An alternative relationship to determine future movement of sardine recruits between the "west" and "south" stocks

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Introduction

de Moor and Butterworth (2013a) explored some possible relationships between the proportion of "west" stock recruits moving to the "south" stock and "west" or "south" stock 1+ biomass or recruitment. A relationship based on the ratio of "south" to "west" stock 1+ biomass in the previous November was used for initial testing of Candidate Management Procedures under a two stock sardine hypothesis.

Jarre et al. (2013) have suggested that the proportion of "west" stock recruits moving to the "south" stock may increase or decrease with time depending on whether a "favourable" or "unfavourable" environment exists south of Cape Agulhas.

A model which assumes that there are two possible regimes, each with its own "equilibrium" proportion of "west" stock recruits moving to the "south" stock, has been fit to historic data. The model thus allows the predicted proportion of "west" stock recruits moving to the "south" stock, $move_y$, to approach an equilibrium level (either $\overline{move_1}$ or $\overline{move_2}$) asymptotically via a geometric series:

$move_y - \overline{move_1} = a \times \left(move_{y-1} - \overline{move_1}\right)$ for $1994 \le y < 2003$ and $y \ge 2009$, so that

$move_y = a \times move_{y-1} + \overline{move_1} \times (1-a)$ for $1994 \le y < 2003$ and $y \ge 2009$, and similarly

$move_y = a \times move_{y-1} + \overline{move_2} \times (1-a)$ for $2004 \le y < 2009$

The choice of years in which a new regime was modeled to begin was based on those reported by Jarre et al. (2013) which were based on an application of the STARS method to a time series of upwelling for Cape Agulhas (Blamey et al., 2012).

This model is assumed to predict annual movement up to a random adjustment $\varepsilon_y \sim N\left(0, \sigma^2\right)$. To ensure that after taking random adjustment into account, future proportions remain between 0 and 1, the model is fit in logit space. The parameters $0 \le \overline{move_1} \le 1$, $0 \le \overline{move_2} \le 1$, a, $0 < move_{1984} \le 1$ and $\sigma > 0$ are thus estimated by minimizing the negative log likelihood:

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$$-\ln L = \sum_{y=1984}^{2011} \left\{ \frac{1}{2}\ln(2\sigma^2\pi) + \frac{\left(\log it\left(move_y\right) - \log it\left(move_y^{obs}\right)\right)^2}{2\sigma^2} \right\}.$$

This model is fit to two different sets of "observations", $move_y^{obs}$, being i) the time series of estimated proportion moving at the joint posterior mode (de Moor and Butterworth, 2013a), and ii) the time series of annual medians of the posterior distributions of proportions moving (de Moor and Butterworth, 2013a, extended with results for the full posterior distribution).

Results of Model Fits

When the model is fit to the estimated proportions moving at the joint posterior mode, the model parameters are estimated as being $\overline{move_1} = 1.00$, $\overline{move_2} = 0.19$, $a = 0.87$, $move_{1984} = 0.04$ and $\sigma = 0.89$ (Figure 1a). When it is fit instead to the estimated medians of the posteriors for the proportions moving, the model parameters are estimated as being $\overline{move_1} = 1.00$, $\overline{move_2} = 0.08$, $a = 0.91$, $move_{1984} = 0.23$ and $\sigma = 0.57$ (Figure 1b). The reasons for the difference in the lower equilibrium level is primarily because the proportions moving in 1994-1996 estimated at the joint posterior mode lie in the tails of the posterior distributions (Figure 2).

Future Projections

The model above can then be used in the underlying operating model of the two stock sardine hypothesis when simulation testing Candidate Management Procedures (de Moor and Butterworth 2013b). Given that an increasing regime is assumed to have begun in 2009, this is assumed to continue at the beginning of the projection period from 2012, using the model estimated movement in 2011 for each random draw from the posterior distribution (Figure 2).

A switch to a new regime shift is assumed to occur as follows:

i) Randomly draw $Y \in \{1,2,3\}$. A regime change (to equilibrium $\overline{move_2}$) is modeled to occur in year 2012+Y years (i.e. between 5 to 7 years from 2009).

ii) Randomly draw $X \in \{5,6,7\}$. A regime change is modeled to occur after another X years.

iii) Step ii) is repeated until the final projection year (2032) is reached.

