Scoping MSE for South African sardine

C.L. de Moor[*]

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

This document details the Operating Model (OM) used for the scoping MSE for South African sardine, based largely on the updated assessment of the revised two stock hypothesis.

Keywords: management strategy evaluation, operating model, sardine, scoping MSE, South Africa

Introduction

A sardine-only 'scoping MSE' was undertaken as a pre-cursor to the next joint sardine-anchovy Management Strategy Evaluation (MSE) as a means to provide some indication of future levels of harvest which will meet management objectives given the substantial revision to the South African sardine stock structure hypothesis (e.g. de Moor *et al*. 2023) which has occurred since the previous OMP (de Moor 2018). This document provides the details of the Operating Model for the sardine-only scoping MSE as this is used for some of the projections provided by Primary Documents to the International Stock Assessment Workshop. One Candidate Management Procedure that is also used by the Primary Documents is also described.

MSE Operating Model

The Operating Model is detailed in the Appendix, based largely on the recent assessment of sardine (de Moor 2025a, updated by de Moor 2025b). This OM does not simulate future recruitment pulses in WTS; this will be included in the joint sardine-anchovy MSE. This model currently assumes the future proportion of Warm Temperate Sardine (WTS) 0-year-olds which move from the west to the south coast, and the proportion of WTS recruitment which recruit to the west coast is drawn randomly from the estimates for the most recent 10 years (Table A1). Alternative models, such as a dependence of movement on WTS biomass may be considered in future results.

Unless noted otherwise, future bycatches and catch patterns have been advised based off data from 2006 to 2024. This start year corresponds to the beginning of the previous fisheries rights allocation period. It is reasonable to assume that future catch patterns will not necessarily reflect those of the 1980-1990s. In addition, given delayed starts to the fishing season and interim TAC/Bs since Exceptional Circumstances were first declared in December 2018, future catch patterns will likely not reflect those of the most recent 10 years.

Candidate Management Procedure

The candidate sardine-only scoping MP used for future catch scenarios in Primary Documents outputs the following TAC/Bs (in thousand tons):

i) An annual >14cm sardine TAB with directed round herring and anchovy fishing[1], $TAB^S_{big} = 0.0332 \times B^{obs}_{w,y-1}$.

ii) An annual ≤14cm sardine TAB with round herring and with sardine[1], $TAB^S_{y,small} = 0.00375 \times B^{obs}_{w,y-1}$.

iii) An annual ≤14cm sardine TAB with anchovy[1], $TAB^S_{y,anc} = 0.0072 \times B^{obs}_{w,y-1}$.

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

[1] Based on 2025 TABs.

iv) An annual directed >14cm sardine TAC, TAC_y^S, which is split by area, $TAC_{s,y}^S = 0.1 \times B_{s,y-1}^{obs}$ and $TAC_{w,y}^S = (0.1 - 0.0332 - 0.00375 - 0.0072) \times B_{w,y-1}^{obs}$

Acknowledgements

Janet Coetzee and Dagmar Merkle are thanked for providing historical catch and bycatch data by species, and for associated discussions regarding the most appropriate use of these data.

References

de Moor CL. 2018. The 2018 Operational Management Procedure for the South African sardine and anchovy resource. DFFE: Branch Fisheries Document FISHERIES/2018/DEC/SWG-PEL/37.

de Moor CL. 2025a. The updated assessment model for the revised sardine stock structure hypothesis. DFFE: Branch Fisheries Document FISHERIES/2025/APR/SWG-PEL/17rev.

de Moor CL. 2025b. Revisions to the updated assessment model for the revised sardine stock structure hypothesis. International Stock Assessment Workshop Document IWS/2025/Sardine/BG3. (Also FISHERIES/2025/OCT/SWG-PEL/54rev.)

de Moor CL. 2025c. Initial testing of the Scoping MSE for South African sardine. DFFE: Branch Fisheries Document FISHEIRES/2025/JUN/SWG-PEL/32.

de Moor CL, Coetzee JC and Butterworth DS. 2024a. Calculating an informative prior distribution for the bias of hydro-acoustic survey estimates of the South African sardine biomass. DFFE: Branch Fisheries Document FISHERIES/2024/SEP/SWG-PEL/44.

de Moor CL, van der Lingen CD and Teske PR. 2023. A revised hypothesis for South African sardine stock structure. International Stock Assessment Workshop, 27 November – 1 December 2023, Cape Town. Document MARAM/IWS/2023/Sardine/P3.

OLSPS. 2023. Further sardine length-weight regressions for survey and commercial lengths. DFFE: Branch Fisheries Document FISHERIES/2023/NOV/SWG-PEL/24.

Appendix A: Operating Model for the Scoping MSE for South African sardine (updated from de Moor 2025c)

The MSE is simulated from January $y_{n+1} = 2025$ to December $y_N = 2044$. The following subscript/superscript notation is used:

- stock $j = CTS$ or $j = WTS$ denote Cool Temperate Sardine or Warm Temperate Sardine, respectively;
- coast $c = w$ or $c = s$ denote the west and south coasts, respectively;
- quarters $q = 1$ denoting January to March, $q = 2$ denoting April to June, $q = 3$ denoting July to September and $q = 4$ denoting October to December;
- ages $a = 0$ to a plus group of $a = 5^+$; and
- lengths from a minus group of $l = 2.5^- cm$ to a plus group of $l = 24^+ cm$.

All parameters are defined in Table A1.

