A proposal for determining the final desirable maximum catch of directed sardine west of Cape Agulhas during 2017

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The maximum directed >14cm sardine catch recommended to be caught west of Cape Agulhas during 2017 was initially set at 21 400t (DAFF 2016) based on the method set out in de Moor and Butterworth (2016). The mid-year revision in the South African sardine and anchovy TACs and TABs for 2017 is to be based on OMP-14, as OMP-17 is still under development. The maximum directed >14cm sardine catch recommended to be caught west of Cape Agulhas thus requires some revision to take account of further work on the underlying sardine Operating Model and information resulting from the 2017 recruit survey.

Method for Projections

de Moor and Butterworth (2017) projected the sardine west component from November 2015 to November 2017 taking into account the November 2015, June 2016 and November 2016 survey observations. They considered the risk to the resource under different levels of catch west of Cape Agulhas as being represented by the probability that the sardine 2+ biomass would be below the 'kink' point of the hockey stick stock recruit relationship calculated assuming spawner biomass is equal to the 2+ biomass.

This document uses the simulation projection framework already developed for OMP-17 testing (de Moor 2017 with further updates), and will similarly consider the risk to the sardine west component in November 2017 under different levels of catch west of Cape Agulhas. The relevant equations are reproduced in the Appendix of this document. The following changes are made from the projection framework being used to develop OMP-17:

i) The proportion of 1-year-old sardine moving from the west to the south component each November is assumed to be the median (and average) proportion of 1-year-olds moving between 2010 and 2015 of 0.37[1].

ii) The split of directed >14cm sardine catch between the west and south components is determined by a range of fixed alternatives for the catch west of Cape Agulhas, rather than the relationship used in de Moor and Butterworth (2017).

iii) The stock recruitment relationship selected for this analysis is the general parametric curve (de Moor and Butterworth 2017).

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[1] This was agreed to be used to inform the decision to calculate the initial maximum recommended sardine directed >14cm catch west of Cape Agulhas.

iv) A range of alternative fixed values of survey estimated sardine June 2017 recruitment west of Cape Infanta will be used. The survey estimated sardine recruitment east of Cape Infanta and anchovy recruitment are taken to be the average 2011-2015 values of 0.9757[2] billion and 221.71[3] billion, respectively.

The baseline operating models are from de Moor (2016a,b), with the "General Parametric" stock recruitment relationship (de Moor and Butterworth 2017) for sardine fitted separate from the assessment model. In order to monitor the risk to the sardine resource of differing levels of sardine catch west of Cape Agulhas, a risk threshold must be chosen. The General Parametric stock recruitment curve is forced to go through an 'end point' corresponding to the mean of the five largest spawner biomass and corresponding recruitment 'data' points which are output from the sardine assessment. For the purpose of this analysis, a risk threshold of the spawner biomass which corresponds to the recruitment at a percentage of the 'end point' is put forward. Figure 1 demonstrates the calculation of this threshold. Figure 2 shows the full range of the 'end point' and, as an example, the recruitment at 75% of the 'end point' with corresponding spawner biomass.

Initial Results

Table 1 shows the probability of the west component spawner biomass falling below the selected threshold for a range of threshold values and assumed June 2017 survey estimates of sardine recruitment west of Capen Infanta. The probabilities in Table 1 are clearly very high. This results from short term projections of a resource which is already at low biomass. The median projected west component biomass in November 2016 is 415 000t [217 000t, 893 000t] with a median spawner biomass of 98 000t [38 000t, 337 000t].

While Table 1 considers alternative fixed catches west of Cape Agulhas, note that any final catch west of Cape Agulhas would naturally be limited by the final directed >14cm sardine TAC from for 2017 (Table 2).

Next Steps

It is clear that low probabilities of the west component spawner biomass being below a spawner biomass threshold by the end of 2017 are not possible given the already below average status of the resource. Given this, the SWG-PEL needs to consider what reasonable additional risk to the resource is merited for catches west of Cape Agulhas. An example would be to allow for an additional 0.03 probability of spawner biomass being below an agreed threshold from that predicted under a no catch scenario.

Final results will be run using the survey estimated recruitment for anchovy and sardine, west and east of Cape Infanta from the June 2017 hydroacoustic survey. Additional data updated in the final run will include the sardine and anchovy catch prior to the survey and the juvenile sardine:anchovy ratios which are standard input into OMP-14 Harvest Control Rules (see Appendix for further details).

[2] Median / Average 1985-2015 is 0.8814 / 1.2995 billion
[3] Median / Average 1985-2015 142.64 / 230.57 billion

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Table 1. The probability of the November 2017 spawner biomass being below the spawner biomass threshold corresponding to recruitment at a percentage of the general parametric stock recruitment 'end point' recruitment, for a range of percentages, a range of west coast catches during 2017, $C_{j,2017}$, and a range of the survey estimated sardine recruitment during May 2017. The grey shaded cells correspond to an example of 0.03 increase in probability from the no catch scenario.

	60% of end point					70% of end point					75% of end point					80% of end point				
	$N^{S,obs}_{j=1,2017,r}$																			
$C_{j,2017}$[4]	1	3	5	7.3[5]	13[6]	1	3	5	7.3	13	1	3	5	7.3	13	1	3	5	7.3	13
0t	0.438	0.376	0.346	0.319	0.268	0.518	0.459	0.430	0.396	0.340	0.600	0.559	0.518	0.482	0.424	0.663	0.627	0.607	0.587	0.535
10 000t	0.452	0.405	0.361	0.331	0.280	0.538	0.478	0.446	0.412	0.349	0.613	0.573	0.537	0.509	0.449	0.681	0.639	0.618	0.598	0.541
20 000t	0.465	0.414	0.366	0.339	0.287	0.554	0.490	0.453	0.421	0.357	0.624	0.581	0.543	0.516	0.450	0.691	0.644	0.625	0.603	0.546
21 400t	0.465	0.416	0.367	0.340	0.289	0.556	0.493	0.455	0.421	0.358	0.625	0.584	0.543	0.516	0.452	0.691	0.648	0.627	0.603	0.547
30 000t	0.479	0.423	0.377	0.344	0.297	0.566	0.502	0.460	0.428	0.364	0.632	0.587	0.554	0.524	0.454	0.700	0.654	0.630	0.608	0.557
40 000t	0.488	0.427	0.390	0.351	0.306	0.575	0.513	0.468	0.441	0.370	0.639	0.595	0.564	0.534	0.458	0.712	0.659	0.632	0.613	0.564
50 000t	0.506	0.438	0.404	0.361	0.316	0.585	0.523	0.478	0.448	0.378	0.649	0.603	0.573	0.540	0.470	0.716	0.668	0.644	0.622	0.576

Table 2. The final directed >14cm sardine TAC (rounded to nearest 1000t) under OMP-14, given a range of possible June 2017 survey estimates of recruitment in billions.

$N^{S,obs}_{j=1,2017,r}$	TAC
1	32 000t
3	36 000t
5	41 000t
7.3	46 000t
13	58 000t

[4] Note that in this table the catches west of Cape Agulhas are set independently of OMP-14, while the anchovy catches and all bycatches are set according to OMP-14 in the catch scenarios. The catch east of Cape Agulhas is only modelled to be non zero in cases where the OMP-14 calculated TAC is greater than the catch assumed west of Cape Agulhas.
[5] Average 2011-2015 survey estimated sardine recruitment west of Cape Infanta.
[6] Average 2011-2015 survey estimated sardine recruitment west of Cape Infanta.

