstrated a very small (2%) proportion of eggs spawned on the west coast could be successfully transported to their pre-defined south coast nursery area. This contribution to south coast recruitment from west coast spawning was ignored in these analyses, as it was expected to have only a small impact. However, the above analyses could easily be extended to include the proportion of west coast spawning products resulting in recruits on the south coast.

While this analysis has been based on estimates of B^{sp} and recruitment at the joint posterior mode of de Moor (2016a), it may be more prudent to repeat the analysis based on the posterior medians once available.

References

Butterworth, D.S. 2016. An Assignment of Probabilities to Alternative Assumptions concerning the Contribution of Sardine Spawning Biomass on the South Coast to Recruitment on the West Coast. Department of Agriculture, Forestry and Fisheries Document FISHERIES/2016/NOV/SWG-PEL/66. Also **MARAM/IWS/DEC16/Sardine/P9**.

Coetzee, J.C. 2014. Potential indicators of the effective spawning biomass derived from the proportion of eggs transported to or retained in either a west coast or south coast nursery area. Department of Agriculture, Forestry and Fisheries Document FISHERIES/2014/AUG/SWG-PEL/49.

de Moor, C.L. 2016a. The two mixing stock hypothesis for South African sardine without an assumed stock-recruit relationship. Department of Agriculture, Forestry and Fisheries Document FISHERIES/2016/NOV/SWG-PEL/57. Also **MARAM/IWS/DEC16/Sardine/P5**.

de Moor, C.L. 2016b. An alternative two mixing stock hypothesis for South African sardine. Department of Agriculture, Forestry and Fisheries Document FISHERIES/2016/OCT/SWG-PEL/45. Also **MARAM/IWS/DEC16/Sardine/P4**.

Miller, D.C.M., Moloney, C.L., van der Lingen, C.D., Lett, C., Mullon, C., and Field, J.G. 2006. Modelling the effects of physical–biological interactions and spatial variability in spawning and nursery areas on transport and retention of sardine *Sardinops sagax* eggs and larvae in the southern Benguela ecosystem. *Journal of Marine Systems* 61: 212–229.

van der Lingen, C.D., Coetzee, J.C., and McGrath, A. 2016. Data for informing the choice of a prior for the contribution of South Coast spawner biomass to West Coast recruitment. Department of Agriculture, Forestry and Fisheries Document FISHERIES/2016/NOV/SWG-PEL/58. Also **MARAM/IWS/DEC16/Sardine/P8**.

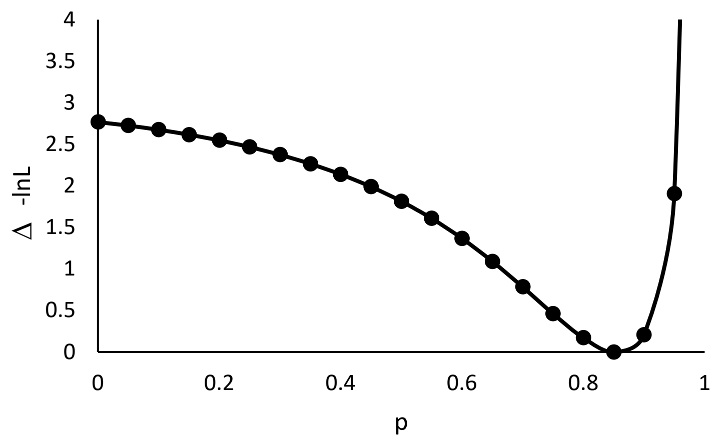

Figure 1. The negative log-likelihood profile for p, where $\Delta - lnL$ denotes the difference between the –lnL for each given p value and the minimum –lnL over all p values.