<u>Population Dynamics and Fishery Model</u>

Numbers-at-age at 1 January

$$N^j_{c,y,1,a} = \left(N^j_{c,y-1,4,a} e^{-M^j_{c,y,a}/8} - C^j_{c,y-1,4,a}\right) e^{-M^j_{c,y,a}/8} \qquad c = \{w,s\},\ 0 \le a \le 5^+ \quad \text{(A1)}$$

Numbers-at-age at 1 April ($q = 2$) and 1 July ($q = 3$)

$$N^j_{c,y,q,a} = \left(N^j_{c,y,q-1,a} e^{-M^j_{c,y,a}/8} - C^j_{c,y,q-1,a}\right) e^{-M^j_{c,y,a}/8} \qquad c = \{w,s\},\ 0 \le a \le 5^+ \quad \text{(A2)}$$

Numbers-at-age 1+ at 1 October

$$N^j_{w,y,4,a} = \begin{cases} \left((1 - move^j_{y,a-1})N^j_{w,y,3,a-1} e^{-M^j_{w,y,a-1}/8} - C^j_{w,y,3,a-1}\right) e^{-M^j_{w,y,a-1}/8} & 1 \le a \le 4 \\ \left((1 - move^j_{y,4})N^j_{w,y,3,4} e^{-M^j_{w,y,4}/8} - C^j_{w,y,3,4}\right) e^{-M^j_{w,y,4}/8} + \left((1 - move^j_{y,5+})N^j_{w,y,3,5+} e^{-M^j_{w,y,5+}/8} - C^j_{w,y,3,5+}\right) e^{-M^j_{w,y,5+}/8} & a = 5^+ \end{cases}$$

$$N^{CTS}_{s,y,4,a} = 0 \qquad 1 \le a \le 5^+ \text{ [2]}$$

$$N^{WTS}_{s,y,4,a} = \begin{cases} \left(move^{WTS}_{y,a-1} N^{WTS}_{w,y,3,a-1} e^{-M^{WTS}_{w,y,a-1}/8} + N^{WTS}_{s,y,3,a-1} e^{-M^{WTS}_{s,y,a-1}/8} - C^{WTS}_{s,y,3,a-1}\right) e^{-M^{WTS}_{s,y,a-1}/8} & 1 \le a \le 4 \\ \left(N^{WTS}_{s,y,3,4} e^{-M^{WTS}_{s,y,4}/8} - C^{WTS}_{s,y,3,4}\right) e^{-M^{WTS}_{s,y,4}/8} + \left(N^{WTS}_{s,y,3,5+} e^{-M^{WTS}_{s,y,5+}/8} - C^{WTS}_{s,y,3,5+}\right) e^{-M^{WTS}_{s,y,5+}/8} & a = 5^+ \end{cases} \quad \text{(A3) [3]}$$

Recruits at 1 October

$$N^{CTS}_{w,y,4,0} = R^{CTS}_y$$
$$N^{CTS}_{s,y,4,0} = 0$$
$$N^{WTS}_{w,y,4,0} = p_y R^{WTS}_y$$
$$N^{WTS}_{s,y,4,0} = (1 - p_y) R^{WTS}_y \quad \text{(A4)}$$

Recruitment is dependent on spawner biomass, but not necessarily a parametric stock-recruitment relationship. These are detailed in the Primary Documents:

$$R^j_y = f\left(\sum_c SSB^j_{c,y}\right) e^{\varepsilon^j_y \sigma^j_r} \text{ [4]} \quad \text{(A5)}$$

where, for parameteric stock-recruitment relationships,

$$\varepsilon^j_y = s^j_{cor}\varepsilon^j_{y-1} + \omega^j_y \sqrt{1 - \left(s^j_{cor}\right)^2}, \text{ where } \omega^j_y \sim N(0,1) \quad \text{(A6)}$$

Spawning biomass at 1 October

$$SSB^j_{c,y} = \sum_{l=2.5^-}^{24^+} w_l f_l \sum_{a=1}^{5^+} A^{Oct}_{c,y,a,l} N^j_{c,y,4,a} \qquad c = \{w,s\} \quad \text{(A7)}$$

where

---

[2] 0-year-old CTS available to the fishery off the south coast at the mid-point of the 3rd quarter will be $move^{CTS}_{y,0} N_{w,y,3,0}^{-M^{CTS}_{w,y,0}/8}$ (equation A10).

[3] No movement of 3+-year olds is modelled.

[4] The bias correction $R^j_y = f\left(\sum_c SSB^j_{c,y}\right) e^{\varepsilon^j_y \sigma^j_r - 0.5\left(\sigma^j_r\right)^2}$ is not used so that the variability in the past corresponds with that estimated historically.

$$f_l = 1/\left(1+e^{-(l-L_{50})/\delta^{mat}}\right) \qquad 2.5^{-}cm \le l \le 24^{+}cm \text{ (A8)}$$ [5]

Biomass at the time of the November survey

$$B_{c,y} = \sum_j \sum_{l=2.5^-}^{24^+} w_l \sum_{a=0}^{5^+} A_{c,y,a,4,l}\left(Nmid_{c,y,4,a}^{j} - C_{c,y,4,a}^{j}\right) \qquad c=\{w,s\} \text{ (A9)}$$

Numbers at age mid-way through each quarter, before catch

$$Nmid_{c,y,q,a}^{j} = \begin{cases} N_{c,y,q,a}^{j} e^{-M_{c,y,a}^{j}/8} & q \in \{1,2\} \\ N_{c,y,q,a}^{j} e^{-M_{c,y+1,a}^{j}/8} & q=4 \end{cases} \qquad c=\{w,s\},\ 0 \le a \le 5^{+}$$

$$Nmid_{w,y,3,a}^{j} = \left(1-move_{y,a}^{j}\right) N_{w,y,3,a}^{j} e^{-M_{w,y,a}^{j}/8} \qquad 0 \le a \le 5^{+}$$

$$Nmid_{s,y,3,a}^{j} = move_{y,a}^{j} N_{w,y,3,a}^{j} e^{-M_{w,y,a}^{j}/8} + N_{s,y,3,a}^{j} e^{-M_{s,y,a}^{j}/8} \qquad 0 \le a \le 5^{+} \text{ (A10)}$$

Number of recruits at the time of the recruit survey

$$N_{c,y}^{rec} = \left(\sum_j N_{c,y,2,0}^{j} e^{-0.5(1+t_y)M_{c,y,0}^{j}/12} - C_{c,y}^{bs}\right) e^{-0.5(1+t_y)M_{c,y,0}^{*}/12} \qquad \text{(A11)}$$

Since the survey is simulated to occur at 1st June in the future (see Table A1), $C_{c,y}^{bs} = \frac{2}{3} C_{c,y,2,0}^{j}$ and $M_{c,y,0}^{*} = M_{c,y,0}^{j}$.

