Interim OMP-18

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Introduction

A new joint Operational Management Procedure (OMP) is under development for South African sardine and anchovy, to be implemented in time for the 2019 TAC/TAB recommendations for small pelagics. The Small Pelagic Scientific Working Group (SPSWG) has adopted an interim OMP, "Interim OMP-18", to be used to finalise the TACs and TABs for 2018, while work to finalise OMP-18 continues.

Important Changes from OMP-14

Some of the key differences between OMP-14 (de Moor and Butterworth 2014), which was used to recommend TACs and TABs for sardine and anchovy from 2015 to 2017, and Interim OMP-18 are as follows (Table 1).

i) The maximum total anchovy TAC has been decreased from 450 000t to 350 000t, to reflect the maximum catch which the industry is expected to be able to achieve (Figure 1).

ii) A minimum directed sardine TAC of 10 000t has been implemented, to reflect the expectation that the industry would never be completely closed in practice.

iii) The stable (referred to as minimum in OMP-14) directed sardine TAC has been decreased from 90 000t to 65 000t.

iv) The maximum directed sardine TAC has been decreased from 500 000t to 200 000t, reflecting the low expectancy for another pulse in sardine biomass (and therefore catches) in the near future. This, together with the 2-tier threshold which has been temporarily removed from the sardine HCR, may be revised in OMP-18 if robustness tests for future sardine pulses indicate a need for this.

v) The directed sardine TAC is now recommended based only on the November hydro-acoustic estimate of sardine biomass, with no mid-season adjustment as per OMP-14 (this as the mid-season sardine recruitment estimate is considered too imprecise to be used reliably to adjust the TAC). The precautionary 'buffer rule' applied under OMP-14 is thus no longer used.

vi) The constraints on inter-annual variability in directed sardine TACs above the Critical Biomass (referred to as Exceptional Circumstances in OMP-14) threshold have been decreased: the maximum proportion by which directed sardine TAC can be reduced from one year to the next has been increased from 0.2 to 0.5.

vii) The range over which linear smoothing above the Critical Biomass threshold applies has been decreased from 400 000t to 100 000t. Linear smoothing is required as a result of the constraints mentioned in vi), so as to ensure that no discontinuity arises as the Critical Biomass threshold is approached from above.

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viii) Constraints on inter-annual variability in directed sardine TACs below the Critical Biomass threshold have been introduced: the maximum proportion by which directed sardine TAC can be increased or decreased from one year to the next is now 0.5.

ix) Linear smoothing below the Critical Biomass threshold applies over a range of 50 000t. Linear smoothing is required as a result of the constraints mentioned in viii), so as to ensure no discontinuity arises as the Critical Biomass threshold is approached from below.

Leftward Shift and Trade-Off Curve

Risk to the sardine and anchovy populations have been redefined for Interim OMP-18 as:

$Risk_S$: the probability of the sardine west component effective spawner biomass[1] being below that of the 2007[2] level over the projection period.

$Risk_A$: the probability of the anchovy spawner biomass being below that of a quarter of the 1996[3] level over the projection period.

The comparatively lower threshold selected for anchovy (a quarter of the lowest historical spawner biomass) is primarily due to the relatively higher uncertainty surrounding anchovy projections compared to those of sardine. This is due to the higher variability about the stock-recruitment curve and the shorter life span. Anchovy future biomass is thus more dependent on the uncertain recruitment than is the case for sardine. The acceptable level of risk changes from one management procedure to the next, given changes in the perceived level of productivity of a resource resulting from the inclusion of revised and new data when conditioning the underlying operating models. Interim OMP-18 has been developed using a single baseline Operating Model for anchovy and for sardine, conditioned on data from 1984 to 2015.

In keeping with the method used for past OMPs, the key control parameter of the sardine HCR has been tuned so that the level of depletion at the 20%ile of the projected total biomass distributions is the same under Interim OMP-18 as it was under OMP-08 and OMP-14 (de Moor 2018c). The 'leftward shift' of the biomass distribution from a no catch to a catch scenario after 20 years of projection is thus the same (at the 20%ile) for Interim OMP-18 (Figure 3) as it was for previous OMPs. Given this method, Interim OMP-18 has a maximum sardine risk level of 0.198.

As was the case when developing OMP-14, a similar objective method to determine the acceptable maximum level of risk for anchovy could not be followed (de Moor 2018a). The key control parameter of the anchovy HCR has been tuned so that Interim OMP-18 satisfies a maximum risk level of 0.082, where this risk level was selected as that resulting from applying OMP-14 to the updated Operating Model (de Moor 2018a).

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[1] The sardine found off the west and south coasts of South Africa do not form a single homogeneous stock (de Moor *et al*. 2017). The baseline Operating Model used to simulation test Management Procedures for South African sardine assumes two sardine components, distributed west and south-east of Cape Agulhas, with some mixing between them. The 'effective spawner biomass' for the west component is defined as the west component spawner biomass together with an additional proportion (8% used when tuning Interim OMP-18) of the south component spawner biomass.

[2] 2007 is the lowest historical year for the sardine Operating Model with p=0.08 and MoveR.

[3] 1996 is the lowest historical year for the baseline anchovy Operating Model.

The trade-off curve, with $Risk_S < 0.198$ and $Risk_A < 0.082$ is shown in Figure 4. Interim OMP-18 corresponds to the 'corner point' of this curve, where the directed average sardine catch is maximised while maintaining a maximum average anchovy catch.

Spatial Management

Interim OMP-18 has been developed and tested using a two-component Operating Model of population dynamics for the South African sardine resource. Simulations assume that the proportion of future catch west of Cape Agulhas will mimic that which has been observed in the past (Figure 5). While a relatively wide range in proportions has been simulated, the proportion of directed sardine catch taken west of Cape Agulhas is assumed to decrease when the ratio (TAC : west coast biomass) increases, particularly once this ratio increases above about 0.25 (Figure 5). In 8 of the most recent 10 years the industry has caught between 60 and 75% of its catch west of Cape Agulhas (Figure 6).

