Interim OMP-18: the directed sardine Harvest Control Rule

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Introduction

A new joint Operational Management Procedure (OMP) is under development for South African sardine and anchovy. An interim-OMP is to be agreed shortly, to be used to finalise the TACs and TABs for 2018. This interim-OMP is to mimic OMP-18 as closely as possible, although some changes from the interim-OMP may be required following further analyses during the latter half of 2018.

The Harvest Control Rule for setting the anchovy TAC, and the sardine TABs are already agreed (see Appendix). Three constraints in the directed sardine Harvest Control Rule have yet to be finalised (de Moor 2018a). This document provides results from four Candidate Management Procedures (CMPs), to assist in selecting the remaining constraint values.

Method

The CMPs being considered for interim OMP-18 have the following constraints (see Appendix), as agreed as the July meeting of the Small Pelagics Scientific Working Group:

- A stable directed sardine TAC of 65 000t.
- A minimum directed sardine TAC of 10 000t.
- A maximum directed sardine TAC of 200 000t.
- Linear smoothing of the HCR applying from the Critical Biomass threshold to 100 000t above that threshold[1].
- Linear smoothing of the metarule applying from 50 000t below the Critical Biomass threshold to that threshold[2].

The remaining three thresholds/constraints are as follows:

- The Critical Biomass threshold, B^S_{crit}, on total November survey estimated sardine biomass.
- Above B^S_{crit}, the maximum proportion by which the directed sardine TAC can be decreased from one year to the next (in the absence of the Critical Biomass metarule and linear smoothing), c^S_{mxdn}.
- Below B^S_{crit}, the maximum proportion by which the directed sardine TAC can be increased[3] or decreased from the previous year's TAC (in the absence of linear smoothing) is p^S_{crit}.

The Candidate Management Procedures considered in this document include:

- CMP1 : $B^S_{crit} = 350$, with $c^S_{mxdn} = 0.2$ and $p^S_{crit} = 0.4$.
- CMP2 : $B^S_{crit} = 300$, with $c^S_{mxdn} = 0.2$ and $p^S_{crit} = 0.4$.

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[1] This is to avoid any discontinuities in the rule at B^S_{crit} when the metarule below B^S_{crit} does not allow for the same % constraint in the decrease in directed sardine TAC from one year to the next.

[2] This is to avoid any discontinuities in the rule at B^S_{crit} given the metarule has a constraint on the increase in directed sardine TAC from one year to the next, which does not apply above B^S_{crit}.

[3] The maximum of 10 000t or $(1+p^S_{crit})TAC^S_{y-1}$ is used as the constraint.

- CMP3 : $B^S_{crit} = 350$, with $c^S_{mxdn} = 0.5$ and $p^S_{crit} = 0.5$.
- CMP4 : $B^S_{crit} = 300$, with $c^S_{mxdn} = 0.5$ and $p^S_{crit} = 0.5$.

Simulations were run assuming the baseline OM for anchovy and the baseline sardine OM with MoveR and p=0.08.

Results and discussion

The β control parameter for each CMP was tuned such that the 20%ile of the total biomass depletion in the final projection year matched that considered appropriate for former OMPs (Table 1, Figure 1). This resulted in βs ranging from 0.102 to 0.160 with corresponding sardine risk - the probability of the effective west component spawner biomass falling below the lowest historical level during the projection period of 20 years – ranging from 0.197 to 0.199.

If the Critical Biomass threshold were to be decreased from the Reference Case 350 000t to 300 000t, the projected total directed sardine catch decreases. This is offset by a decrease in the median annual variation in total directed sardine catch for the cases with tighter constraints only, i.e. $c^S_{mxdn} = 0.2$ and $p^S_{crit} = 0.4$ (Table 1, Figures 2-3).

As weaker restrictions on inter-annual variability are applied (i.e. $c^S_{mxdn} = 0.2$ and $p^S_{crit} = 0.4$ changes to $c^S_{mxdn} = 0.5$ and $p^S_{crit} = 0.5$), the total directed sardine catch increases. This is offset by an increase in the median annual variation in total directed sardine catch (Table 1, Figures 2). Larger inter-annual changes in the directed sardine catches can be seen by comparing the individual catch trajectories under CMP1 and CMP2 to that under CMP3 and CMP4 (Figure 3).

