# Further results towards finalising HCRs for OMP-18

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The baseline Operating Models to be used to tune a new OMP for South African sardine and anchovy have been updated, and the performance statistics from a CMP ("CMP5") assuming only implicit spatial management are given. This "implicit" spatial management of the sardine fishery will be linked to 'red flags'. Preventative red flags introduce corrective measures when the survey estimated biomass west of Cape Agulhas is low. Penalty red flags, with corresponding benefit green flags, are intended to introduce corrective measures if the future spatial distribution of catches differs from that seen historically and assumed when tuning the CMP. Results in this document should allow a selection of preventative and penalty/benefit flags in order to finalise OMP-18.

**Introduction**

This document consolidates a number of recent updates to the baseline sardine and anchovy Operating Models (OMs) to be used to develop OMP-18. It also provides some further results towards finalising the Harvest Control Rules (HCRs) together with 'preventative' and 'penalty' red flags (linked to 'benefit' green flags) in conjunction with implicit spatial management for the sardine fishery.

**Methods**

The following updates to the underlying OMs have taken place:

1) The anchovy OM has been updated to include a patch to the generation of future recruitment (Bergh 2018).
2) Following the recommendation of de Moor (2018a), the sardine baseline OM has been changed to use the density-dependent hypothesis of future movement of sardine from the west to the south component, i.e. MoveD. The proportion of south component spawner biomass contributing to west component effective spawner biomass remains at 0.08.
3) The sardine baseline OM generating the proportion of the future directed sardine TAC which is taken west of Cape Agulhas has been updated with an upper limit of 0.9.

The Candidate Management Procedure (CMP) tuned to acceptable risk levels based on these updated OMs – where the sardine OM is called OM5 below - is called CMP5.

CMP5 assumes 'implicit' spatial management of the sardine fishery (de Moor and Butterworth 2018). This method assumes a range of proportions of directed sardine catch to be taken west of Cape Agulhas, with higher/lower proportions taken on the west coast during years of low/high ratios of TAC to west component biomass (Figure 1), but limited to a maximum of 0.9 and a minimum of 0.4 (de Moor 2018c). Implicit spatial management was originally agreed to together with the idea that there would be a departure from this (initially proposed as a switch to explicit spatial management) once 'red flags' were raised (de Moor 2017, 2018c). Further work on the 'preventative' and 'penalty' red flags are as follows:

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4) Two thresholds of survey estimated biomass west of Cape Agulhas, $B_{west}^{obs}$, were considered for preventative red flags, namely 100 000t and 150 000t. The corrective measures tested (applying to year *y*) once a preventative red flag is raised (based on the survey estimated biomass in November *y*-1) were as follows:

   - implicit spatial management, but with the TAC being a percentage (50-70%) of that calculated by the original HCR, and

   - requiring a percentage (30-40%) of the TAC to be taken west of Cape Agulhas prior to closure of this area to directed sardine fishing.

   Corrective measures are implemented over a smooth range. No corrective measure (i.e. 100% of the TAC for the former option and OM5-simulated proportion of TAC taken west of Cape Agulhas for latter option) occurs at the threshold + 10% and above. The full corrective measure (e.g. 70% of the TAC for the former option and 40% of the TAC west of Cape Agulhas for latter option) occurs at the threshold – 10% and below. The smoothing is applied linearly between these such that at the threshold half the corrective measure applied (e.g. 85% of the TAC for the former option and half way between 40% of the TAC taken west of Cape Agulhas and the % that arises from the OM5-simulated proportion of TAC).

5) The thresholds for penalty red flags and benefit green flags have been adjusted such that they follow the general shape of the relationship shown by past data which reflects lower/higher proportions of catch taken west of Cape Agulhas when the ratio of TAC to west component biomass is high/low. The thresholds are a multiple of 1.2 and 1/1.2 of the median relationship (Figure 1). The penalty/benefit flags are implemented as follows:

   i) The proportion of the HCR-calculated TAC is initially set to 1.

   ii) At the start of each year the proportion is re-adjusted from the previous year's proportion ($p_{y-1}$), towards 1, i.e. $p_{y,start} = x \times 1 + (1 - x)p_{y-1}$.

   iii) If a penalty red flag is raised, the proportion is then decreased by an amount (e.g. -0.10).

   iv) If a benefit green flag is raised, the proportion is then increased by an amount (e.g. +0.01), subject to reaching a maximum of 1.1.

   The same three alternative models of how future catches may not follow the baseline (OM5) assumptions as de Moor (2018c) are used:

   - OM-60, where the proportion of catch taken west of Cape Agulhas is related to the ratio of the west component biomass to the total TAC, with the restriction that future catch is distributed with a minimum of 60% west of Cape Agulhas and a maximum of 90%.

   - OM-UL, where the relationship between the proportion of catch taken west of Cape Agulhas and the ratio of the west component biomass to the total TAC is moved in a upward and leftward direction (by multiplying the two estimated parameters of the relationship by 1.2).

   - OM-70, where the proportion of catch taken west of Cape Agulhas is assumed to be 70% in every year, regardless of the distribution of the underlying biomass.

   The alternative OMs are used from 2025 to 2032 only, i.e. the last 12 years of simulation, with the assumption that fish-as-in-the-past would apply up to and including 2024. The reason for commencing only in 2025 is to exclude the effect of initial transients in the dynamics.

**Results and discussion**

*Updated anchovy OM and retuning the anchovy HCR to an acceptable level of risk*

The revised anchovy OM results in a closer match between the distribution of stock recruitment residuals generated from the assessment conditioned on historical data and that generated from the OM projections (Figure 2). The higher recruitments result in higher projected anchovy (spawner) biomass over time. Given this revised range of future spawner biomass, the risk threshold was able to be revised back to that originally intended (Cox et al. 2017). The anchovy risk threshold has thus been revised to *the lowest (1996) historical spawner biomass* (Figure 3).

The SPSWG OMP TT previously agreed to consider the acceptable level of anchovy risk to be that given by the OMP-14 anchovy HCR, under the updated anchovy OM conditioned on data up to November 2015 (de Moor 2018b). Under the OMP-14 HCR, the probability that the anchovy spawner biomass falls below the lowest historical spawner biomass level of 1996 is 0.134. This level of risk is thus selected as a basis for tuning anchovy HCRs for OMP-18 (Table 1).

*Updated sardine OM and retuning the sardine HCR (without any red flags) to an acceptable level of risk*

The sardine baseline OM now limits the proportion of future directed sardine TAC taken west of Cape Agulhas to a maximum of 0.9 (Figure 1) and is based on a MoveD hypothesis. The former change has little impact on the sardine risk level and does not require readjustment to the sardine $\beta$ control parameter. The latter results in more optimistic projections for the sardine resource under both a no catch and a future catch option. Retuning the $\beta$ control parameter such that the 20%ile of the distribution of total biomass in 2036 under CMP5 is 68% of that under a no catch scenario results in $\beta = 0.175$ and a probability of sardine west component effective spawning biomass falling below the lowest historical level (2007) of 0.182 (Figure 4, Table 1).

*Preventative red flags*

The alternative preventative red flag options listed in Table 2 were tuned so that the probability of west component biomass being less than 150 000t was 0.144. Alternatives were tuned so that the average and median total catches are similar to those under CMP5 (Table A.1). These alternatives therefore offer some conservation improvement to the sardine resource (in particular in terms of west component biomass, Table 3 and Figure 5). The alternatives restricting the catch west of Cape Agulhas to be at most 35% or 40% of the TAC results in slightly lower inter-annual variation in the total catches. Raising the preventative red flag at 150 000t instead of 100 000t results in a lower risk to the sardine resource for the same control parameter, but the red flag is simulated to be raised more frequently. Robinson et al. (2015) showed a sharp increase in adult natural mortality of Robben island penguins once the survey estimate of sardine biomass west of Cape Agulhas decreased below about 350 000t. As these preventative red flags are only raised at a fraction of this threshold, the probability of future survey estimated biomass west of Cape Agulhas being below this threshold is large (Table 2).

Table A.1 lists some further alternatives previously considered by the OMP TT and the SPSWG.