Growth

In line with de Moor (2025a), there are coast-specific growth curves, with the mean length-at-age off the south coast being adjusted to accommodate sardine which move from the west coast to the south coast.

$$A_{c,y,a,l}^{Oct} \sim N\left(\bar{L}_{c,y,a}^{Oct}, \vartheta_{c,0}^{2}\right) \qquad c=\{w,s\},\ 0 \le a \le 5^{+},\ 2.5^{-}cm \le l \le 24^{+}cm \text{ (A12)}$$ [6] [7]

where

$$\bar{L}_{w,y,a}^{Oct} = L_{w,\infty}\left(1-e^{-\kappa_w(a-t_{0,w})}\right) \qquad 0 \le a \le 5^{+}$$

$$\bar{L}_{s,y,a}^{Oct} = \begin{cases} L_{s,\infty}\left(1-e^{-\kappa_s(a-t_{0,s})}\right) & a=0 \\ \bar{L}_{s,y,3,a-1} + \left(L_{\infty} - \bar{L}_{s,y,3,a-1}\right)\left(1-e^{-\kappa_s/8}\right) & 1 \le a \le 5^{+} \end{cases} \qquad \text{(A13)}$$

$$A_{c,y,a,q,l} \sim N\left(\bar{L}_{c,y,q,a}^{mid}, \vartheta_{c,a,q}^{2}\right) \qquad c=\{w,s\},\ 1 \le q \le 4,\ 0 \le a \le 5^{+},\ 2.5^{-}cm \le l \le 24^{+}cm \text{ (A14)}$$

where

$$\bar{L}_{w,y,q,a}^{mid} = \begin{cases} L_{w,\infty}\left(1-e^{-\kappa_w(a+(2q+1)/8-t_{0,w})}\right) & 1 \le q \le 3 \\ L_{w,\infty}\left(1-e^{-\kappa_w(a+1/8-t_{0,w})}\right) & q=4 \end{cases}$$

$$\bar{L}_{s,y,q=4,a}^{mid} = \begin{cases} L_{s,\infty}\left(1-e^{-\kappa_s(a+1/8-t_{0,s})}\right) & a=0 \\ \bar{L}_{s,y,a}^{Oct} + \left(L_{s,\infty} - \bar{L}_{s,y,a}^{Oct}\right)\left(1-e^{-\kappa_s/8}\right) & 1 \le a \le 5^{+} \end{cases}$$

$$\bar{L}_{s,y,q=1,a}^{mid} = \begin{cases} L_{s,\infty}\left(1-e^{-\kappa_s(a+(2q+1)/8-t_{0,s})}\right) & a=0 \\ \bar{L}_{s,y-1,4,a}^{mid} + \left(L_{s,\infty} - \bar{L}_{s,y-1,4,a}^{mid}\right)\left(1-e^{-\kappa_s/4}\right) & 1 \le a \le 5^{+} \end{cases}$$

$$\bar{L}_{s,y,q=2,a}^{mid} = \begin{cases} L_{s,\infty}\left(1-e^{-\kappa_s(a+(2q+1)/8-t_{0,s})}\right) & a=0 \\ \bar{L}_{s,y,1,a}^{mid} + \left(L_{s,\infty} - \bar{L}_{s,y,1,a}^{mid}\right)\left(1-e^{-\kappa_s/4}\right) & 1 \le a \le 5^{+} \end{cases}$$

$$\bar{L}_{s,y,q=3,a}^{mid} = \frac{\sum_j \sum_p \bar{L}_{w,y,3,a}^{mid} move_{y,a}^{j} N_{w,p,y,3,a}^{j} e^{-M_{w,y,a}^{j}/8} + \acute{L}_{s,y,3,a} N_{s,p,y,3,a}^{j} e^{-M_{s,y,a}^{j}/8}}{move_{y,a}^{j} N_{w,p,y,3,a}^{j} e^{-M_{w,y,a}^{j}/8} + N_{s,p,y,3,a}^{j} e^{-M_{s,y,a}^{j}/8}} \qquad 0 \le a \le 5^{+} \text{ (A15)}$$

where

$$\acute{L}_{s,y,q=3,a} = \begin{cases} L_{s,\infty}\left(1-e^{-\kappa_s(a+(2q+1)/8-t_{0,s})}\right) & a=0 \\ \bar{L}_{s,y,2,a}^{mid} + \left(L_{s,\infty} - \bar{L}_{s,y,2,a}^{mid}\right)\left(1-e^{-\kappa_s/4}\right) & 1 \le a \le 5^{+} \end{cases} \qquad \text{(A16)}$$

[5] Where length is used in an equation, the mid-point of the length class is used.

[6] There may be some proportion of this distribution below a length of zero (recruitment after 1st October). In these cases, this proportion is removed from the proportion-at-length of the minus length class.

[7] The proportion is calculated as the area under the curve between the lower limit and upper limit of length class l. The lower and upper tails are included in the proportions calculated for the minus and plus groups, respectively.