The trade-off curves show the range of projected average directed sardine catch and directed anchovy catch that jointly satisfy the risk conditions of $risk_A < 0.082$ and $risk_S < 0.199$ (Figure 4). For comparative purposes, the same sardine risk threshold was used for these plots, though note that the risk differs slightly between the four CMPs (Table 1). All four CMPs are near the corner-point of these trade-off curves, corresponding to the maximum projected average directed sardine catch possible without any decrease in projected anchovy catch.

References

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

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. The ratio of the lower percentiles of the distribution of sardine biomass at the end of the projection period under the four CMPs : no catch scenario.

		Total				West Component		South Component	
		OMP-08	OMP-14	$\beta = 0.125$	$\beta = 0.126$	$\beta = 0.125$	$\beta = 0.126$	$\beta = 0.125$	$\beta = 0.126$
CMP1	10%ile	0.50	0.59	0.61	0.60	0.67	0.67	0.56	0.56
	20%ile	**0.68**	**0.68**	0.69	**0.68**	0.72	0.72	0.61	0.60
	30%ile	0.72	0.73	0.71	0.71	0.74	0.74	0.62	0.62
	40%ile	0.73	0.76	0.73	0.73	0.77	0.77	0.66	0.66
	50%ile	0.72	0.78	0.73	0.73	0.77	0.77	0.68	0.68
		OMP-08	OMP-14	$\beta = 0.101$	$\beta = 0.102$	$\beta = 0.101$	$\beta = 0.102$	$\beta = 0.101$	$\beta = 0.102$
CMP2	10%ile	0.50	0.59	0.62	0.62	0.67	0.67	0.57	0.57
	20%ile	**0.68**	**0.68**	0.69	**0.68**	0.72	0.72	0.63	0.63
	30%ile	0.72	0.73	0.72	0.72	0.75	0.75	0.63	0.63
	40%ile	0.73	0.76	0.74	0.74	0.77	0.77	0.68	0.67
	50%ile	0.72	0.78	0.75	0.75	0.77	0.77	0.70	0.70
		OMP-08	OMP-14	$\beta = 0.159$	$\beta = 0.160$	$\beta = 0.159$	$\beta = 0.160$	$\beta = 0.159$	$\beta = 0.160$
CMP3	10%ile	0.50	0.59	0.62	0.62	0.66	0.66	0.54	0.54
	20%ile	**0.68**	**0.68**	0.69	**0.68**	0.71	0.71	0.59	0.59
	30%ile	0.72	0.73	0.70	0.70	0.74	0.74	0.62	0.62
	40%ile	0.73	0.76	0.73	0.73	0.77	0.77	0.65	0.65
	50%ile	0.72	0.78	0.72	0.72	0.77	0.77	0.67	0.67
		OMP-08	OMP-14	$\beta = 0.143$	$\beta = 0.144$	$\beta = 0.143$	$\beta = 0.144$	$\beta = 0.143$	$\beta = 0.144$
CMP4	10%ile	0.50	0.59	0.63	0.63	0.67	0.67	0.56	0.56
	20%ile	**0.68**	**0.68**	0.69	**0.68**	0.72	0.72	0.60	0.60
	30%ile	0.72	0.73	0.71	0.71	0.75	0.75	0.62	0.62
	40%ile	0.73	0.76	0.73	0.73	0.77	0.77	0.66	0.66
	50%ile	0.72	0.78	0.73	0.73	0.77	0.77	0.68	0.68

Table 2. Sardine performance statistics for the alternative sardine CMPs. All CMPs have been tuned so that the ratio of the 20%ile of the catch : no catch distributions are the same (Table 1). Where appropriate, medians [90% probability intervals] are provided, and for some statistics the means are additionally provided in **bold**. All biomasses are given in thousands of tons.