*Penalty red flags*

As previously shown by de Moor (2018c), Table 4 again shows that the risk to the sardine resource, as well as the probability that the west component biomass falls below 150 000t increase if future fishing patterns do not conform to those generated

by the relationship based on past fishing behaviour. As before, penalties and benefits to the HCR-calculated TAC when penalty red/green flags were raised were sought such that there would be little impact on the performance statistics if implicit spatial management continued as in the past (OM5), but that the risk to the resource would be brought down towards that possible under OM5's implicit spatial management should future fishing patterns differ from that informed by 'fish-as-in-the-past'. While the new curved thresholds (Figure 1) result in higher false negatives and false positives (i.e. red and green flags being raised under OM5, Table 4) than perhaps ideal, widening the gap between the median relationship and the thresholds (e.g. using a multiple of 1.3) results in insufficient corrective action under alternative catch patterns. 'Opt1' of Table 4 which corresponds to a penalty of -0.10, a benefit of 0.03 and an annual 10% readjustment towards 1 results in the closest probability of west component biomass being below 150 000t to the 0.128 obtained under OM5 and CMP5. There are further alternatives which result in improved corrective measures under OM-60, OM-UL and OM-70 with little impact on OM5, but these require higher penalties/benefits (Table A.2, e.g. a penalty of -0.20, a benefit of 0.10 and an annual 20% readjustment towards 1).

**Summary**

This document has included a new CMP ("CMP5") tuned to revised anchovy and sardine OMs. As mentioned by de Moor (2018c), the results presented herein are based on selecting the $\beta$ control parameter for the sardine HCR by considering the 'leftward shift' in the total sardine biomass. The resultant risk level for sardine is 18% prior to the introduction of red flags. This does not imply 'acceptance' of this risk level and a different risk level may be appropriate (de Moor 2018d, SPSWG aide memoire 12th September 2018).

The new OMP for South African sardine is being developed assuming implicit spatial management, i.e. the distribution of future directed sardine catches east and west of Cape Agulhas is spread according to past behaviour, subject to adjusting this if 'red flags' are raised.

Two thresholds (survey estimated biomass west of Cape Agulhas of 100 000t and 150 000t) and four forms of corrective measures (70% or 75% of the HCR-calculated TAC or closing the west coast after 35% or 40% of the TAC is caught west of Cape Agulhas) for preventative red flags have been proposed by the OMP TT. All eight alternatives maintain the same probability of west component biomass being below 150 000t. The 35% of TAC west of Cape Agulhas options have a higher average/median total catch, and the west coast closure options have a slightly lower MAV than the options which reduce the HCR-calculated TAC. None of the options are sufficiently conservative to provide much improvement on the probability of the survey estimated biomass west of Cape Agulhas being below 336 000t.

Three penalty red flags, with associated benefit green flags have been proposed by the OMP TT, all maintaining at most a 10% penalty on the HCR-calculated TAC. With such a restriction, however, the ability of the penalty/benefit flags to correct the higher risk to the resource should future fishing patterns be different to – and in particular further to the west than - that assumed by implicit spatial management is constrained.

Table 5 gives the performance statistics when both the preventative and penalty (benefit) red flags are simulated to be implemented simultaneously. These statistics include indicators of the impact of the OMP on the ecosystem using a model of Robben island penguin dynamics dependent on west coast sardine biomass (Robinson et al. 2015). These performance

statistics suggest that even in the absence of fishing the penguin populations on the west coast will continue to decline. The decline is estimated to be 28% (5 years), 47% (10 years) and 56% (15 years) faster under CMP5 compared to a no catch scenario (Table 3).

The performance statistics corresponding to a corrective measure of closure of the west coast once 35% of the TAC is taken west of Cape Agulhas when a preventative red flag is raised at $B_{y-1}^{obs,S} < 100$, together with a penalty/benefit red/green flag combination of -0.10 and +0.01 after an annual 20% readjustment towards 1 are given in Table 1. Figure 6 shows the corresponding trade-off curve.

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**Table 1.** Key summary performance statistics for a no catch scenario using the revised anchovy and sardine OMs, CMP5, and the CMP including a corrective measure of closure of the west coast once 35% of the TAC is taken west of Cape Agulhas when a preventative red flag is raised at $B^{obs,S}_{west,y-1} < 100$, together with a penalty/benefit red/green flag combination of -0.10 and +0.01 after an annual 20% readjustment towards 1. Where appropriate, medians and 90%iles 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 | CMP5 | CMP5 with flags | | No Catch | CMP5 | CMP5 with flags |
| Risk statis | $\beta$ | - | 0.175 | 0.151 | $\alpha$ | - | 1.314 | 1.314 |
| | $Risk_S$ | 0.070 | 0.182 | 0.161 | $Risk_A$ | 0.026 | 0.134 | 0.134 |
| | p(TAC$^S$<20) | - | 0.02 | 0.02 | | | | |
| Biomass statistics | $B^S_{tot,2036}$ | **416** 373 [172,821] | **272** 235 [81,609] | **286** 245 [89,622] | $B^A_{2036}$ | **2699** 2074 [457,6852] | **1936** 1266 [119,5783] | **1937** 1266 [119,5783] |
| | $B^S_{west,2036}$ | **178** 147 [25,438] | **117** 91 [10,316] | **123** 96 [13,329] | | | | |
| | $B^S_{south,2036}$ | **238** 209 [83,477] | **155** 129 [41,356] | **162** 135 [45,366] | | | | |
| | $B^S_{tot,2036}/B^S_{tot,2015}$ | 4.4 [1.5,23.4] | 2.8 [0.7,16.0] | 2.9 [0.8,16.7] | $B^A_{2036}/B^A_{2015}$ | 1.4 [0.3,5.3] | 0.9 [0.1,4.5] | 0.9 [0.1,4.5] |
| | $B^S_{west,2036}/B^S_{west,2015}$ | 3.0 [0.4,21.7] | 1.8 [0.2,15.3] | 2.0 [0.2,16.0] | | | | |
| | $B^S_{south,2036}/B^S_{south,2015}$ | 1.1 [0.5,2.8] | 0.7 [0.2,2.0] | 0.7 [0.2,2.1] | | | | |
| | $B^S_{tot,min}$ | 180 [115,263] | 106 [42,187] | 113 [49,194] | $B^A_{min}$ | 869 [271,1900] | 429 [73,1505] | 429 [73,1505] |
| | $B^S_{west,min}$ | 25 [5,71] | 14 [1,47] | 16 [1,50] | | | | |
| | $B^S_{south,min}$ | 90 [49,148] | 49 [14,101] | 52 [16,105] | | | | |
| Catch statistics | $C^S_{tot}$ | **2** 0 [0,31] | **104** 93 [31,200] | **96** 81 [31,200] | $C^A$ | **0** 0 [0,217] | **303** 350 [47,350] | **303** 350 [209,350] |
| | Med $C^S_{tot}$ | 0 [0,0] | 94 [65,141] | 82 [65,120] | Med $C^A$ | 0 [0,0] | 350 [209,350] | 350 [210,350] |
| | $C^S_{west}$ | **1** 0 [0,26] | **70** 61 [22,155] | **64** 57 [13,148] | | | | |
| | $C^S_{south}$ | **0** 0 [0,5] | **34** 25 [5,100] | **32** 23 [5,89] | | | | |
| | $C^S_{west}/C^S_{tot}$ | 0.00 [0.00,0.82] | 0.73 [0.40,0.90] | 0.72 [0.35,0.90] | | | | |
| | $ByC^S_{tot}$ | **0.3** 0.0 [0.0,5.2] | **19.7** 11.2 [2.1,64.4] | **19.7** 11.2 [2.1,64.2] | | | | |
| | $ByC^S_{west}$ | **0.3** 0.0 [0.0,5.2] | **19.7** 11.2 [2.0,64.4] | **19.7** 11.2 [2.0,64.2] | | | | |
| | $ByC^S_{south}$ | **0.0** 0.0 [0.0,0.0] | **0.0** 0.0 [0.0,0.0] | **0.0** 0.0 [0.0,0.0] | | | | |
| | $MAV^S_{tot}$ | - | 0.49 [0.26,0.50] | 0.48 [0.27,0.50] | $MAV^A$ | - | 0.00 [0.00,0.36] | 0.00 [0.00,0.36] |
| | $MAV^S_{west}$ | - | 0.37 [0.23,0.51] | 0.44 [0.26,0.63] | | | | |
| | $MAV^S_{south}$ | - | 0.67 [0.47,0.84] | 0.62 [0.42,0.82] | | | | |
| Critical Biomass statistics | $p(B^{Sobs}_y < B^S_{crit}, B_y < B^S_{crit}/k^S_N)$ | - | 0.10 | 0.08 | $p(B^{Aobs}_y < B^A_{crit}, B_y < B^A_{crit}/k^A_N)$ | - | 0.11 | 0.11 |
| | $p(B^{Sobs}_y < B^S_{crit}, B_y \geq B^S_{crit}/k^S_N)$ | - | 0.15 | 0.15 | $p(B^{Aobs}_y < B^A_{crit}, B_y \geq B^A_{crit}/k^A_N)$ | - | 0.01 | 0.01 |
| | $p(B^{Sobs}_y \geq B^S_{crit}, B_y < B^S_{crit}/k^S_N)$ | - | 0.06 | 0.06 | $p(B^{Aobs}_y \geq B^A_{crit}, B_y < B^A_{crit}/k^A_N)$ | - | 0.01 | 0.01 |
| | $p(B^{Sobs}_y \geq B^S_{crit}, B_y \geq B^S_{crit}/k^S_N)$ | - | 0.69 | 0.71 | $p(B^{Aobs}_y \geq B^A_{crit}, B_y \geq B^A_{crit}/k^A_N)$ | - | 0.87 | 0.87 |