Commercial selectivity for >14cm directed and bycatch with round herring and anchovy

$$S_{c,q,l} = \begin{cases} 0 & l \leq 5.5cm \\ \frac{1}{1+exp\left\{-(l-\bar{l}_{c,q})/(\sigma^{sel})^2\right\}} & 6cm \leq l \leq l_{max} = 23cm \\ S_{c,q,lmax} & l > l_{max} \end{cases} \qquad c = \{w,s\},\ 1 \leq q \leq 4 \text{ (A17)}$$

Total catch

$$C^{j}_{c,y,q,a} = C^{by,j}_{c,y,q,a} + C^{dir,j}_{c,y,q,a} \qquad c = \{w,s\},\ 1 \leq q \leq 4,\ 0 \leq a \leq 5^+ \text{ (A18)}$$

$$C^{by,j}_{c,y,q,a} = Nmid^{j}_{c,y,q,a} F^{j,By}_{c,y,q,a} \qquad c = \{w,s\},\ 1 \leq q \leq 4,\ 0 \leq a \leq 1 \text{ (A19)}$$

$$C^{dir,j}_{c,y,q,a} = \left(Nmid^{j}_{c,y,q,a} - C^{by,j}_{c,y,q,a}\right) F^{j}_{c,y,q} \sum_{l=2.5^-}^{24^+} A_{c,y,a,q,l} S_{c,q,l} \qquad c = \{w,s\},\ 1 \leq q \leq 4,\ 0 \leq a \leq 5^+ \text{ (A20)}$$

Fished proportion of the available age 0 and 1 biomass from the small sardine bycatch

Defining exploitable biomass of ages 0 and 1 by stock and coast as $B^{j,exp}_{c,y,q,a} = \sum_{l=2.5^-}^{24^+} w_l A_{c,y,a,q,l} Nmid^{j}_{c,y,q,a}$,

$$F^{j,By}_{s,y,q,a=0} = F^{By}_{s,y,q,a=0} = \frac{ByC_{s,y,q}}{\sum_j B^{j,exp}_{c=s,y,q,a=0}} \qquad F^{j,By}_{s,y,q,1} = F^{By}_{s,y,q,a=1} = \frac{ByC_{s,y,q}}{\sum_j B^{j,exp}_{c=s,y,q,a=1}} \qquad \text{(A21a)}$$

$$F^{CTS,By}_{w,y,q,0} = ByC_{sw,y,q}\left[\frac{1}{\Phi_1 B^{WTS,exp}_{w,y,q,0} + B^{CTS,exp}_{w,y,q,0}}\right] + ByC_{nw,y,q}\left[\frac{\Phi_2}{\Phi_2 B^{CTS,exp}_{w,y,q,0} + Nmid^{WTS,exp}_{w,y,q,0}}\right]$$

$$F^{CTS,By}_{w,y,q,1} = ByC_{sw,y,q}\left[\frac{1}{\Phi_1 B^{WTS,exp}_{w,y,q,1} + B^{CTS,exp}_{w,y,q,1}}\right] + ByC_{nw,y,q}\left[\frac{\Phi_2}{\Phi_2 B^{CTS,exp}_{w,y,q,1} + B^{WTS,exp}_{w,y,q,1}}\right]$$

$$F^{WTS,By}_{w,y,q,0} = ByC_{sw,y,q}\left[\frac{\Phi_1}{\Phi_1 B^{WTS,exp}_{w,y,q,0} + B^{CTS,exp}_{w,y,q,0}}\right] + ByC_{nw,y,q}\left[\frac{1}{\Phi_2 B^{CTS,exp}_{w,y,q,0} + B^{WTS,exp}_{w,y,q,0}}\right]$$

$$F^{WTS,By}_{w,y,1,1} = ByC_{sw,y,q}\left[\frac{\Phi_1}{\Phi_1 B^{WTS,exp}_{w,y,q,1} + B^{CTS,exp}_{w,y,q,1}}\right] + ByC_{nw,y,q}\left[\frac{1}{\Phi_2 B^{CTS,exp}_{w,y,q,1} + B^{WTS,exp}_{w,y,q,1}}\right] \qquad \text{(A21b)}$$

A penalty is imposed to ensure that $F^{j,By}_{c,y,q,a} < 0.95$.

Fished proportion of the available biomass from the directed sardine catch and sardine bycatch with round herring fishery

Defining exploitable biomass by stock and coast as $B^{j,exp}_{c,y,q} = \sum_{l=2.5^-}^{24^+} w_l S_{c,q,l} \sum_{a=0}^{5+} A_{c,y,a,q,l}\left(Nmid^{j}_{c,y,q,a} - C^{by,j}_{c,y,q,a}\right)$,

$$F^{j}_{s,y,q} = F_{s,y,q} = \frac{C_{s,y,q}}{\sum_j B^{j,exp}_{c=s,y,q}} \qquad \text{(A22a)}$$

$$F^{CTS}_{w,y,q} = C_{SW,y,q}\left[\frac{1}{\Phi_1 B^{WTS,exp}_{w,y,q} + B^{CTS,exp}_{w,y,q}}\right] + C_{NW,y,q}\left[\frac{\Phi_2}{\Phi_2 B^{CTS,exp}_{w,y,q} + B^{WTS,exp}_{w,y,q}}\right]$$

$$F^{WTS}_{w,y,q} = C_{SW,y,q}\left[\frac{\Phi_1}{\Phi_1 B^{WTS,exp}_{w,y,q} + B^{CTS,exp}_{w,y,q}}\right] + C_{NW,y,q}\left[\frac{1}{\Phi_2 B^{CTS,exp}_{w,y,q} + B^{WTS,exp}_{w,y,q}}\right] \qquad \text{(A22b)}$$

A penalty is imposed to ensure that $F^{j}_{c,y,q} < 0.95$.