	No Catch	CMP1	CMP2	CMP3	CMP4
B^S_{crit}	-	350	300	350	300
c^S_{mxdn}	-	0.2	0.2	0.5	0.5
p^S_{crit}	-	0.4	0.4	0.5	0.5
β	-	0.126	0.102	0.160	0.144
$Risk^S$	0.076	0.199	0.197	0.199	0.198
p(TAC^S<20)	-	0.05	0.03	0.07	0.05
$B^S_{tot,2036}$	**379** 320 [141,805]	**253** 207 [56,607]	**259** 212 [58,614]	**250** 206 [58,591]	**253** 206 [58,593]
$B^S_{west,2036}$	**183** 136 [29,506]	**126** 86 [11,379]	**128** 87 [11,384]	**125** 86 [12,371]	**126** 86 [12,375]
$B^S_{south,2036}$	**195** 164 [68,426]	**127** 104 [27,315]	**132** 109 [28,324]	**125** 102 [27,307]	**127** 104 [29,313]
$\frac{B^S_{tot,2036}}{B^S_{tot,2015}}$	4.2 [1.3,21.3]	2.6 [0.6,15.2]	2.7 [0.6,15.7]	2.6 [0.6,14.2]	2.6 [0.6,14.8]
$\frac{B^S_{west,2036}}{B^S_{west,2015}}$	3.0 [0.6,19.3]	1.9 [0.2,13.5]	1.9 [0.2,14.1]	1.9 [0.2,13.0]	1.9 [0.2,13.1]
$\frac{B^S_{south,2036}}{B^S_{south,2015}}$	0.9 [0.4,2.4]	0.6 [0.2,1.7]	0.6 [0.2,1.7]	0.6 [0.2,1.7]	0.6 [0.2,1.7]
$B^S_{tot,min}$	157 [92,233]	89 [31,163]	92 [32,169]	88 [32,164]	90 [30,166]
$B^S_{west,min}$	31 [8,71]	18 [3,51]	18 [3,52]	18 [3,50]	18 [3,51]
$B^S_{south,min}$	78 [37,134]	39 [9,87]	42 [10,92]	37 [8,84]	39 [9,88]
C^S_{tot}	**1** 0 [0,28]	**86** 73 [23,200]	**79** 65 [24,172]	**90** 78 [18,200]	**87** 71 [21,200]
Med C^S_{tot} [4]	0 [0,0]	73 [46,123]	65 [55,108]	80 [44,122]	72 [54,111]
C^S_{west}	**1** 0 [0,24]	**61** 53 [15,142]	**58** 53 [17,128]	**63** 54 [13,150]	**62** 54 [15,146]
C^S_{south}	**0** 0 [0,4]	**25** 17 [1,78]	**21** 15 [1,65]	**27** 18 [1,88]	**25** 17 [1,80]
$\frac{C^S_{west}}{C^S_{tot}}$	0 [0,0.87]	0.77 [0.35,0.98]	0.79 [0.37,0.99]	0.77 [0.34,0.98]	0.77 [0.35,0.98]
ByC^S_{tot}	**0.3** 0 [0,5.2]	**18** 10.6 [1.4,59.0]	**17.9** 10.6 [1.4,59.0]	**18.0** 10.6 [1.4,59.2]	**18** 10.6 [1.4,59.2]
ByC^S_{west}	**0.3** 0 [0,5.2]	**18** 10.6 [1.4,59.0]	**17.9** 10.6 [1.4,59.0]	**18.0** 10.6 [1.4,59.2]	**18** 10.6 [1.4,59.2]
ByC^S_{south}	**0.0** 0 [0,0]	**0** 0[0,0]	**0** 0[0,0]	**0** 0[0,0.1]	**0** 0[0,0]
MAV^S_{tot} [5]	-	0.40 [0.20,0.40]	0.27 [0.17,0.40]	0.50 [0.31,0.50]	0.50 [0.27,0.50]
MAV^S_{west}	-	0.34 [0.21,0.49]	0.31 [0.19,0.46]	0.41 [0.26,0.54]	0.39 [0.25,0.53]
MAV^S_{south}	-	0.72 [0.46,1.00]	0.70 [0.46,0.99]	0.79 [0.55,1.00]	0.79 [0.53,1.00]
$p(B^{Sobs}_y < B^S_{crit}, B_y < B^S_{crit}/k^S_N)$	-	0.24	0.16	0.24	0.16
$p(B^{Sobs}_y < B^S_{crit}, B_y \geq B^S_{crit}/k^S_N)$	-	0.14	0.15	0.14	0.16
$p(B^{Sobs}_y \geq B^S_{crit}, B_y < B^S_{crit}/k^S_N)$	-	0.12	0.08	0.12	0.08
$p(B^{Sobs}_y \geq B^S_{crit}, B_y \geq B^S_{crit}/k^S_N)$	-	0.50	0.61	0.50	0.60

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

[5] Median and 90%ile of $AAV^b_y = \left|C^{S,b}_{tot,y} - C^{S,b}_{tot,y-1}\right| / C^{S,b}_{tot,y-1}$