**Table 1 (continued).**

| | | Sardine | | |
|---|---|---|---|---|
| | | No Catch | CMP5 | CMP5 with flags |
| Ecosystem statistics | ROI (5yrs) | -0.077 [-0.16,0.07] | -0.111 [-0.16,0.04] | -0.110 [-0.16,0.04] |
| | ROI (10yrs) | -0.061 [-0.09,0.02] | -0.079 [-0.09,-0.03] | -0.079 [-0.09,-0.02] |
| | ROI (15yrs) | -0.052 [-0.06,0.01] | -0.060 [-0.07,-0.04] | -0.060 [-0.07,-0.04] |
| | # Moulters (2022:2017) | 0.614 [0.21,1.36] | 0.445 [0.20,1.19] | 0.450 [0.20,1.19] |
| | #Moulters (2027:2017) | 0.389 [0.08,1.23] | 0.207 [0.05,0.75] | 0.214 [0.06,0.78] |
| | #Moulters (2032:2017) | 0.226 [0.03,1.14] | 0.099 [0.02,0.44] | 0.103 [0.02,0.46] |
| | $p(B_w^{obs,S} < 336)$ | 0.51 | 0.62 | 0.61 |
| | $avg\ \#\ years\ B_w^{obs,S} < 336$ | 2.69 | 3.41 | 3.29 |

**Table 2.** Summary performance statistics for CMP5 without any preventative red flag, and with preventative red flags raised at a survey estimate of sardine biomass west of Cape Agulhas of 150 000t or 100 000t. Where appropriate, medians and 90%iles are provided, and for some statistics the means are shown additionally in **bold**. All biomasses are given in thousands of tons. All scenarios assume the proportion of catch taken west of Cape Agulhas has a minimum of 0.4 and a maximum of 0.9.

| Red Flag at: | N/A | $B^{obs,S}_{west,y-1} < 150$[1] | | | | $B^{obs,S}_{west,y-1} < 100$[2] | | | |
|---|---|---|---|---|---|---|---|---|---|
| Corrective Measure once red flag raised: | N/A (CMP5) | Implicit 0.70*TAC | Implicit 0.75*TAC | Max 40% TAC west | Max 35% TAC west | Implicit 0.70*TAC | Implicit 0.75*TAC | Max 40% TAC west | Max 35% TAC west |
| $\beta$ | 0.175 | 0.160 | 0.153 | 0.149 | 0.164 | 0.145 | 0.141 | 0.139 | 0.151 |
| $Risk_S$ | 0.182 | 0.163 | 0.163 | 0.161 | 0.163 | 0.162 | 0.162 | 0.161 | 0.163 |
| $p(B^S_w < 150)$ | 0.128 | 0.114 | 0.114 | 0.114 | 0.114 | 0.114 | 0.114 | 0.114 | 0.114 |
| $C^S_{tot}$ | **104** 93 [31,200] | **95** 80 [23,200] | **94** 77 [24,200] | **97** 82 [31,200] | **102** 89 [31,200] | **93** 76 [23,200] | **92** 75 [24,200] | **93** 77 [31,200] | **98** 82 [31,200] |
| $C^S_{west}$ | **70** 61 [22,155] | **67** 57 [17,152] | **66** 57 [18,150] | **63** 56 [13,149] | **65** 57 [11,153] | **65** 57 [18,147] | **65** 57 [19,146] | **64** 56 [14,145] | **65** 58 [13,149] |
| $C^S_{south}$ | **34** 25 [5,100] | **29** 20 [3,87] | **28** 19 [3,86] | **34** 27 [5,90] | **37** 30 [5,98] | **27** 19 [3,84] | **27** 19 [4,82] | **30** 22 [5,84] | **33** 24 [5,91] |
| $MAV^S_{tot}$ | 0.49 [0.26,0.50] | 0.50 [0.31,0.65] | 0.50 [0.30,0.62] | 0.48 [0.26,0.50] | 0.49 [0.26,0.50] | 0.50 [0.28,0.65] | 0.49 [0.27,0.62] | 0.47 [0.25,0.50] | 0.48 [0.26,0.50] |
| $MAV^S_{west}$ | 0.37 [0.23,0.51] | 0.43 [0.27,0.60] | 0.41 [0.26,0.57] | 0.48 [0.28,0.66] | 0.50 [0.29,0.69] | 0.40 [0.24,0.57] | 0.40 [0.24,0.55] | 0.42 [0.24,0.60] | 0.43 [0.25,0.62] |
| $MAV^S_{south}$ | 0.67 [0.47,0.84] | 0.74 [0.50,0.89] | 0.73 [0.49,0.87] | 0.57 [0.40,0.80] | 0.58 [0.41,0.80] | 0.70 [0.48,0.87] | 0.70 [0.48,0.87] | 0.62 [0.43,0.82] | 0.63 [0.43,0.82] |
| p(preventative) | - | 0.23 | 0.23 | 0.25 | 0.25 | 0.13 | 0.13 | 0.14 | 0.14 |
| $p(B^{obs,S}_w < 336)$ | 0.62 | 0.61 | 0.61 | 0.60 | 0.60 | 0.61 | 0.61 | 0.60 | 0.61 |
| $avg\ \#\ years\ B^{obs,S}_w < 336$ | 3.41 | 3.30 | 3.30 | 3.27 | 3.27 | 3.32 | 3.32 | 3.30 | 3.30 |

**Table 3.** The cumulative proportion of west component total biomass below different threshold levels (cf Figure 5). The red values indicate the lowest proportion across the alternatives.

| Red Flag at: | N/A | $B^{obs,S}_{y-1} < 150$ | | | | $B^{obs,S}_{y-1} < 100$ | | | |
|---|---|---|---|---|---|---|---|---|---|
| Corrective Measure once red flag raised: | CMP5 | Implicit 0.70*TAC | Implicit 0.75*TAC | Max 40% TAC west | Max 35% TAC west | Implicit 0.70*TAC | Implicit 0.75*TAC | Max 40% TAC west | Max 35% TAC west |
| $\beta$ | 0.175 | 0.160 | 0.153 | 0.149 | 0.164 | 0.145 | 0.141 | 0.139 | 0.151 |
| $p(B^S_w < 20)$ | 0.01 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| $p(B^S_w < 40)$ | 0.01 | 0.01 | 0.01 | 0.01 | 0.01 | 0.01 | 0.01 | 0.01 | 0.01 |
| $p(B^S_w < 60)$ | 0.02 | 0.02 | 0.02 | 0.02 | 0.02 | 0.02 | 0.02 | 0.02 | 0.02 |
| $p(B^S_w < 80)$ | 0.04 | 0.03 | 0.03 | 0.03 | 0.03 | 0.03 | 0.03 | 0.03 | 0.03 |
| $p(B^S_w < 100)$ | 0.06 | 0.05 | 0.05 | 0.05 | 0.05 | 0.05 | 0.05 | 0.05 | 0.05 |
| $p(B^S_w < 120)$ | 0.08 | 0.07 | 0.07 | 0.07 | 0.07 | 0.07 | 0.07 | 0.07 | 0.07 |
| $p(B^S_w < 140)$ | 0.12 | 0.10 | 0.10 | 0.10 | 0.10 | 0.10 | 0.10 | 0.10 | 0.10 |
| $p(B^S_w < 160)$ | 0.15 | 0.14 | 0.14 | 0.14 | 0.14 | 0.14 | 0.14 | 0.14 | 0.14 |
| $p(B^S_w < 180)$ | 0.19 | 0.17 | 0.17 | 0.17 | 0.17 | 0.17 | 0.17 | 0.17 | 0.17 |
| $p(B^S_w < 200)$ | 0.23 | 0.21 | 0.21 | 0.21 | 0.21 | 0.21 | 0.21 | 0.21 | 0.21 |

[1] The corrective measure is implemented smoothly over a linear range from full implementation at 135 000t (150 000t–10%) to no corrective measure at 165 000t (150 000t+10%).
[2] The corrective measure is implemented smoothly over a linear range from full implementation at 90 000t (100 000t–10%) to no corrective measure at 110 000t (100 000t+10%).