<u>Observation Model</u>

Survey estimates for total biomass and recruitment are generated as follows:

$$B^{obs}_{c,y} = k_{ac} B_{c,y} e^{\varepsilon^{Nov}_{c,y}} \qquad c = \{w,s\} \text{ (A23a)}$$

where $\varepsilon^{Nov}_{c,y} = \eta^{Nov}_{c,y}\tilde{\sigma}^{Nov}_{c,y}$, (A23b)

and $$\tilde{\sigma}^{Nov}_{c,y} = \sqrt{min\left(CV^2_{max}; A + \frac{B}{B_{c,y}}\right) + \varphi^2_{ac} + \lambda^2_N} \qquad \text{(A23c)}$$

$$N^{obs}_{c,y} = k_{c,r} N^{rec}_{c,y} e^{\varepsilon^{rec}_{c,y}} \qquad c = \{w,s\} \text{ (A24a)}$$

where $\varepsilon^{rec}_{c,y} = \eta^{rec}_{c,y}\tilde{\sigma}^{rec}_{c,y}$, (A24b)

and $$\tilde{\sigma}^{rec}_{w,y} = \sqrt{min\left(CV^2_{max}; A + \frac{B}{N^{rec}_{c,y}}\right) + \varphi^2_{ac} + \lambda^2_r} \qquad \text{(A24c)}$$

where CV_{max} is the historical observed maximum survey CV, and the parameters A and B are obtained from a regression of the observed CV against the OM predicted biomass between 1984 and 2024 at the joint posterior mode (Figures A1,A2).

Implementation Model

All the >14cm sardine TAB is expected to be taken off the west coast only. The adult catch tonnages are calculated using quarterly proportions of the directed sardine catch[8] based off historical tonnages landed between 2006-2024:

$C_{sw,y,1} = C_{nw,y,1} = 0.5 \times \left(0.30 \times TAC^{S}_{w,y} + 0.42 \times \acute{t}_j \times TAB^{S}_{big}\right)$ $C_{s,y,1} = 0.15 * TAC^{S}_{s,y}$

$C_{sw,y,1} = C_{nw,y,1} = 0.5 \times \left(0.31 \times TAC^{S}_{w,y} + 0.41 \times \acute{t}_j \times TAB^{S}_{big}\right)$ $C_{s,y,2} = 0.43 * TAC^{S}_{s,y}$

$C_{sw,y,1} = C_{nw,y,1} = 0.5 \times \left(0.11 \times TAC^{S}_{w,y} + 0.12 \times \acute{t}_j \times TAB^{S}_{big}\right)$ $C_{s,y,3} = 0.22 * TAC^{S}_{s,y}$

$C_{sw,y,1} = C_{nw,y,1} = 0.5 \times \left(0.28 \times TAC^{S}_{w,y} + 0.05 \times \acute{t}_j \times TAB^{S}_{big}\right)$ $C_{s,y,4} = 0.20 * TAC^{S}_{s,y}$

An alternative based off historical tonnages landed between 2009-2018 is also tested, being the 10 years prior to the declaration of Exceptional Circumstances and considered reasonable by industry for future patterns:

$C_{sw,y,1} = C_{nw,y,1} = 0.5 \times \left(0.43 \times TAC^{S}_{w,y} + 0.44 \times \acute{t}_j \times TAB^{S}_{big}\right)$ $C_{s,y,1} = 0.15 * TAC^{S}_{s,y}$

$C_{sw,y,1} = C_{nw,y,1} = 0.5 \times \left(0.25 \times TAC^{S}_{w,y} + 0.41 \times \acute{t}_j \times TAB^{S}_{big}\right)$ $C_{s,y,2} = 0.49 * TAC^{S}_{s,y}$

$C_{sw,y,1} = C_{nw,y,1} = 0.5 \times \left(0.09 \times TAC^{S}_{w,y} + 0.12 \times \acute{t}_j \times TAB^{S}_{big}\right)$ $C_{s,y,3} = 0.24 * TAC^{S}_{s,y}$

$C_{sw,y,1} = C_{nw,y,1} = 0.5 \times \left(0.23 \times TAC^{S}_{w,y} + 0.03 \times \acute{t}_j \times TAB^{S}_{big}\right)$ $C_{s,y,4} = 0.11 * TAC^{S}_{s,y}$

The ≤14cm sardine bycatches are assumed to be 0-year olds in quarters 1 to 3 and 1-year-olds in quarter 4.

The ≤14cm sardine bycatches are assumed to be taken off the west coast only. In recent years 1% of the ≤14cm sardine bycatch has been landed east of Cape Agulhas. The small sardine bycatch tonnages are calculated using quarterly proportions based off historical ≤14cm bycatch tonnages[9] landed between 2006-2024.

$ByC_{sw,y,1} = ByC_{nw,y,1} = 0.5 \times \left(0.22 \times TAB^{S}_{y,small} + 0.09 \times TAB^{S}_{y,anc}\right)$

$ByC_{sw,y,1} = ByC_{nw,y,1} = 0.5 \times \left(0.53 \times TAB^{S}_{y,small} + 0.72 \times TAB^{S}_{y,anc}\right)$

$ByC_{sw,y,1} = ByC_{nw,y,1} = 0.5 \times \left(0.16 \times TAB^{S}_{y,small} + 0.18 \times TAB^{S}_{y,anc}\right)$

$ByC_{sw,y,1} = ByC_{nw,y,1} = 0.5 \times \left(0.09 \times TAB^{S}_{y,small} + 0.01 \times TAB^{S}_{y,anc}\right)$

Future work may include modelling a proportion of $TAB^{S}_{y,small}$ to be removed from the population based off historical data.

[8] These data included any ≤14cm sardine landed with directed sardine fishing. However, a separate check on data of a lesser quality having not undergone rigorous checking, but consisting of only >14cm sardine landed with directed sardine fishing, resulted in similar proportions.

[9] The ≤14cm sardine quarterly catch by directed species were calculated from raw data which have not undergone rigorous checking, but are the only data available which separate the small sardine bycatch by species.

Table A1. Parameter definitions. Where 'Sampled' is given in the right column, the parameter value is sampled from Bayesian posterior distributions.

