Recruitment to the south component of South African sardine

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A new model for simulating future recruitment to the south component of South African sardine is recommended. This model simply assumes recruitment fluctuates about one of two levels, independent of south component spawner biomass.

Introduction

Future recruitment to the south component of South African sardine has previously been modelled based on the hockey-stick stock recruitment relationship with lognormal deviations about that relationship (de Moor 2016, 2017). Here an alternative function for simulating future south component recruitment, which is independent of spawning biomass, is considered.

Method

The methods described here were based on fitting relationships to the historical south component spawner biomass ($SSB_{s,y}$) and recruitment ($N_{s,y}$) estimates from the sardine assessment model without an assumed stock-recruitment relationship during conditioning (de Moor 2016, 2018). Projections are simulated assuming no future catch.

Hockey-stick stock recruitment model:

For simulation i,

$$N_{s,y}^{pred,i} = \begin{cases} a_s^i & if\ SSB_{s,y}^i \geq b_s^i \\ \frac{a_s^i}{b_s^i} SSB_{s,y}^i & if\ SSB_{s,y}^i < b_s^i \end{cases}, \text{ for } 1984 \leq y \leq 2014 \tag{H1}$$

parameter a_s^i was estimated by minimising: $-lnL_j = \sum_{y=1984}^{2014}\left[\ln(\sigma_s^i) + \frac{\left(ln(N_{s,y}^i) - ln\left(N_{s,y}^{pred}\right)\right)^2}{2\left(\sigma_s^i\right)^2}\right]$. (H2)

where $\sigma_s^i = \frac{1}{31-1}\sum_{y=1984}^{2014}\left(ln(N_{s,y}^i) - ln\left(N_{s,y}^{pred,i}\right)\right)^2$ (H3)

and, given the lack of data to reliably estimate the hinge point, it was fixed at 1% of carrying capacity:

$$b_s^i = 0.01 \times K_s^i = 0.01 \times a_s^i \left(\sum_{a=1}^{4}\left(w_{s,y,a}^i f_{s,y,a}^i e^{-M_0-(a-1)M_a}\right) + w_{s,y,5+}^i f_{s,y,5+}^i \frac{e^{-M_0-4M_{5+}}}{1-e^{-M_{5+}}}\right) \tag{H4}$$

Future recruitments to the south component were generated as follows:

$$N_{s,y}^{pred,i} = \begin{cases} a_s^i e^{0.9\times\varepsilon_{s,y}^i} & if\ SSB_{s,y}^i \geq b_s^i \\ \frac{a_s^i}{b_s^i} SSB_{s,y}^i e^{0.9\times\varepsilon_{s,y}^i} & if\ SSB_{s,y}^i < b_s^i \end{cases} \tag{H5}$$

where

$$\varepsilon_{s,y}^i = s_{s,cor}^i \varepsilon_{s,y-1}^i + \omega_{s,y}^i\sqrt{1-\left(s_{s,cor}^i\right)^2}, \text{ where } \omega_{s,y}^i \sim N(0,1). \tag{H6}$$

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Two-step model:

The "two-step" model was originally designed based on the observation that recruitment to the south component has historically been mostly low, but was occasionally relatively high (Figure 1). For simulation i, having reordered $N_{s,y}^{i}$, $1984 \leq y \leq 2014$ into ascending order $N_{s,t}^{i}$, $1 \leq t \leq N = 31$:

$$R_1^i = \frac{\sum_{\forall t<p^iN} ln\left(N_{s,t}^i\right)}{p^iN} \qquad \text{(S1)}$$

$$R_2^i = \frac{\sum_{\forall t\geq p^iN} ln\left(N_{s,t}^i\right)}{(1-p^i)N} \qquad \text{(S2)}$$

parameter p^i was estimated by minimising: $\sum_{\forall t<p^iN}\left(ln\left(N_{s,t}^i\right) - R_1^i\right)^2 + \sum_{\forall t\geq p^iN}\left(ln\left(N_{s,t}^i\right) - R_2^i\right)^2$. (S3)