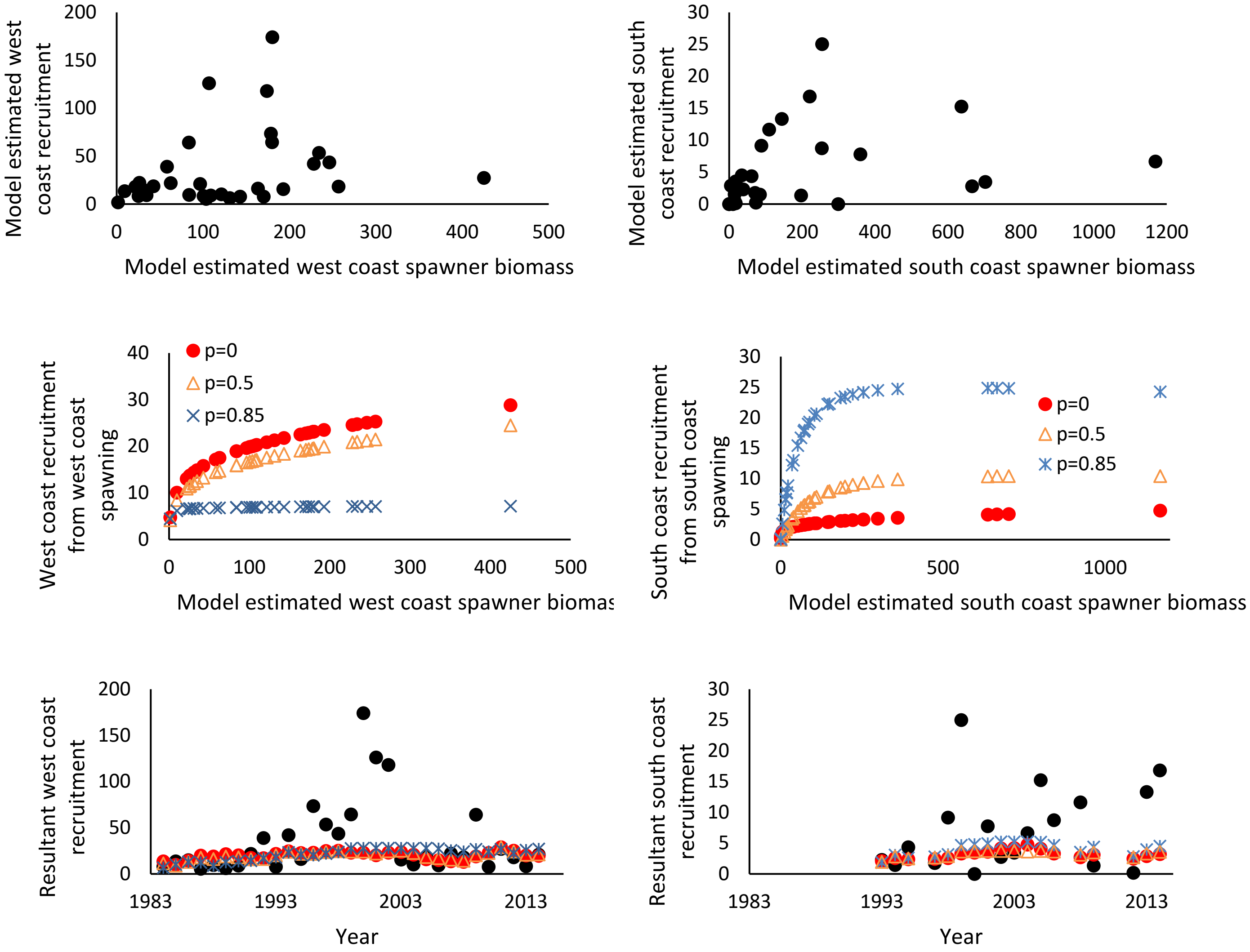

Figure 2. The assessment model estimated B^{sp} and recruitment (top row), the estimated recruitment from B^{sp} on each coast for three p values (middle row), and a comparison between the resultant recruitment to each coast and the assessment model estimated recruitment (lower row). The lower plots only show recruitment for the years for which a corresponding May hydroacoustic survey estimate of recruitment is available.