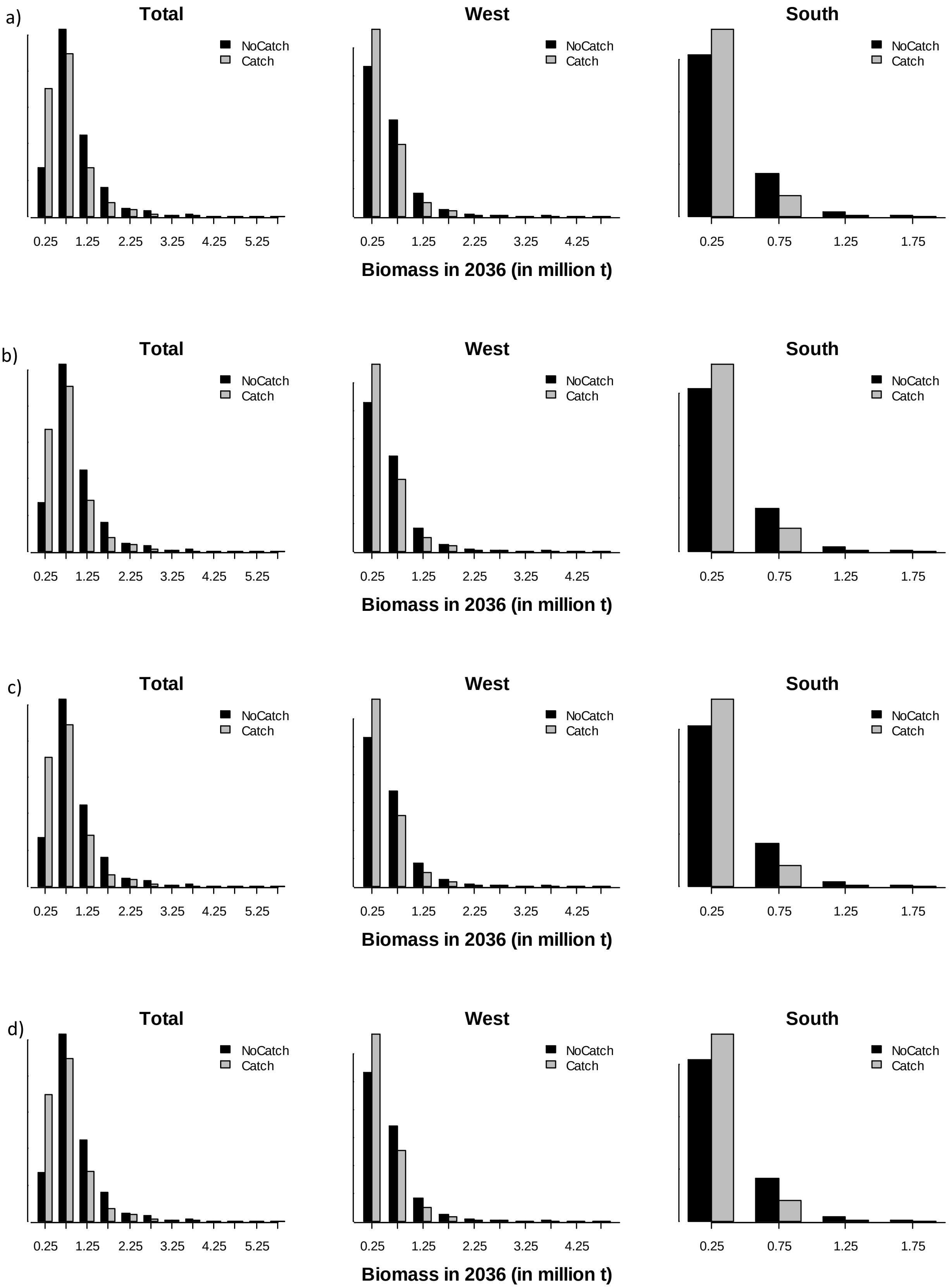
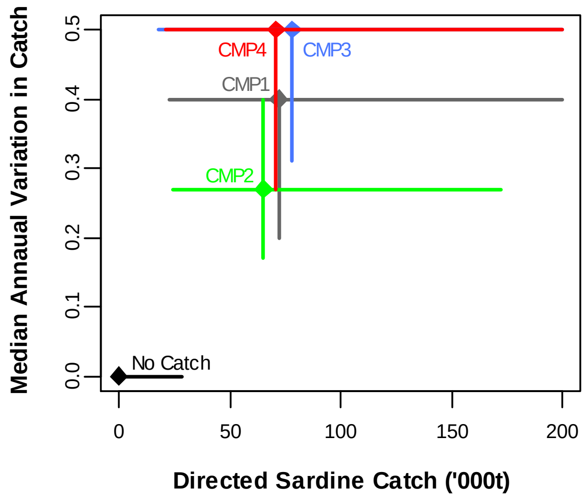