Calculate $\sigma_1^i = \sqrt{\left(\frac{1}{p^iN-1}\right)\sum_{\forall t<p^iN}\left(ln\left(N_{s,t}^i\right) - R_1^i\right)^2}$ (S4)

and $\sigma_2^i = \sqrt{\left(\frac{1}{(1-p^i)N-1}\right)\sum_{\forall t\geq p^iN}\left(ln\left(N_{s,t}^i\right) - R_2^i\right)^2}$ (S5)

Future recruitments to the south component were generated as follows:

$$ln\left(N_{s,y}^{pred,i}\right) = \begin{cases} u_1^i + \epsilon_{1,y}^i & if\ \varepsilon_y^i < p^i \\ u_2^i + \epsilon_{2,y}^i & if\ \varepsilon_y^i \geq p^{i}, \end{cases} \qquad \text{(S6)}$$

where $\varepsilon_y^i \sim Random[0,1]$, $\epsilon_{1,y}^i \sim N\left(0, {\sigma_1^i}^2\right)$ and $\epsilon_{2,y}^i \sim N\left(0, {\sigma_2^i}^2\right)$ (S7)

These future recruitments were bounded to be within the range historically estimated by either (i) redrawing when outside the historical range, or (ii) setting estimates that are too low/high to the historical minimum/maximum.

Results and discussion

There is little clear relationship between recruitment to the south component and its spawner biomass (Figure 2). A hockey stick stock recruitment relationship has previously been used to mimic the lack of dependence of recruitment on spawner biomass, except for the assumption that at a very low level of spawner biomass (1% of carrying capacity), recruitment would be expected to be impaired. Variability about this relationship was thus estimated to be extremely high (median σ_s^i = 3.76) when no stock-recruitment relationship was assumed during conditioning, with the resultant large inter-annual changes in south component recruitment influenced (mostly) by the estimates of recruitment from surveys east of Cape Infanta used during conditioning. The same assumption of a constant (for all simulations) variability about the stock recruitment curve has been made for the south component as that made for the west component (Bergh 2018). However, even if the variability was increased substantially, the future simulated recruitments did not adequately reflect the range of that observed historically (Table 1). Given a stock-recruitment relationship, one would typically expect the range to be dependent on predicted spawner biomass. However, it was assumed reasonable to ignore that dependence in this comparison given the relatively low hinge point assumed for the south component.

By fitting the two-step model in log-space (as detailed above) instead of in normal-space, the recruitment was estimated to be low about 30% of the time, compared to about 80% of the time had normal-space been used (Figure 3).

When using the two-step model for south component recruitment, the distribution of future recruitments better matched that historically estimated when values that were below/above the historical minimum/maximum were set at the minimum/maximum rather than redrawing from the distribution (Table 1, Figure 4). The projections allow for a full range of possible recruitment values each year, in contrast to the historical estimates with substantially varying upper and lower percentiles. Despite this, however, and informed by the percentiles of Table 1, the OMP Task Team recommends the two-step model with future recruitments bounded to the historical minimum/maximum be used for simulating future recruitment to the south component of South African sardine.

Acknowledgements

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References

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Table 1. The historical and simulated future percentiles of recruitment to the south component over all years and simulations, based on the hockey-stick model with (i) $\sigma_S^i = 0.9$ and (ii) $\sigma_S^i = 2.0$, and the two-step model with draws outside the historical range either (i) redrawn or (ii) set equal to the historical minimum/maximum.

	Historical	Hockey-stick (i)	Hockey-stick (ii)	Two-step (i)	Two-step (ii)
1%ile	0.0001	0.03	0.003	0.0001	0.0000
5%ile	0.001	0.06	0.01	0.0003	0.0003
10%ile	0.005	0.09	0.02	0.001	0.001
25%ile	0.58	0.16	0.08	0.02	0.01
50%ile	2.63	0.32	0.33	1.08	1.32
75%ile	8.69	0.63	1.30	4.07	4.32
90%ile	17.09	1.17	4.39	9.57	12.23
95%ile	23.52	1.67	9.10	13.93	21.73
99%ile	24.35	3.52	35.72	21.15	24.53
Average	5.71	0.54	2.49	3.11	3.88