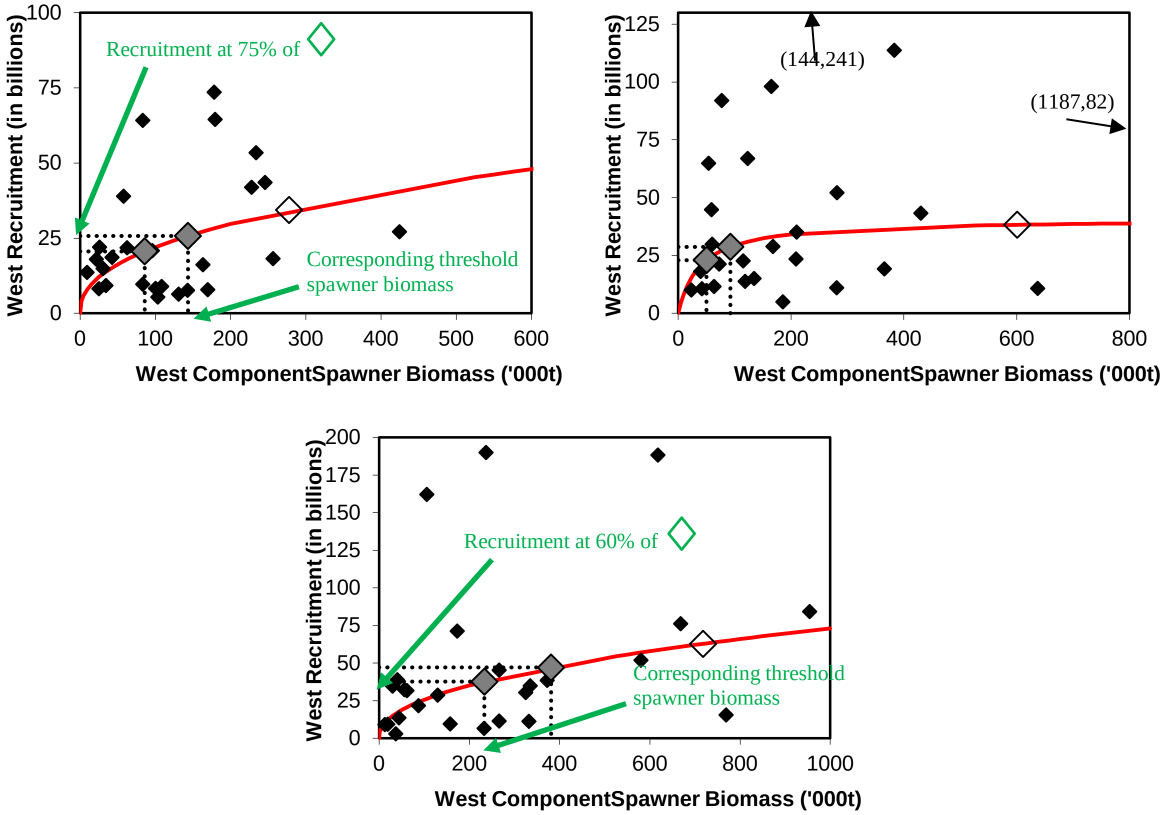

Figure 1. Three examples (the top left corresponding to the joint posterior mode) of the general parametric stock recruitment curve fit to spawner biomass and recruitment 'data' for the west component of sardine. The open diamond corresponds to the 'end point' mean of the 5 largest spawner biomass 'data' points, while the grey-coloured diamonds correspond to points on the curve that are at 75% and 60% of the recruitment at the 'end point'. The spawner biomass corresponding to these grey-coloured diamonds is put forward as the risk threshold level for use in these analyses.

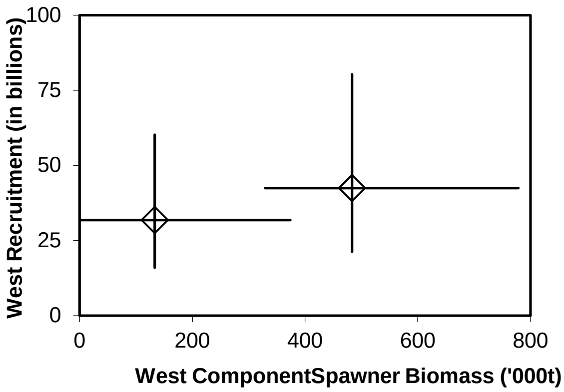

Figure 2. The posterior median (diamond) and 95% probability intervals (lines) of the 'end points' of the general parametric stock recruitment curves, and the points corresponding to 75% of the recruitment at the 'end point'.

Appendix: Extracts from the framework used to simulation test OMP-17 (de Moor 2017 with further updates), with changes shown in green highlights

Catches-at-age are given in numbers of fish (billions), whereas the TACs and TABs are given in biomass (in thousands of tons). All parameters are listed in Table A1.

Population dynamics model

Sardine:

$$N_{j,y,1}^{S,pred} = \left(N_{j,y-1,0}^{S,pred} e^{-M_{ju}^{S}/2} - C_{j,y,0}^{S,pred}\right) e^{-M_{ju}^{S}/2}$$

$$N_{j,y,a}^{S,pred} = \left(N_{j,y-1,a-1}^{S,pred} e^{-M_{ad}^{S}/2} - C_{j,y,a-1}^{S,pred}\right) e^{-M_{ad}^{S}/2},\ 2 \le a \le 4$$

$$N_{j,y,5^+}^{S,pred} = \left(N_{j,y-1,4}^{S,pred} e^{-M_{ad}^{S}/2} - C_{j,y,4}^{S,pred}\right) e^{-M_{ad}^{S}/2} \left(N_{j,y-1,5^+}^{S,pred} e^{-M_{ad}^{S}/2} - C_{j,y,5^+}^{S,pred}\right) e^{-M_{ad}^{S}/2}$$

$$B_{j,y}^{S,pred} = \sum_{a=0}^{5+} N_{j,y,a}^{S,pred} \overline{w}_{j,a}^{S}$$

$$SSB_{j,y}^{S,pred} = \sum_{a=1}^{5+} f_{j,a}^{S} N_{j,y,a}^{S,pred} \overline{w}_{j,a}^{S} \qquad \text{(A.1)}$$