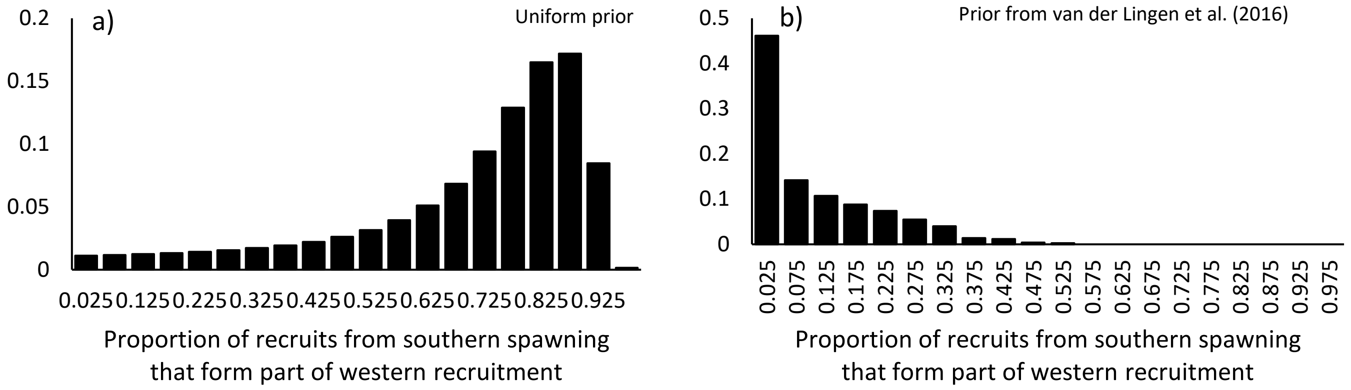

Figure 3. Historgrams for p calculated using Akaike weights assuming a) a uniform prior distribution for p, and b) a prior distribution for p from van der Lingen et al. (2016).

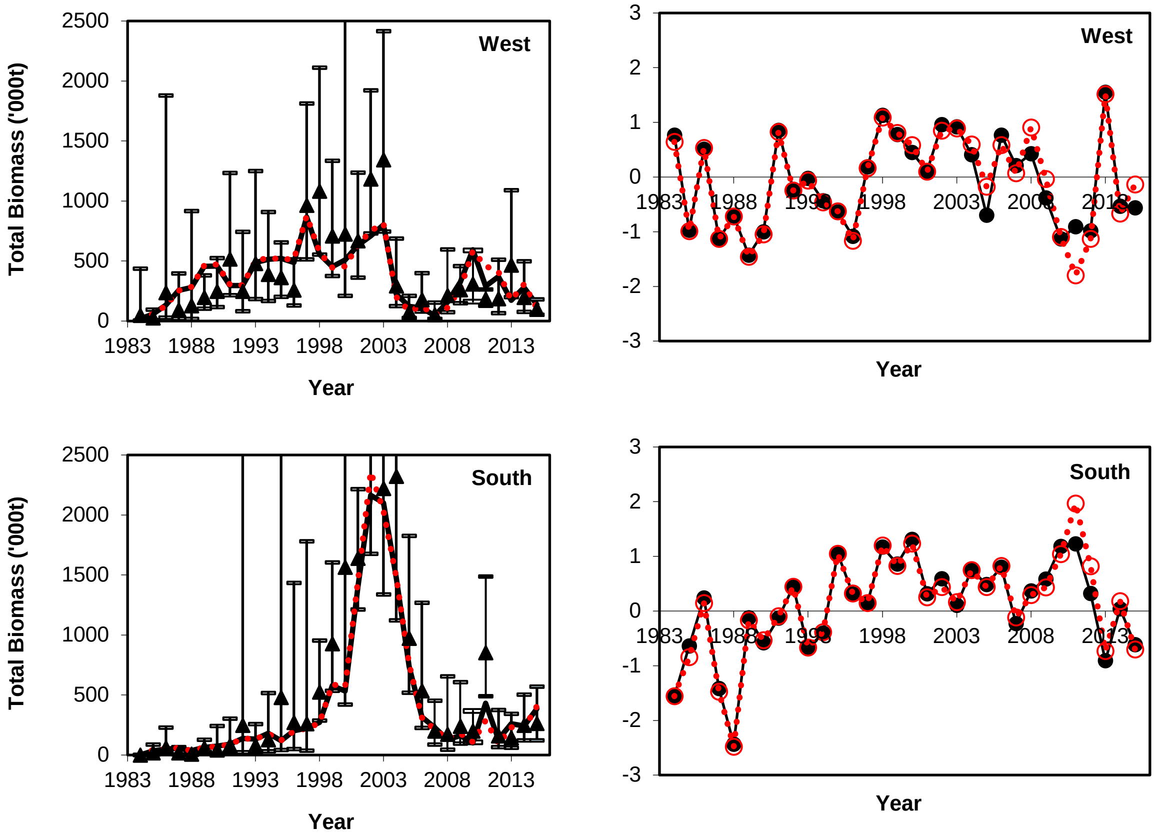

Figure 4 [Figure 1 of de Moor 2016]. Acoustic survey estimated and model predicted November sardine total biomass from 1984 to 2015 for the two mixing stock hypothesis with no south coast contribution to west coast effective spawning (red dotted lines) and with variable south coast contribution to west coast effective spawning (black solid lines). The observed indices are shown with 95% confidence intervals. The standardised residuals from the fits are given in the right hand plots.