Summary

The Harvest Control Rules of Interim OMP-18 are fully described in the Appendix, while Table 1 lists the control parameters, with comparisons to previous OMPs. Table 2 lists the data required for input to Interim OMP-18. Table 3 lists some key summary performance statistics for sardine and anchovy under Interim OMP-18. Figures 7 and 8 show simulated future directed sardine and anchovy catches.

References

de Moor CL. 2018a. Considering alternative constraints to the anchovy Harvest Control Rule. DAFF: Branch Fisheries Document FISHERIES/2018/APR/SWG-PEL/06.

de Moor CL. 2018b. Final anchovy TAC and small pelagic TABs for 2018. DAFF: Branch Fisheries Document FISHERIES/2018/JUL/SWG-PEL/20.

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de Moor CL, Coetzee J, Durholtz D, Merkle D, van der Westhuizen JJ and Butterworth DS. 2012. A record of the generation of data used in the 2012 sardine and anchovy assessments. DAFF Branch Fisheries document: FISHERIES/2012/AUG/SWG-PEL/41.

Table 1. Definitions of the control parameters and constraints used in the Interim OMP-18 Harvest Control Rules. Values are given for OMP-08, OMP-14 and Interim OMP-18, with recent changes in **bold** text. All mass-related quantities are given in thousands of tons.

		Definition	OMP-08	OMP-14	Interim OMP-18
Key Control Parameters	β	Directed sardine catch control parameter	0.097	0.0869	**0.144**[4]
	α	Directed anchovy catch control parameter for normal season	0.78	0.871	**0.914**[5]
Fixed TABs	TAB_{big}^{S}	Fixed >14cm sardine bycatch	3.5	7	7
	TAB^{A}	Fixed anchovy bycatch for sardine only right holders	N/A	0.5	0.5
	$TAB_{y,small,rh}^{S}$	Fixed ≤14cm sardine bycatch with round herring	N/A	1.0	1.0
Fixed Control Parameters and Constraints	δ	Scale-down factor applied to initial anchovy TAC to provide a buffer against possible poor recruitment	0.85	0.85	0.85
	p	Weighting given to recruitment survey compared to November survey in setting anchovy TAC	0.7	0.7	0.7
	q	Constant reflecting average annual TAC under OMP-99 if $\alpha = 1$	300	300	300
	$\bar{B}_{Nov}^{A}$	Historical average 1984 to 1999 November survey estimate of anchovy total biomass	1380	1380	1380
	$\bar{N}_{0}^{A}$	Average of 1985 to 1999 May survey estimated anchovy recruitment, back-calculated to 1 November of the previous year	198 billion	217 billion	222 billion
	ω	Estimate of the maximum proportion of ≤14cm sardine bycatch in the >14cm sardine catch	N/A	0.07	0.07
	γ_{y}	Initial (conservative) estimate of anticipated juvenile sardine : anchovy ratio	OMP.7	OMP.7	OMP.7
	γ_{max}	Maximum of the logistic curve for γ_{y}	0.1	0.1	0.1
	B_{50}	Survey estimate of sardine total biomass where the logistic curve for γ_{y} reaches 50%	2000	2000	2000
	B_{95}	Survey estimate of sardine total biomass where the logistic curve for γ_{y} reaches 95%	3178	3178	3178
	c_{mntac}^{S}	Absolute minimum directed sardine TAC	N/A	N/A	**10**
	c_{stbl}^{S}	Stable directed sardine TAC	90	90	**65**
	c_{stbl}^{A}	Stable anchovy TAC	120	120	120
	c_{mxtac}^{S}	Maximum directed sardine TAC	500	500	**200**
	c_{mxtac}^{A}	Maximum total anchovy TAC	600	450	**350**
	c_{tier}^{S}	Two-tier threshold for directed sardine TAC	255	255	**N/A**
	c_{tier}^{A}	Two-tier threshold for anchovy TAC	330	330	330
	c_{mxdn}^{S}	Maximum proportion by which directed sardine TAC can be reduced annually, if $B_{y-1}^{obs,S} \geq B_{crit}^{S}$	0.2	0.2	**0.5**
	p_{crit}^{S}	Maximum proportion by which directed sardine TAC can be reduced annually, if $B_{y-1}^{obs,S} < B_{crit}^{S}$	N/A	N/A	**0.5**
	c_{mxdn}^{A}	Maximum proportion by which anchovy TAC can be reduced annually	0.25	0.25	0.25
	B_{crit}^{S}	November survey estimated biomass threshold below which Critical Biomass metarules are invoked for sardine	300	300	300
	B_{crit}^{A}	November survey estimated biomass threshold below which Critical Biomass metarules are invoked for anchovy	400	600	600

[4] These control parameters are tuned to meet target risk levels.

[5] This has been updated from the value which was used to set the final 2018 TAC (de Moor 2018b). The former value had been agreed based on de Moor (2018a), which did not use median values for k_N^A, k_r^A, $\bar{w}_1^A$ and $\bar{w}_2^A$ in the HCRs, but rather the 1000 draws from the posterior distribution.

Table 1 (continued).