The future proportion of "west" stock recruits moving to the "south" stock is thus given by:

Model i):

$$move_y = \frac{\exp\left\{\ln\left(\frac{move_y^*}{1-move_y^*}\right)+\xi_y\right\}}{1+\exp\left\{\ln\left(\frac{move_y^*}{1-move_y^*}\right)+\xi_y\right\}}, \text{ where } \xi_y \sim N\left(0, 0.89^2\right).$$

$move_y^* = 0.8666 move_{y-1}^* + 1.000 \times (1-0.8666)$ during an increasing regime

$move_y^* = 0.8666 move_{y-1}^* + 0.1856 \times (1-0.8666)$ during a decreasing regime

Model ii):

$$move_y = \frac{\exp\left\{\ln\left(\frac{move_y^*}{1-move_y^*}\right)+\xi_y\right\}}{1+\exp\left\{\ln\left(\frac{move_y^*}{1-move_y^*}\right)+\xi_y\right\}}, \text{ where } \xi_y \sim N\left(0, 0.57^2\right).$$

$move_y^* = 0.9051 move_{y-1}^* + 1.000 \times (1-0.9051)$ during an increasing regime

$move_y^* = 0.9051 move_{y-1}^* + 0.076 \times (1-0.9051)$ during a decreasing regime

Results of Future Projections

The range of future projected movement of "west" stock recruits to the "south" stock is plotted in Figure 3, assuming no future catch. Options of assuming only a favourable south coast environment (movement increasing to the maximum equilibrium level) or only an unfavourable south coast environment (movement decreasing to the minimum equilibrium level) have been run to bound potential extremes. The models developed in this document result in oscillating patterns of future movement (Figure 3b,c), which reach higher and lower proportions than that for the model which assumes movement is related to the ratio of "south" to "west" stock 1+ biomass (Figure 3a).

Although the lower equilibrium level is estimated to be lower when the model is fit to the posterior medians (model ii)) compared to the values at the joint posterior mode (model i)), the future projected proportions do not go much lower under model ii) (Figure 3c) compared to model i) (Figure 3b).

References

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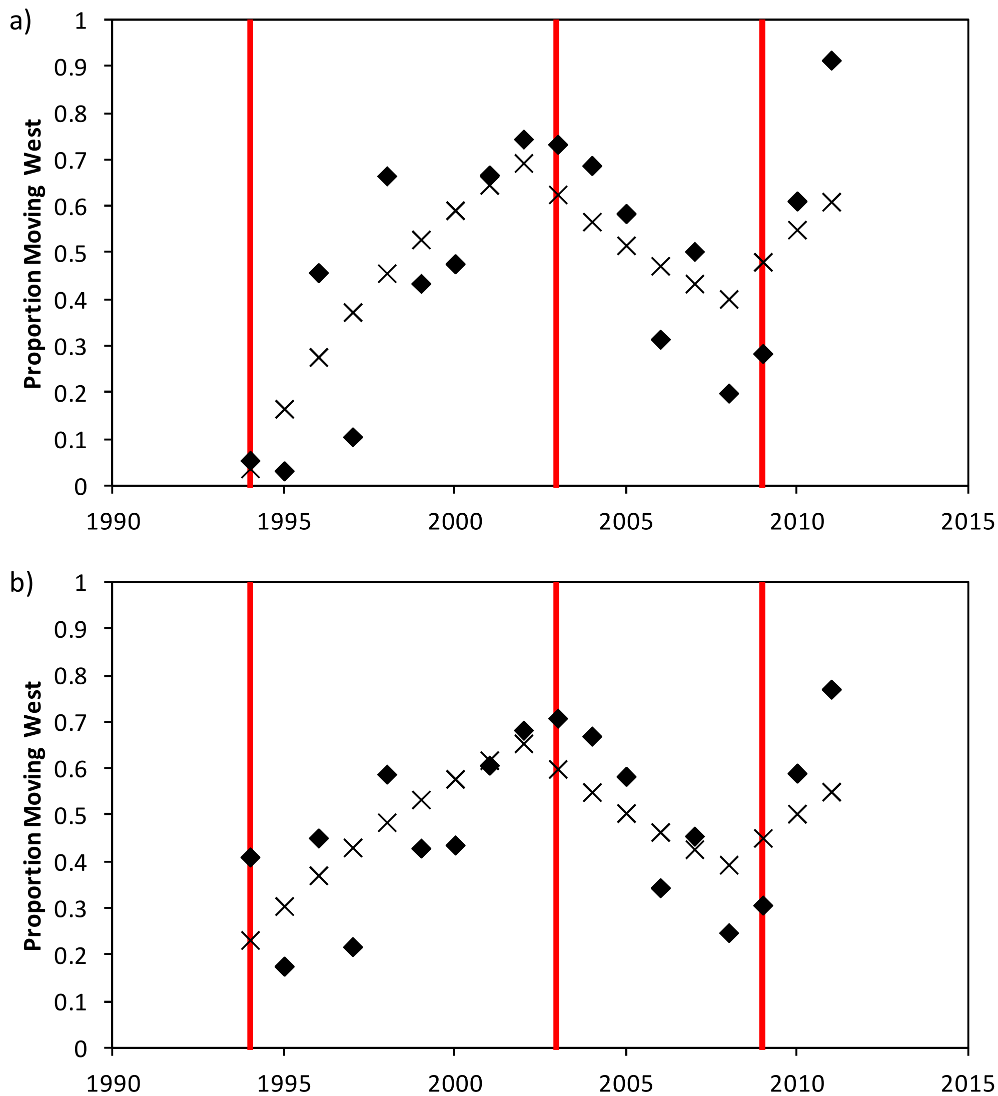