Anchovy:

$$N_{j,y,1}^{A,pred} = \left(N_{j,y-1,0}^{A,pred} e^{-8M_{ju}^{A}/12} - C_{j,y,0}^{A,pred}\right) e^{-4M_{ju}^{A}/12}$$

$$N_{j,y,2}^{A,pred} = \left(N_{j,y-1,1}^{A,pred} e^{-5M_{ad}^{A}/12} - C_{j,y,1}^{A,pred}\right) e^{-7M_{ad}^{A}/12}$$

$$N_{j,y,3}^{A,pred} = N_{j,y-1,2}^{A,pred} e^{-M_{ad}^{A}}$$

$$N_{j,y,4^+}^{A,pred} = N_{j,y-1,3}^{A,pred} e^{-M_{ad}^{A}} + N_{j,y-1,4^+}^{A,pred} e^{-M_{ad}^{A}}$$

$$B_{j,y}^{A,pred} = \sum_{a=0}^{4+} N_{j,y,a}^{A,pred} \overline{w}_{j,a}^{A}$$

$$SSB_{j,y}^{A,pred} = \sum_{a=1}^{4+} f_{j,a}^{A} N_{j,y,a}^{A,pred} \overline{w}_{j,a}^{A} \qquad \text{(A.2)}$$

$$N_{1,y,a}^{S,pred} = \left(1 - move_{y,a}\right) N_{1,y,a}^{S^*}$$

$$N_{2,y,a}^{S,pred} = N_{2,y,a}^{S^*} + move_{y,a} N_{1,y,a}^{S^*} \qquad y_1 \le y \le y_n \qquad \text{(A.4)}$$

where $N_{j,y,a}^{S^*}$ is simply the numbers-at-age a given by equation (A.1) prior to movement, with $move_{y,a} =$ 0.37 and $move_{y,2} = \phi \times move_{y,1}$.

Letting $f\left(SSB_{j,y}^{i,pred}\right)$ denote the stock recruitment curve of the chosen model, with parameters a_j^i and b_j^i, then future recruitment $N_{j,y,0}^{i,pred}$ is assumed to be log-normally distributed about a stock recruitment relationship as follows:

$$N_{j,y,0}^{i,pred} = f\left(SSB_{j,y}^{i,pred}\right) e^{\varepsilon_{j,y}^{i}\sigma_{j,r}^{i} - 0.5\left(\sigma_{j,r}^{i}\right)^2} \qquad \text{(A.5)}$$

where

$$\varepsilon_{j,y}^{i} = s_{j,cor}^{i}\varepsilon_{j,y-1}^{i} + \omega_{j,y}^{i}\sqrt{1 - \left(s_{j,cor}^{i}\right)^2}, \text{ where } \omega_{j,y}^{i} \sim N(0,1) \qquad \text{(A.6)}$$

In the two component OM of sardine, some recruits originating from the south component ($j = 2$) are assumed to contribute to west component ($j = 1$) recruitment at the beginning of November:

$$N_{1,y,0}^{S,pred} = N_{1,y,0}^{S^*,pred} + pN_{2,y,0}^{S^*,pred}$$

$$N_{2,y,0}^{S,pred} = (1-p)N_{2,y,0}^{S^*,pred} \qquad y_1 \le y \le y_n \qquad \text{(A.7)}$$

where $N_{j,y,0}^{S^*,pred}$ is simply the recruits given by equation (A.5) prior to movement.

Implementation model

Defining $TAC_{j,y}^S$ to be the directed >14cm sardine TAC assumed taken from component j, the following separation of TAC by component is effected, given a range of fixed values for $TAC_{1,y}^S$:

$$TAC_{2,y}^S = TAC_y^S - TAC_{1,y}^S. \qquad \text{(A.8)}$$

Sardine adult catch

$$C_{j,y,a}^{S,pred} = N_{j,y-1,a}^{S,pred} e^{-M_{ad}^S/2} S_{j,a}^S F_{j,y}, \;\; 1 \le a \le 5^+ \qquad \text{(A.9)}$$

$$\text{where } F_{j,y} = \frac{TAC_{j,y}^S + \acute{t}_j TAB_{big}^{S,draw}}{N_{j,y-1,0}^{S,pred} e^{-M_{ju}^S/2} S_{j,0}^S \bar{w}_{j,0c}^S + \Sigma_{a=1}^{5^+} N_{j,y-1,a}^{S,pred} e^{-M_{ad}^S/2} S_{j,a}^S \bar{w}_{j,ac}^S}, \qquad \text{(A.10)}$$

Anchovy 1-year-old catch

$$C_{1,y,1}^{A,pred} = 0.38 \times \frac{TAC_y^{1,A} + 0.5TAB^A}{\bar{w}_{1c}^A}. \qquad \text{(A.11)}$$

Anchovy 0-year-old catch

$$C_{1,y,Obs}^{A,pred} = 0.29 \times \frac{TAC_y^{1,A} + 0.5TAB^A}{\bar{w}_{0c}^A}. \qquad \text{(A.12)}$$

$$C_{1,y,O}^{A,pred} = \frac{1}{\bar{w}_{0c}^A}\left(TAC_y^{2,A} + TAB^A - \bar{w}_{1c}^A C_{1,y,1}^{A,pred}\right) \qquad \text{(A.13)}$$

Sardine 0-year-old catch prior to the recruit survey

$$C_{1,y,0bs}^{S,pred} = 0.5\frac{\acute{t}_1 TAB_{small,rh}^S}{\bar{w}_{1,0c}^S} + 0.6\frac{\omega_{1,y}^{draw} TAC_{1,y}^S}{\bar{w}_{1,0c}^S} + k_{janmay}\frac{N_{1,y-1,0}^{S,pred}}{N_{1,y-1,0}^{A,pred}} e^{\sigma_{janmay}\eta_{y,janmay}} \times 0.26\frac{TAC_y^{1,A}}{\bar{w}_{1,0c}^S},$$

$$C_{2,y,0bs}^{S,pred} = 0.5\frac{\acute{t}_2 TAB_{small,rh}^S}{\bar{w}_{2,0c}^S} + 0.6\frac{\omega_{2,y}^{draw} TAC_{2,y}^S}{\bar{w}_{2,0c}^S}, \qquad \text{where } \eta_{y,janmay} \sim N(0,1) \qquad \text{(A.14)}$$

Sardine 0-year-old catch (in billions)

$$C_{1,y,0}^{S,pred} = \frac{1}{\bar{w}_{1,0c}^S}\left(\left(\lambda_y TAC_y^{1,A} + r_y\left(TAC_y^{2,A} - TAC_y^{1,A}\right)\right) + \acute{t}_1 TAB_{small,rh}^S + \omega_{1,y}^{draw} TAC_{1,y}^S\right) +$$

$$N_{1,y-1,0}^{S,pred} e^{-M_{ju}^S/2} S_{1,0}^S F_{1,y}$$

$$C_{2,y,0}^{S,pred} = \frac{1}{\bar{w}_{2,0c}^S}\left(\acute{t}_2 TAB_{small,rh}^S + \omega_{2,y}^{draw} TAC_{2,y}^S\right) + N_{2,y-1,0}^{S,pred} e^{-M_{ju}^S/2} S_{2,0}^S F_{2,y} \qquad \text{(A.15)}$$

where

$$\lambda_y = max\{\gamma_y, r_y\}, \tag{A.16}$$

$$r_y = \frac{1}{2}\left(r_{y,sur} + r_{y,com}\right), \text{ and} \tag{A.17}$$

$$r_{y,sur} = \frac{N_{1,y,r}^{S,obs}}{N_{1,y,r}^{A,obs}}. \tag{A.18}$$

$$r_{y,com} = k_{may}\frac{N_{1,y,r}^{S,pred}}{N_{1,y,r}^{A,pred}}e^{\sigma_{may}\varepsilon_{y,may}}. \tag{A.19}$$

$$\text{where } \varepsilon_{y,may} = \rho_{may}\eta_{y,janmay} + \sqrt{1-\left(\rho_{may}\right)^2}\eta_{y,may}, \tag{A.20}$$

with $\eta_{y,may} \sim N(0,1)$ and $\eta_{y,jan:may}$ is given by equation (A.14).