		Definition	OMP-08	OMP-14	Interim OMP-18
Fixed Control Parameters and Constraints	Δ^S	Linear smoothing is introduced between B^S_{crit} and $B^S_{crit}+\Delta^S$	500	400	**100**
	Δ'^S	Linear smoothing is introduced between $B^S_{crit}-\Delta'^S$ and B^S_{crit}	N/A	N/A	**50**
	Δ^A	Linear smoothing is introduced below $B^A_{crit}+\Delta^A$ before sardine Critical Biomass metarules are applied (to ensure continuity)	100	100	100
	x^S	The proportion of B^S_{crit} below which the metarule sets the directed sardine TAC to zero	0.25	0.25	0.25
	x^A	The proportion of B^A_{crit} below which the metarule sets the anchovy TAC to zero	0.25	0.25	0.25
Working parameters	$N^A_{y-1,0}$	The survey estimate of anchovy recruitment, $N^{obs,A}_y$, back-calculated to 1 November $y-1$ by taking natural and fishing mortality into account			Eqn OMP.12
	r_y	The ratio of juvenile sardine to anchovy "in the sea" during May of year y, calculated as the average of $r_{y,sur}$ and $r_{y,com}$			
	$B^A_{y,proj}$	Total projected survey estimate of anchovy biomass in November of year y			Eqn OMP.19
	k^A_N	Multiplicative bias associated with the November survey of anchovy total biomass (median of posterior distribution used)	N/A	N/A	0.633
	k^A_r	Multiplicative bias associated with the recruit survey of anchovy recruitment (median of posterior distribution used)	N/A	N/A	0.525

Table 2. Definitions of the data required in the Harvest Control Rule formulae for Interim OMP-18. Values are given for OMP-08, OMP-14 and Interim OMP-18.

		Definition	OMP-08	OMP-14	Interim OMP-18
December	$B^{obs,S}_{y-1}$	November survey estimate of sardine total biomass in year $y-1$ (in thousands of tons)	From survey		
	$B^{obs,A}_{y-1}$	November survey estimate of anchovy total biomass in year $y-1$ (in thousands of tons)	From survey		
June	$N^{obs,A}_y$	May survey estimate of anchovy recruitment in year y (in billions)	From survey		
	t_y	Day of commencement of recruitment survey in year y (time in months after 1 May)	From survey		
	$C^A_{y,1}$	Anchovy catch at age 1[6] from 1 November of year $y-1$ to the day before the commencement of the recruitment survey (in billions)	From commercial catches		
	$C^A_{y,0bs}$	Anchovy catch at age 0[8] from 1 November of year $y-1$ to the day before the commencement of the recruitment survey (in billions)	From commercial catches		
	$r_{y,sur}$	Ratio of juvenile sardine to anchovy (by mass) indicated by the recruitment survey	From survey		
	$r_{y,com}$	Ratio of juvenile sardine to anchovy (by mass) in the commercial catches[7] during May, based on the commercial catches comprising at least 50% anchovy only	From commercial catches		
	$\bar{w}^A_1$	Average historical anchovy weight-at-age 1 in November (in gm)	9.724	10.689	10.833
	$\bar{w}^A_2$	Average historical anchovy weight-at-age 2 in November (in gm)	13.942	13.671	14.503
	$\bar{w}^A_{0c}$	Average historical catch weight-at-age 0 (in gm)	4.875	4.847	5.484
	$\bar{w}^A_{1c}$	Average historical catch weight-at-age 1 (in gm)	-	10.983	12.702

[6] Monthly cut-off lengths are used to split the anchovy catch into age 0 and age 1. The monthly cut-off lengths for November to March are given in de Moor *et al.* (2012), while the monthly cut-off lengths for April, May and June (if needed) are dependent on the recruit cut-off length used for the recruit survey in year y.

[7] Only commercial catches comprising at least 50% anchovy with sardine bycatch are considered.

Table 3. Key summary performance statistics for Interim OMP-18. Where appropriate, medians are provided, and for some statistics the means are provided additionally and shown in **bold**. All biomasses are given in thousands of tons.

	Sardine			Anchovy		
		No Catch	Interim OMP-18		No Catch	Interim OMP-18
Risk statistics	β	-	0.144	α	-	0.914
	$Risk_S$	0.076	0.198	$Risk_A$	0.026	0.082
	p(TAC^S<20)	-	0.05			
Biomass statistics	$B_{tot,2036}^S$	**379** 320	**253** 206	B_{2036}^A	**1333** 960	**807** 410
	$B_{west,2036}^S$	**183** 136	**126** 86			
	$B_{south,2036}^S$	**195** 164	**127** 104			
	$\frac{B_{tot,2036}^S}{B_{tot,2015}^S}$	4.2	2.6	$\frac{B_{2036}^A}{B_{2015}^A}$	0.7	0.3
	$\frac{B_{west,2036}^S}{B_{west,2015}^S}$	3.0	1.9			
	$\frac{B_{south,2036}^S}{B_{south,2015}^S}$	0.9	0.6			
	$B_{tot,min}^S$	157	90	B_{min}^A	447	178
	$B_{west,min}^S$	31	18			
	$B_{south,min}^S$	78	39			
Catch statistics	C_{tot}^S	**1** 0	**87** 71	C^A	**10** 0	**226** 248
	Med C_{tot}^S[8]	0	72	Med C^A	0	247
	C_{west}^S	**1** 0	**62** 54			
	C_{south}^S	**0** 0	**25** 17			
	$\frac{C_{west}^S}{C_{tot}^S}$	0	0.77			
	ByC_{tot}^S	**0.3** 0	**18** 10.6			
	ByC_{west}^S	**0.3** 0	**18** 10.6			
	ByC_{south}^S	**0.0** 0	**0** 0			
	MAV_{tot}^S[9]	-	0.50	MAV^A	-	0.22
	MAV_{west}^S	-	0.39			
	MAV_{south}^S	-	0.79			
Critical Biomass statistics	$p(B_y^{Sobs} < B_{crit}^S, B_y < B_{crit}^S/k_N^S)$	-	0.16	$p(B_y^{Aobs} < B_{crit}^A, B_y < B_{crit}^A/k_N^A)$	-	0.28
	$p(B_y^{Sobs} < B_{crit}^S, B_y \geq B_{crit}^S/k_N^S)$	-	0.16	$p(B_y^{Aobs} < B_{crit}^A, B_y \geq B_{crit}^A/k_N^A)$	-	0.02
	$p(B_y^{Sobs} \geq B_{crit}^S, B_y < B_{crit}^S/k_N^S)$	-	0.08	$p(B_y^{Aobs} \geq B_{crit}^A, B_y < B_{crit}^A/k_N^A)$	-	0.02
	$p(B_y^{Sobs} \geq B_{crit}^S, B_y \geq B_{crit}^S/k_N^S)$	-	0.60	$p(B_y^{Aobs} \geq B_{crit}^A, B_y \geq B_{crit}^A/k_N^A)$	-	0.68