**Table 4.** Summary performance statistics for CMP5 and alternative CMPs using different corrective measures in year *y* once a **penalty red flag** of $\mathrm{p(y-1)} \geq 1.2 \times \left[0.905035 \times \left(1 - exp\left\{-0.416847\left(B^{obs,S}_{west,y-2}/0.70783\right)/TAC_{y-1}\right\}\right)\right]$ is raised. These measures also include a benefit in year *y* if a 'green flag' of $\mathrm{p(y-1)} \leq \left[0.905035 \times \left(1 - exp\left\{-0.416847\left(B^{obs,S}_{west,y-2}/0.70783\right)/TAC_{y-1}\right\}\right)\right]/1.2$ is raised. All alternatives use $\beta = 0.175$. All biomasses are given in thousands of tons. All scenarios assume the proportion of catch taken west of Cape Agulhas has a minimum of 0.4 and a maximum of 0.9. Penalty flags and alternative OMs are applied from *2025-2035 only*. The red values indicate the option with the closest probability of west component biomass being below 150 000t to that of CMP5 and no penalty/benefit flags under OM5, i.e. 0.128.

| Operating Model | CMP | Annual readjustment towards 1 | Penalty if red flag | Benefit if green flag | Max proportion | $Risk_S$ | $p(B^S_w < 150)$ | $C^S_{tot}$ | p(Red flag) | p(Green flag) | p(Red flag x2) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| OM5 | CMP5 | N/A | N/A | N/A | N/A | 0.182 | 0.128 | 104 | N/A | N/A | N/A |
| | Opt1 | 10% | -0.10 | +0.03 | 1.1 | 0.178 | 0.126 | 101 | 0.19 | 0.23 | 0.05 |
| | Opt2 | 20% | -0.10 | +0.01 | 1.1 | 0.178 | 0.125 | 101 | 0.19 | 0.23 | 0.05 |
| | Opt3 | 20% | -0.075 | +0.01 | 1.1 | 0.179 | 0.126 | 102 | 0.19 | 0.23 | 0.05 |
| OM-60 | CMP5 | N/A | N/A | N/A | N/A | 0.200 | 0.138 | 104 | N/A | N/A | N/A |
| | Opt1 | 10% | -0.10 | +0.03 | 1.1 | 0.186 | 0.131 | 98 | 0.26 | 0.18 | 0.09 |
| | Opt2 | 20% | -0.10 | +0.01 | 1.1 | 0.186 | 0.132 | 99 | 0.26 | 0.18 | 0.09 |
| | Opt3 | 20% | -0.075 | +0.01 | 1.1 | 0.188 | 0.133 | 100 | 0.27 | 0.18 | 0.09 |
| OM-UL | CMP5 | N/A | N/A | N/A | N/A | 0.198 | 0.139 | 104 | N/A | N/A | N/A |
| | Opt1 | 10% | -0.10 | +0.03 | 1.1 | 0.187 | 0.132 | 95 | 0.31 | 0.07 | 0.11 |
| | Opt2 | 20% | -0.10 | +0.01 | 1.1 | 0.189 | 0.133 | 97 | 0.32 | 0.07 | 0.12 |
| | Opt3 | 20% | -0.075 | +0.01 | 1.1 | 0.191 | 0.134 | 99 | 0.33 | 0.07 | 0.12 |
| OM-70 | CMP5 | N/A | N/A | N/A | N/A | 0.206 | 0.145 | 103 | N/A | N/A | N/A |
| | Opt1 | 10% | -0.10 | +0.03 | 1.1 | 0.193 | 0.136 | 99 | 0.24 | 0.28 | 0.09 |
| | Opt2 | 20% | -0.10 | +0.01 | 1.1 | 0.193 | 0.136 | 99 | 0.24 | 0.28 | 0.09 |
| | Opt3 | 20% | -0.075 | +0.01 | 1.1 | 0.196 | 0.138 | 100 | 0.25 | 0.27 | 0.10 |

**Table 5a.** Summary performance statistics for i) CMP5, ii) CMP5 together with a **preventative red flag of 40% of the TAC taken west of Cape Agulhas when $B_{y-1}^{obs,S} < 100$**[3], and iii) the simultaneous implementation of a penalty (of -0.10 of HCR-calculated TAC) red flag when $\mathrm{p}(\mathrm{y}-1) \geq 1.2 \times \left[0.905035 \times \left(1 - exp\left\{-0.416847\left(B_{west,y-2}^{obs,S}/0.70783\right)/TAC_{y-1}\right\}\right)\right]$, with a benefit (of +0.01 of HCR-calculated TAC) green flag when $\mathrm{p}(\mathrm{y}-1) \leq \left[0.905035 \times \left(1 - exp\left\{-0.416847\left(B_{west,y-2}^{obs,S}/0.70783\right)/TAC_{y-1}\right\}\right)\right]/1.2$, and an annual 20% readjustment towards 1 (i.e. Opt2 of Table 4). Where appropriate, medians and 90%iles are provided, and for some statistics the means are shown additionally in **bold**. All biomasses are given in thousands of tons. Penalty flags are applied from *2025-2035 only*.

| Operating Model | Preventative red flag? | Penalty/benefit flags? | $\beta$ | $Risk_S$ | $p(B_w^S < 150)$ | $C_{tot}^S$ | $C_{west}^S$ | $C_{south}^S$ | $MAV_{tot}^S$ | $MAV_{west}^S$ | $MAV_{south}^S$ | p(prevent flag) | p(Red flag) | p(Green flag) | p(Red flag x2) | p(both red) | Min (TAC prop) | $p(B_w^{obs,S} < 336)$ | $avg\ \#\ years\ B_w^{obs,S} < 336$ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| OM5 | x | x | 0.175 | 0.182 | 0.128 | **104** 93 [31,200] | **70** 61 [22,155] | **34** 25 [5,100] | 0.49 [0.26,0.50] | 0.37 [0.23,0.51] | 0.67 [0.47,0.84] | - | - | - | - | - | 1 | 0.62 | 3.41 |
| | √ | x | 0.139 | **0.161** | **0.114** | **93** 77 [31,200] | **64** 56 [14,145] | **30** 22 [5,84] | 0.47 [0.25,0.50] | 0.42 [0.24,0.60] | 0.62 [0.43,0.82] | 0.14 | - | - | - | - | 1 | 0.60 | 3.30 |
| | √ | √ | 0.139 | 0.160 | 0.113 | **92** 75 [31,200] | **63** 55 [14,144] | **29** 21 [5,83] | 0.47 [0.25,0.50] | 0.43 [0.24,0.61] | 0.62 [0.43,0.82] | 0.14 | 0.08 | 0.28 | 0.01 | 0.05 | 0.72 | 0.60 | 3.29 |
| OM-60 | x | x | 0.175 | 0.196 | 0.138 | **104** 92 [31,200] | **72** 62 [22,154] | **31** 24 [5,80] | 0.49 [0.26,0.50] | 0.38 [0.25,0.50] | 0.64 [0.44,0.81] | - | - | - | - | - | 1 | 0.62 | 3.48 |
| | √ | x | 0.139 | 0.166 | 0.119 | **93** 76 [31,200] | **65** 57 [14,145] | **28** 22 [5,77] | 0.47 [0.25,0.50] | 0.43 [0.25,0.62] | 0.59 [0.40,0.80] | 0.14 | - | - | - | - | 1 | 0.61 | 3.32 |
| | √ | √ | 0.139 | 0.164 | 0.117 | **92** 75 [31,200] | **64** 56 [14,144] | **28** 21 [5,74] | 0.47 [0.25,0.51] | 0.44 [0.25,0.63] | 0.60 [0.40,0.80] | 0.14 | 0.10 | 0.25 | 0.02 | 0.05 | 0.72 | 0.61 | 3.31 |
| OM-UL | x | x | 0.175 | 0.198 | 0.149 | **104** 92 [31,200] | **78** 67 [24,177] | **26** 17 [4,86] | 0.49 [0.27,0.50] | 0.39 [0.24,0.50] | 0.66 [0.44,0.85] | - | - | - | - | - | 1 | 0.63 | 3.50 |
| | √ | x | 0.139 | 0.171 | 0.121 | **93** 76 [31,200] | **69** 59 [14,166] | **24** 16 [5,72] | 0.47 [0.25,0.50] | 0.45 [0.25,0.63] | 0.60 [0.40,0.83] | 0.15 | - | - | - | - | 1 | 0.61 | 3.35 |
| | √ | √ | 0.139 | 0.167 | 0.119 | **90** 73 [31,199] | **67** 58 [14,159] | **22** 15 [5,69] | 0.47 [0.26,0.52] | 0.46 [0.26,0.64] | 0.60 [0.40,0.83] | 0.15 | 0.17 | 0.13 | 0.04 | 0.06 | 0.66 | 0.61 | 3.33 |
| OM-70 | x | x | 0.175 | 0.206 | 0.145 | **103** 92 [31,200] | **71** 62 [21,140] | **32** 27 [5,65] | 0.49 [0.27,0.50] | 0.44 [0.24,0.50] | 0.50 [0.34,0.64] | - | - | - | - | - | 1 | 0.62 | 3.51 |
| | √ | x | 0.139 | 0.169 | 0.121 | **93** 76 [31,200] | **63** 54 [14,140] | **30** 26 [5,60] | 0.47 [0.25,0.50] | 0.47 [0.25,0.63] | 0.48 [0.29,0.63] | 0.14 | - | - | - | - | 1 | 0.61 | 3.32 |
| | √ | √ | 0.139 | 0.167 | 0.120 | **92** 75 [31,200] | **62** 54 [14,141] | **30** 25 [5,62] | 0.47 [0.25,0.50] | 0.47 [0.26,0.63] | 0.49 [0.29,0.63] | 0.14 | 0.08 | 0.40 | 0.02 | 0.05 | 0.76 | 0.61 | 3.31 |