$$C_{1,y,0}^{S*,pred} = \frac{1}{\bar{w}_{1,0c}^S}\left(\acute{t}_1 TAB_{small,rh}^S + \omega_{1,y}^{draw} TAC_{1,y}^S\right) + N_{1,y-1,0}^{S,pred} e^{-M_{ju}^S/2} S_{1,0}^S F_{1,y} + 1.327 \times \left(C_{1,y,0bs}^{S,pred} - 0.5\frac{\acute{t}_1 TAB_{small,rh}^S}{\bar{w}_{1,0c}^S} - 0.6\frac{\omega_{1,y}^{draw} TAC_{1,y}^S}{\bar{w}_{1,0c}^S}\right) + \frac{1}{\bar{w}_{1,0c}^S}\left(r_{y,jun}C_{y,jun}^{A,pred} + r_{y,jul}C_{y,jul}^{A,pred} + r_{y,aug}C_{y,aug}^{A,pred} + r_{y,sep}C_{y,sep}^{A,pred} + r_{y,octdec}C_{y,octdec}^{A,pred}\right) \tag{A.21}$$

$$r_{y,m} = k_m\frac{N_{1,y,r}^{S,pred}}{N_{1,y,r}^{A,pred}}e^{\sigma_m\varepsilon_{y,m}}, \quad \text{where } m = jun, jul, aug, sep, octdec \tag{A.22}$$

$$\varepsilon_{y,jun} = \rho_{jun}\varepsilon_{y,may} + \sqrt{1-\left(\rho_{jun}\right)^2}\eta_{y,jun}$$

$$\varepsilon_{y,jul} = \rho_{jul}\varepsilon_{y,jun} + \sqrt{1-\left(\rho_{jul}\right)^2}\eta_{y,jul}$$

$$\varepsilon_{y,aug} = \rho_{aug}\varepsilon_{y,jul} + \sqrt{1-\left(\rho_{aug}\right)^2}\eta_{y,aug}$$

$$\varepsilon_{y,sep} = \rho_{sep}\varepsilon_{y,aug} + \sqrt{1-\left(\rho_{sep}\right)^2}\eta_{y,sep}$$

$$\varepsilon_{y,octdec} = \rho_{octdec}\varepsilon_{y,sep} + \sqrt{1-(\rho_{octdec})^2}\eta_{y,octdec}. \tag{A.23}$$

where $\varepsilon_{y,may}$ is from equation (A.20), and $\eta_{y,m} \sim N(0,1)$, $m = jun, jul, aug, sep, octdec$.

$$C_{y,jun}^{A,pred} = 0.24 \times TAC_y^{1,A} \tag{A.24}$$

$$C_{y,jul}^{A,pred} = p_{jul}\left(TAC_y^{2,A} - TAC_y^{1,A}\right) \tag{A.25}$$

$$C_{y,aug}^{A,pred} = p_{aug}\left(TAC_y^{2,A} - TAC_y^{1,A}\right) \tag{A.26}$$

$$C_{y,sep}^{A,pred} = p_{sep}\left(TAC_y^{2,A} - TAC_y^{1,A}\right) \tag{A.27}$$

$$C_{y,octdec}^{A,pred} = \left(1 - p_{jul} - p_{aug} - p_{sep}\right)\left(TAC_y^{2,A} - TAC_y^{1,A}\right) \tag{A.28}$$

where $p_{jul} = 0.42$, $p_{aug} = 0.26$ and $p_{sep} = 0.20$.

Closure of the anchovy fishery

$$C_{1,y,0}^{S^{**},pred} =$$

$$min\left\{C_{1,y,0}^{S^{*},pred}; min\left\{0; \frac{TAB_{y,anch}^{2,S}}{\overline{w}_{1,0c}^{S}} + \frac{1}{\overline{w}_{1,0c}^{S}}\left(\acute{\tau}_1 TAB_{small,rh}^{S} + \omega_{1,y}^{draw} TAC_{1,y}^{S}\right) + N_{1,y-1,0}^{S,pred} e^{-M_{ju}^{S}/2} S_{1,0}^{S} F_{1,y}\right\}\right\}$$

(A.29)

$$C_{1,y,0}^{A^{*},pred} = min\left\{C_{1,y,0}^{A,pred}; min\left\{0; \frac{1}{\overline{w}_{1,0c}^{A}}\left(TAB^{A} - \overline{w}_{1c}^{A} C_{1,y,1}^{A,pred} + \right.\right.\right.$$

$$TAC_{y}^{2,A}\left[\frac{TAB_{y,anch}^{2,S}}{1.327\times\left(\overline{w}_{1,0c}^{S} C_{1,y,0bs}^{S,pred} - 0.5\acute{\tau}_1 TAB_{small,rh}^{S} - 0.6\omega_{1,y}^{draw} TAC_{1,y}^{S}\right) + \left(r_{y,jun} C_{y,jun}^{A,pred} + r_{y,jul} C_{y,jul}^{A,pred} + r_{y,aug} C_{y,aug}^{A,pred} + r_{y,sep} C_{y,sep}^{A,pred} + r_{y,octdec} C_{y,oc}^{A,pr}\right.}\right.$$

(A.30)

Assumptions made for 2016

As the stock assessments (de Moor 2016a, de Moor and Butterworth 2016a,b) covered the period to November 2015, the MP testing framework begins from November 2015 and projects to November 2036. A number of parameters that would be simulated in the testing framework for 2016, have however already been observed. Thus the following changes are made to the simulation framework above for 2016:

i) The TAC/TABs (in thousands of tons) for 2016 have already been set using OMP-14, thus $TAC_{2016,init}^{S} = 64.563$, $TAB_{2016,small,init}^{S} = 4.519$, $TAC_{2016}^{S} = 64.928$, $TAB_{2016,small}^{S} = 5.545$, $TAC_{2016}^{1,A} = 254.483$, $TAB_{2016,anch}^{1,S} = 25.866$, $TAC_{2016}^{2,A} = 354.326$, $TAB_{2016,anch}^{2,S} = 31.463$.
For candidate MPs which calculate area-specific sardine TAC/Bs, the assumption is made that the TAC was awarded as 40.540[7] west of Cape Agulhas and 22.763 east of Cape Agulhas (van der Westhuizen pers comm).

ii) As the May 2016 survey observations are available, no error is required, thus equation (A.36) is replaced by $N_{j=1,2016,r}^{obs,S} = 0.811$ billion (CV of 0.425) for either the single stock OM or the west component of the two component OM, $N_{j=2,2016,r}^{obs,S} = 0.850$ billion (CV of 0.887) for the south component of the two component OM, and $N_{j=1,2016,r}^{obs,A} = 118.075$ billion (CV of 0.221) (Coetzee *et al*. 2016a and D. Merkle pers comm.).

iii) The ratio of juvenile sardine to anchovy "in the sea" used in equation (A.13) is $r_{2016} = 0.5 \times (0.0231 + 0.089)$.