[8] This gives the median and 90%ile of the 1000 median (over 20 years for each simulation) catches.

[9] Median and 90%ile of $AAV_y^b = \left|C_{tot,y}^{S,b} - C_{tot,y-1}^{S,b}\right| / C_{tot,y-1}^{S,b}$

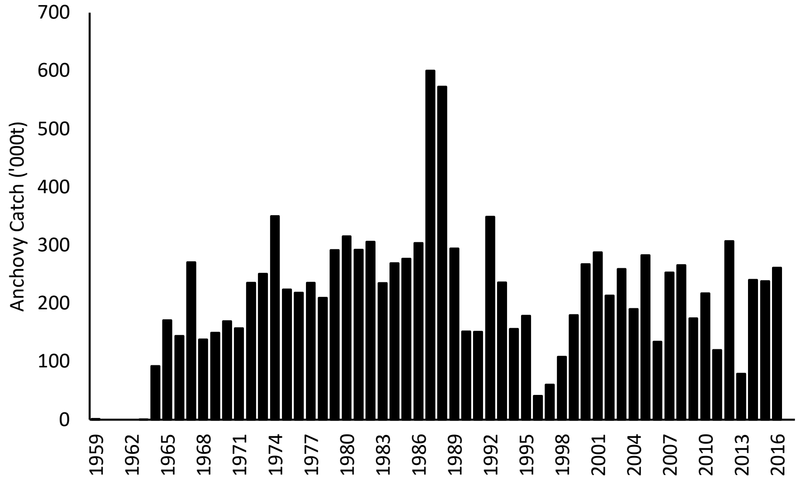

Figure 1. The **historical** annual landings of South African anchovy.

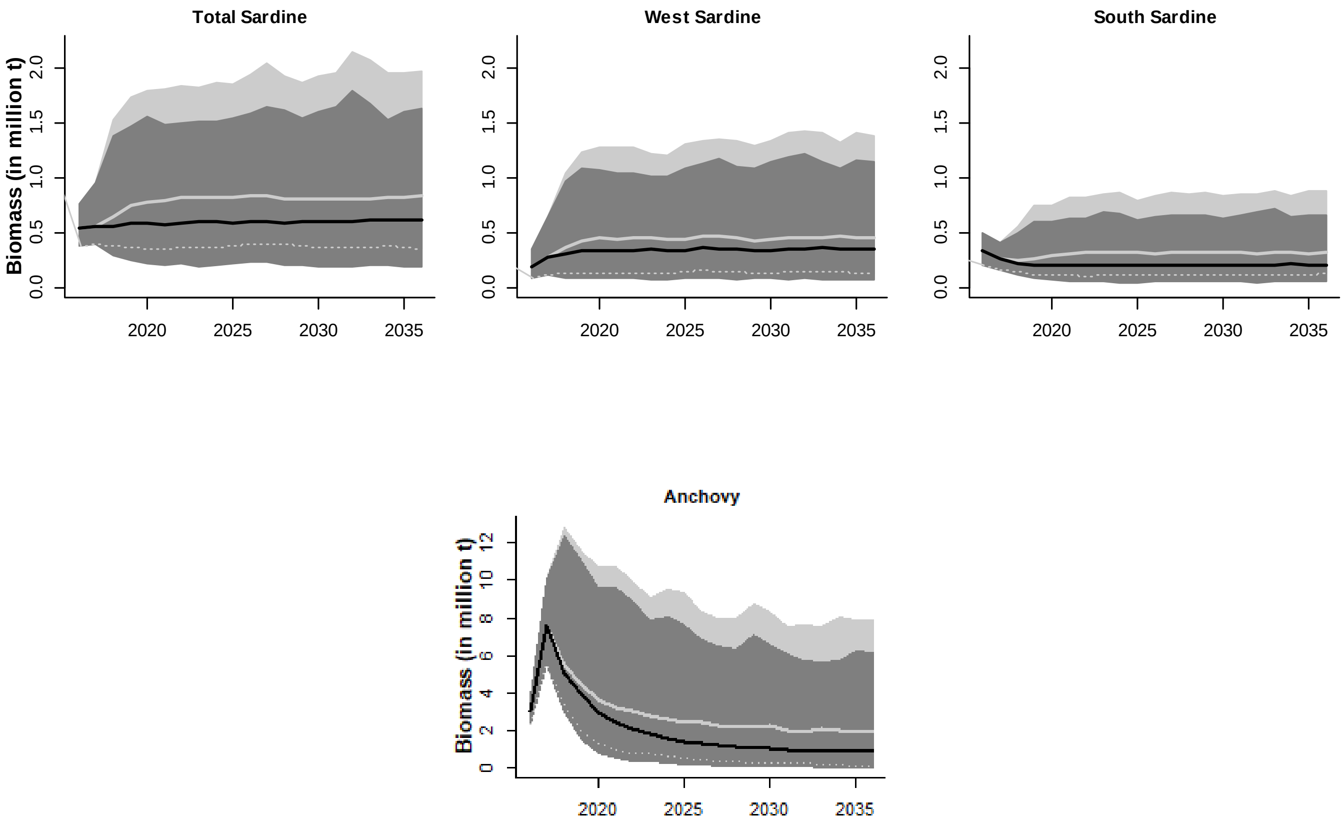

Figure 2. The median (solid lines) and 90% probability intervals of future projected a) total, west component and south component sardine biomass and b) anchovy biomass under a no future catch scenario (light lines and shading) compared to Interim OMP-18 (dark lines and shading).

