The 2018 Operational Management Procedure for the South African sardine and anchovy resources

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Introduction

This document details OMP-18, the Operational Management Procedure (OMP) to be used to recommend total allowable catches (TACs) and bycatches (TABs) for sardine *Sardinops sagax* and anchovy *Engraulis encrasicolus* in South African waters. This OMP is to be used to recommend catch and bycatch limits for 2019 to 2022[1].

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 initial 2018, and 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 directed fishery is expected to be able to achieve.

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

iii) The stable (referred to as minimum in OMP-14) directed sardine TAC has been decreased from 90 000t to 65 000t, a consequence of the lower sardine biomass and lower productivity than estimated in 2013 and the need to keep risk to the sardine resource at acceptable levels.

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 Harvest Control Rule (HCR), may be revised in future OMPs 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. This choice allows for slightly higher catches on average, at the expense of larger inter-annual variability in directed sardine TAC and reflects the preference of SWG-PEL observers representing industry given current low biomass and anticipated TAC levels.

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[1] See Appendix B for procedures for deviating from this OMP.

vii) The range over which linear smoothing above the Critical Biomass threshold applies has been decreased from 400 000t to 100 000t, given small differences in projected risk and average catch for a Critical Biomass threshold of 300 000t and a stable TAC of 65 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.

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. This reflects the expectation that large changes in the directed sardine TAC at values below 65 000t would best be avoided.

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

x) A 'preventative red flag' which triggers spatial management of the directed sardine TAC, if the biomass of sardine surveyed west of Cape Agulhas is below 100 000t has been introduced. If the red flag is triggered, at most 40% of the directed sardine TAC may be taken west of Cape Agulhas. This reflects the need to offer greater protection to the more productive sardine west coast component at low west coast biomass levels.

xi) A combination of a 'penalty red flag' and a 'benefit green flag' have been introduced. These flags are triggered if the spatial distribution of future catches deviates appreciably from the relationship assumed during OMP testing, and result respectively in decreases or increases in the TAC when the proportion of the catch west of Cape Agulhas was appreciably higher or appreciably lower than expected. It is expected that this will discourage higher than anticipated catches in the area to the west of Cape Agulhas.

Risk

Risk measures for the sardine and anchovy populations have been defined as:

$Risk_S$: the probability of the sardine west component effective spawner biomass[2] being below that of the 2007[3] level over the projection period.

$Risk_A$: the probability of the anchovy spawner biomass being below that of the 1996[4] level over the projection period.

The acceptable level of risk (i.e. acceptable probability) 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. The control parameters of OMP-18 have been tuned using a single baseline Operating Model for anchovy and for sardine, conditioned on data from 1984 to 2015.

The method employed for determining an acceptable maximum risk to the sardine resource during previous OMPs could not be applied straightforwardly during OMP-18 development due to substantial changes in the Operating Models. These

[2] 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 OMP-18) of the south component spawner biomass.

[3] 2007 is the lowest historical year since 2000 for the baseline sardine Operating Models.

[4] 1996 is the lowest historical year since 2000 for the baseline anchovy Operating Model.

changes included modelling of the sardine population as consisting of two mixing components, with recruitment to the population primarily dependent on the west component effective spawning biomass. The definition of risk under OMP-18 is dependent on this latter biomass measure, while OMP-14 considered risk to the population to be dependent on the total biomass. The previous method for determining a maximum risk probability focussed on the impact of the OMP on the total biomass. This method involved tuning a key control parameter (β) of the sardine HCR so that the depletion at the 20 percentile of the projected total biomass distribution was the same under the candidate MP as it was under preceding OMPs. In order to consider the same biomass measure in this 'leftward shift' analysis as that used in the definition of risk, the maximum risk probability for OMP-18 was determined by tuning β so that the depletion at the 20 percentile of the projected west component effective spawning biomass equalled that of the total spawning biomass under OMP-08 and OMP-14 (Figure 1, de Moor 2019a). Using this method, and following the incorporation of preventative red flag and penalty/benefit red/green flags, OMP-18 has a $Risk_S$ of 0.153.

As was the case when developing OMP-14, a similar method (to that involving depletion at the 20 percentiles) to determine the maximum acceptable $Risk_A$ could not be followed (de Moor 2018). The key control parameter of the anchovy HCR has been tuned so that OMP-18 yields a maximum $Risk_A$ value of 0.089, where this probability was that resulting from applying OMP-14 to the updated 2018 baseline Operating Model (de Moor 2019b).

Trade-off curve

The trade-off curve, with $Risk_S < 0.153$ and $Risk_A < 0.089$ is shown in Figure 2. 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 and 'Red Flags'

OMP-18 has been developed and tested using a two-component Operating Model of population dynamics for the South African sardine resource. Simulations assume "implicit" spatial management in that the proportion of future catch west of Cape Agulhas will mimic that which has been observed in the past (Appendix C), with the provision that if the survey estimate of biomass west of Cape Agulhas is less than a "preventative red flag" threshold of 100 000t, then a maximum of 40% of the directed sardine TAC may be taken west of Cape Agulhas.

Summary

The Harvest Control Rules of OMP-18 are fully described in Appendix A, while Table 1 lists the control parameters, with comparisons to previous OMPs. Table 2 lists the data required for input to OMP-18. Table 3 lists some key summary performance statistics for sardine and anchovy under OMP-18. Figure 3 shows the simulated future distributions of total biomass, and Figures 4 and 5 show the simulated future distributions of (effective) spawning biomass. Figures 6 and 7 show simulated future directed sardine and anchovy catches. While OMPs are typically updated every 4-5 years, Appendix B describes the agreed procedures for deviating from the recommended OMP TAC/Bs and for initiating an earlier-than-intended OMP review. Appendix C gives the ranges of survey indices and other outputs simulated during the development of this OMP that can be compared with future observations from the fishery.

References

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

		Definition	OMP-08	OMP-14	OMP-18
Key Control Parameters	β	Directed sardine catch control parameter	0.097	0.0869	**0.124**
	α	Directed anchovy catch control parameter for normal season	0.78	0.871	**1.16**
Fixed TABs	TAB^S_{big}	Fixed >14cm sardine bycatch	3.5	7	7
	TAB^A	Fixed anchovy bycatch for sardine only right holders	N/A	0.5	0.5
	$TAB^S_{y,small,rh}$	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
	$\bar{B}^A_{Nov}$	Historical average 1984 to 1999 November survey estimate of anchovy total biomass	1380	1380	1380
	$\bar{N}^A_0$	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	Eqn OMP.9	Eqn OMP.9	Eqn OMP.9
	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^S_{mntac}	Absolute minimum directed sardine TAC	N/A	N/A	**10**
	c^S_{stbl}	Stable directed sardine TAC	90	90	**65**
	c^A_{stbl}	Stable anchovy TAC	120	120	120
	c^S_{mxtac}	Maximum directed sardine TAC	500	500	**200**
	c^A_{mxtac}	Maximum total anchovy TAC	600	450	**350**
	c^S_{tier}	Two-tier threshold for directed sardine TAC	255	255	**N/A**
	c^A_{tier}	Two-tier threshold for anchovy TAC	330	330	330
	c^S_{mxdn}	Maximum proportion by which directed sardine TAC can be reduced annually, if $B^{obs,S}_{y-1} \geq B^S_{crit}$	0.2	0.2	**0.5**
	p^S_{crit}	Maximum proportion by which directed sardine TAC can be reduced annually, if $B^{obs,S}_{y-1} < B^S_{crit}$	N/A	N/A	**0.5**
	c^A_{mxdn}	Maximum proportion by which anchovy TAC can be reduced annually	0.25	0.25	0.25
	B^S_{crit}	November survey estimated biomass threshold below which Critical Biomass metarules are invoked for sardine	300	300	300
	B^A_{crit}	November survey estimated biomass threshold below which Critical Biomass metarules are invoked for anchovy	400	600	600

Table 1 (continued).

		Definition	OMP-08	OMP-14	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
	B^S_{prev}	The survey estimate of sardine biomass west of Cape Agulhas below which the preventative red flag is triggered	N/A	N/A	100
Working parameters	$N^A_{y-1,0}$	The survey estimate of anchovy recruitment, $N_y^{obs,A}$, 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 OMP-18. Values are given for OMP-08, OMP-14 and OMP-18.

		Definition	OMP-08	OMP-14	OMP-18
December	$B_{y-1}^{obs,S}$	November survey estimate of sardine total biomass in year $y-1$ (in thousands of tons)	From survey[5]		
	$B_{west,y-1}^{obs,S}$	November survey estimate of sardine biomass west of Cape Agulhas in year $y-1$ (in thousands of tons)	From survey[6]		
	$B_{y-1}^{obs,A}$	November survey estimate of anchovy total biomass in year $y-1$ (in thousands of tons)	From survey[6]		
June	$N_y^{obs,A}$	May survey estimate of anchovy recruitment in year y (in billions)	From survey[6]		
	t_y	Day of commencement of recruitment survey in year y (time in months after 1 May)	From survey[6]		
	$C_{y,1}^A$	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		
	$C_{y,0obs}^A$	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		
	$\bar{w}_1^A$	Average historical anchovy weight-at-age 1 in November (in gm)	9.724	10.689	10.788
	$\bar{w}_2^A$	Average historical anchovy weight-at-age 2 in November (in gm)	13.942	13.671	14.526
	$\bar{w}_{0c}^A$	Average historical catch weight-at-age 0 (in gm)	4.875	4.847	5.484
	$\bar{w}_{1c}^A$	Average historical catch weight-at-age 1 (in gm)	-	10.983	12.702

[5] Coetzee et al. (2008) details the method for estimating the survey biomass. Appendix B of de Moor et al. (2016) details the method used to estimate numbers of recruitment from survey estimated recruit biomass.