Figure 1. The annual proportion of "west" stock recruits moving to the "south" stock as estimated a) at the joint posterior mode and b) the median of the posterior distributions by de Moor and Butterworth (2013a) (♦) and without the annual random adjustment as then estimated by the model in this document (×). The vertical lines indicate the years in which a new regime is assumed to begin.

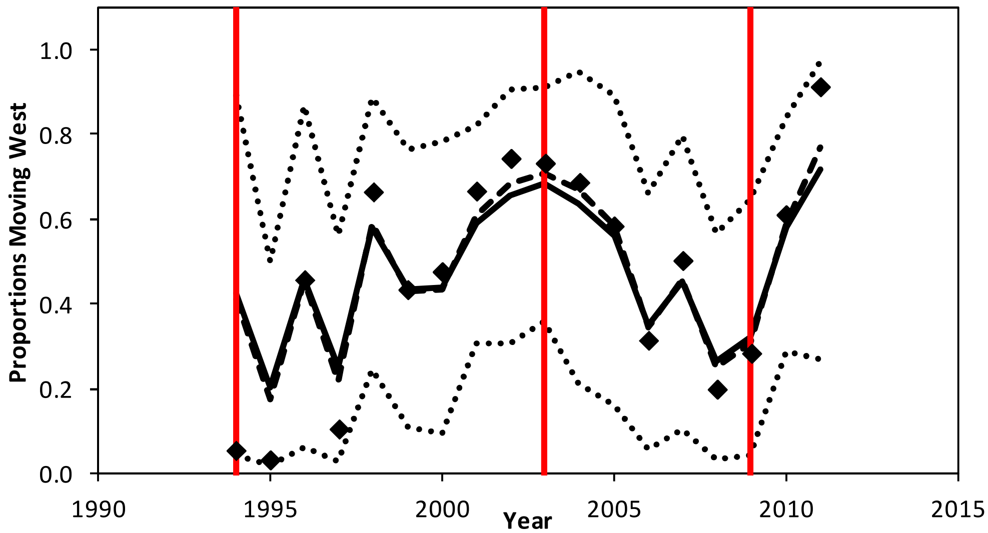

Figure 2. The average (solid line), median (dashed line) and 90% probability intervals for the proportion of "west" stock recruits moving to the "south" stock (de Moor and Butterworth, 2013a extended with results for the full posterior distribution), shown against the proportions estimated at the joint posterior mode (solid diamonds). The vertical lines indicate the years in which a new regime is assumed to begin.