Figure 1. Histograms of the total, west component and south component sardine November biomass in the final projection year under a no-catch scenario and the alternative Candidate Management Procedures: a) CMP1 with $\beta = 0.126$, b) CMP2 with $\beta = 0.102$, c) CMP3 with $\beta = 0.160$, and d) CMP4 with $\beta = 0.144$. All CMPs have been tuned so that the ratio of the 20%ile of the catch : no catch distributions are the same (i.e. the "leftward shift" method) (Table 1).



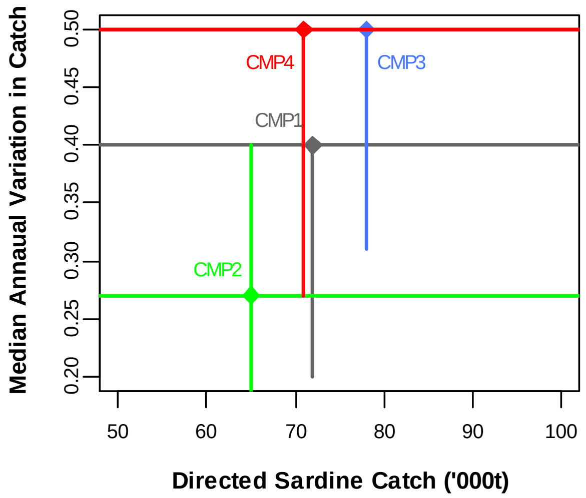


Figure 2. The median and 90% probability intervals of MAV in the total directed sardine catch and median total directed sardine catch under a no-catch scenario and the four alternative Candidate Management Procedures. All CMPs have been tuned so that the ratio of the 20%ile of the catch : no catch distributions are the same (i.e. the "leftward shift" method) (Table 1). The right hand plot is a repeat of the left over smaller ranges for both axes.