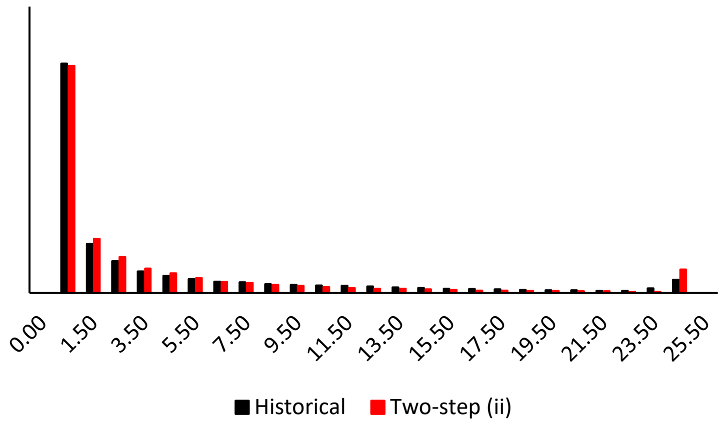

Figure 1. The histogram of historically estimated south component recruitment (de Moor 2018).

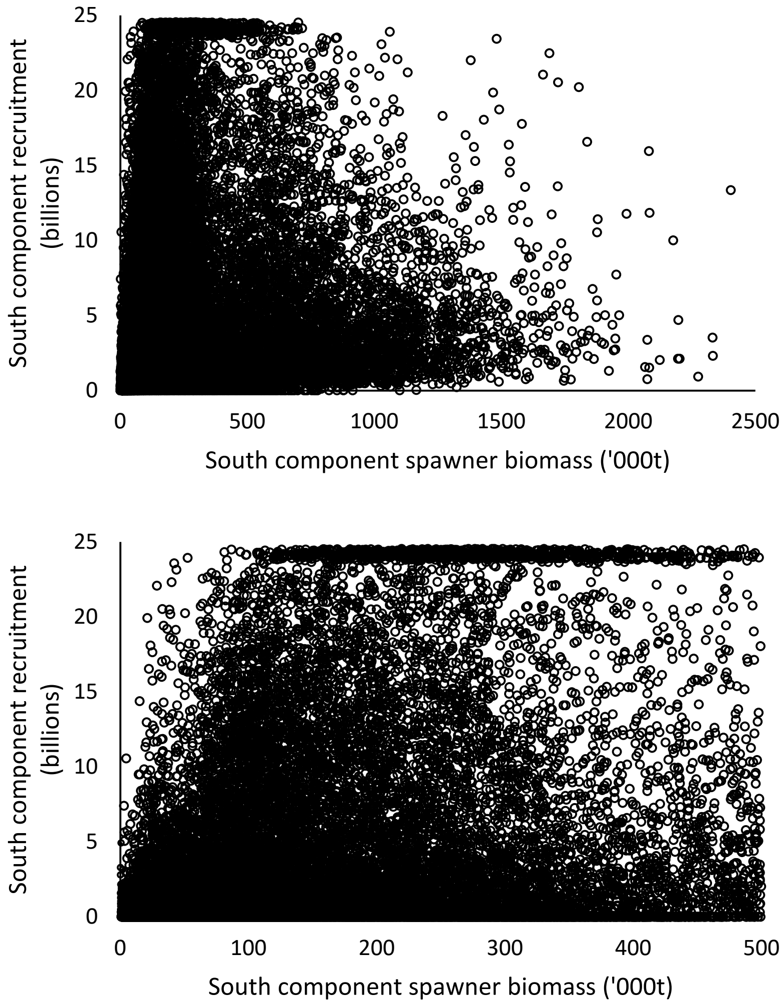

Figure 2. The distribution of historically estimated south component spawner biomass and recruitment over all years and simulations (de Moor 2018). The lower panel is a repeat of the upper panel, but with a smaller horizontal axis range.