[3] The corrective measure is implemented smoothly over a linear range from full implementation at 90 000t (100 000t–10%) to no corrective measure at 110 000t (100 000t+10%).

**Table 5b.** Summary performance statistics for i) CMP5, ii) CMP5 together with a **preventative red flag of closure of the west coast to directed sardine fishing when 35% of the TAC is taken west of Cape Agulhas, when $B_{y-1}^{obs,S} < 150$**[4], and iii) the simultaneous implementation of a penalty (of -0.10 of HCR-calculated TAC) red flag when $\mathrm{p}(\mathrm{y}-1) \geq 1.2 \times \left[0.905035 \times \left(1 - exp\left\{-0.416847\left(B_{west,y-2}^{obs,S}/0.70783\right)/TAC_{y-1}\right\}\right)\right]$, with a benefit (of +0.01 of HCR-calculated TAC) green flag when $\mathrm{p}(\mathrm{y}-1) \leq \left[0.905035 \times \left(1 - exp\left\{-0.416847\left(B_{west,y-2}^{obs,S}/0.70783\right)/TAC_{y-1}\right\}\right)\right]/1.2$, and an annual 20% readjustment towards 1 (i.e. Opt2 of Table 4). The order of the application in scenarios where both preventative and penalty/benefit flags are raised is first the preventative and then the penalty/benefit. Where appropriate, medians and 90%iles are provided, and for some statistics the means are shown additionally in **bold**. All biomasses are given in thousands of tons. Penalty flags are applied from *2025-2035 only*.

| Operating Model | Preventative red flag? | Penalty/benefit flags? | $\beta$ | $Risk_S$ | $p(B_w^S < 150)$ | $C_{tot}^S$ | $C_{west}^S$ | $C_{south}^S$ | $MAV_{tot}^S$ | $MAV_{west}^S$ | $MAV_{south}^S$ | p(prevent flag) | p(Red flag) | p(Green flag) | p(Red flag x2) | p(both red) | Min (TAC prop) | $p(B_w^{obs,S} < 336)$ | $avg\ \#\ years\ B_w^{obs,S} < 336$ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| OM5 | x | x | 0.175 | 0.182 | 0.128 | **104** 93 [31,200] | **70** 61 [22,155] | **34** 25 [5,100] | 0.49 [0.26,0.50] | 0.37 [0.23,0.51] | 0.67 [0.47,0.84] | - | - | - | - | - | 1 | 0.62 | 3.41 |
| | √ | x | 0.164 | **0.163** | **0.114** | **102** 89 [31,200] | **65** 57 [11,153] | **37** 30 [5,98] | 0.49 [0.26,0.50] | 0.50 [0.29,0.69] | 0.58 [0.41,0.80] | 0.25 | - | - | - | - | 1 | 0.60 | 3.27 |
| | √ | √ | 0.164 | 0.163 | 0.114 | **102** 88 [31,200] | **64** 57 [12,152] | **37** 30 [5,98] | 0.48 [0.27,0.50] | 0.49 [0.29,0.68] | 0.58 [0.40,0.80] | 0.25 | 0.05 | 0.40 | 0.01 | 0.08 | 0.76 | 0.60 | 3.26 |
| OM-60 | x | x | 0.175 | 0.196 | 0.138 | **104** 92 [31,200] | **72** 62 [22,154] | **31** 24 [5,80] | 0.49 [0.26,0.50] | 0.38 [0.25,0.50] | 0.64 [0.44,0.81] | - | - | - | - | - | 1 | 0.62 | 3.48 |
| | √ | x | 0.164 | 0.168 | 0.118 | **102** 89 [31,200] | **66** 58 [11,153] | **36** 30 [5,80] | 0.49 [0.26,0.50] | 0.50 [0.28,0.71] | 0.55 [0.37,0.80] | 0.25 | - | - | - | - | 1 | 0.61 | 3.29 |
| | √ | √ | 0.164 | 0.167 | 0.118 | **101** 88 [31,200] | **66** 58 [12,152] | **35** 30 [5,82] | 0.48 [0.27,0.50] | 0.50 [0.29,0.71] | 0.55 [0.36,0.79] | 0.25 | 0.06 | 0.37 | 0.01 | 0.08 | 0.72 | 0.61 | 3.28 |
| OM-UL | x | x | 0.175 | 0.198 | 0.149 | **104** 92 [31,200] | **78** 67 [24,177] | **26** 17 [4,86] | 0.49 [0.27,0.50] | 0.39 [0.24,0.50] | 0.66 [0.44,0.85] | - | - | - | - | - | 1 | 0.63 | 3.50 |
| | √ | x | 0.164 | 0.172 | 0.120 | **101** 88 [31,200] | **71** 59 [11,176] | **31** 21 [5,88] | 0.49 [0.27,0.50] | 0.50 [0.30,0.74] | 0.59 [0.43,0.83] | 0.25 | - | - | - | - | 1 | 0.61 | 3.30 |
| | √ | √ | 0.164 | 0.170 | 0.119 | **99** 86 [31,200] | **69** 59 [11,166] | **30** 20 [5,85] | 0.49 [0.27,0.51] | 0.50 [0.30,0.74] | 0.59 [0.41,0.83] | 0.25 | 0.12 | 0.25 | 0.02 | 0.09 | 0.70 | 0.61 | 3.29 |
| OM-70 | x | x | 0.175 | 0.206 | 0.145 | **103** 92 [31,200] | **71** 62 [21,140] | **32** 27 [5,65] | 0.49 [0.27,0.50] | 0.44 [0.24,0.50] | 0.50 [0.34,0.64] | - | - | - | - | - | 1 | 0.62 | 3.51 |
| | √ | x | 0.164 | 0.172 | 0.121 | **102** 89 [31,200] | **64** 56 [11,140] | **37** 33 [5,79] | 0.49 [0.27,0.50] | 0.50 [0.29,0.73] | 0.48 [0.27,0.62] | 0.25 | - | - | - | - | 1 | 0.61 | 3.28 |
| | √ | √ | 0.164 | 0.172 | 0.120 | **101** 88 [31,202] | **64** 56 [12,142] | **37** 33 [5,79] | 0.48 [0.26,0.50] | 0.50 [0.29,0.73] | 0.48 [0.27,0.62] | 0.14 | 0.05 | 0.44 | 0.01 | 0.09 | 0.76 | 0.61 | 3.28 |

[4] The corrective measure is implemented smoothly over a linear range from full implementation at 1350 000t (150 000t–10%) to no corrective measure at 165 000t (150 000t+10%).

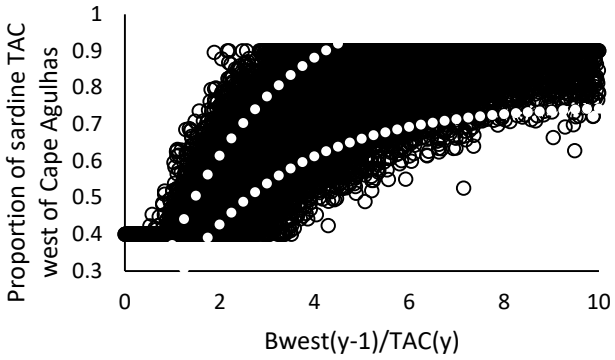


**Figure 1.** The future simulated proportion of directed sardine TAC taken west of Cape Agulhas, plotted against the ratio of the west component biomass to the total TAC for CMP5. The upper and lower white dotted lines indicate $1.2 \times \left[0.905035 \times \left(1 - exp\left\{-0.416847\left(B_{west,y-2}^{obs,S}/0.70783\right)/TAC_{y-1}\right\}\right)\right]$ and $\left[0.905035 \times \left(1 - exp\left\{-0.416847\left(B_{west,y-2}^{obs,S}/0.70783\right)/TAC_{y-1}\right\}\right)\right]/1.2$ used as the penalty red flag threshold and benefit green flag threshold, respectively.