[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 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	OMP-18		No Catch	OMP-18
Risk statistics	β	-	0.124	α	-	1.16
	$Risk_S$	0.070	0.153	$Risk_A$	0.018	0.089
	p(TAC^S<20)	-	0.02			
Biomass statistics	$B^{sp,S}_{tot,2036}$	**416** 373	**297** 254	$B^{sp,A}_{2036}$	**3384** 2341	**2669** 1613
	$B^{sp,S}_{west,2036}$	**178** 147	**127** 98			
	$B^{sp,S}_{south,2036}$	**238** 209	**170** 145			
	$B^{sp,S}_{tot,2036}/B^{sp,S}_{tot,2015}$	4.4	3.0	$B^{sp,A}_{2036}/B^{sp,A}_{2015}$	1.6	1.1
	$B^{sp,S}_{west,2036}/B^{sp,S}_{west,2015}$	3.0	2.1			
	$B^{sp,S}_{south,2036}/B^{sp,S}_{south,2015}$	1.1	0.8			
	$effB^{sp,S}_{west,2036}/effB^{sp,S}_{west,2007}$	4.1	2.7	$B^{sp,A}_{2036}/B^{sp,A}_{1996}$	4.9	3.4
	$effB^{sp,S}_{west,2036}/K^S_{west}$	0.5	0.3	$B^{sp,A}_{2036}/K^A$	1.2	0.9
	$B^{sp,S}_{tot,min}$	180	121	$B^{sp,A}_{min}$	920	543
	$B^{sp,S}_{west,min}$	25	16			
	$B^{sp,S}_{south,min}$	90	57			
	$effB^{sp,S}_{west,min}/effB^{sp,S}_{west,2007}$	1.0	0.7	$B^{sp,A}_{min}/B^{sp,A}_{1996}$	2.0	1.2
	$effB^{sp,S}_{west,min}/K^S_{west}$	0.1	0.1	$B^{sp,A}_{min}/K^A$	0.5	0.3
Catch statistics	C^S_{tot}	**2** 0	**87** 68	C^A	**11** 0	**311** 350
	Med C^S_{tot}[8]	0	70	Med C^A	0	350
	C^S_{west}	**1** 0	**61** 54			
	C^S_{south}	**0** 0	**26** 19			
	C^S_{west}/C^S_{tot}	0	0.75			
	ByC^S_{tot}	**0.3** 0	**19** 11			
	ByC^S_{west}	**0.3** 0	**19** 11			
	ByC^S_{south}	**0.0** 0	**0** 0			
	MAV^S_{tot}[9]	-	0.44	MAV^A	-	0.00
	MAV^S_{west}	-	0.42			
	MAV^S_{south}	-	0.61			
Critical Biomass statistics	$p\left(B^{Sobs}_y < B^S_{crit}, B_y < B^S_{crit}/k^S_N\right)$	-	0.07	$p\left(B^{Aobs}_y < B^A_{crit}, B_y < B^A_{crit}/k^A_N\right)$	-	0.07
	$p\left(B^{Sobs}_y < B^S_{crit}, B_y \geq B^S_{crit}/k^S_N\right)$	-	0.15	$p\left(B^{Aobs}_y < B^A_{crit}, B_y \geq B^A_{crit}/k^A_N\right)$	-	0.01
	$p\left(B^{Sobs}_y \geq B^S_{crit}, B_y < B^S_{crit}/k^S_N\right)$	-	0.05	$p\left(B^{Aobs}_y \geq B^A_{crit}, B_y < B^A_{crit}/k^A_N\right)$	-	0.01
	$p\left(B^{Sobs}_y \geq B^S_{crit}, B_y \geq B^S_{crit}/k^S_N\right)$	-	0.73	$p\left(B^{Aobs}_y \geq B^A_{crit}, B_y \geq B^A_{crit}/k^A_N\right)$	-	0.91
	Avg # years $B^{Sobs}_y < B^S_{crit}$ consecutively	-	1.4 yrs	Avg # years $B^{Aobs}_y < B^A_{crit}$ consecutively		2.3 yrs
Ecosystem statistics	ROI (5yrs)	-0.095	-0.109	P(Bsar+Banch) < historical min	0.01	0.07
	ROI (10yrs)	-0.073	-0.078			
	ROI (15yrs)	-0.057	-0.060			
	# Moulters (2022:2017)	0.525	0.457			
	#Moulters (2027:2017)	0.273	0.217			
	# Moulters (2032:2017)	0.145	0.106			
	$p(B^{obs,S}_w < 336)$	0.51	0.60			
	$avg\ \#\ years\ B^{obs,S}_w < 336$	2.69	3.26			

[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 $AAV^b_y = \left|C^{S,b}_{tot,y} - C^{S,b}_{tot,y-1}\right| / C^{S,b}_{tot,y-1}$

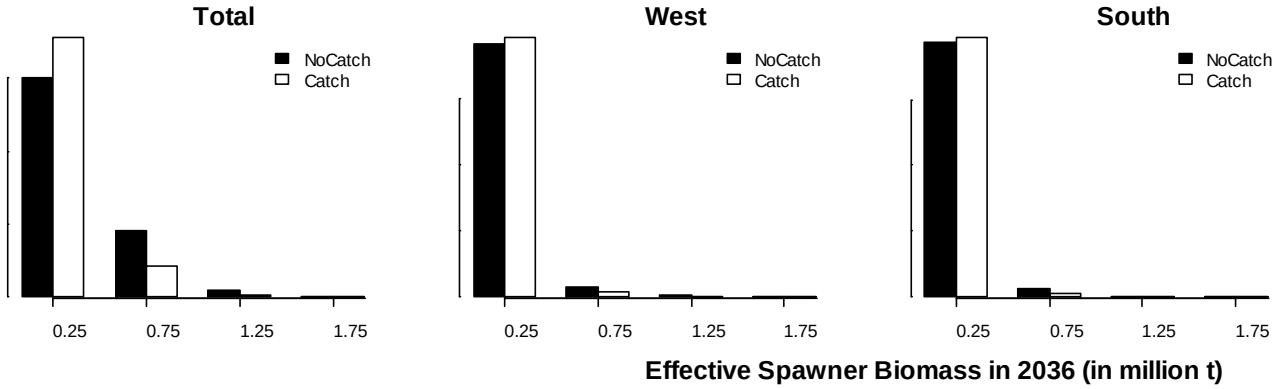

Figure 1. Histograms of the total, west component[10] and south component sardine effective spawner biomass in the final projection year under a no-catch scenario and under OMP-18.

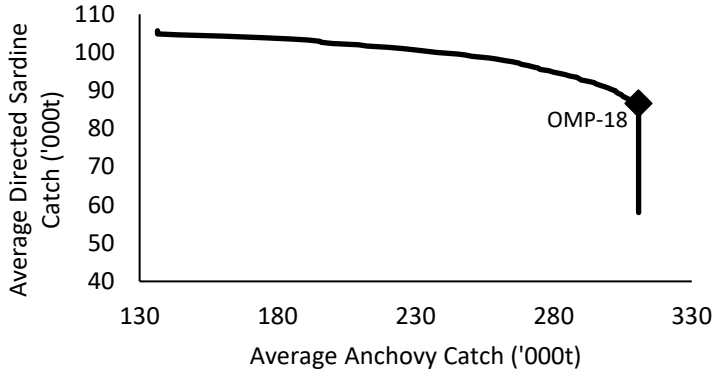

Figure 2. The trade-off curves of average directed total sardine catch against average anchovy catch, determined by satisfying $Risk_A \leq 0.0889$ and $Risk_S \leq 0.153$. Note the axes do not start at (0,0). OMP-18 is indicated by the diamond.