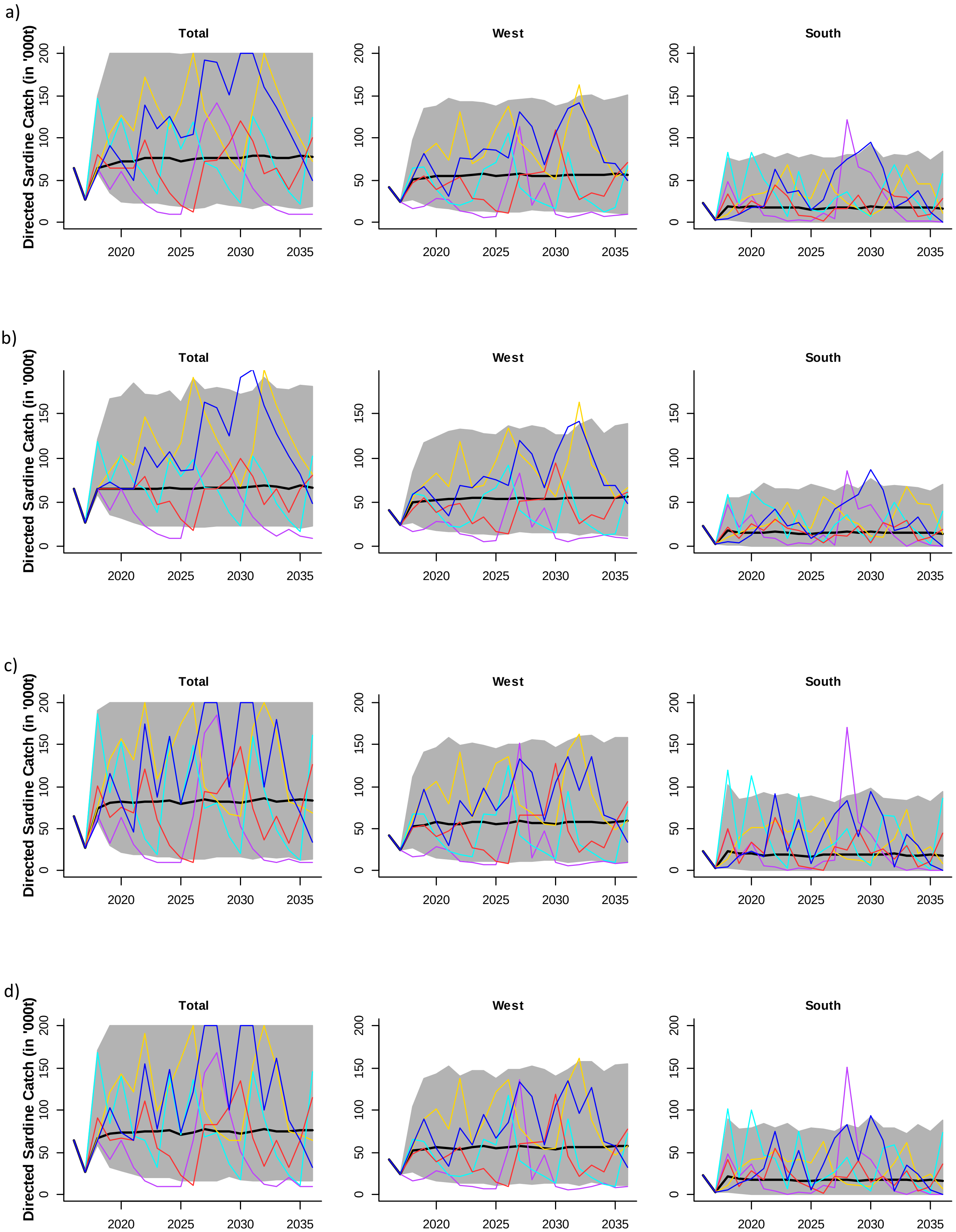


Figure 3. Median (black line) and 90%ile (shaded area) of annual a) Total, b) West and c) South directed sardine catch, with the first 5 trajectories shown for a) CMP1 with $\beta = 0.126$, b) CMP2 with $\beta = 0.102$, c) CMP3 with $\beta = 0.160$, and d) CMP4 with $\beta = 0.144$.

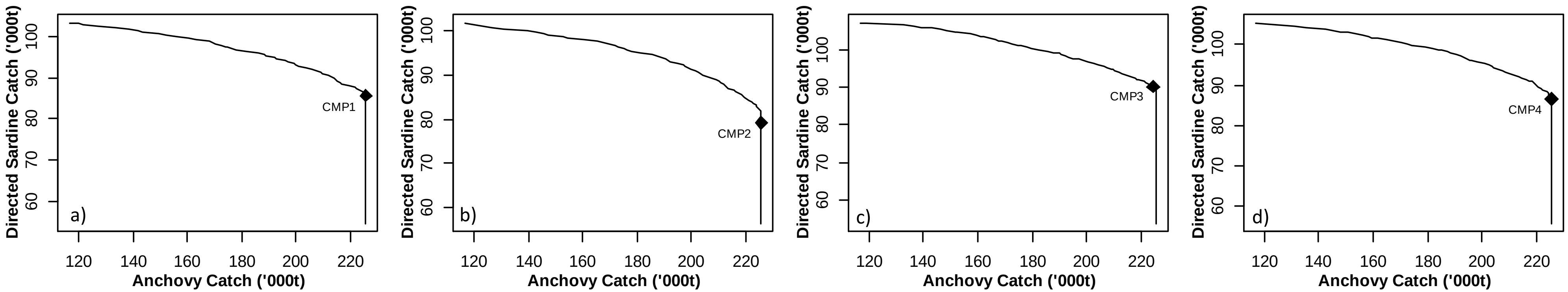


Figure 4. The trade-off curves determined by satisfying $risk_A < 0.082$ and $risk_S < 0.199$. The four plots have constraints corresponding to those of a) CMP1, b) CMP2, c) CMP3 and d) CMP4, and the four CMPs are indicated by the diamonds on the curves.

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

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 and below, the following linear smoothing is applied.