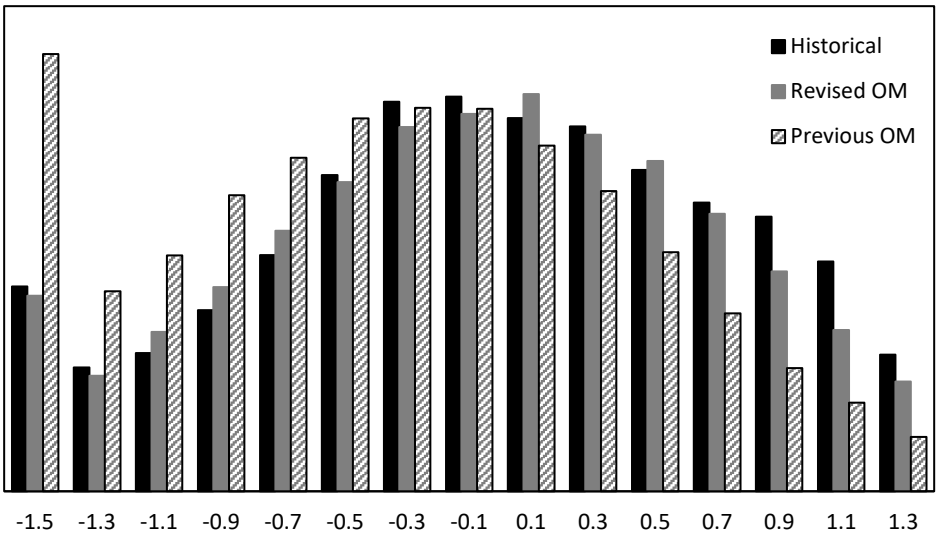


**Figure 2.** The distribution of residuals about the anchovy Beverton Holt stock recruitment relationship generated from the assessment conditioned to historical data ("historical"), and the distributions generated from projections from the previous anchovy Operating Model ("Previous OM") and the revised OM used in this document ("Revised OM").

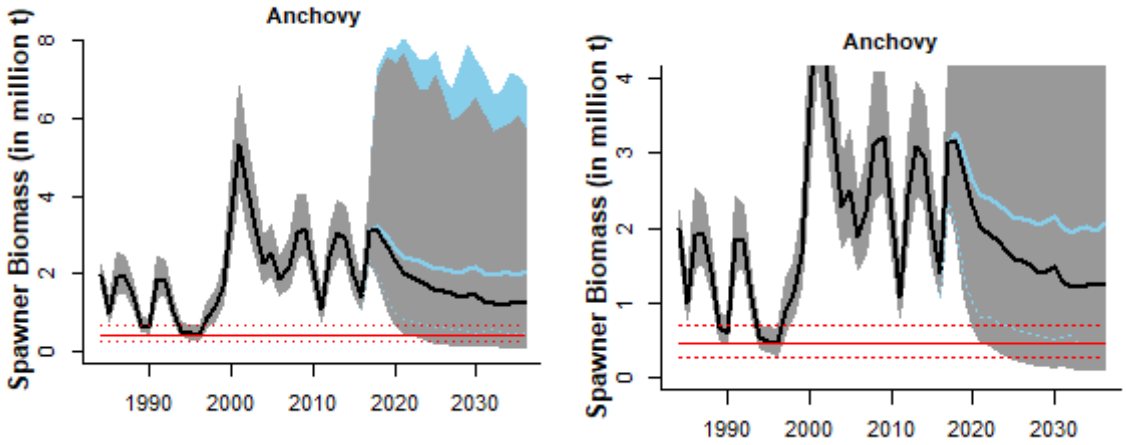


**Figure 3.** The median and 90%iles of anchovy spawner biomass for CMP5 (grey) compared to a no future catch scenario (blue). The right plot is a repeat of the left plot, but over a smaller vertical axis range to more clearly show the anchovy risk threshold (red) of the lowest historical spawner biomass.

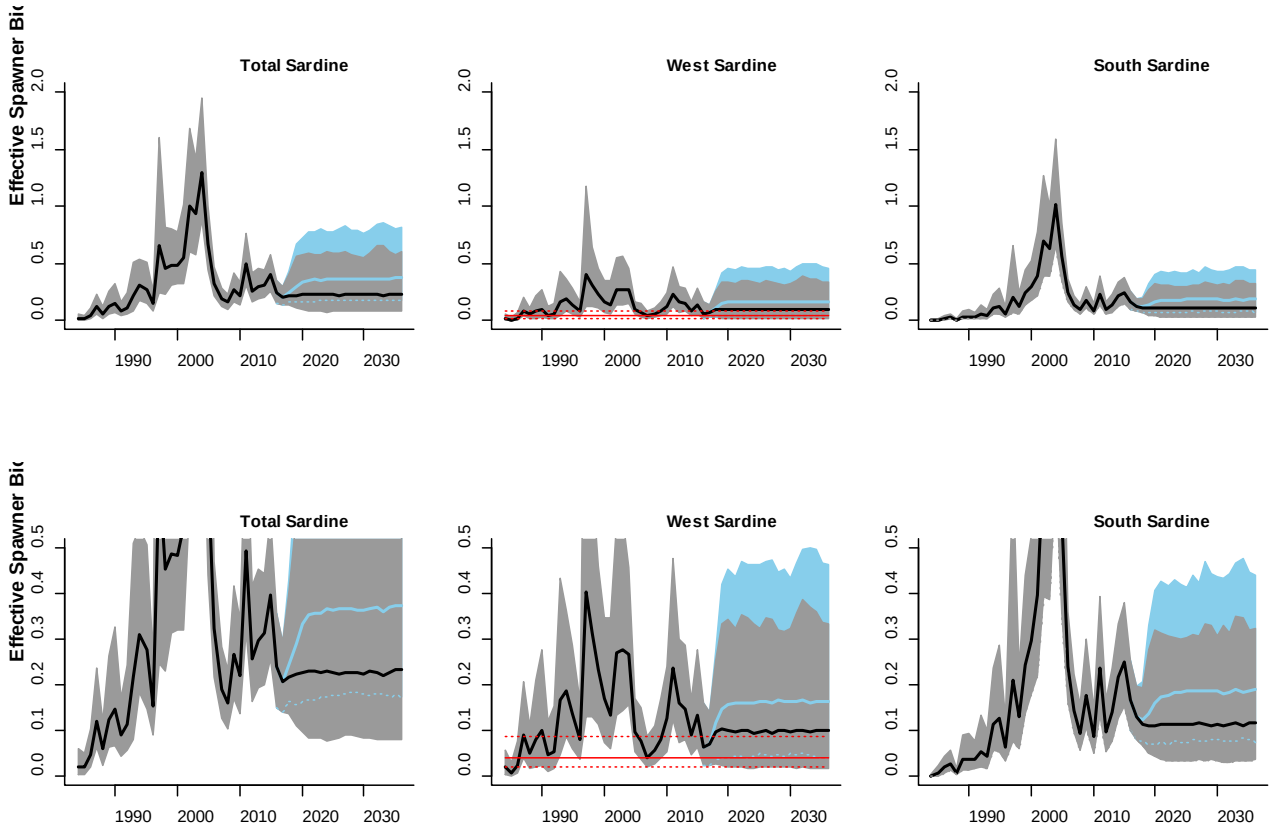


**Figure 4.** The median and 90%iles of sardine effective spawner biomass for CMP5 (grey) compared to a no future catch scenario (blue). The lower set of plots are a repeat of the upper set, but over a smaller vertical axis range to more clearly show the sardine risk threshold (red) of the lowest historical spawner biomass.