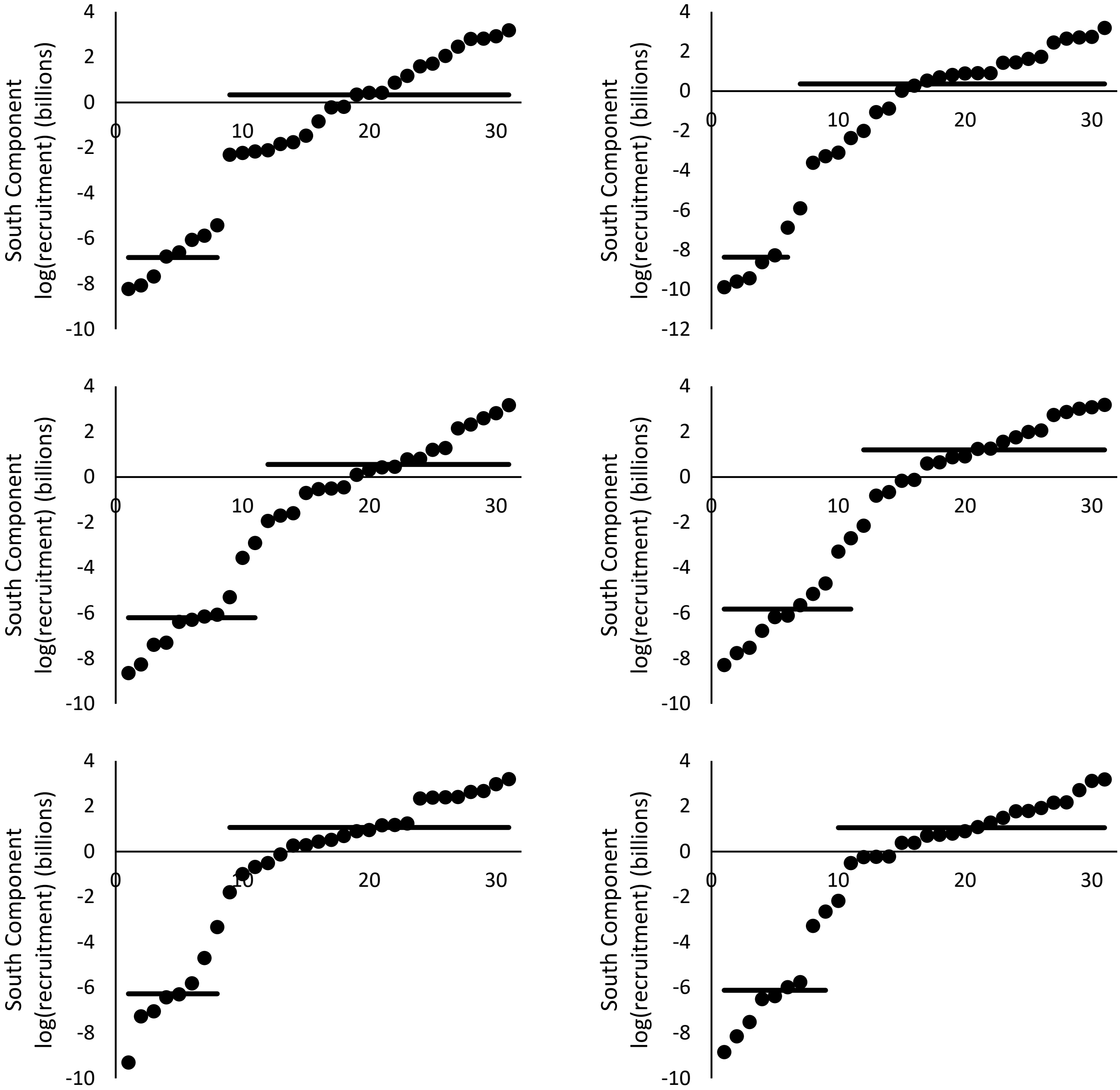

Figure 3. The historical log(recruitments) to the south component plotted in increasing order, with the estimated two-step model for the first 6 simulations.