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

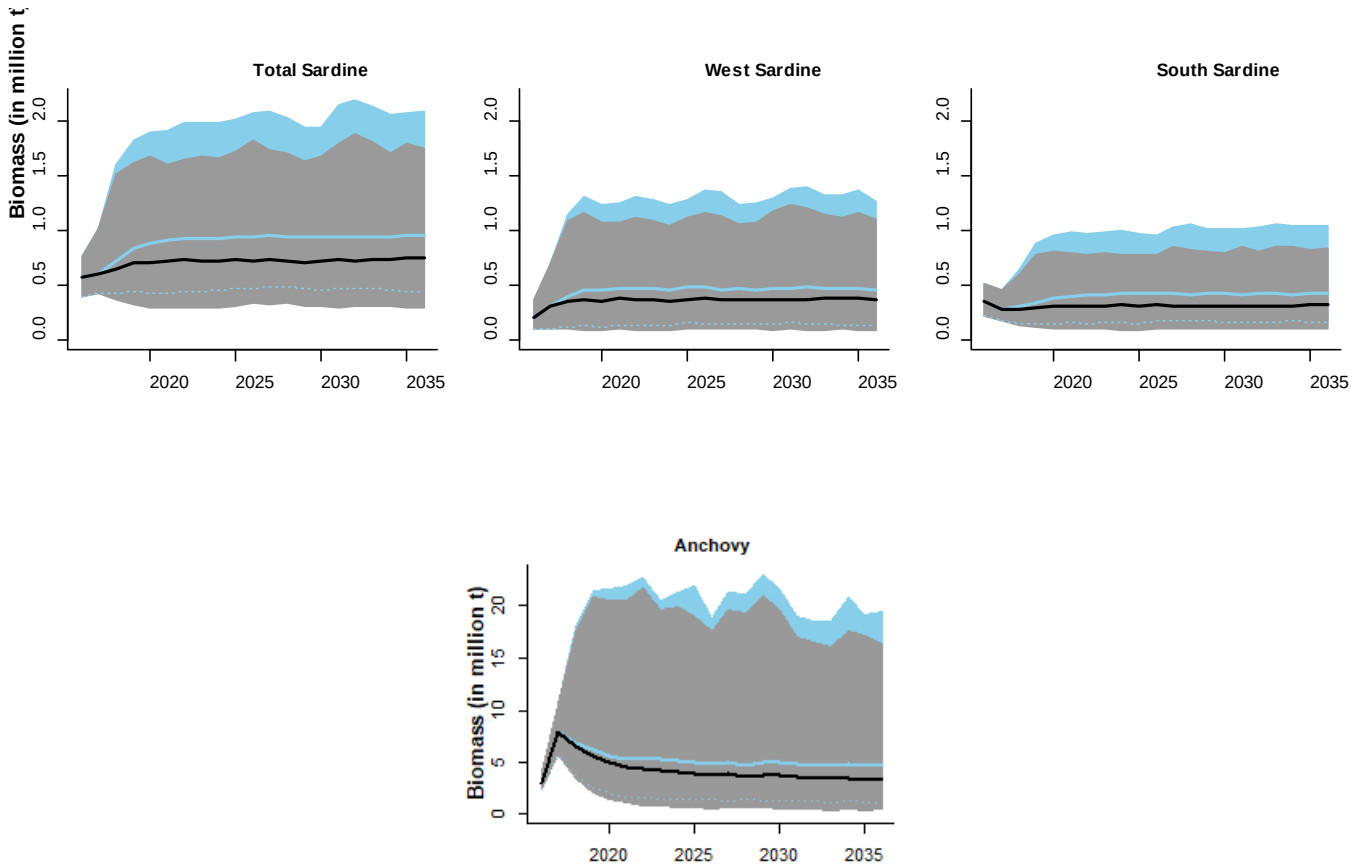

Figure 3. The median (solid lines) and 90% probability intervals of future projected total, west component and south component sardine biomass (upper plots) and anchovy biomass (lower plot) under a no future catch scenario (blue) compared to OMP-18 (grey).

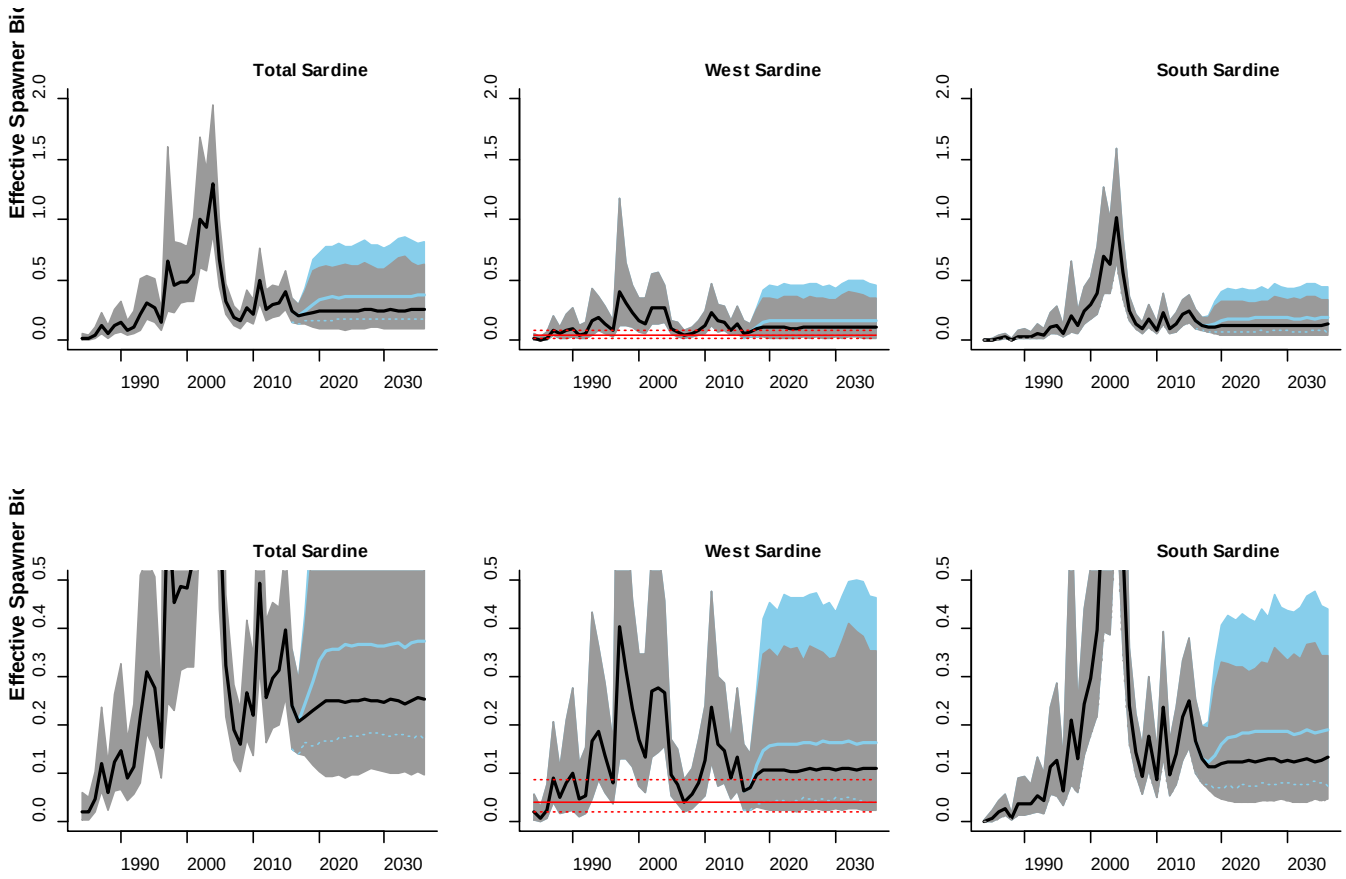

Figure 4. The median (solid lines) and 90% probability intervals of future projected a) total, west component and south component sardine effective spawning biomass under OMP-18 (grey) compared to under a no future catch scenario (blue). The lower set of plots are a repeat of the upper set, but over a smaller vertical axis range to more clearly show the sardine risk threshold (red) of the 2007 (lowest) historical effective spawning biomass.

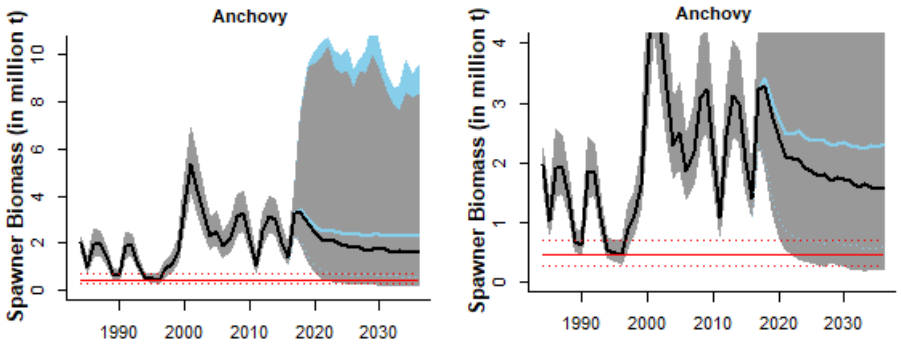

Figure 5. The median (solid lines) and 90% probability intervals of future projected anchovy spawning biomass under OMP-18 (grey) compared to under a no future catch scenario (blue). The right hand plot is a repeat of the left one, but over a smaller vertical axis range to more clearly show the anchovy risk threshold (red) of the 1996 (lowest) historical spawning biomass.

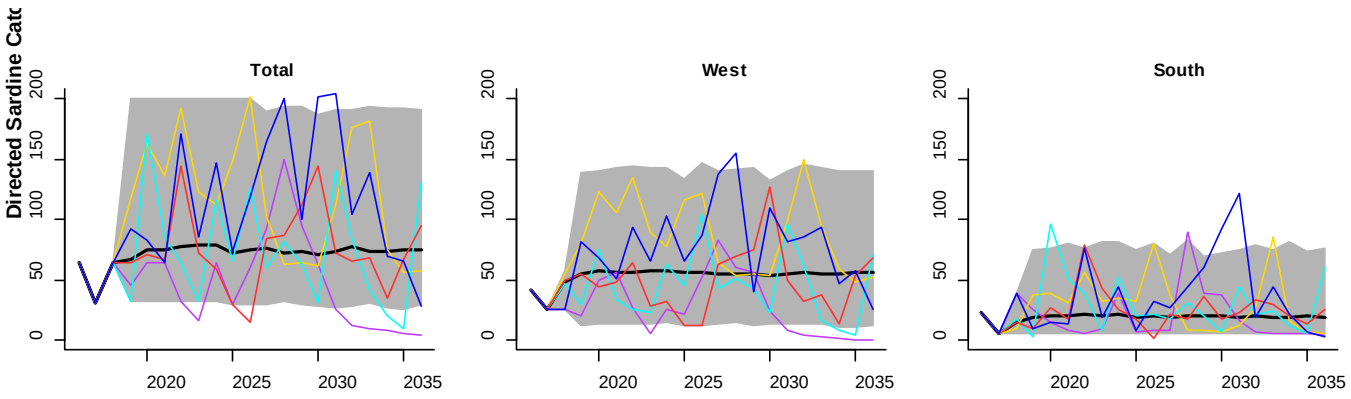

Figure 6. Median (black line) and 90%ile (shaded area) of simulated future annual a) Total, b) West and c) South directed sardine catches under OMP-18. Five individual trajectories are additionally plotted to illustrate typical future inter-annual variability.