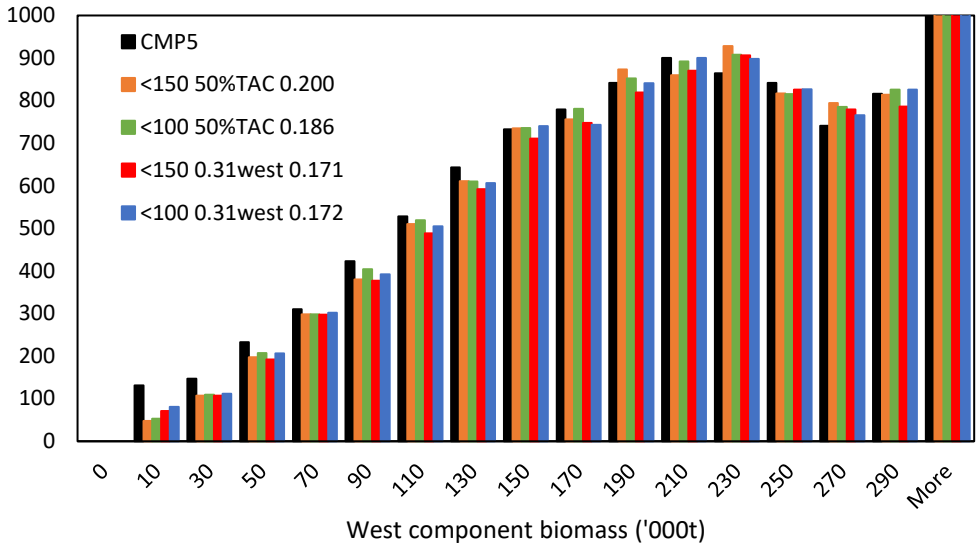


**Figure 5a.** Histograms (focussing on the lower end of the range) for the model predicted west component biomass under CMP5 compared to alternatives which either decrease the TAC by 50% or allow 31% of the TAC to be taken west of Cape Agulhas during year *y* if a preventative red flag of survey estimated biomass west of Cape Agulhas in *y*-1 of less than 100 000t or 150 000t is raised.

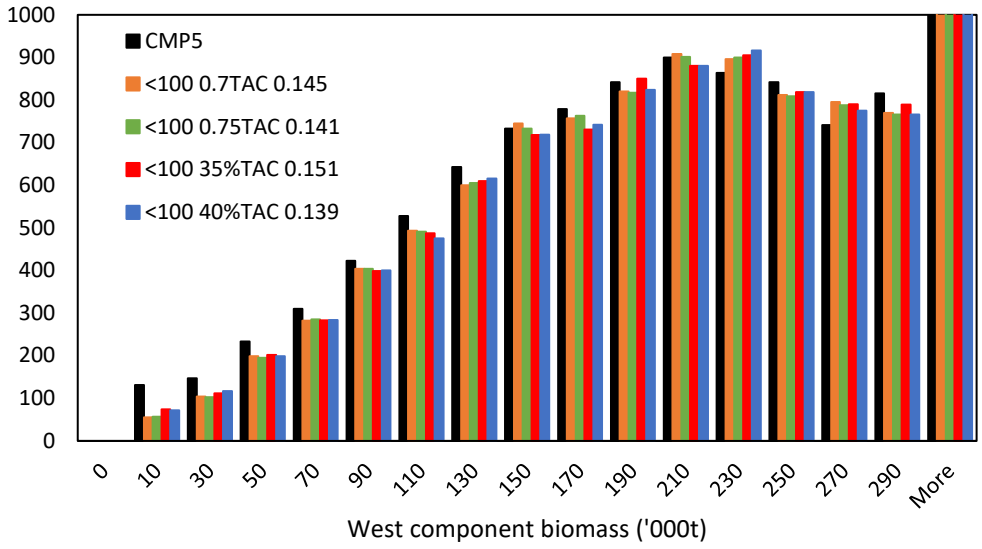


**Figure 5b.** Histograms (focussing on the lower end of the range) for the model predicted west component biomass under CMP5 compared to alternatives which either decrease the TAC by 30% or 25% or allow 40% or 35% of the TAC to be taken west of Cape Agulhas during year *y* if a preventative red flag of survey estimated biomass west of Cape Agulhas in *y*-1 of less than 100 000t is raised.

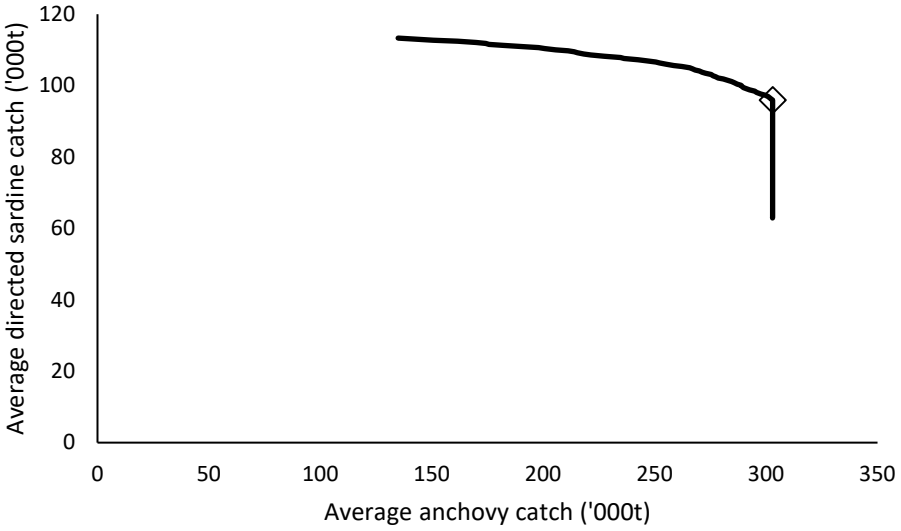


**Figure 6.** The trade-off curve between average total directed sardine catches and average total anchovy catches, for CMPs with both preventative and penalty red flags included (see Table 1), obtained with $Risk_S < 0.161$ and $Risk_A < 0.134$. The diamond corresponds to $\beta = 0.150$ and $\alpha = 1.313$.

**Appendix: Additional results**

Table A.1 provides additional results for preventative red flags.

Table A.2 provides additional results for penalty red flags.

Tables A.3 and A.4 provide additional results for both preventative and penalty red flags.

**Table A.1a.** Summary performance statistics for CMP5 without any preventative red flag, and with **preventative red flags** raised at a survey estimate of sardine biomass west of Cape Agulhas of **150 000t**. Where appropriate, medians and 90%iles are provided, and for some statistics the means are shown additionally in **bold**. All biomasses are given in thousands of tons. All scenarios assume the proportion of catch taken west of Cape Agulhas has a minimum of 0.4 and a maximum of 0.9.

| Red Flag at: | $B_{y-1}^{obs,S} < 150$[5] | | | | | | |
|---|---|---|---|---|---|---|---|
| Corrective Measure once red flag raised: | N/A (CMP5) | Implicit 0.50*TAC | Implicit 0.50*TAC | Max 40% TAC west | Max 32% TAC west | Max 31% TAC west | Max 31% TAC west |
| $\beta$ | 0.175 | 0.175 | 0.200 | 0.149 | 0.175 | 0.171 | 0.175 |
| $Risk_S$ | 0.182 | 0.159 | 0.164 | 0.161 | 0.164 | 0.162 | 0.163 |
| $p(B_w^S < 150)$ | 0.128 | 0.111 | 0.114 | 0.114 | 0.114 | 0.112 | 0.113 |
| $C_{tot}^S$ | **104** 93 [31,200] | **96** 84 [16,200] | **103** 94 [16,200] | **97** 82 [31,200] | **105** 94 [31,200] | **104** 93 [31,200] | **105** 94 [31,200] |
| $C_{west}^S$ | **70** 61 [22,155] | **67** 58 [13,155] | **70** 61 [13,158] | **63** 56 [13,149] | **66** 58 [11,155] | **65** 58 [11,154] | **65** 58 [11,155] |
| $C_{south}^S$ | **34** 25 [5,100] | **29** 20 [2,93] | **33** 23 [2,101] | **34** 27 [5,90] | **40** 33 [5,104] | **39** 32 [5,102] | **40** 33 [5,104] |
| $MAV_{tot}^S$ | 0.49 [0.26,0.50] | 0.55 [0.32,0.75] | 0.57 [0.30,0.75] | 0.48 [0.26,0.50] | 0.49 [0.26,0.50] | 0.49 [0.27,0.50] | 0.49 [0.26,0.50] |
| $MAV_{west}^S$ | 0.37 [0.23,0.51] | 0.48 [0.28,0.69] | 0.48 [0.28,0.69] | 0.48 [0.28,0.66] | 0.50 [0.29,0.71] | 0.50 [0.29,0.73] | 0.50 [0.29,0.73] |
| $MAV_{south}^S$ | 0.67 [0.47,0.84] | 0.79 [0.54,0.93] | 0.80 [0.54.0.94] | 0.57 [0.40,0.80] | 0.58 [0.40,0.80] | 0.58 [0.40,0.80] | 0.58 [0.40,0.80] |
| p(prevent) | - | 0.23 | 0.23 | 0.25 | 0.25 | 0.26 | 0.26 |

[5] The corrective measure is implemented smoothly over a linear range from full implementation at 135 000t (150 000t–10%) to no corrective measure at 165 000t (150 000t+10%).