iv) The model predicted recruitment in November 2015 is an inverse variance weighted average of the logarithms of two estimates (logarithms are taken as the distributions of the estimates themselves are assumed to be log-normal). The first estimate comes from the recruitment observed in the 2016 recruit survey:
$N_{j,2016,r}^{i,pred} = \frac{1}{k_{j,r}^{i}} N_{j,2016,r}^{i,obs}$ (the best estimate from equation (A.36) for component j of species i)

[7] 2016 catch data to be confirmed for final run.

$$\tilde{N}^{S,pred}_{1,2015,0} = \left(N^{S,pred}_{1,2016,r} e^{0.5(6+t_{2016})M^S_{ju}/12} + \acute{C}^S_{1,2016,0bs}\right) e^{0.5(6+t_{2016})M^S_{ju}/12} -$$

$$\frac{p}{1-p}\left(N^{S,pred}_{2,2016,r} e^{0.5(6+t_{2016})M^S_{ju}/12} + \acute{C}^S_{2,2016,0bs}\right) e^{0.5(6+t_{2016})M^S_{ju}/12}$$ (equations A.41 and A.7)

$$\tilde{N}^{S,pred}_{2,2015,0} = \frac{1}{1-p}\left(N^{S,pred}_{2,2016,r} e^{0.5(6+t_{2016})M^S_{ju}/12} + \acute{C}^S_{2,2016,0bs}\right) e^{0.5(6+t_{2016})M^S_{ju}/12}$$

(equations A.41 and A.7)

$$\tilde{N}^{A,pred}_{j,2015,0} = \left(N^{A,pred}_{j,2016,r} e^{t_{2016}M^A_{ju}/12} + \acute{C}^A_{j,2016,0bs}\right) e^{0.5M^A_{ju}}$$ (equation (A.41))

where $\acute{C}^A_{2016,Obs} = 20.777$ billion, and $\acute{C}^S_{j=1,2016,Obs} = 0.673$, and $\acute{C}^S_{j=2,2016,Obs} = 0.00$ billion being the juvenile anchovy and sardine catch, respectively from 1 November 2015 to the day before the recruit survey in June 2016, which was 7th June, i.e. $t_{2016} = 1.233$ (de Moor 2016). The standard errors associated with the logarithms of these estimates are:

$$\tilde{\sigma}^S_{1,2016,rec} = \sqrt{0.425^2 + (\varphi^S_{ac})^2 + \left(\lambda^s_{1,r}\right)^2}$$

$$\tilde{\sigma}^S_{2,2016,rec} = \sqrt{0.887^2 + (\varphi^S_{ac})^2 + \left(\lambda^s_{2,r}\right)^2}$$

$$\tilde{\sigma}^A_{1,2016,rec} = \sqrt{0.221^2 + \left(\lambda^A_{1,r}\right)^2}$$

v) The second estimate comes from the stock recruitment curve, but needs to take account of the serial correlation in residuals about this curve, and so depends on the residual estimated about this curve for November 2014. Thus:

$$\breve{N}^{i,pred}_{j,2015,0} = f\left(SSB^{i,pred}_{j,2015}\right) e^{s^i_{j,cor}\varepsilon^i_{j,2014}\sigma^i_{j,r}}$$

with a standard error of the logarithm of this estimate being given by:

$$\breve{\sigma}^i_{j,2015} = \sqrt{1-\left(s^i_{j,cor}\right)^2}\,\sigma^i_{j,r}$$

vi) The inverse variance weighted average of the logarithms of these two estimates is then given by:

$$ln\left(N^{i,pred}_{j,2015,0}\right) = \frac{\frac{ln\left(\tilde{N}^{i,pred}_{j,2015,0}\right)}{\left(\tilde{\sigma}^i_{j,2016,rec}\right)^2} + \frac{ln\left(\breve{N}^{i,pred}_{j,2015,0}\right)}{\left(\breve{\sigma}^i_{j,2015}\right)^2}}{\frac{1}{\left(\tilde{\sigma}^i_{j,2016,rec}\right)^2} + \frac{1}{\left(\breve{\sigma}^i_{j,2015}\right)^2}}$$

This process is essentially shrinking the estimate provided by the survey towards the mean provided by the stock recruitment relationship (adjusted for serial correlation).

vii) The recruitment residual in November 2015, required in the calculation of the recruitment residual in November 2016 (equation A.6), is obtained from equation (A.5) as follows:

$$\varepsilon^i_{j,2015} = ln\left(\frac{N^{i,pred}_{j,2015,0}}{f\left(SSB^{i,pred}_{j,2015}\right)}\right) \Big/ \sigma^i_{j,r}$$

viii) As the November 2016 survey observations are available, no error is required, thus equation (A.31) is replaced by $B^{A,obs}_{j=1,2016} = 1733.040$ thousand tons, $B^{S,obs}_{j=1,2016} = 258.5746$ thousand tons for single area HCRs, and $B^{S,obs}_{j=1,2016} = 183.3558$ and $B^{S,obs}_{j=2,2016} = 75.2188$ thousand tons for two area HCRs (Coetzee *et al*. 2016b).

ix) As the November 2016 survey observations are available, no error is required, thus equation (A.31) is replaced by $B^{obs,S}_{j=1,2016} = 258\,575$t (CV of 0.353) for the single stock OM or $B^{obs,S}_{j=1,2016} = 183\,356$t (CV of 0.709) $B^{obs,S}_{j=2,2016} = 75\,219$t (CV of 0.291) the west and south components, respectively, of the two component OM, and $B^{obs,A}_{2016} = 1733\,040$t (CV of 0.227) (Coetzee *et al*. 2016b).

Assumptions made for 2017

A number of parameters that would be simulated in the testing framework for 2017, can be further informed through external sources. Thus the following changes are made to the simulation framework above for 2017:

i) The TAC/TABs (in thousands of tons) for 2017 will be set using OMP-14, thus $TAC^{S}_{2017,init} = 29.955$, $TAB^{S}_{2017,small,init} = 2.097$, $TAC^{1,A}_{2017} = 247.500$, $TAB^{1,S}_{2017,anch} = 25.064$, and TAC^{S}_{2017}, $TAB^{S}_{2017,small}$, $TAC^{2,A}_{2017}$, and $TAB^{2,S}_{2017,anch}$ will be informed by the survey estimates of recruitment and associated catch data.

ii) The May 2017 survey observations will be available for the final run of this analysis. Initial results presented in this document assume fixed values for $N^{obs,S}_{j=1,2016,r}$, $N^{obs,S}_{j=2,2016,r}$, and $N^{obs,A}_{j=1,2016,r}$ (see main text for values chosen).

iii) The ratio of juvenile sardine to anchovy "in the sea" used in equation (A.13) will be available for the final run of this analysis. For the results in this document $r_y = 0.042$, which is the average from 2011-2015.

iv) The model predicted recruitment in November 2016 is an inverse variance weighted average of the logarithms of two estimates (logarithms are taken as the distributions of the estimates themselves are assumed to be log-normal). The first estimate comes from the recruitment observed in the 2017 recruit survey:

$N^{i,pred}_{j,2017,r} = \frac{1}{k^{i}_{j,r}} N^{i,obs}_{j,2017,r}$ (the best estimate from equation (A.36) for component j of species i)

$$\tilde{N}^{S,pred}_{1,2016,0} = \left(N^{S,pred}_{1,2017,r} e^{0.5(6+t_{2017})M^{S}_{ju}/12} + \acute{C}^{S}_{1,2017,0bs}\right) e^{0.5(6+t_{2017})M^{S}_{ju}/12} - \frac{p}{1-p}\left(N^{S,pred}_{2,2017,r} e^{0.5(6+t_{2017})M^{S}_{ju}/12} + \acute{C}^{S}_{2,2017,0bs}\right) e^{0.5(6+t_{2017})M^{S}_{ju}/12} \quad \text{(equations A.41 and A.7)}$$

$$\tilde{N}^{S,pred}_{2,2016,0} = \frac{1}{1-p}\left(N^{S,pred}_{2,2017,r} e^{0.5(6+t_{2017})M^{S}_{ju}/12} + \acute{C}^{S}_{2,2017,0bs}\right) e^{0.5(6+t_{2017})M^{S}_{ju}/12}$$

(equations A.41 and A.7)

$$\tilde{N}^{A,pred}_{j,2016,0} = \left(N^{A,pred}_{j,2017,r} e^{t_{2017}M^{A}_{ju}/12} + \acute{C}^{A}_{j,2017,0bs}\right) e^{0.5M^{A}_{ju}} \quad \text{(equation (A.41))}$$

where $\acute{C}^{A}_{2017,0bs}$, and $\acute{C}^{S}_{j=1,2017,0bs}$, and $\acute{C}^{S}_{j=2,2017,0bs}$ being the juvenile anchovy and sardine catch, respectively from 1 November 2016 to the day before the recruit survey in June 2017, which was 11th June, i.e. $t_{2017} = 1.367$, will be available for the final run of this analysis. For the results in this document, $\acute{C}^{A}_{2017,Obs} = X^{A} N^{A,obs}_{2017,r}$, $\acute{C}^{S}_{j,2017,Obs} = X^{S}_{j} N^{S,obs}_{j,2017,r}$, and $\acute{C}^{S}_{j,2017,Obs} = 0$ with $X^{A} = 0.027$, and $X^{S}_{1} = 0.041$ being the 2011 to 2015 average of $\frac{\acute{C}^{A}_{y,Obs}}{N^{A,obs}_{y,r}}$ and $\frac{\acute{C}^{S}_{1,y,Obs}}{N^{S,obs}_{1,y,r}}$, respectively.

The standard errors associated with the logarithms of these estimates are:

$$\tilde{\sigma}^{S}_{1,2017,rec} = \sqrt{0.444^2 + (\varphi^{S}_{ac})^2 + \left(\lambda^{s}_{1,r}\right)^2}$$

$$\tilde{\sigma}^{S}_{2,2017,rec} = \sqrt{0.736^2 + (\varphi^{S}_{ac})^2 + \left(\lambda^{s}_{2,r}\right)^2}$$

$$\tilde{\sigma}^{A}_{1,2017,rec} = \sqrt{0.218^{\quad 2} + \left(\lambda^{A}_{1,r}\right)^2}$$

where *CVs*[8] will be upated with the CVs associated with the 2017 survey estimates of recruitment for the final run of this analysis.

v) The second estimate comes from the stock recruitment curve, but needs to take account of the serial correlation in residuals about this curve, and so depends on the residual estimated about this curve for November 2015. Thus:

$$\breve{N}^{i,pred}_{j,2016,0} = f\left(SSB^{i,pred}_{j,2016}\right) e^{s^{i}_{j,cor} \varepsilon^{i}_{j,2015} \sigma^{i}_{j,r}}$$

with a standard error of the logarithm of this estimate being given by:

$$\breve{\sigma}^{i}_{j,2016} = \sqrt{1 - \left(s^{i}_{j,cor}\right)^2}\, \sigma^{i}_{j,r}$$

vi) The inverse variance weighted average of the logarithms of these two estimates is then given by:

$$ln\left(N^{i,pred}_{j,2016,0}\right) = \frac{\frac{ln\left(\tilde{N}^{i,pred}_{j,2016,0}\right)}{\left(\tilde{\sigma}^{i}_{j,2017,rec}\right)^2} + \frac{ln\left(\breve{N}^{i,pred}_{j,2016,0}\right)}{\left(\breve{\sigma}^{i}_{j,2016}\right)^2}}{\frac{1}{\left(\tilde{\sigma}^{i}_{j,2017,rec}\right)^2} + \frac{1}{\left(\breve{\sigma}^{i}_{j,2016}\right)^2}}$$

This process is essentially shrinking the estimate provided by the survey towards the mean provided by the stock recruitment relationship (adjusted for serial correlation).

vii) The recruitment residual in November 2016, required in the calculation of the recruitment residual in November 2017 (equation A.6), is obtained from equation (A.5) as follows:

$$\varepsilon^{i}_{j,2016} = ln\left(\frac{N^{i,pred}_{j,2016,0}}{f\left(SSB^{i,pred}_{j,2016}\right)}\right) \Big/ \sigma^{i}_{j,r}$$

External inputs

Correlation in survey residuals

$$\varepsilon^{i}_{y,Nov} = ln\left(B^{i,obs}_{1,y}\right) - ln\left(k^{i}_{1,N} \hat{B}^{i}_{1,y}\right), \qquad 1984 \le y \le 2015 \qquad \text{(A.42)}$$

[8] Average of 2011-2015 for results in this document.

$$\sigma^i_{Nov} = \sqrt{\frac{\sum_{y=1984}^{2015}\left(\varepsilon^i_{y,Nov}\right)^2}{\sum_{y=1984}^{2015} 1}}, \qquad \text{(A.43)}$$

$$\rho_{Nov} = \frac{\sum_{y=1984}^{2015} \varepsilon^S_{y,Nov}\varepsilon^A_{y,Nov}}{\left(\sum_{y=1984}^{2015} 1\right)\sigma^S_{Nov}\sigma^A_{Nov}}. \qquad \text{(A.44)}$$

$$\varepsilon^i_{y,rec} = ln\left(N^{i,obs}_{1,y,r}\right) - ln\left(k^i_{1,r}\widehat{N}^i_{1,y,r}\right), \qquad 1985 \leq y \leq 2015 \qquad \text{(A.45)}$$

$$\sigma^i_{rec} = \sqrt{\frac{\sum_{y=1985}^{2015}\left(\varepsilon^i_{y,rec}\right)^2}{\sum_{y=1985}^{2015} 1}} \quad . \qquad \text{(A.46)}$$

$$\rho_{rec} = \frac{\sum_{y=1985}^{2015} \varepsilon^S_{y,rec}\varepsilon^A_{y,rec}}{\left(\sum_{y=1985}^{2015} 1\right)\sigma^S_{rec}\sigma^A_{rec}} \quad . \qquad \text{(A.47)}$$