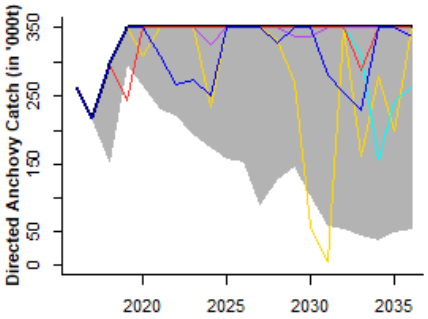

Figure 7. Median (black line) and 90%ile (shaded area) of simulated future annual anchovy catch under OMP-18. Five individual trajectories are additionally plotted to illustrate typical future inter-annual variability.

Appendix A: 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 Tables 1 and 2.

TABs that do not change annually

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 and a fixed allocation for $\leq$ 14cm sardine bycatch with round herring, $TAB^S_{y,smallrh}$ (Table 1).

Sardine TAC and associated small sardine TAB (January)

The directed >14cm sardine TAC is based on the results of the November biomass survey. This TAC is 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. A higher or lower proportion of this HCR-calculated TAC would be recommended by OMP-18 in year y if the spatial distribution of catches in year $y-1$ deviates appreciably from the relationship assumed during OMP-18 testing (see end of Appendix A).

An allocation for $\leq$ 14cm sardine bycatch in the >14cm directed sardine landings is set proportional to the directed sardine TAC.

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

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

≤14cm sardine TAB with directed >14cm sardine catch: $TAB^S_{y,small} = \omega TAC^S_y$ (OMP.3)

To maintain continuity in the directed sardine TAC as the Critical Biomass threshold (see below), B^S_{crit}, is approached from above, in cases where the TAC is constrained by a maximum decrease from the previous year's TAC (OMP.2), the following linear smoothing is applied.

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

$$TAC^S_y = \left(1 - \frac{B^{obs,S}_{y-1} - B^S_{crit}}{\Delta^S}\right) c^S_{stbl} + \left(\frac{B^{obs,S}_{y-1} - B^S_{crit}}{\Delta^S}\right) TAC^{S\prime}_y \quad \text{(OMP.4)}$$

where c^S_{stbl} is the TAC output from equation (OMP.16) when $B^{obs,S}_{y-1} = B^S_{crit}$, while $TAC^{S\prime}_y$ is the value output from equation (OMP.2) when $B^{obs,S}_{y-1} = B^S_{crit} + \Delta^S$.

Initial anchovy TAC and associated small sardine TAB (January)

The 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 anchovy initial TAC is based on how the most recent November survey estimate of survey biomass 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.

A ≤14cm sardine TAB with anchovy is set proportional to the anchovy TAC.

Initial directed anchovy TAC: $$TAC^{A}_{y,init} = \alpha\delta q\left(p + (1-p)\frac{B^{obs,A}_{y-1}}{\bar{B}^{A}_{Nov}}\right) \quad \text{(OMP.5)}$$

subject to: $$\begin{matrix} max\{(1-c^{A}_{mxdn})TAC^{A}_{y-1}; c^{A}_{mntac}\} \leq TAC^{A}_{y,init} \leq c^{A}_{mxtac} & if\ TAC^{A}_{y-1} \leq c^{A}_{tier} \\ max\{(1-c^{A}_{mxdn})c^{A}_{tier}; c^{A}_{mntac}\} \leq TAC^{A}_{y,init} \leq c^{A}_{mxtac} & if\ TAC^{A}_{y-1} > c^{A}_{tier} \end{matrix} \quad \text{(OMP.6)}$$

To maintain continuity in the initial anchovy TAC as the Critical Biomass threshold (see below), B^{A}_{crit}, is approached from above, in cases where the TAC is constrained by a maximum decrease from the previous year's TAC (OMP.6), the following linear smoothing is applied.

If $B^{A}_{crit} \leq B^{obs,A}_{y-1} \leq B^{A}_{crit} + \Delta^{A}$:

$$TAC^{A}_{y,init} = \left(1 - \frac{B^{obs,A}_{y-1} - B^{A}_{crit}}{\Delta^{A}}\right)c^{A}_{stbl} + \left(\frac{B^{obs,A}_{y-1} - B^{A}_{crit}}{\Delta^{A}}\right)TAC^{A\prime}_{y} \quad \text{(OMP.7)}$$

where c^{A}_{stbl} is the TAC output from equation (OMP.18) when $B^{obs,A}_{y-1} = B^{A}_{crit}$, while $TAC^{A\prime}_{y}$ is the value output from equation (OMP.6) when $B^{obs,A}_{y-1} = B^{A}_{crit} + \Delta^{A}$.

Initial ≤14cm sardine TAB with anchovy: $$TAB^{S}_{y,anch,init} = \gamma_{y} TAC^{A}_{y,init} \quad \text{(OMP.8)}$$

where: $$\gamma_{y} = 0.1 + \frac{\gamma_{max}}{1+exp\left(-ln(19)\frac{B^{obs,S}_{y-1} - B_{50}}{B_{95} - B_{50}}\right)}. \quad \text{(OMP.9)}$$

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

Final anchovy TAC and associated small sardine 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: $$\begin{matrix} max\{TAC_{y,init}^A; (1-c_{mxdn}^A)TAC_{y-1}^A; c_{mntac}^A\} \leq TAC_y^A \leq c_{mxtac}^A & if\ TAC_{y-1}^A \leq c_{tier}^A \\ max\{TAC_{y,init}^A; (1-c_{mxdn}^A)c_{tier}^A; c_{mntac}^A\} \leq TAC_y^A \leq c_{mxtac}^A & if\ TAC_{y-1}^A > c_{tier}^A \end{matrix} \quad \text{(OMP.11)}$$

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:

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

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 $B_{crit}^A \leq B_{y,proj}^A \leq B_{crit}^A + \Delta^A$:

$$TAC_y^A = \left(1 - \frac{B_{y,proj}^A - B_{crit}^A}{\Delta^A}\right) c_{stbl}^A + \left(\frac{B_{y,proj}^A - B_{crit}^A}{\Delta^A}\right) TAC_y^{A\prime} \quad \text{(OMP.13)}$$

where c_{stbl}^A is the TAC output from equation (OMP.23) when $B_{y-1}^{obs,A} = B_{crit}^A$, while $TAC_y^{A\prime}$ is the value output from equation (OMP.11) when $B_{y-1}^{obs,A} = B_{crit}^A + \Delta^A$, and $B_{y,proj}^A$ is defined by equation (OMP.20).

Revised <14cm sardine TAB with anchovy:

$$TAB_{y,anch}^S = \lambda_y TAC_{y,init}^A + r_y\left(TAC_y^A - TAC_{y,iniy}^A\right) \quad \text{(OMP.14)}$$

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

Note that by construction $TAB_{y,anch}^S \geq TAB_{y,anch,init}^S$ and $TAC_y^A \geq TAC_{y,init}^A$.

Critical Biomass Metarule

Sardine directed TAC

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

$$TAC_y^S = \begin{cases} c_{mntac}^S & if\ \frac{B_{y-1}^{obs,S}}{B_{crit}^S} < x^S \\ max\left\{c_{mntac}^S; c_{stbl}^S \left(\frac{\frac{B_{y-1}^{obs,S}}{B_{crit}^S} - x^S}{1-x^S}\right)^2\right\} & if\ x^S < \frac{B_{y-1}^{obs,S}}{B_{crit}^S} < 1 \end{cases} \quad \text{(OMP.15)}$$

subject to: $$(1-p_{crit}^S)TAC_{y-1}^S \leq TAC_y^S \leq TAC_{y-1}^S + max\{10, p_{crit}^S TAC_{y-1}^S\} \quad \text{(OMP.16)}$$

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

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

$$TAC_y^S = \left(1 - \frac{B_{crit}^S - B_{y-1}^{obs,S}}{\Delta'^S}\right) TAC_y^{S\prime} + \left(\frac{B_{crit}^S - B_{y-1}^{obs,S}}{\Delta'^S}\right) TAC_y^{S\prime\prime} \quad \text{(OMP.17)}$$

where $TAC_y^{S\prime}$ is the value output from equation (OMP.2) when $B_{y-1}^{obs,S} = B_{crit}^S$, while $TAC_y^{S\prime\prime}$ is the TAC output from equation (OMP.16) when $B_{y-1}^{obs,S} = B_{crit}^S - \Delta'^S$.