Parameter	Description	Units	Input Value or Equation
$N^j_{c,y,q,a}$	Numbers-at-age a of stock j on coast c at the beginning of quarter q in year y	Billions	A1 – A4, $N^j_{c,yn,1,a}$ sampled
$M^j_{c,y,a}$	Rate of natural mortality at age a of stock j on coast c in year y	Year[-1]	$M^{WTS}_{s,y,0} = M^{CTS}_{w,y,0} + M^{diff}_{juv}$; $M^{WTS}_{s,y,1^+} = M^{WTS}_{s,y,0} - M^{diff}_{ad}$ $M^{CTS}_{s,y,a} = M^{CTS}_{w,y,a} + M^{CTS}_{inc}$; $M^{WTS}_{w,y,a} = M^{WTS}_{s,y,a} + M^{WTS}_{inc}$ $M^{CTS}_{w,y,0}, M^{CTS}_{w,y,1^+}, M^j_{inc}, M^{diff}_{juv}, M^{diff}_{ad}$ sampled
$move^j_{y,a}$	Proportion of stock j sardine of age a which move to the south coast at the middle of the 3rd quarter in year y	-	$move^{CTS}_{y,0}$ sampled $move^{WTS}_{y,0}$ randomly sampled from last 10 years $move^{WTS}_{y,1} = \phi \times move^{WTS}_{y,0}$; ϕ sampled $move^{CTS}_{y,1+} = 0$; $move^{WTS}_{y,2} = 1$; $move^{WTS}_{y,3+}$ – NA
R^j_y	Number of recruits of stock j spawned in year y	Billions	A5
p_y	Proportion of WTS recruitment which recruit to the area west of Cape Agulhas in year y (incorporating both west coast spawning and passive movement of spawning products from the south coast)	-	Randomly sampled from last 10 years
ε^j_y	Standardised recruitment residual for stock j in year y	-	A6, ε^j_{yn} sampled
σ^j_r	Standard deviation of the recruitment residuals for stock j	-	Sampled
s^j_{cor}	Recruitment serial correlation for stock j	-	Sampled
$SSB^j_{c,y}$	Spawning biomass of stock j on coast c at the beginning of October in year y	Thousand tons	A7
w_l	Mean mass of sardine in length class l (in cm)	Grams	$0.0071118 \times l^{3.181}$ [10]
f_l	Proportion of sardine of length l (in cm) that are mature	-	A8
L_{50}	Length at 50% maturity	Cm	11.88[11]
δ^{mat}	Rate of increase in maturity at length	-	1.93[11]
$B_{c,y}$	Total biomass on coast c at the middle of November in year y	Thousand tons	A9
$Nmid^j_{c,y,q,a}$	Numbers-at-age a of stock j on coast c mid-way through quarter q in year y	Billions	A10
$\bar{L}^{Oct}_{c,y,a}$	Mean length of age a sardine on coast c at 1 October in year y	Cm	A13
$\bar{L}^{mid}_{c,y,q,a}$	Mean length of age a sardine on coast c mid-way through quarter q of year y	Cm	A15
$\acute{L}_{s,y,q=3,a}$	Mean length of age a sardine on the south coast before movement mid-way through quarter 3 of year y	Cm	A16
$A^{Oct}_{c,y,a,l}$	Proportion of age a sardine on coast c that falls in the length group l at 1 October in year y	-	A12

[10] A coast-wide length-weight relationship was calculated from samples collected from November surveys and taken to apply both to the time of spawning and November survey (OLSPS 2023). This relationship is currently assumed to additionally apply to commercial catches. A robustness test will investigate the impact of using different relationships for the commercial catches for the west and south coasts; the latter estimated from commercial samples from the south coast is substantially different from the November survey relationship.

[11] Median ogive of most recent 10 years maturity ogives excluding years for which data were not available, i.e. 2021, 2023, 2024 (cf Table A.3 of de Moor 2025a).

Table A1 (Continued).

Parameter	Description	Units	Input Value or Equation
$A_{c,y,a,q,l}$	Proportion of age a sardine on coast c that falls in the length group l mid-way through quarter q of year y	-	A14
κ_c	Somatic growth rate parameter for sardine on coast c	Year^{-1}	Sampled from median of most recent 10 years
$L_{c,\infty}$	Maximum length (in expectation) of sardine on coast c	Cm	Sampled
$t_{0,c}$	Age at which the length (in expectation) is zero on coast c	Year	Sampled
$\vartheta_{c,a}$	Standard deviation of the distribution about the mean length-at-age a on coast c at 1 October	-	Sampled
$\vartheta_{c,a,q}$	Standard deviation of the distribution about the mean length-at-age a on coast c midway through quarter q	-	Sampled
$S_{c,q,l}$	Commercial selectivity-at-length l during quarter q on coast c	-	A17
$\bar{l}_{c,q}$	Length at 50% selectivity in the commercial selectivity logistic distribution for coast c in quarter q	cm	Sampled from median of most recent 10 years
$(\sigma^{sel})^2$	Variance of the commercial selectivity logistic distribution	cm	Sampled
$C_{c,y,q,a}^{j}$	Total number of age a fish of stock j caught on coast c during quarter q of year y	Billions	A18
$C_{c,y,q,a}^{by,j}$	Number of age $a \leq 14$cm sardine bycatch of stock j on coast c in quarter q of year y	Billions	A19
$C_{c,y,q,a}^{dir,j}$	Number of age a fish of stock j caught in the sardine-directed and round herring bycatch fisheries on coast c in quarter q of year y	Billions	A20
$F_{c,y,q,a}^{j,By}$	Fished proportion of stock j, age $a \leq 14cm$ sardine bycatch in quarter q of year y on coast c	-	A21
$F_{c,y,q}^{j}$	Fished proportion of stock j in the directed and round herring bycatch fisheries in quarter q of year y for a fully selected length class on coast c	-	A22
ϕ_1	Relative weighting towards WTS in catches off the south west coast	-	Different fixed values for alternative models
ϕ_2	Relative weighting towards CTS in catches off the north west coast	-	Different fixed values for alternative models
$N_{c,y}^{rec}$	Number of recruits on coast c at the time of the recruit survey in year y	Billions	A11
t_y	Time lapsed between 1 May and the start of the recruit survey in year y	Months	$t_y = 1$ [12]
$B_{c,y}^{obs}$	Simulated November survey estimate of total biomass on coast c in year y	Thousand tons	A23a
$N_{c,y}^{obs}$	Simulated survey estimate of recruitment on coast c in year y	Billions	A24a
k_{ac}	Multiplicative bias associated with the hydro-acoustic survey	-	Sampled
$k_{c,r}$	Multiplicative bias associated with the recruit survey on coast c	-	Sampled
$\varepsilon_{c,y}^{Nov}$	Residuals in the simulated observation of November survey estimate of total biomass from OM predicted biomass in year y of coast c	-	A23b
$\tilde{\sigma}_{c,y}^{Nov}$	Standard deviation of the residuals $\varepsilon_{c,y}^{Nov}$, being the November survey sampling CV	-	A23c
$\varepsilon_{c,y}^{rec}$	Residuals in the simulated observation of survey estimate of recruitment from OM predicted recruitment in year y of coast c	-	A24b