Ratio of sardine bycatch to anchovy between January and May

$$k_{janmay} = exp\left\{\frac{\sum_{y=2006}^{2015} ln\left(C^{S,byc}_{y,janmay}/C^A_{y,janmay}\right) - ln\left(\widehat{N}^S_{1,y-1,0}/\widehat{N}^A_{1,y-1,0}\right)}{\sum_{y=2006}^{2015} 1}\right\} \qquad \text{(A.48)}$$

$$\varepsilon'_{y,janmay} = ln\left(C^{S,byc}_{y,janmay}/C^A_{y,janmay}\right) - ln\left(k_{janmay}\widehat{N}^S_{1,y-1,0}/\widehat{N}^A_{1,y-1,0}\right) \qquad 2006 \leq y \leq 2015 \quad \text{(A.49)}$$

$$\sigma_{janmay} = \sqrt{\sum_{y=2006}^{2015}\left(\varepsilon'_{y,janmay}\right)^2 / \sum_{y=2006}^{2015} 1}. \qquad \text{(A.50)}$$

Ratio of sardine bycatch to anchovy in the commercial fishery during May

$$k_m = exp\left\{\frac{\sum_{y=2006}^{2015} ln\left(C^{S,byc}_{y,m}/C^A_{y,m}\right) - ln\left(\widehat{N}^S_{1,y,r}/\widehat{N}^A_{1,y,r}\right)}{\sum_{y=2006}^{2015} 1}\right\} \qquad \text{(A.51)}$$

$$\varepsilon'_{y,m} = ln\left(C^{S,byc}_{y,m}/C^A_{y,m}\right) - ln\left(k_m\widehat{N}^S_{1,y,r}/\widehat{N}^A_{1,y,r}\right), \qquad 2006 \leq y \leq 2015 \qquad \text{(A.52)}$$

$$\sigma_m = \sqrt{\sum_{y=2006}^{2015}\left(\varepsilon'_{y,m}\right)^2 / \sum_{y=2006}^{2015} 1} \qquad \text{(A.53)}$$

$$\rho_m = \frac{\sum_{y=2006}^{2015} \varepsilon'_{y,m-1}\varepsilon'_{y,m}}{\sigma_{m-1}\sigma_m\left(\sum_{y=2006}^{2015} 1\right)} \qquad \text{(A.54)}$$

Table A1. Parameter definitions.

	Operating Model parameters	Units	Used in Equation	Notes
$N_{j,y,a}^{i,pred}$	OM predicted numbers at age a of species i, component j, at the beginning of November in year y	billions	A.1, A.2, (A.9,A.10)	$N_{j,2015,a}^{i,pred}$ sampled from Bayesian posterior distributions
M_{ju}^{i}	Natural mortality rate of juvenile (age 0) fish of species i	year^{-1}	A.1, A.2	sampled from Bayesian posterior distributions
M_{ad}^{i}	Natural mortality rate of adult (age 1^{+}) fish of species i	year^{-1}	A.1, A.2	sampled from Bayesian posterior distributions
$C_{j,y,a}^{i,pred}$	OM predicted future catches at age a in year y of component j of species i	billions	A.9,(A.1, A.2)	
$C_{j,y,0bs}^{i,pred}$	OM predicted future catches at age 0 prior to the May recruit survey in year y of component j of species i	billions	A.12,A.14,(A.41)	
$B_{j,y}^{i,pred}$	OM predicted November total biomass in year y of component j of species i	Thousands of tons	A.1, A.2	
$\hat{B}_{j,y}^{i}$	OM predicted November total biomass in year y of component j of species i	Thousands of tons	(A.42)	Sampled from Bayesian posterior distributions
$SSB_{j,y}^{i,pred}$	OM predicted November spawner biomass in year y of component j of species i	Thousands of tons	A.1, A.2	
$\bar{w}_{j,a}^{i}$	Historical average November weights-at-age a of component j of species i	Grams		Weight is given by length in the OM, and thus: $w_a^A = \sum_l w_l^A A_{a,l}^{sur} = \sum_l 0.0079 \times l^{3.0979} A_{a,l}^{sur}$ $w_{j,a}^{S} = \frac{1}{5}\sum_{y=2011}^{2015}\sum_{l} w_{j,y,l}^{S} A_{j,y,a,l}^{sur}$ [9]

[9] This differs for each sample from the posterior distribution and thus a table of weights is not provided in this document.

Table A1. Parameter definitions.

	Operating Model parameters	Units	Used in Equation	Notes
$f_{j,a}^{i}$	Proportion of component j of species i that is mature at age a	-	(A.1, A.2)	Maturity is given by length in the OM, and thus: $f_a^A = \sum_l f_l^A A_{a,l}^{sur} = \sum_l A_{a,l}^{sur} / \left(1 + e^{-(l-10.61)/0.66}\right)$ $f_{j,a}^S = \frac{1}{5}\sum_{y=2011}^{2015}\sum_l f_l^S A_{j,y,a,l}^{sur} = \frac{1}{5}\sum_{y=2011}^{2015}\sum_l A_{j,y,a,l}^{sur} / \left(1 + e^{-(l-17.4)/0.95}\right)$
$move_{y,a}$,	Proportion of sardine at age a moving from the west to the south component in year y (2 component OM only)	-	A.3, A.4	$move_{y,a}$, $2006 \le y \le 2015$, sampled from Bayesian posterior distributions
ϕ	The proportion of 2^{+}-year-olds which move from the west to the south component in year y is this time-invariant proportion ϕ of the 1-year-olds moving in year y	-	A.4	
a_j^i	Stock-recruitment parameter for component j of species i (e.g. maximum median recruitment in Hockey Stick stock-recruitment relationship)	e.g. billions	(A.5)	Sampled from Bayesian posterior distributions
b_j^i	Stock-recruitment parameter for component j of species i (e.g. spawner biomass below which median recruitment declines)	e.g. thousands of tons	(A.5)	Sampled from Bayesian posterior distributions
$\varepsilon_{j,y}^i$	Standardised November recruitment residual for component j of species i in year y		A.6	$\varepsilon_{j,2014}^i$ sampled from Bayesian posterior distributions
$\sigma_{j,r}^i$	Standard deviation of the recruitment residuals for component j of species i		(A.5)	Sampled from Bayesian posterior distributions

Table A1. Parameter definitions.

	Operating Model parameters	Units	Used in Equation	Notes
$s_{j,cor}^{i}$	Recruitment serial correlation for component j of species i		(A.6)	
$\omega_{j,y}^{i}$	Random variable	-	A.6	$\omega_{j,y}^{i} \sim N(0,1)$
τ	The proportion of the directed >14cm sardine TAC assumed caught west of Cape Agulhas. The ≤14cm sardine bycatch with directed >14cm sardine is assumed to be proportioned west/south of Cape Agulhas in the same manner as the TAC.	-	A.8	
$S_{j,a}^{S}$	Commercial selectivity-at-age a of sardine component j	-	(A.9,A.10)	Sampled from Bayesian posterior distributions. Selectivity is estimated by length in the OM, and thus: $S_{j,a}^{S} = \frac{1}{5}\sum_{y=2011}^{2015}\sum_{l} 0.5\left(S_{j,y,2,l}^{S} A_{j,y,2,a,l}^{com} + S_{j,y,3,l}^{S} A_{j,y,3,a,l}^{com}\right)$ [10], $0 \leq a \leq 5^{+}$
$F_{j,y}$	Commercial fishing mortality of sardine component j in year y	-	A.10 (A.9)	
$\overline{w}_{j,ac}^{i}$	Historical average weights-at-age a in the catches from component j of species i	grams	(A.10)	Table A2
$\acute{\tau}_j$	Proportion of the ≤14cm and >14cm sardine TAB with round herring[11] assumed caught west of Cape Agulhas	-	(A.10,A.14,A.15)	$\acute{\tau}_1 = 1$ and $\acute{\tau}_2 = 1$
$TAB_{big,y}^{S,draw}$	>14cm sardine bycatch with round herring and anchovy in year y			Randomly sampled from historical bycatches
ω	Proportion of the directed >14cm sardine TAC used to set the ≤14cm sardine TAB with directed sardine fishing	-		$\omega = 0.07$; in the case of a two-area MP, $\omega_{west} = 0.07$ and $\omega_{south} = 0.02$

[10] The average over quarters 2 and 3 is assumed since in past years, on average, 11% of the directed catch was in quarter 1 and 15% in quarter 4, while 43% and 32% were in quarters 2 and 3, respectively.
[11] The >14cm TAB also allows for some bycatch with anchovy.