Initial Anchovy TAC

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

Initial TAC:
$$TAC_{y,init}^A = \begin{cases} 0 & if\ \frac{B_{y-1}^{obs,A}}{B_{crit}^A} < x^A \\ c_{stbl}^A \left(\frac{\frac{B_{y-1}^{obs,A}}{B_{crit}^A} - x^A}{1 - x^A} \right)^2 & if\ x^A < \frac{B_{y-1}^{obs,A}}{B_{crit}^A} < 1 \end{cases} \quad \text{(OMP.18)}$$

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_{crit}^A.

Final 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 ($B_{y,proj}^A$) for the forthcoming November survey, and hence have a basis for invoking the Critical Biomass metarule, if necessary. Defining $TAC_y^{A\prime\prime}$ as the value output from equation (OMP.11) for $B_{y-1}^{obs,A}$ and $N_{y-1,0}^A$:

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

$$B_{y,proj0}^A = k_N^A \times max\left\{0; \left(\frac{N_y^{obs,A}}{k_r^A} - \left[\frac{TAC_y^{A\prime\prime} + TAB^A - \bar{w}_{1c}^A C_{y,1}^A}{\bar{w}_{0c}^A} - C_{y,0bs}^A\right]\right) e^{-(6-t_y)\times 1.2/12} \bar{w}_1^A\right\}. \quad \text{(OMP.19)}$$

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

$$B_{y,proj}^A = k_N^A \left(\frac{B_{y-1}^{obs,A}}{k_N^A \bar{w}_1^A} e^{-5\times 1.2/12} - C_{y,1}^A\right) e^{-7\times 1.2/12} \bar{w}_2^A + B_{y,proj0}^A \quad \text{(OMP.20)}$$

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

$$\theta = \frac{\left[B_{crit}^A - \left(B_{y,proj}^A - B_{y,proj0}^A\right)\right]}{k_N^A \bar{w}_1^A} e^{(6-t_y)\times 1.2/12} + \frac{TAC_y^{A\prime\prime} + TAB^A - \bar{w}_{1c}^A C_{y,1}^A}{\bar{w}_{0c}^A} - C_{y,0bs}^A \quad \text{(OMP.21)}$$

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

$$N_{y-1,0}^{A*} = \left(k_r^A \theta e^{t_y \times 1.2/12} + C_{y,0bs}^A\right) e^{6\times 1.2/12} \quad \text{(OMP.22)}$$

If $B_{y,proj}^A < B_{crit}^A$, then Critical Biomass metarules apply for the anchovy TAC. The anchovy TAC is calculated by reducing c_{stbl}^A 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 $= \frac{p\frac{N^A_{y-1,0}}{\bar{N}^A_0}+(1-p)\frac{B^{obs,A}_{y-1}}{\bar{B}^A_{Nov}}}{p\frac{N^{A*}_{y-1,0}}{\bar{N}^A_0}+(1-p)\frac{B^{obs,A}_{y-1}}{\bar{B}^A_{Nov}}}$:

$$TAC^S_y = \begin{cases} max\{0; TAC^A_{y,init}\} & if\ R < x^A \\ max\left\{TAC^A_{y,init}; c^A_{stbl}\left(\frac{R-x^A}{1-x^A}\right)^2\right\} & if\ x^A < R < 1 \end{cases} \quad \text{(OMP.23)}$$

Penalty red flag and benefit green flag for directed sardine TAC

In order to encourage future directed sardine catches continue to be distributed west and east of Cape Agulhas according to past patterns assumed during "implicit" spatial management, a combination of "red penalty" and "green benefit" flags are included with OMP-18. These impact the proportion of the HCR-calculated TAC that is recommended as a final output from OMP-18. The proportion begins at 1. In every subsequent year the following readjustment (if any) to this proportion takes place:

i) The proportion is readjusted towards 1, where $\acute{p}_{west,y} = 0.2 + 0.8p_{west,y-1}$.

ii) If the proportion of the directed sardine TAC taken west of Cape Agulhas in year $y-1$ was greater than or equal to $1.2 \times \left[0.905035 \times \left(1 - exp\{-0.416847\left(B^{obs,S}_{west,y-2}/0.70783\right)/TAC_{y-1}\}\right)\right]$, then $p_{west,y} = \acute{p}_{west,y} - 0.1$.

iii) Else if the proportion of the directed sardine TAC taken west of Cape Agulhas in year $y-1$ was less than or equal to $\left[0.905035 \times \left(1 - exp\{-0.416847\left(B^{obs,S}_{west,y-2}/0.70783\right)/TAC_{y-1}\}\right)\right]/1.2$ then $p_{west,y} = \acute{p}_{west,y} + 0.01$.

iv) Else $p_{west,y} = \acute{p}_{west,y}$.

Appendix B: Procedures for deviating from OMP output for the recommendation for a TAC, and for initiating an OMP review

1. Metarule Process

Metarules can be thought of as "rules" which pre-specify what should happen in unlikely, exceptional circumstances when application of the TAC generated by the OMP is considered to be highly risky or inappropriate. Metarules are not a mechanism for making small adjustments, or 'tinkering' with the TAC from the OMP. It is difficult to provide firm definitions of, and to be sure of including all possible, exceptional circumstances. Instead, a process for determining whether exceptional circumstances exist is described below (see Figure B1). The need for invoking a metarule should be evaluated by the DAFF BRANCH FISHERIES [Small Pelagics] Scientific Working Group (hereafter indicated by WG), but only provided that appropriate supporting information is presented so that it can be reviewed at a WG meeting.

1.1 Description of Process to Determine Whether Exceptional Circumstances Exist

While the broad circumstances that may invoke the metarule process can be identified, it is not always possible to pre-specify the data that may trigger a metarule. If a WG Member or Observer, or DAFF BRANCH FISHERIES Management, is to propose an exceptional circumstances review, then such person(s) must outline in writing the reasons why they consider that exceptional circumstances exist, and must either indicate where the data or analyses are to be found supporting the review, or must supply those data or analyses in advance of the WG meeting at which their proposal is to be considered.

Every year the WG will:

- Review population and fishery indicators, and any other relevant data or information on the population, fishery and ecosystem, and time permitting, conduct a simple routine updated assessment (likely no more than the core Reference Case model used in the OMP testing refitted taking a further year's data into account).
- On the basis of this, determine whether there is evidence for exceptional circumstances.

Examples of what might constitute an exceptional circumstance in the case of [sardine and anchovy] include, but are not necessarily limited to:

- [Survey estimates of abundance that are appreciably outside the bounds predicted in the OMP testing.
- Spatial distribution of directed sardine catches that are appreciably outside the bounds predicted in the OMP testing.
- New data or information to suggest a substantial revision of assumptions of stock structure]

Every two years the WG will:

- Conduct a stock assessment (more intensive than the annual process above, and in particular including the full Reference Set of assessment models and conducting of a range of sensitivity tests).
- On the basis of the assessment, indicators and any other relevant information, determine whether there is evidence for exceptional circumstances.

The primary focus for concluding that exceptional circumstances exist is if the population assessment/indicator review process provides results appreciably outside the range of simulated population and/or other indicator trajectories considered in OMP evaluations. This includes the core (Reference case or set of) operating models used for these

evaluations, and likely also (though subject to discussion) the operating models for the robustness tests for which the OMP was considered to have shown adequate performance. Similarly, if the review process noted regulatory changes likely to effect appreciable modifications to outcomes predicted in terms of the assumptions used for projections in the OMP evaluations (e.g. as a result, perhaps, of size limit changes or closure of areas), or changes to the nature of the data collected for input to the OMP beyond those for which allowance may have been made in those evaluations, this would constitute grounds for concluding that exceptional circumstances exist in the context of continued application of the current OMP.

(Every year) IF the WG concludes that there is no or insufficient evidence for exceptional circumstances, the WG will:

- Report to the Chief Director Research, DAFF BRANCH FISHERIES that exceptional circumstances do not exist.

IF the WG has agreed that exceptional circumstances exist, the WG will:

- Determine the severity of the exceptional circumstances.
- Follow the "Process for Action" described below.

1.2 Specific issues that will be considered annually (regarding Underlying Assumptions of the Operating Models (OMs) for the OMP Testing Process)

The following critical aspects of assumptions underlying the OMs for [sardine and anchovy] need to be monitored after OMP implementation. Any appreciable deviation from these underlying assumptions may constitute an exceptional circumstance (i.e. potential metarule invocation) and will require a review, and possible revision, of the OMP:

- [Whether survey estimates of abundance are appreciably outside the bounds predicted in the OMP testing.
- Whether the spatial distribution of directed sardine catches are appreciably outside the bounds predicted in the OMP testing.
- Whether selectivities-at-length differ substantially from assumptions made to generate operating model projections.
- Whether future recruitment levels are within the 95% probability envelopes for projections generated by the operating models.
- Whether updates of major data sets or ageing practices indicate substantial differences from what were used to condition the operating models for the OMP testing.
- Whether there have been a series of instances where the catches actually made exceeded the TACs or TABs allocated to non-trivial extents.
- Whether new data or information suggest a substantial revision of assumptions of stock structure or estimates of stock status.
- Whether there is information to suggest a substantial change in the relationship between ≤14cm sardine bycatch and anchovy directed catch from that assumed in the OMP testing, particularly during the last four months of the year.]