[12] Average 1985-2024 and 2014-2024 (excluding 2018 when there was no survey) start date of the recruit surveys has been 27th May and 4th June, respectively.

Table A1 (Continued).

Parameter	Description	Units	Input Value or Equation
$\tilde{\sigma}^{rec}_{c,y}$	Standard deviation of the residuals $\varepsilon^{rec}_{c,y}$, being the recruit survey sampling CV	-	A24c
φ_{ac}	CV associated with factors which cause bias in the acoustic survey estimates and which vary inter-annually rather than remain fixed over time	-	=0.198 [13]
$(\lambda_{N/r})^2$	Additional variance (over and above $(\tilde{\sigma}^{Nov/rec}_{c,y})^2$ and φ^2_{ac}) associated with the November/recruit surveys	-	0
$CV^{Nov/rec}_{max}$	Historical observed maximum survey CV for the November/recruit surveys	-	Figure A1,A2
$\acute{\tau}_j$	The proportion of TAB^S_{big} simulated to be removed from the population in future years	-	Sampled from historical proportions, see Figure A4

[13] de Moor *et al*. (2024a).

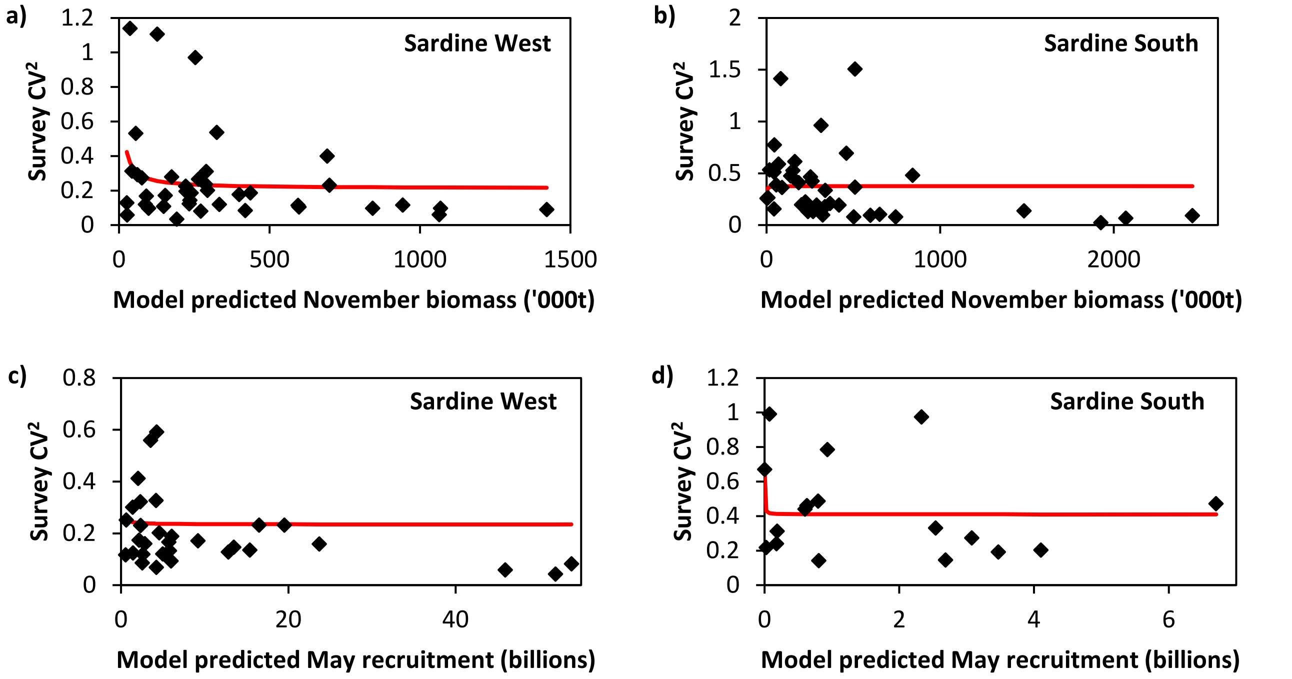

Figure A1. The regressions between observed survey CV^2 and S_{BH} model predicted abundance for a) sardine November biomass west of Cape Agulhas (with $CV^2_{max} = 1.140, A = 0.213, B = 5.483$) , b) sardine November biomass east of Cape Agulhas (with $CV^2_{max} = 1.507, A = 0.375, B = -0.162$) , c) sardine June recruitment west of Cape Agulhas (with $CV^2_{max} = 0.592, A = 0.234, B = 0.013$), and d) sardine June recruitment east of Cape Agulhas (with $CV^2_{max} = 0.991, A = 0.410, B = 0.001$).