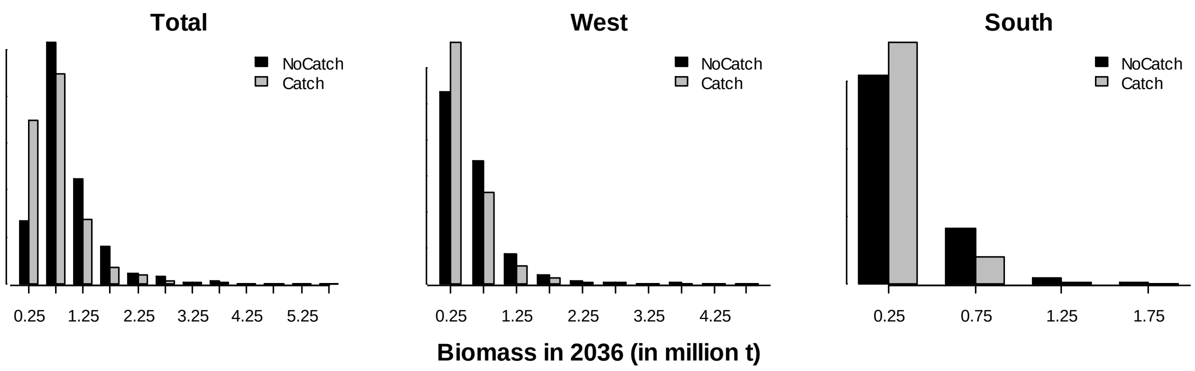

Figure 3. Histograms of the total, west component[10] and south component sardine November biomass in the final projection year under a no-catch scenario and under Interim OMP-18.

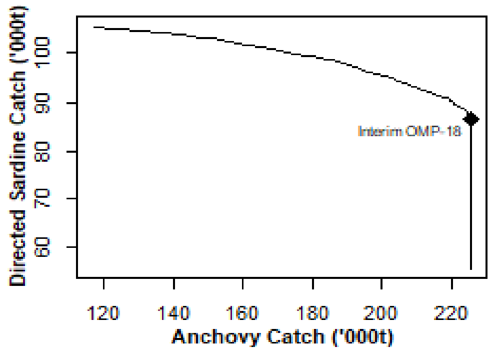

Figure 4. The trade-off curves of average directed total sardine catch against average anchovy catch, determined by satisfying $risk_A < 0.082$ and $risk_S < 0.199$. Interim OMP-18 is indicated by the diamond.

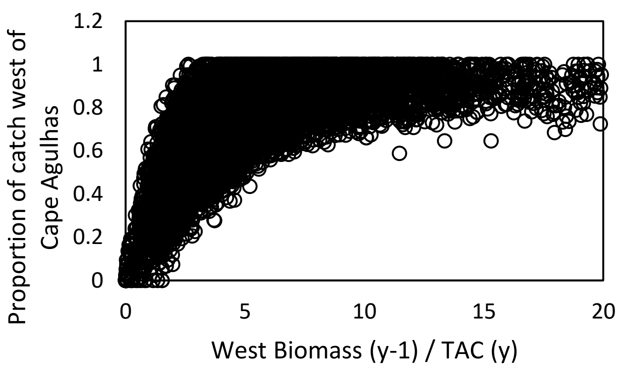

Figure 5. The **future** generated proportion of directed sardine catch taken west of Cape Agulhas in year y plotted against the ratio of the west coast biomass in November (y-1) : TAC(y) for the 1000 simulations of Interim OMP-18 on the baseline Operating Model with p=0.08 and MoveR.

[10] Sardine are modelled to consist of two mixing-components distributed west and south-east of Cape Agulhas (de Moor *et al.* 2017).

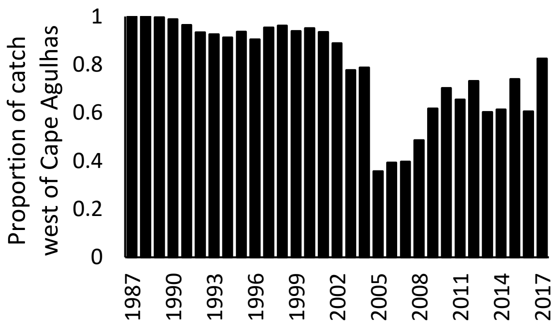

Figure 6. The **historical** proportion of directed sardine catch taken west of Cape Agulhas.