1.3 Description of Process for Action

If making a determination that there is evidence of exceptional circumstances, the WG will with due promptness:

- Consider the severity of the exceptional circumstances (for example, how severely "out of bounds" are the recent survey abundance estimates).
- Follow the principles for action (see examples below).
- Formulate advice on the action required (this could include an immediate change in TAC, a review of the OMP, the relatively urgent collection of ancillary data, or conduct of analyses to be reviewed at a further WG meeting in the near future).
- Report to the Director Research, DAFF BRANCH FISHERIES that exceptional circumstances exist and provide advice on the action to take.

The Chief Director Research, DAFF BRANCH FISHERIES will:

- Consider the advice from the WG.
- Decide on the action to take, or recommendations to make to his/her principals.

Examples of 'Principles for Action'

If the risk is to the resource, or to dependent or related components of the ecosystem, principles may be:

- The OMP-derived TAC should be an upper bound.
- Action should be at least an x% decrease in the TAC output by the OMP, depending on severity.

If the risk is to socio-economic opportunities within the fishery, principles may be:

- The OMP-derived TAC should be a minimum.
- Action should be at least a y% increase in the TAC output by the OMP, depending on severity.

For certain categories of exceptional circumstances, specific metarules may be developed and pre-agreed for implementation should the associated circumstances arise (for example, as has been the case for OMP's for the sardine-anchovy fishery where specific modified TAC algorithms come into play if abundance estimates from surveys fall below pre-specified thresholds). Where such development is possible, it is preferable that it be pursued.

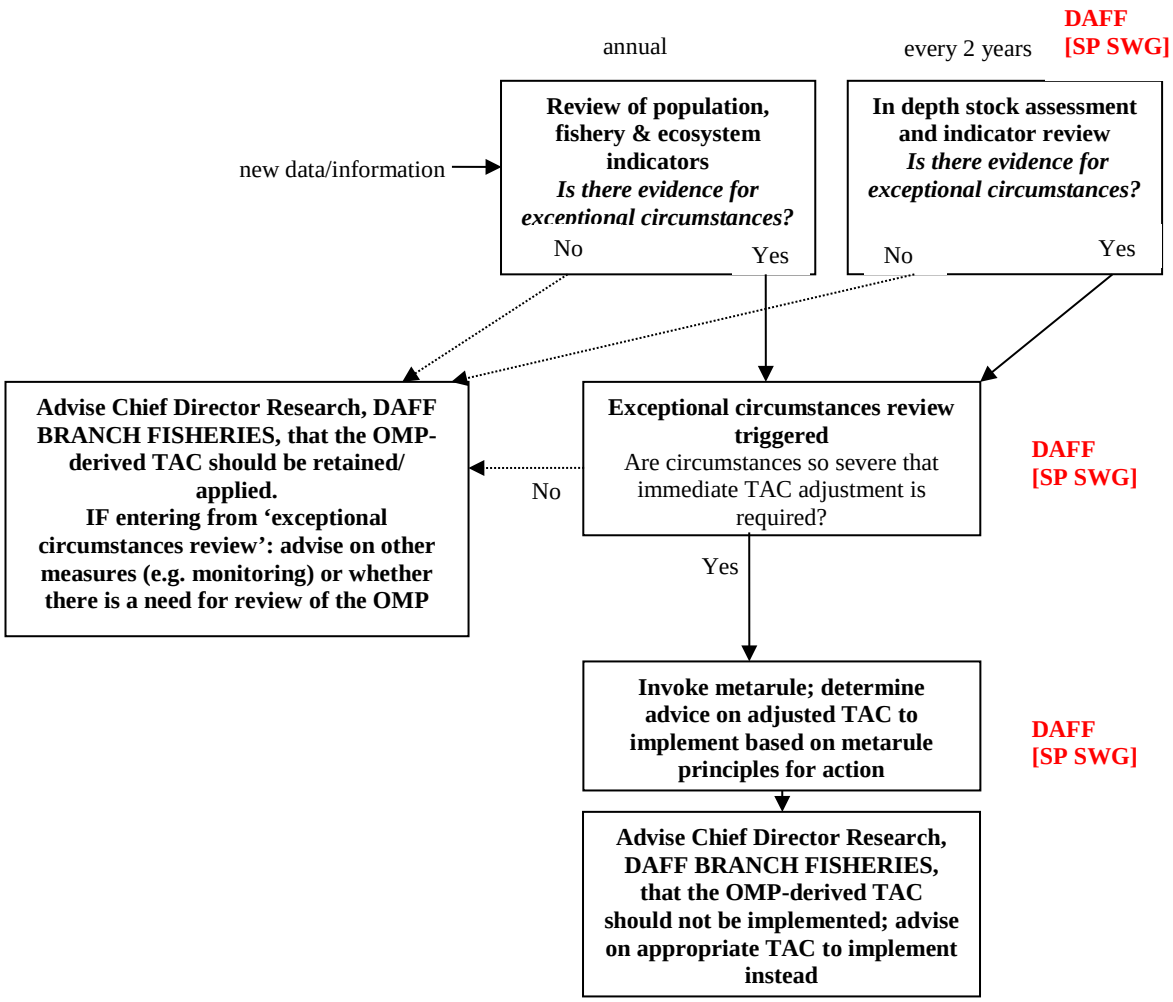

Figure B1: Flowchart for Metarules Process

2. Regular OMP Review and Revision Process

The procedure for regular review and potential revision of the OMP is the process for updating and incorporating new data, new information and knowledge into the management procedure, including the operating models (OMs) used for testing the procedure. This process should happen on a relatively long time-scale to avoid jeopardising the performance of the OMP, but can be initiated at any time if the WG consider that there is sufficient reason for this, and that the effect of the revision would be substantial. During the revision process the OMP should still be used to generate TAC recommendations unless a metarule is invoked.

2.1 Description of Process for Regular Review (see Figure B2)

Every year the WG will:

- Consider whether the procedure for Metarule Process has triggered a review/revision of the OMP. Note that if proposals by a WG Member or Observer, or DAFF BRANCH FISHERIES Management, for an exceptional circumstances review include suggestions for an OMP review and possible revision, they must outline in writing the reasons why they consider this necessary, and must either indicate where the data or analyses are to be found supporting their proposed

review, or must supply those data or analyses in advance of the WG meeting at which their proposal is to be considered. This includes the possibility of a suggested improvement in the manner in which the OMP calculates catch limitation recommendations; this would need to be motivated by reporting results for this amended OMP when subjected to the same set of trials as were used in the selection of the existing OMP, and arguing that improvements in anticipated performance were evident.

Every two years the WG will:

- Conduct an in depth stock assessment and review population, fishery and related ecosystem indicators, and any other relevant data or information on the population, fishery and ecosystem.
- On the basis of this, determine whether the assessment (or other) results are outside the ranges for which the OMP was tested (note that evaluation for exceptional circumstances would be carried out in parallel with this process; see procedures for the Metarule Process), and whether this is sufficient to trigger a review/revision of the OMP.
- Consider whether the procedure for the Metarule Process triggered a review / revision of the OMP.

Every four years since the last revision of the OMP the WG will:

- Review whether enough has been learnt to appreciably improve/change the operating models (OMs), or to improve the performance of the OMP, or to provide new advice on tuning level (chosen to aim to achieve management objectives).
- On the basis of this, determine whether the new information is sufficient to trigger a review/revision of the OMP.

In any year, IF the WG concludes that there is sufficient new information to trigger a review/revision of the OMP, the WG will:

- Outline the work plan and timeline (e.g. over a period of one year) envisaged for conducting a review.
- Report to the Chief Director Research, DAFF BRANCH FISHERIES that a review/revision of the OMP is required, giving details of the proposed work plan and timeline.
- Advise the Chief Director Research, DAFF BRANCH FISHERIES that the OMP can still be applied while the revision process is being completed (unless exceptional circumstances have been determined to apply and a metarule invoked).

In any year, IF the WG concludes that there is no need to commence a review/revision of the OMP, the WG will:

- Report to the Chief Director Research, DAFF BRANCH FISHERIES that a review/revision of the OMP is not yet required.

The Chief Director Research, DAFF BRANCH FISHERIES will:

- Review the report from the WG.
- Decide whether to initiate the review/revision process.