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

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

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

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

where c_{stbl}^A is the TAC output from equation (OMP.16) 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: $$TAC_y^A = \alpha q \left(p \frac{N_{y-1,0}^A}{\bar{N}_0^A} + (1-p)\frac{B_{y-1}^{obs,A}}{\bar{B}_{Nov}^A}\right) \qquad \text{(OMP.10)}$$

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

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:

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

Revised <14cm sardine TAB with anchovy:

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

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

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

where c^A_{stbl} is the TAC output from equation (OMP.21) when $B^{obs,A}_{y-1} = B^A_{crit}$, while $TAC^{A'}_y$ 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.18).

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.

Initial Anchovy TAC

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

Initial TAC: $$TAC^A_{y,init} = \begin{cases} 0 & if\ \frac{B^{obs,A}_{y-1}}{B^A_{crit}} < x^A \\ c^A_{stbl}\left(\frac{\frac{B^{obs,A}_{y-1}}{B^A_{crit}} - x^A}{1 - x^A}\right)^2 & if\ x^A < \frac{B^{obs,A}_{y-1}}{B^A_{crit}} < 1 \end{cases} \qquad \text{(OMP.16)}$$

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:

$$B_{y,proj0}^{A} = k_N^A \times max\left\{0; \left(\frac{N_y^{obs,A}}{k_r^A} - \left[\frac{TAC_y^{A''} + TAB^A - \bar{w}_{1c}^A C_{y,1}^A}{\bar{w}_{0c}^A} - C_{y,0bs}^A\right]\right) e^{-(6-t_y)\times 1.2/12} \bar{w}_1^A\right\}. \quad \text{(OMP.17)}$$

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

$$B_{y,proj}^{A} = k_N^A \left(\frac{B_{y-1}^{obs,A}}{k_N^A \bar{w}_1^A} e^{-5\times 1.2/12} - C_{y,1}^A\right) e^{-7\times 1.2/12} \bar{w}_2^A + B_{y,proj0}^A \quad \text{(OMP.18)}$$

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:

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

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

$$N_{y-1,0}^{A*} = \left(k_r^A \theta e^{t_y \times 1.2/12} + C_{y,0bs}^A\right) e^{6\times 1.2/12} \quad \text{(OMP.20)}$$

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 $= \frac{p\frac{N_{y-1,0}^A}{\bar{N}_0^A} + (1-p)\frac{B_{y-1}^{obs,A}}{\bar{B}_{Nov}^A}}{p\frac{N_{y-1,0}^{A*}}{\bar{N}_0^A} + (1-p)\frac{B_{y-1}^{obs,A}}{\bar{B}_{Nov}^A}}$:

$$TAC_y^S = \begin{cases} max\left\{0; TAC_{y,init}^A\right\} & if\ R < x^A \\ max\left\{TAC_{y,init}^A; c_{stbl}^A \left(\frac{R - x^A}{1 - x^A}\right)^2\right\} & if\ x^A < R < 1 \end{cases} \quad \text{(OMP.21)}$$

Table A1. Definitions of the control parameters and constraints, together with their values, as well as other data input required in the Harvest Control Rule formulae. All mass-related quantities are given in thousands of tons.