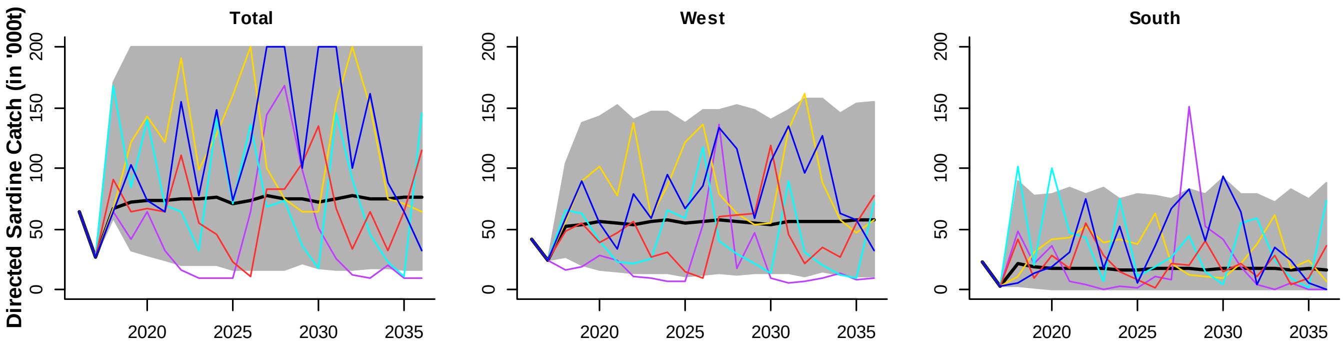

Figure 7. Median (black line) and 90%ile (shaded area) of simulated future annual a) Total, b) West and c) South directed sardine catches under Interim OMP-18. Five individual trajectories are additionally plotted to illustrate typical future inter-annual variability.

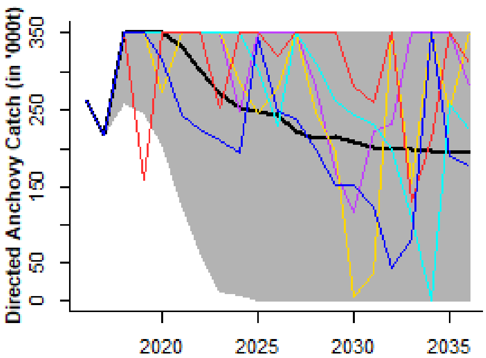

Figure 8. Median (black line) and 90%ile (shaded area) of simulated future annual anchovy catch under Interim OMP-18. Five individual trajectories are additionally plotted to illustrate typical future inter-annual variability.

Appendix: Interim OMP-18 Harvest Control Rules

In this Appendix, catches-at-age are given in numbers of fish (in billions), whereas the TACs and TABs are given in thousands of tons. Sardine and anchovy total allowable catches (TACs) and sardine total allowable bycatches (TABs) are set at the start of the year and the latter two are revised during the year. All parameters are defined in Table A.1.

Initial TACs / TAB (January)

The directed >14cm sardine TAC and initial directed anchovy TAC and TAB for ≤14cm sardine bycatch with anchovy directed fishing are based on the results of the November biomass survey. These limits are announced prior to the start of the pelagic fishery at the beginning of each year.

The directed sardine TAC is set at a proportion of the previous year's November survey estimate of biomass, but subject to the constraints of a minimum, stable and a maximum value. The TAC is subject to a maximum percentage decrease from the previous year's TAC. Different constraints on inter-annual decreases above and below a 'two-tier' threshold will be investigated before the final OMP-18 is agreed, but are omitted from this interim OMP-18.

The directed anchovy initial TAC is based on how the most recent November survey estimate of biomass survey relates to the historical average between 1984 and 1999. In the absence of further information, which will become available after the May recruitment survey, this initial TAC assumes the forthcoming recruitment (which will form the bulk of the catch) will be the *historical* average. A 'scale-down' factor, δ, is therefore introduced to provide a buffer against possible poor recruitment. The anchovy TAC is subject to similar constraints as apply for sardine, but includes a two-tier threshold.

OMP-18 includes a fixed anchovy TAB, TAB^A, for sardine-only right holders, and a fixed >14cm sardine TAB, TAB^S_{big}, consisting mainly of adult sardine bycatch with round herring and to a lesser extent with anchovy (see Table A.1). OMP-18 also includes a fixed allocation for $\leq$ 14cm sardine bycatch with round herring, $TAB^S_{y,smallrh}$ (Table A.1), and an allocation for $\leq$ 14cm sardine bycatch in the >14cm directed sardine landings, set proportional to the directed sardine TAC. Finally, a ≤14cm sardine TAB with anchovy is set proportional to the anchovy TAC.

Directed >14cm sardine TAC: $$TAC^S_y = \beta B^{obs,S}_{y-1} \quad \text{(OMP.1)}$$

subject to: $$max\{(1-c^S_{mxdn})TAC^S_{y-1}; c^S_{stbl}\} \leq TAC^S_y \leq c^S_{mxtac} \quad \text{(OMP.2)}$$

Initial directed anchovy TAC: $$TAC^A_{y,init} = \alpha\delta q\left(p + (1-p)\frac{B^{obs,A}_{y-1}}{\bar{B}^A_{Nov}}\right) \quad \text{(OMP.3)}$$

subject to: $$\begin{aligned} &max\{(1-c^A_{mxdn})TAC^A_{y-1}; c^A_{mntac}\} \leq TAC^A_{y,init} \leq c^A_{mxtac} \quad if\ TAC^A_{y-1} \leq c^A_{tier} \\ &max\{(1-c^A_{mxdn})c^A_{tier}; c^A_{mntac}\} \leq TAC^A_{y,init} \leq c^A_{mxtac} \quad if\ TAC^A_{y-1} > c^A_{tier} \end{aligned} \quad \text{(OMP.4)}$$

≤14cm sardine TAB with directed >14cm sardine catch: $$TAB^S_{y,small} = \omega TAC^S_y \quad \text{(OMP.5)}$$

Initial ≤14cm sardine TAB with anchovy: $$TAB^S_{y,anch,init} = \gamma_y TAC^A_{y,init} \quad \text{(OMP.6)}$$

where: $$\gamma_y = 0.1 + \frac{\gamma_{max}}{1+exp\left(-ln(19)\frac{B_{y-1}^{obs,S}-B_{50}}{B_{95}-B_{50}}\right)}. \quad \text{(OMP.7)}$$

Here γ_y increases according to a logistic curve from 10% in years in which the survey estimated sardine biomass, $B_{y-1}^{obs,S}$, is poor to average, towards a maximum when sardine biomass is higher.