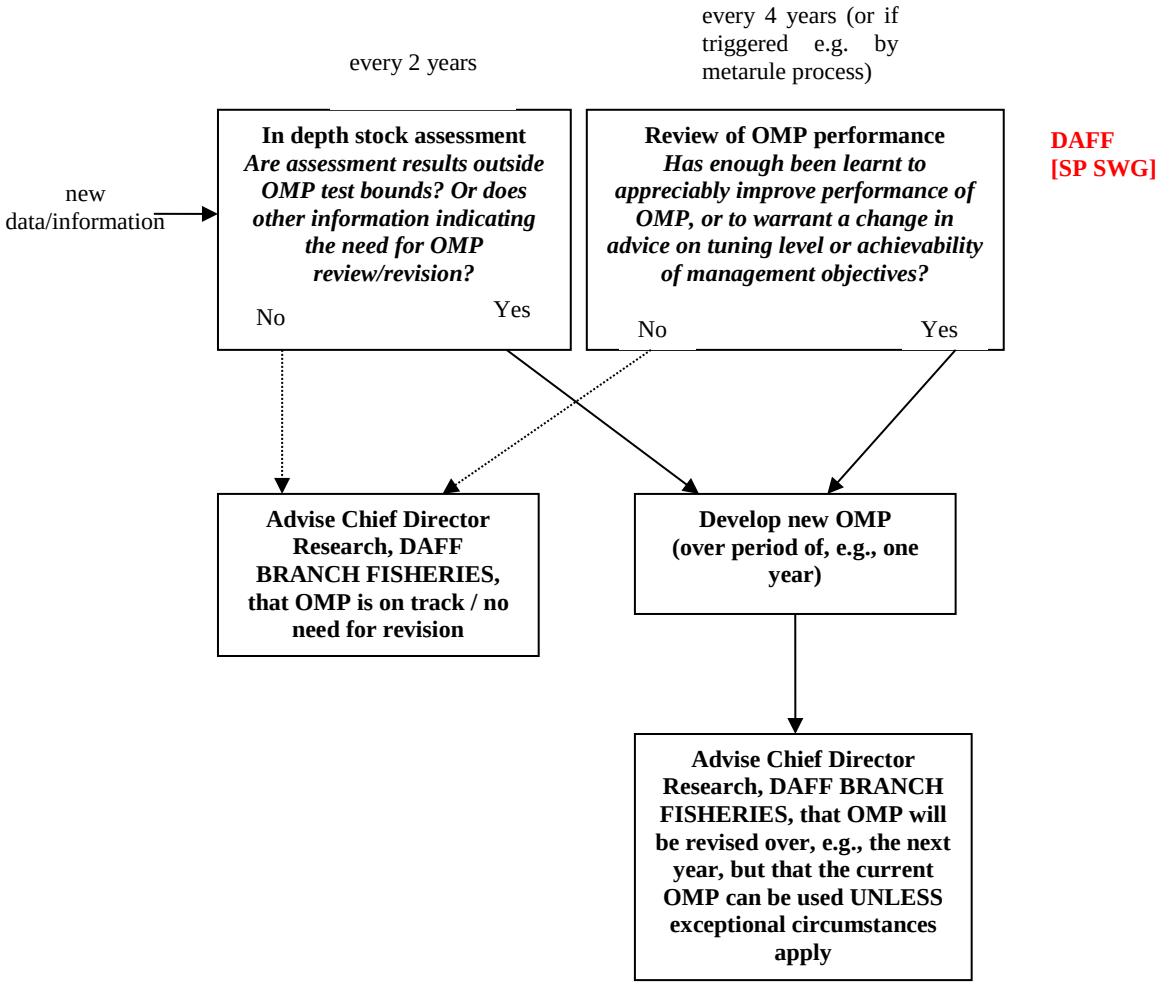

Figure B2: Flowchart for Regular Review and Revision Process

Appendix C: Ranges of simulated future observables under OMP-18 for the base case Operating Models

Table C1. Lower and upper probability intervals for survey estimates of biomass (in thousands of tons) simulated during the development of OMP-18

	Survey estimated total anchovy biomass				Survey estimated total sardine biomass				Survey estimated sardine biomass west of Cape Agulhas				Survey estimated sardine biomass east of Cape Agulhas			
	5%ile	10%ile	90%ile	95%ile	5%ile	10%ile	90%ile	95%ile	5%ile	10%ile	90%ile	95%ile	5%ile	10%ile	90%ile	95%ile
2018	2138.2	2447.9	8570.2	10722.3	176.1	231.8	1333.4	1776.7	51.1	78.3	871.6	1258.6	45.5	59.6	612.5	821.3
2019	1281.1	1603.4	9307.8	13200.5	171.3	221.4	1435.1	1852.8	47.3	74.8	916.2	1221.2	46.0	64.3	706.9	1021.5
2020	864.4	1078.3	9268.2	12185.5	183.5	222.2	1482.6	1976.4	44.7	69.3	836.9	1209.0	42.4	63.3	758.8	1074.5
2021	645.8	922.1	9098.6	13440.6	166.4	221.9	1442.6	1877.8	45.3	69.9	924.8	1292.4	43.3	61.4	733.4	935.4
2022	524.5	806.4	8864.6	14229.0	163.1	226.3	1447.3	1800.6	41.7	70.4	857.9	1126.3	46.5	64.8	774.4	1093.4
2023	490.5	733.7	8830.7	12387.3	163.5	214.4	1464.9	1958.4	36.2	68.8	915.1	1210.1	40.6	58.6	840.0	1108.3
2024	426.0	681.1	8724.1	12159.3	160.0	209.3	1351.6	1816.3	42.6	68.1	775.6	1033.8	34.9	55.0	733.0	1059.4
2025	451.2	645.7	9046.3	12353.0	166.4	217.2	1584.9	2077.7	42.4	76.1	939.4	1269.9	41.0	59.1	810.5	1136.5
2026	356.2	622.5	7799.6	11408.1	164.3	226.0	1421.8	1871.6	48.9	68.3	921.1	1235.2	43.7	63.6	699.7	1004.7
2027	362.0	551.4	7722.9	11765.5	183.0	236.6	1518.2	1989.3	47.9	77.2	886.8	1269.7	42.8	63.9	798.1	1138.5

Table C2. Lower and upper probability intervals for the proportion of survey estimates of sardine biomass distributed west of Cape Agulhas simulated during the development of OMP-18

	Proportion west of Cape Agulhas			
	5%ile	10%ile	90%ile	95%ile
2018	0.14	0.20	0.88	0.92
2019	0.13	0.18	0.88	0.92
2020	0.11	0.17	0.87	0.91
2021	0.12	0.18	0.87	0.92
2022	0.11	0.15	0.87	0.92
2023	0.10	0.15	0.86	0.90
2024	0.11	0.15	0.87	0.92
2025	0.11	0.18	0.88	0.93
2026	0.12	0.18	0.87	0.92
2027	0.10	0.16	0.86	0.92

Table C3. Lower and upper probability intervals for survey estimates of recruitment west of Cape Infanta simulated during the development of OMP-18

	Survey estimated anchovy recruitment				Survey estimated sardine recruitment			
	5%ile	10%ile	90%ile	95%ile	5%ile	10%ile	90%ile	95%ile
2018	49.21	76.42	997.85	1371.50	0.849	1.312	26.483	38.024
2019	36.34	60.19	990.38	1529.56	0.909	1.490	27.719	37.248
2020	30.71	49.45	1019.01	1510.21	0.789	1.279	27.346	37.739
2021	31.02	48.16	913.82	1325.21	0.616	1.068	26.013	36.464
2022	26.80	42.87	977.70	1567.67	0.583	1.207	28.899	42.814
2023	24.95	39.11	935.21	1438.42	0.659	1.346	27.977	39.354
2024	22.93	38.71	925.38	1379.73	0.748	1.275	25.228	39.890
2025	24.19	38.40	879.14	1238.10	0.595	1.139	25.257	40.454
2026	21.14	37.08	748.98	1181.68	0.752	1.360	26.379	39.846
2027	22.22	38.58	800.18	1337.57	0.690	1.270	27.365	38.879

Table C4. Lower and upper probability intervals for the proportion of the directed sardine TAC taken west of Cape Agulhas, dependent on the ratio of the biomass west of Cape Agulhas[11] to the directed sardine TAC (see Figure C3).

West biomass (y-1) / TAC(y)	Proportion of TAC taken west of Cape Agulhas (y)			
	5%ile	10%ile	90%ile	95%ile
<1	0.40	0.40	0.40	0.40
1-2	0.40	0.40	0.55	0.60
2-3	0.40	0.40	0.70	0.75
3-4	0.40	0.40	0.82	0.86
4-5	0.40	0.40	0.88	0.90
5-6	0.40	0.57	0.90	0.90
6-7	0.40	0.62	0.90	0.90
7-8	0.40	0.54	0.90	0.90
8-9	0.40	0.63	0.90	0.90
9-10	0.40	0.40	0.90	0.90
>10	0.40	0.40	0.90	0.90

[11] During implementation, this is approximated by the survey estimate of sardine biomass west of Cape Agulhas divided by 0.70783 which is the median bias in the November survey.