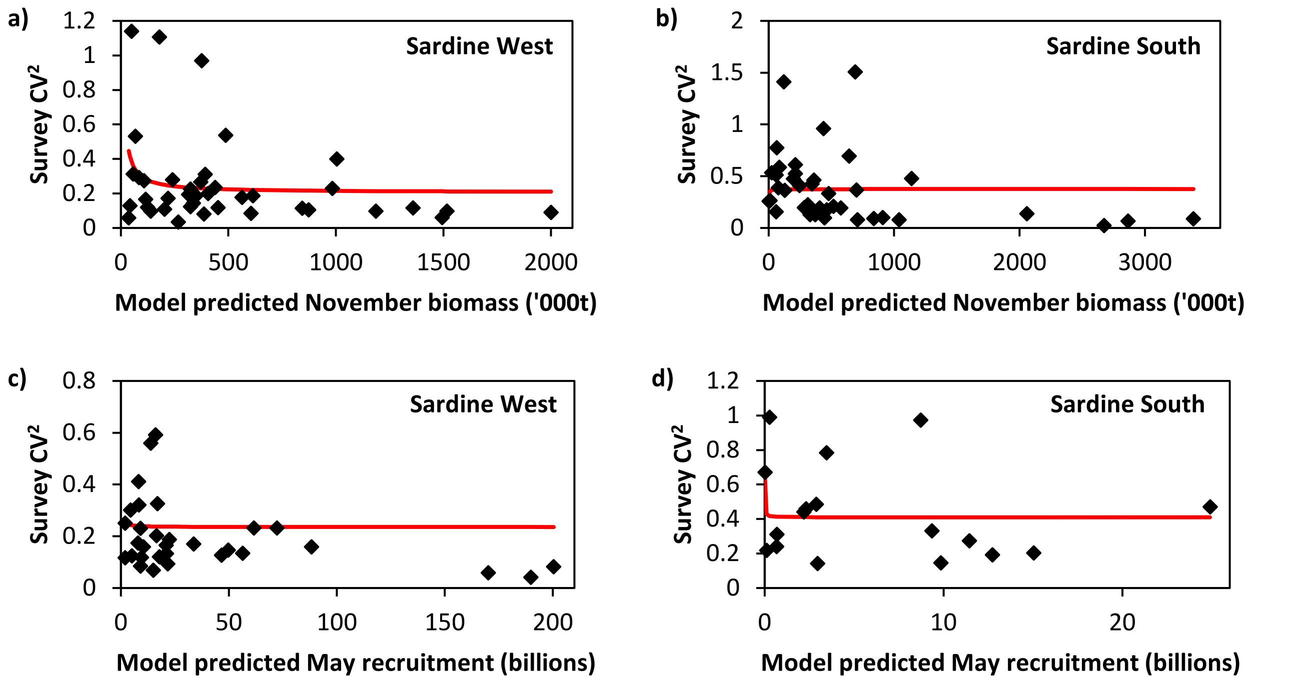

Figure A2. The regressions between observed survey CV^2 and S_0 model predicted abundance for a) sardine November biomass west of Cape Agulhas (with $CV^2_{max} = 1.140, A = 0.206, B = 8.828$) , b) sardine November biomass east of Cape Agulhas (with $CV^2_{max} = 1.507, A = 0.375, B = -0.233$) , c) sardine June recruitment west of Cape Agulhas (with $CV^2_{max} = 0.592, A = 0.235, B = 0.035$), and d) sardine June recruitment east of Cape Agulhas (with $CV^2_{max} = 0.996, A = 0.410, B = 0.002$).

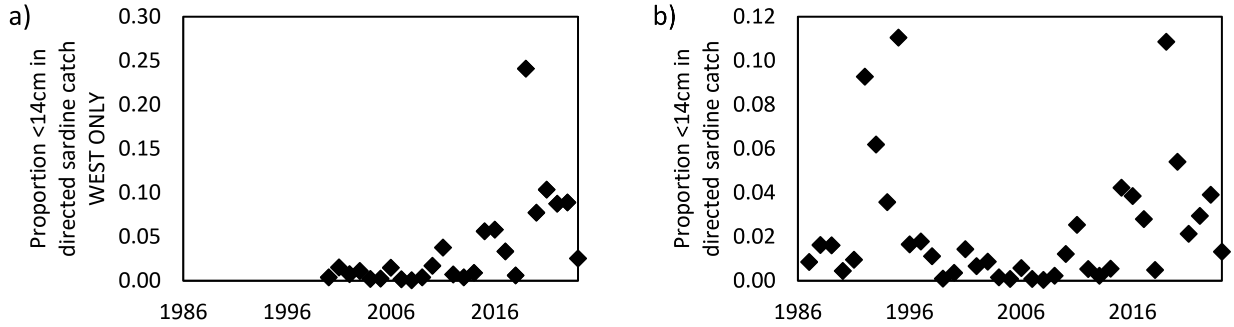

Figure A3. The proportion of <14cm sardine in directed sardine catch landed a) west of Cape Agulhas and b) in total. Excluding the outlier of 2019 which had only <14cm sardine landed in one month, the maximum proportion since 2000 has been a) 0.104 and b) 0.054.

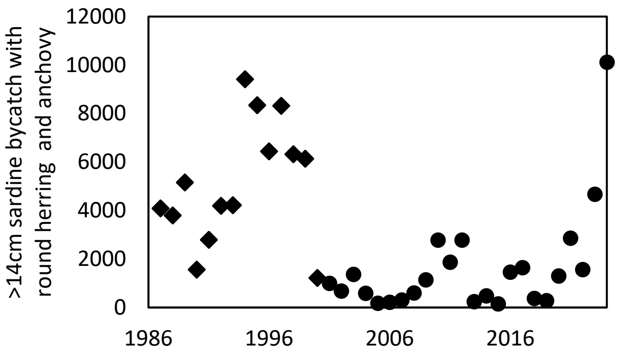

Figure A4. The >14cm sardine bycatch landed with round herring or anchovy directed fishing. 1985-1999 data were previously provided by J. van der Westhuisen. 2000-2024 data are calculated from raw data which have not undergone rigorous checking, but are the only data available which separate the large sardine bycatch by species.