To maintain continuity in the directed sardine and initial anchovy TACs as the Critical Biomass thresholds (see below), B_{crit}^S and B_{crit}^A, are approached from above, the following linear smoothing is applied.
If $B_{crit}^S \le B_{y-1}^{obs,S} \le B_{crit}^S + \Delta^S$:

$$TAC_y^S = \left(1 - \frac{B_{y-1}^{obs,S}-B_{crit}^S}{\Delta^S}\right)c_{stbl}^S + \left(\frac{B_{y-1}^{obs,S}-B_{crit}^S}{\Delta^S}\right)TAC_y^{S\prime} \quad \text{(OMP.8)}$$

where c_{stbl}^S is the TAC output from equation (OMP.15) when $B_{y-1}^{obs,S} = B_{crit}^S$, while $TAC_y^{S\prime}$ is the value output from equation (OMP.2) when $B_{y-1}^{obs,S} = B_{crit}^S + \Delta^S$.
If $B_{crit}^A \le B_{y-1}^{obs,A} \le B_{crit}^A + \Delta^A$:

$$TAC_{y,init}^A = \left(1 - \frac{B_{y-1}^{obs,A}-B_{crit}^A}{\Delta^A}\right)c_{stbl}^A + \left(\frac{B_{y-1}^{obs,A}-B_{crit}^A}{\Delta^A}\right)TAC_y^{A\prime} \quad \text{(OMP.9)}$$

where c_{stbl}^A is the TAC output from equation (OMP.17) when $B_{y-1}^{obs,A} = B_{crit}^A$, while $TAC_y^{A\prime}$ is the value output from equation (OMP.4) when $B_{y-1}^{obs,A} = B_{crit}^A + \Delta^A$.

Revised TACs / TAB (June)

The anchovy TAC and sardine TAB midyear revisions are based on the most recent November and now also recruit survey estimates of abundance. As the estimate of recruitment is now available, the 'scale-down' factor, δ, is no longer required to set the anchovy TAC. The additional constraints include ensuring that the revised anchovy TAC is not less than the initial anchovy TAC.

The revised ≤14cm sardine TAB with anchovy is calculated using an estimate of the ratio, r_y, of juvenile sardine to anchovy, provided this ratio is larger than γ_y, which was used to set the initial TAB.

Revised anchovy TAC: $$TAC_y^A = \alpha q\left(p\frac{N_{y-1,0}^A}{\bar{N}_0^A} + (1-p)\frac{B_{y-1}^{obs,A}}{\bar{B}_{Nov}^A}\right) \quad \text{(OMP.10)}$$

subject to: $$\begin{array}{ll} max\{TAC_{y,init}^A;(1-c_{mxdn}^A)TAC_{y-1}^A;c_{mntac}^A\} \le TAC_y^A \le c_{mxtac}^A & if\ TAC_{y-1}^A \le c_{tier}^A \\ max\{TAC_{y,init}^A;(1-c_{mxdn}^A)c_{tier}^A;c_{mntac}^A\} \le TAC_y^A \le c_{mxtac}^A & if\ TAC_{y-1}^A > c_{tier}^A \end{array} \quad \text{(OMP.11)}$$

The anchovy TAC equations require that $N_y^{obs,A}$, the recruitment numbers estimated in the survey, be back-calculated to November of the previous year, assuming a fixed value of 1.2 *year*$^{-1}$ for M_j^A. The back-calculated recruitment numbers are calculated as follows:

$$N_{y-1,0}^A = \left(N_y^{obs,A}e^{t_y \times 1.2/12} + C_{y,0bs}^A\right)e^{6\times 1.2/12} \quad \text{(OMP.12)}$$

Revised <14cm sardine TAB with anchovy:

$$TAB_{y,anch}^S = \lambda_y TAC_{y,init}^A + r_y\left(TAC_y^A - TAC_{y,iniy}^A\right) \quad \text{(OMP.13)}$$

where: $$\lambda_y = max\{\gamma_y, r_y\}$$

As for the initial TAC, continuity in the revised anchovy TAC as the Critical Biomass threshold is approached from above and below, is maintained by applying the following linear smoothing.

If $B^A_{crit} \leq B^A_{y,proj} \leq B^A_{crit} + \Delta^A$:

$$TAC^A_y = \left(1 - \frac{B^A_{y,proj} - B^A_{crit}}{\Delta^A}\right) c^A_{stbl} + \left(\frac{B^A_{y,proj} - B^A_{crit}}{\Delta^A}\right) TAC^{A\prime}_y \qquad \text{(OMP.14)}$$

where c^A_{stbl} is the TAC output from equation (OMP.22) when $B^{obs,A}_{y-1} = B^A_{crit}$, while $TAC^{A\prime}_y$ is the value output from equation (OMP.11) when $B^{obs,A}_{y-1} = B^A_{crit} + \Delta^A$, and $B^A_{y,proj}$ is defined by equation (OMP.19).

Note that by construction $TAB^S_{y,anch} \geq TAB^S_{y,anch,init}$ and $TAC^A_y \geq TAC^A_{y,init}$.

Critical Biomass Metarule

Sardine directed TAC

If $B^{obs,S}_{y-1} < B^S_{crit}$, then Critical Biomass metarules apply for the directed sardine TAC:

$$TAC^S_y = \begin{cases} c^S_{mntac} & if\ \frac{B^{obs,S}_{y-1}}{B^S_{crit}} < x^S \\ max\left\{c^S_{mntac}; c^S_{stbl}\left(\frac{\frac{B^{obs,S}_{y-1}}{B^S_{crit}} - x^S}{1 - x^S}\right)^2\right\} & if\ x^S < \frac{B^{obs,S}_{y-1}}{B^S_{crit}} < 1 \end{cases}$$

subject to: $$TAC^S_y \geq (1 - p^S_{crit}) TAC^S_{y-1} \qquad \text{(OMP.15)}$$

The metarule is quadratic, tending to zero at a proportion, x^S of the threshold, B^S_{crit}, but there is an additional absolute minimum TAC, c^S_{mntax}, that overrides this rule. To maintain continuity in the directed sardine TAC as B^S_{crit} is approached from below, the following linear smoothing is applied.