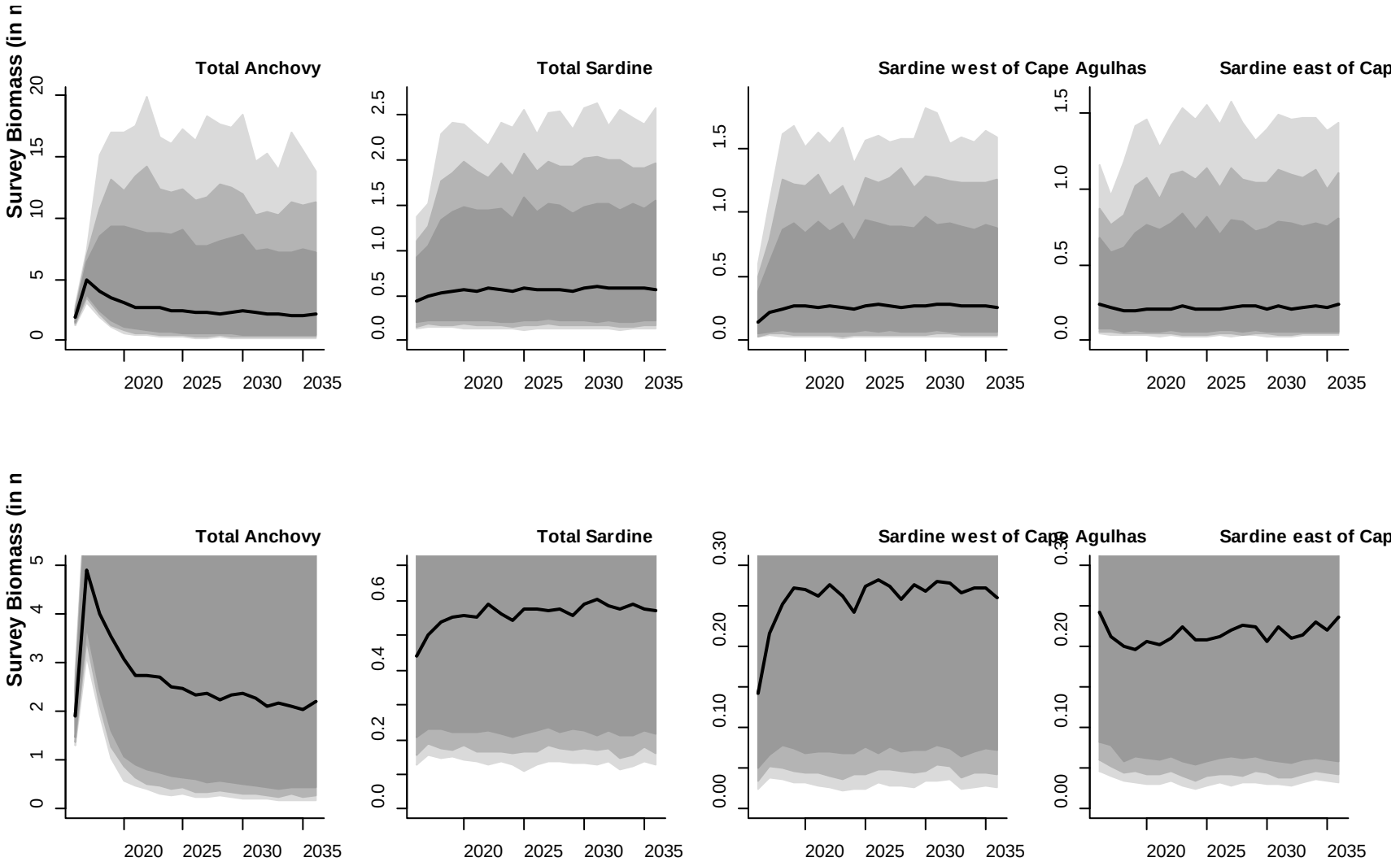

Figure C1. Median (black line), 80%ile, 90%ile and 95%ile (in progressively darker grey colours) probability intervals for November survey estimates of biomass simulated under the baseline OMs during the development of OMP-18. The lower panel of figures is a repeat of the upper panel, but over a smaller vertical axis range to show the lower percentiles more clearly.

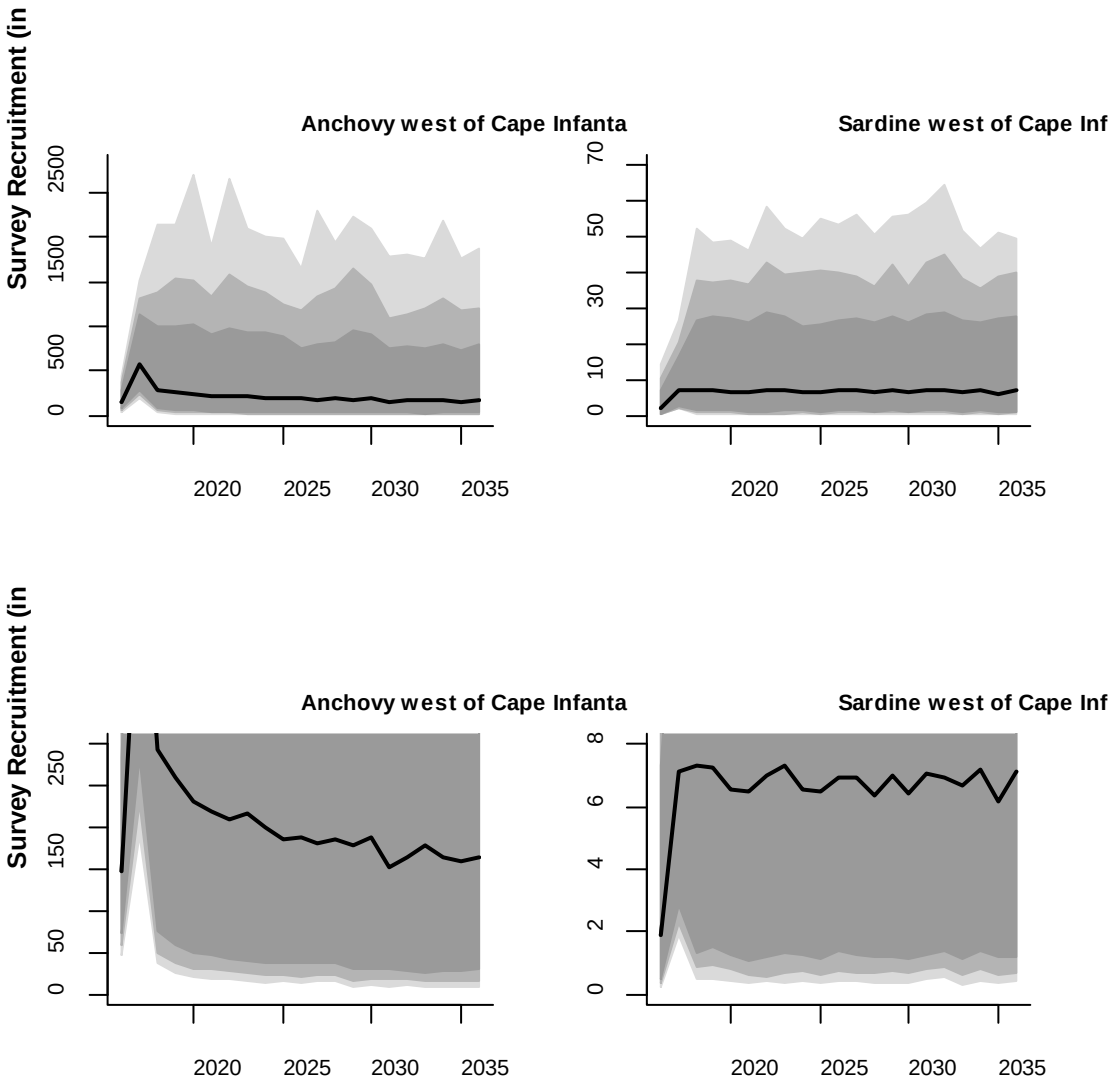

Figure C2. Median (black line), 80%ile, 90%ile and 95%ile (in progressively darker grey colours) probability intervals for May/June survey estimates of recruitment simulated during the development of OMP-18. The lower panel of figures is a repeat of the upper panel, but over a smaller vertical axis range to show the lower percentiles more clearly.

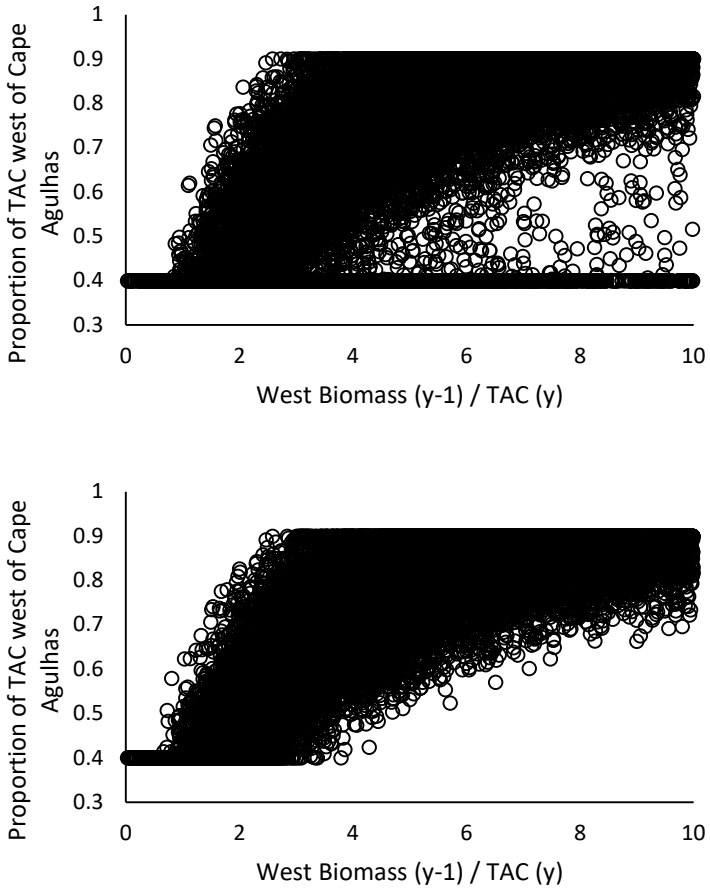

Figure C3. The future generated proportion of directed sardine TAC taken west of Cape Agulhas in year y plotted against the ratio of the west coast biomass in November (y-1) : TAC(y) for the 1000 simulations of OMP-18 on the baseline Operating Models. The lower hand plot shows the proportions resulting of the corresponding Management Procedure without the preventative red flag.