		Definition	Value
Key Control Parameters tuned to meet target risk levels	β	Directed sardine catch control parameter	See main text
	α	Directed anchovy catch control parameter for normal season	0.914[6]
Fixed TABs	TAB^S_{big}	Fixed >14cm sardine bycatch	7
	TAB^A	Fixed anchovy bycatch for sardine only right holders	0.5
	$TAB^S_{y,small,rh}$	Fixed ≤14cm sardine bycatch with round herring	1.0
Fixed Control Parameters and Constraints Constraints	δ	Scale-down factor applied to initial anchovy TAC to provide a buffer against possible poor recruitment	0.85
	p	Weighting given to recruitment survey compared to November survey in setting anchovy TAC	0.7
	q	Constant reflecting average annual TAC under OMP-99 if $\alpha = 1$	300
	$\bar{B}^A_{Nov}$	Historical average 1984 to 1999 November survey estimate of anchovy total biomass	1380
	$\bar{N}^A_0$	Average of 1985 to 1999 May survey estimated anchovy recruitment, back-calculated to 1 November of the previous year	222 billion
	ω	Estimate of the maximum proportion of ≤14cm sardine bycatch in the >14cm sardine catch	0.07
	γ_y	Initial (conservative) estimate of anticipated juvenile sardine : anchovy ratio	OMP.7
	γ_{max}	Maximum of the logistic curve for γ_y	0.1
	B_{50}	Survey estimate of sardine total biomass where the logistic curve for γ_y reaches 50%	2000
	B_{95}	Survey estimate of sardine total biomass where the logistic curve for γ_y reaches 95%	3178
	c^S_{mntac}	Absolute minimum directed sardine TAC	10
	c^S_{stbl}	Stable directed sardine TAC	65
	c^A_{stbl}	Stable anchovy TAC	120
	c^S_{mxtac}	Maximum directed sardine TAC	200
	c^A_{mxtac}	Maximum total anchovy TAC	350
	c^S_{tier}	Two-tier threshold for directed sardine TAC	255
	c^A_{tier}	Two-tier threshold for anchovy TAC	330
	c^S_{mxdn}	Maximum proportion by which directed sardine TAC can be reduced annually, if $B^{obs,S}_{y-1} \geq B^S_{crit}$	See main text
	p^S_{crit}	Maximum proportion by which directed sardine TAC can be reduced annually, if $B^{obs,S}_{y-1} < B^S_{crit}$	See main text
	c^A_{mxdn}	Maximum proportion by which anchovy TAC can be reduced annually	0.25
	B^S_{crit}	November survey estimated biomass threshold below which Critical Biomass metarules are invoked for sardine	See main text
	B^A_{crit}	November survey estimated biomass threshold below which Critical Biomass metarules are invoked for anchovy	600
	Δ^S	Linear smoothing is introduced below $B^S_{crit} + \Delta^S$ before sardine Critical Biomass metarules are applied (to ensure continuity)	350
	Δ^A	Linear smoothing is introduced below $B^A_{crit} + \Delta^A$ before sardine Critical Biomass metarules are applied (to ensure continuity)	100

[6] This has been updated from that which was used to set the final 2018 TAC (de Moor 2018b). The former value had been agreed based on de Moor (2018c). The updated value is due to re-tuning with median values for k^A_N, k^A_r, $\bar{w}^A_1$ and $\bar{w}^A_2$ in the HCRs instead of using 1000 draws from the posterior distribution.

Table A1 (continued).

		Definition	Value
Fixed Control Parameters and Constraints Constraints	x^S	The proportion of B^S_{crit} below which the metarule sets the directed sardine TAC to zero	0.25
	x^A	The proportion of B^A_{crit} below which the metarule sets the anchovy TAC to zero	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	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	OMP.18
	k^A_N	Multiplicative bias associated with the November survey of anchovy total biomass (median of posterior distribution used)	0.633
	k^A_r	Multiplicative bias associated with the recruit survey of anchovy recruitment (median of posterior distribution used)	0.525
Data Used in December $y-1$ HCR Formulae	$B^{obs,S}_{y-1}$	November survey estimate of sardine total biomass in year $y-1$ (in thousands of tons)	
	$B^{obs,A}_{y-1}$	November survey estimate of anchovy total biomass in year $y-1$ (in thousands of tons)	
Data Used in June y HCR Formulae	$N^{obs,A}_y$	May survey estimate of anchovy recruitment in year y (in billions)	
	t_y	Day of commencement of recruitment survey in year y (time in months after 1 May)	
	$C^A_{y,1}$	Anchovy catch at age 1[7] from 1 November of year $y-1$ to the day before the commencement of the recruitment survey (in billions)	
	$C^A_{y,0bs}$	Anchovy catch at age 0[6] from 1 November of year $y-1$ to the day before the commencement of the recruitment survey (in billions)	
	$r_{y,sur}$	Ratio of juvenile sardine to anchovy (by mass) indicated by the recruitment survey	
	$r_{y,com}$	Ratio of juvenile sardine to anchovy (by mass) in the commercial catches[8] during May, based on the commercial catches comprising at least 50% anchovy only	
	$\overline{w}^A_1$	Average historical anchovy weight-at-age 1 in November (in gm) (median of posterior distribution used)	10.833
	$\overline{w}^A_2$	Average historical anchovy weight-at-age 2 in November (in gm) (median of posterior distribution used)	14.503
	$\overline{w}^A_{0c}$	Average historical catch weight-at-age 0 (in gm)	5.484
	$\overline{w}^A_{1c}$	Average historical catch weight-at-age 1 (in gm)	12.702

[7] 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.

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