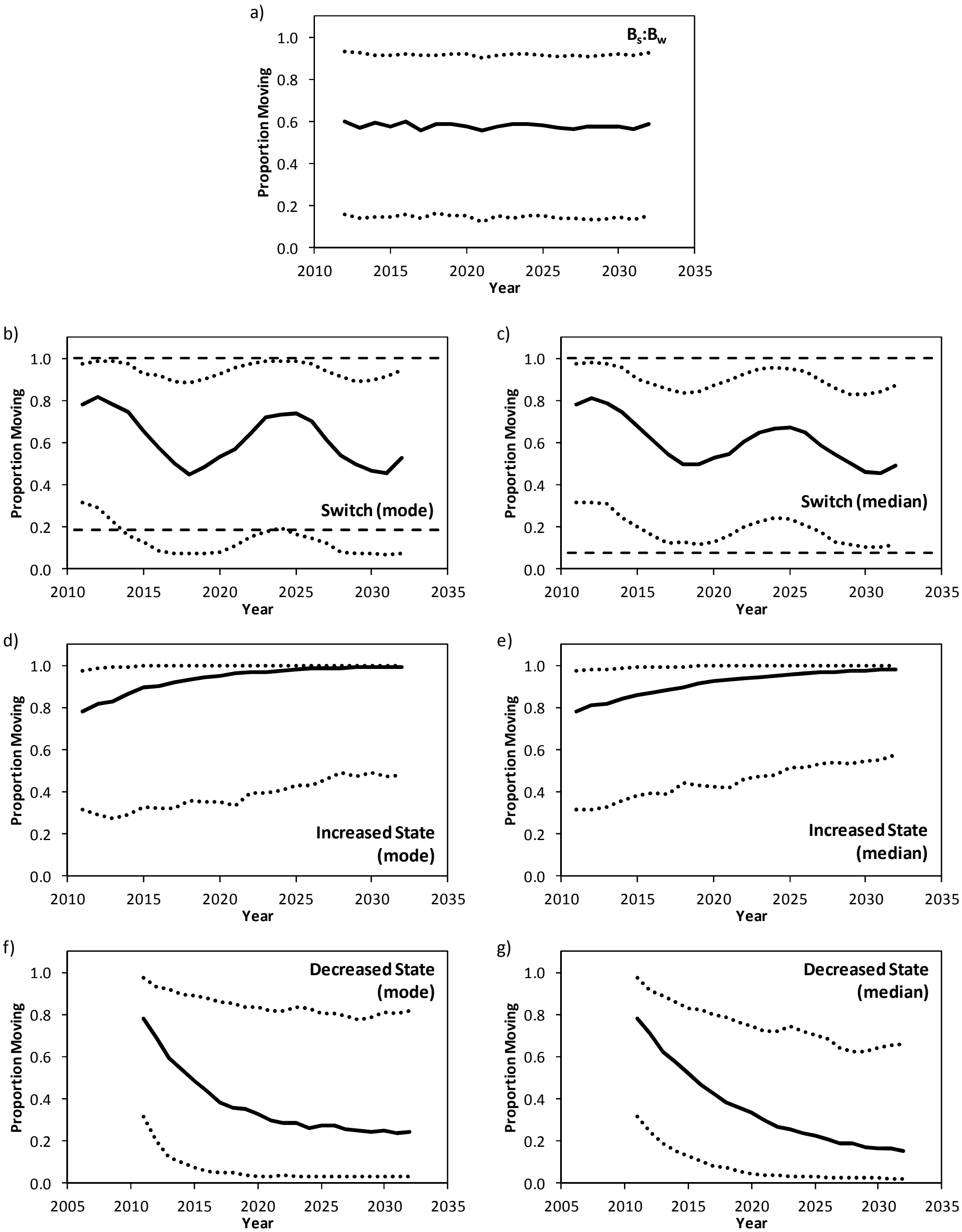

Figure 3. The median and 90% probability interval of future projected proportions of "west" stock recruits moving to the "south" stock under a no catch scenario, but assuming different movement relationships: a) the relationship with the ratio of "south" to "west" stock 1+ biomass in the previous year (de Moor and Butterworth 2013a), b) the model allowing for switches between favourable/unfavourable south coast environment based on model i), c) the model allowing for switches between favourable/unfavourable south coast environment based on model ii), d) assuming no future switch to an unfavourable environment based on model i), e) assuming no future switch to an unfavourable environment based on model ii), f) assuming a future unfavourable environment based on model i), and g) assuming a future unfavourable environment based on model ii).