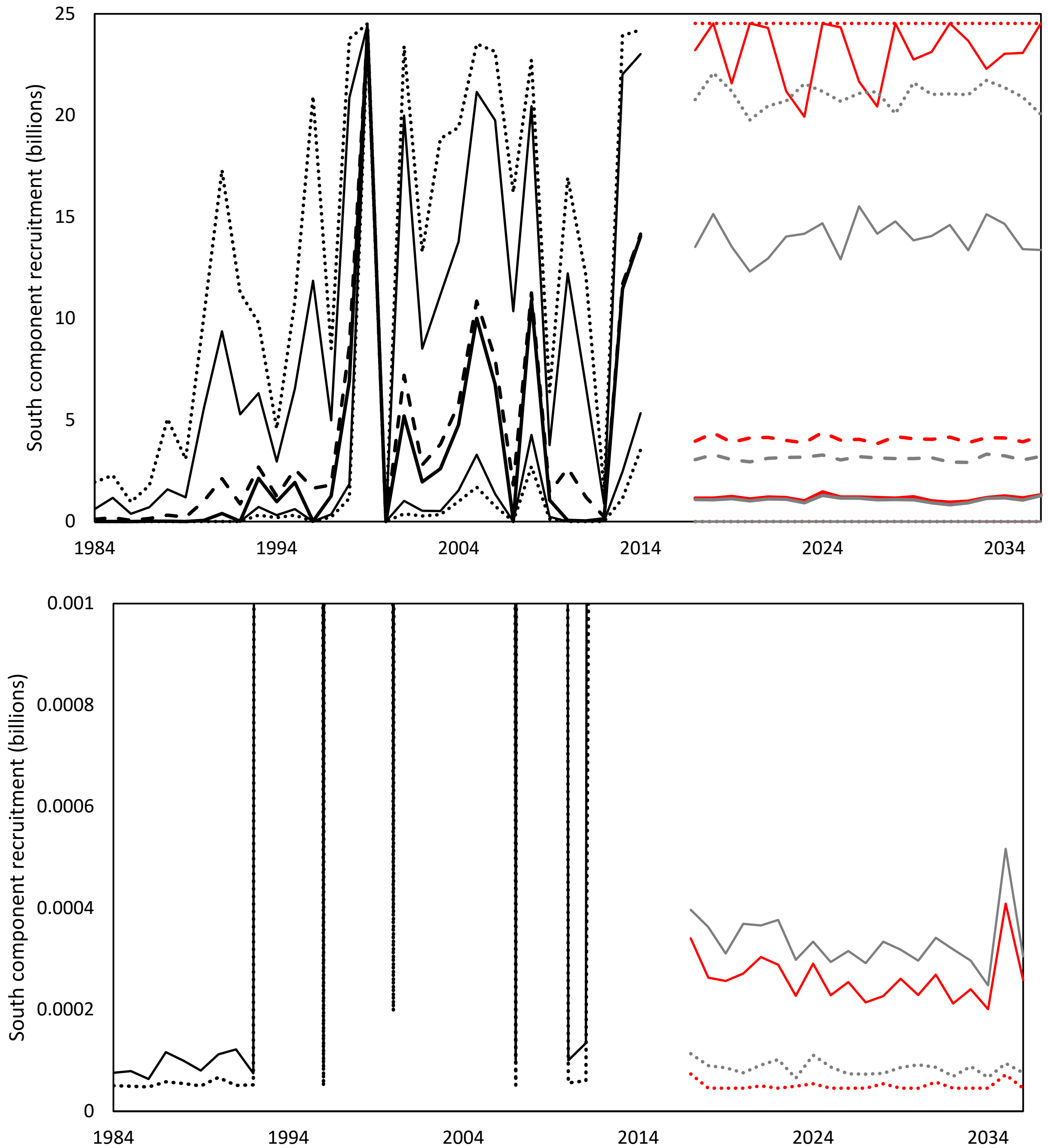

Figure 4. The median (dark line), average (dashed line), 90%ile (thin line) and 98%ile (dotted line) of historically estimated and predicted recruitment to the south component, using the two-step model with values outside the historically estimated range either (i) redrawn (grey lines) or (ii) set equal to the historical minimum/maximum (red lines). The lower plot is a repeat of the top plot, but over a smaller range for the vertical axis to show the lower %iles.