Table A1. Parameter definitions.

	Operating Model parameters	Units	Used in Equation	Notes
$\omega_{j,y}^{draw}$	Proportion of the directed >14cm sardine TAC simulated to be caught as ≤14cm sardine bycatch from component j in year y	-	(A.14)	Randomly sampled from historical proportions
γ_y	Percentage of the initial anchovy TAC used to set the initial ≤14cm sardine TAB with anchovy	-	(A.16)	Equation given as part of Harvest Control Rules
r_y	Ratio of juvenile sardine to anchovy "in the sea" during May	-	A.17 (A.16)	
$r_{y,sur}$	Ratio of juvenile sardine to anchovy observed during the May recruit survey	-	A.18 (A.17)	Observed data input to the Harvest Control Rule
$r_{y,com}$	Ratio of juvenile sardine to anchovy in May commercial catches	-	A.19 (A.17)	Observed data input to the Harvest Control Rule; simulated during OMP testing as A.19
$N_{j,y,r}^{i,obs}$	Acoustic survey estimate of recruitment of component j of species i for May/June of year y	Billions	(A.18)	Observed data input to the Harvest Control Rule; simulated during OMP testing by equation A.36
$N_{j,y,r}^{i,pred}$	OM predicted recruitment of component j of species i in November $y-1$, projected forward to the time of the recruit survey in May/June y	billions	A.41,(A.19)	
$\widehat{N}_{j,y,r}^{i}$	OM predicted recruitment of component j of species i in November $y-1$, projected forward to the time of the recruit survey in May/June y	Billions	(A.45)	Sampled from Bayesian posterior distributions
k_{janmay}	Estimated bias in residuals for juvenile sardine: anchovy from commercial catches between January and May	-	A.48,(A.14)	
σ_{janmay}	Standard deviation from the residuals for juvenile sardine: anchovy from commercial catches between January and May	-	A.50,(A.14)	
$\varepsilon_{y,janmay}$	Residuals for juvenile sardine: anchovy from commercial catches between January and May	-	A.49 (A.50)	
k_m	Estimated bias in residuals for juvenile sardine: anchovy from commercial catches during month m	-	A.51 (A.19,A.22)	

Table A1. Parameter definitions.

	Operating Model parameters	Units	Used in Equation	Notes
$\varepsilon_{y,m}$	Residuals for juvenile sardine: anchovy from commercial catches during month m	-	A.20, A.23 (A.18,A.22)	
σ_m	Standard deviation from the residuals for juvenile sardine: anchovy from commercial catches during month m	-	A.53 (A.19,A.22)	
ρ_m	Correlation coefficient between the residuals for juvenile sardine: anchovy from commercial catches during months $m-1$ and m	-	A.54 (A.20,A.23)	
$C_{y,m}^{A,pred}$	OM predicted anchovy catch in month m of year y, for use in calculating the drop-off in small sardine bycatch with anchovy	Thousands of tons	A.24-A.28 (A.21)	
p_m	Average proportion of total anchovy catch during July to December that is taken in month m	-	(A.25-A.28)	
$B_{j,y}^{i,obs}$	November acoustic survey estimate of total biomass of component j of species i in year y	Thousands of tons	A.31	Observed data input to the Harvest Control Rule; simulated during OMP testing by equation A.31
$k_{j,N}^{i}$	Multiplicative bias associated with the acoustic survey estimate of November total biomass of component j of species i	-	(A.31)	Sampled from Bayesian posterior distributions
$\varepsilon_{j,y,Nov}^{i}$	Residuals in the simulated observation of November survey estimate of total biomass from OM predicted November biomass in year y of component j of species i	-	A.32,A.33(A.31)	
$\tilde{\sigma}_{j,y,Nov}^{i}$	Standard deviation of the residuals $\varepsilon_{j,y,Nov}^{i}$, being the November survey sampling CV	-	A.34,A.35,(A.32,A.33)	
ρ_{Nov}	Correlation in the residuals between sardine and anchovy November survey estimates of total biomass	-	A.44 (A.33)	

Table A1. Parameter definitions.

Operating Model parameters		Units	Used in Equation	Notes
φ_{ac}	CV associated with the factors which cause bias in the sardine acoustic survey estimates and which vary inter-annually rather than remain fixed over time			$(\varphi_{ac})^2 = 0.227$ from de Moor and Butterworth 2016a
$\left(\lambda_{j,N}^{i}\right)^2$	Additional variance (over and above the survey sampling CV and $(\varphi_{ac})^2$) associated with the November survey of component j of species i			
$k_{j,r}^{i}$	Multiplicative bias associated with the acoustic survey estimate of May recruitment of component j of species i	-	(A.36)	Sampled from Bayesian posterior distributions
$\varepsilon_{j,y,rec}^{i}$	Residuals in the simulated observation of May survey estimate of recruitment from OM predicted recruitment in year y of component j of species i	-	A.37,A.38,(A.36)	
$\tilde{\sigma}_{j,y,rec}^{i}$	Standard deviation of the residuals $\varepsilon_{j,y,rec}^{i}$, being the May recruit survey sampling CV	-	A.39,A.40,(A.37,A.38)	
ρ_{rec}	Correlation in the residuals between sardine and anchovy survey estimates of recruitment	-	A.47 (A.38)	
$\left(\lambda_{j,r}^{i}\right)^2$	Additional variance (over and above the survey sampling CV) associated with the May recruit survey of component j of species i			
$C_{y,m}^{A}$	Observed anchovy catch from landings that have targeted anchovy during month m,($m = janmay, may, jun, jul, aug, sep, octdec$) in year y	Thousands of tons	(A.48,A.49)	Observed data
$C_{y,m}^{S,byc}$	Observed <14cm sardine bycatch during from landings that have targeted anchovy during month m,($m = janmay, may, jun, jul, aug, sep, octdec$) in year y	Thousands of tons	(A.48,A.49)	Observed data
$\widehat{N}_{j,y,0}^{i}$	OM predicted recruitment of component j of species i in November y	Billions	(A.48,A.495)	Sampled from Bayesian posterior distributions
K_{j}^{i}	Average pristine level ("carrying capacity") for component j of species i	Thousands of tons		Sampled from Bayesian posterior distributions