If $B^S_{crit} - \Delta'^S \leq B^{obs,S}_{y-1} \leq B^S_{crit}$:

$$TAC^S_y = \left(1 - \frac{B^S_{crit} - B^{obs,S}_{y-1}}{\Delta'^S}\right) TAC^{S\prime}_y + \left(\frac{B^S_{crit} - B^{obs,S}_{y-1}}{\Delta'^S}\right) TAC^{S\prime\prime}_y \qquad \text{(OMP.16)}$$

where $TAC^{S\prime}_y$ is the value output from equation (OMP.2) when $B^{obs,S}_{y-1} = B^S_{crit}$, while $TAC^{S\prime\prime}_y$ is the TAC output from equation (OMP.15) when $B^{obs,S}_{y-1} = B^S_{crit} - \Delta'^S$.

Initial Anchovy TAC

If $B^{obs,A}_{y-1} < B^A_{crit}$, then Critical Biomass metarules apply for the initial anchovy TAC:

Initial TAC: $$TAC^A_{y,init} = \begin{cases} 0 & if\ \frac{B^{obs,A}_{y-1}}{B^A_{crit}} < x^A \\ c^A_{stbl}\left(\frac{\frac{B^{obs,A}_{y-1}}{B^A_{crit}} - x^A}{1 - x^A}\right)^2 & if\ x^A < \frac{B^{obs,A}_{y-1}}{B^A_{crit}} < 1 \end{cases} \qquad \text{(OMP.17)}$$

The metarule allows for the TAC to be set to zero if the survey estimated anchovy biomass falls below x^A of the threshold B^A_{crit}.

Revised Anchovy TAC

The results of the most recent November and recruit surveys are projected forward, taking natural and anticipated fishing mortality into account, in order to provide a proxy ($B^A_{y,proj}$) for the forthcoming November survey, and hence have a basis for invoking the Critical Biomass metarule, if necessary. Defining $TAC^{A''}_y$ as the value output from equation (OMP.11) for $B^{obs,A}_{y-1}$ and $N^A_{y-1,0}$:

A projected survey estimate of anchovy biomass consisting of recruits from year y, $B^A_{y,proj0}$, is calculated as follows:

$$B^A_{y,proj0} = k^A_N \times max\left\{0; \left(\frac{N^{obs,A}_y}{k^A_r} - \left[\frac{TAC^{A''}_y + TAB^A - \bar{w}^A_{1c}C^A_{y,1}}{\bar{w}^A_{0c}} - C^A_{y,0bs}\right]\right) e^{-(6-t_y)\times 1.2/12}\bar{w}^A_1\right\}. \quad \text{(OMP.18)}$$

The total projected survey estimate of anchovy biomass, $B^A_{y,proj}$, is thus:

$$B^A_{y,proj} = k^A_N \left(\frac{B^{obs,A}_{y-1}}{k^A_N \bar{w}^A_1} e^{-5\times 1.2/12} - C^A_{y,1}\right) e^{-7\times 1.2/12}\bar{w}^A_2 + B^A_{y,proj0} \quad \text{(OMP.19)}$$

The recruit survey result in year y (in numbers) that would be sufficient to yield a $B^A_{y,proj}$ value of exactly B^A_{crit} is calculated as follows:

$$\theta = \frac{\left[B^A_{crit} - \left(B^A_{y,proj} - B^A_{y,proj0}\right)\right]}{k^A_N \bar{w}^A_1} e^{(6-t_y)\times 1.2/12} + \frac{TAC^{A''}_y + TAB^A - \bar{w}^A_{1c}C^A_{y,1}}{\bar{w}^A_{0c}} - C^A_{y,0bs} \quad \text{(OMP.20)}$$

This is back-calculated to November of the previous year in the same way as equation (OMP.12) during OMP implementation:

$$N^{A*}_{y-1,0} = \left(k^A_r \theta e^{t_y \times 1.2/12} + C^A_{y,0bs}\right) e^{6\times 1.2/12} \quad \text{(OMP.21)}$$

If $B^A_{y,proj} < B^A_{crit}$, then Critical Biomass metarules apply for the anchovy TAC. The anchovy TAC is calculated by reducing c^A_{stbl} by the ratio (squared) of the 'baseline' TAC (i.e. that from OMP.10) evaluated with the annual recruitment for year y to that calculated using θ. The rule allows for the TAC to be set to zero (or to the initial anchovy TAC, if greater than zero) if the survey estimated anchovy recruitment or biomass falls below a quarter of the corresponding threshold. Defining $= \frac{p\frac{N^A_{y-1,0}}{\bar{N}^A_0} + (1-p)\frac{B^{obs,A}_{y-1}}{\bar{B}^A_{Nov}}}{p\frac{N^{A*}_{y-1,0}}{\bar{N}^A_0} + (1-p)\frac{B^{obs,A}_{y-1}}{\bar{B}^A_{Nov}}}$:

$$TAC^S_y = \begin{cases} max\{0; TAC^A_{y,init}\} & if\ R < x^A \\ max\left\{TAC^A_{y,init}; c^A_{stbl}\left(\frac{R-x^A}{1-x^A}\right)^2\right\} & if\ x^A < R < 1 \end{cases} \quad \text{(OMP.22)}$$