**Table A.1b.** Summary performance statistics for CMP5 without any preventative red flag, and with **preventative red flags** raised at a survey estimate of sardine biomass west of Cape Agulhas of **100 000t**. Where appropriate, medians and 90%iles are provided, and for some statistics the means are shown additionally in **bold**. All biomasses are given in thousands of tons. All scenarios assume the proportion of catch taken west of Cape Agulhas has a minimum of 0.4 and a maximum of 0.9.

| Red Flag at: | $B_{y-1}^{obs,S} < 100$[6] | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Corrective Measure once red flag raised: | N/A (CMP5) | Implicit 0.60*TAC | Implicit 0.60*TAC | Implicit 0.50*TAC | Implicit 0.50*TAC | Max 40% TAC west | Max 31% TAC west | Max 31% TAC west | Max 30% TAC west |
| $\beta$ | 0.175 | 0.160 | 0.200 | 0.175 | 0.186 | 0.151 | 0.172 | 0.175 | 0.175 |
| $Risk_S$ | 0.182 | 0.164 | 0.175 | 0.165 | 0.167 | 0.166 | 0.168 | 0.169 | 0.168 |
| $p(B_w^S < 150)$ | 0.128 | 0.114 | 0.121 | 0.115 | 0.117 | 0.117 | 0.117 | 0.118 | 0.117 |
| $C_{tot}^S$ | **104** 93 [31,200] | **97** 83 [21,200] | **93** 77 [31,200] | **100** 89 [18,200] | **103** 94 [19,200] | **97** 82 [31,200] | **104** 93 [31,200] | **105** 94 [31,200] | **105** 94 [31,200] |
| $C_{west}^S$ | **70** 61 [22,155] | **67** 58 [17,152] | **64** 56 [14,145] | **69** 60 [15,155] | **70** 61 [15,157] | **65** 58 [15,149] | **67** 59 [13,154] | **68** 59 [13,155] | **68** 59 [13,155] |
| $C_{south}^S$ | **34** 25 [5,100] | **29** 20 [3,90] | **30** 22 [5,84] | **31** 22 [3,95] | **33** 23 [3,99] | **32** 24 [5,90] | **37** 28 [5,100] | **37** 29 [5,101] | **37** 29 [5,102] |
| $MAV_{tot}^S$ | 0.49 [0.26,0.50] | 0.50 [0.28,0.70] | 0.47 [0.25,0.50] | 0.50 [0.29,0.75] | 0.50 [0.28,0.75] | 0.48 [0.26,0.50] | 0.49 [0.27,0.50] | 0.49 [0.27,0.50] | 0.49 [0.27,0.50] |
| $MAV_{west}^S$ | 0.37 [0.23,0.51] | 0.42 [0.25,0.60] | 0.42 [0.24,0.60] | 0.44 [0.26,0.64] | 0.44 [0.27,0.64] | 0.42 [0.25,0.59] | 0.45 [0.26,0.65] | 0.45 [0.26,0.65] | 0.45 [0.26,0.66] |
| $MAV_{south}^S$ | 0.67 [0.47,0.84] | 0.73 [0.50,0.89] | 0.62 [0.43,0.82] | 0.75 [0.52,0.92] | 0.75 [0.52,0.91] | 0.62 [0.43,0.81] | 0.63 [0.42,0.82] | 0.63 [0.42,0.82] | 0.63 [0.42,0.82] |
| p(prevent) | - | 0.13 | 0.14 | 0.13 | 0.14 | 0.15 | 0.15 | 0.15 | 0.15 |

[6] The corrective measure is implemented smoothly over a linear range from full implementation at 90 000t (100 000t–10%) to no corrective measure at 110 000t (100 000t+10%).

**Table A.2.** Summary performance statistics for CMP5 and alternative CMPs using different corrective measures in year *y* once a **penalty red flag** of $\mathrm{p(y-1)} \geq 1.2 \times \left[0.905035 \times \left(1 - exp\left\{-0.416847\left(B^{obs,S}_{west,y-2}/0.70783\right)/TAC_{y-1}\right\}\right)\right]$ is raised. These measures also include a benefit in year *y* if a 'green flag' of $\mathrm{p(y-1)} \leq \left[0.905035 \times \left(1 - exp\left\{-0.416847\left(B^{obs,S}_{west,y-2}/0.70783\right)/TAC_{y-1}\right\}\right)\right]/1.2$ is raised. All alternatives use $\beta = 0.175$. All biomasses are given in thousands of tons. All scenarios assume the proportion of catch taken west of Cape Agulhas has a minimum of 0.4 and a maximum of 0.9. Penalty flags and alternative OMs are applied from *2025-2035 only*.

| Operating Model | CMP | Annual readjustment towards 1 | Penalty if red flag | Benefit if green flag | Max proportion | $Risk_S$ | $p(B^S_w < 150)$ | $C^S_{tot}$ | p(Red flag) | p(Green flag) | p(Red flag x2) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| OM5 | CMP5 | N/A | N/A | N/A | N/A | 0.182 | 0.128 | 104 | N/A | N/A | N/A |
| | Opt4 | 10% | -0.10 | +0.10 | 1.1 | 0.177 | 0.125 | 99 | 0.19 | 0.23 | 0.05 |
| | Opt5 | 20% | -0.10 | +0.10 | 1.1 | 0.178 | 0.125 | 100 | 0.19 | 0.23 | 0.05 |
| | Opt6 | 20% | -0.15 | +0.05 | 1.1 | 0.179 | 0.126 | 101 | 0.19 | 0.23 | 0.05 |
| | Opt7 | 20% | -0.20 | +0.05 | 1.1 | 0.177 | 0.124 | 99 | 0.19 | 0.22 | 0.05 |
| | Opt8 | 20% | -0.20 | +0.10 | 1.1 | 0.179 | 0.125 | 100 | 0.19 | 0.23 | 0.05 |
| | Opt9 | 20% | -0.15 | +0.02 | 1.1 | 0.177 | 0.124 | 99 | 0.19 | 0.22 | 0.05 |
| OM-60 | CMP5 | N/A | N/A | N/A | N/A | 0.200 | 0.138 | 104 | N/A | N/A | N/A |
| | Opt4 | 10% | -0.10 | +0.10 | 1.1 | 0.184 | 0.131 | 97 | 0.25 | 0.18 | 0.09 |
| | Opt5 | 20% | -0.10 | +0.10 | 1.1 | 0.185 | 0.131 | 98 | 0.26 | 0.18 | 0.09 |
| | Opt6 | 20% | -0.15 | +0.05 | 1.1 | 0.185 | 0.130 | 98 | 0.26 | 0.18 | 0.08 |
| | Opt7 | 20% | -0.20 | +0.05 | 1.1 | 0.181 | 0.128 | 96 | 0.24 | 0.18 | 0.08 |
| | Opt8 | 20% | -0.20 | +0.10 | 1.1 | 0.183 | 0.129 | 97 | 0.25 | 0.18 | 0.08 |
| | Opt9 | 20% | -0.15 | +0.02 | 1.1 | 0.183 | 0.129 | 97 | 0.25 | 0.18 | 0.08 |
| OM-UL | CMP5 | N/A | N/A | N/A | N/A | 0.198 | 0.139 | 104 | N/A | N/A | N/A |
| | Opt4 | 10% | -0.10 | +0.10 | 1.1 | 0.187 | 0.131 | 95 | 0.31 | 0.07 | 0.11 |
| | Opt5 | 20% | -0.10 | +0.10 | 1.1 | 0.189 | 0.133 | 97 | 0.32 | 0.07 | 0.12 |
| | Opt6 | 20% | -0.15 | +0.05 | 1.1 | 0.186 | 0.131 | 95 | 0.31 | 0.07 | 0.10 |
| | Opt7 | 20% | -0.20 | +0.05 | 1.1 | 0.182 | 0.129 | 92 | 0.29 | 0.06 | 0.09 |
| | Opt8 | 20% | -0.20 | +0.10 | 1.1 | 0.183 | 0.129 | 93 | 0.29 | 0.06 | 0.09 |
| | Opt9 | 20% | -0.15 | +0.02 | 1.1 | 0.185 | 0.130 | 94 | 0.30 | 0.06 | 0.10 |
| OM-70 | CMP5 | N/A | N/A | N/A | N/A | 0.206 | 0.145 | 103 | N/A | N/A | N/A |
| | Opt4 | 10% | -0.10 | +0.10 | 1.1 | 0.191 | 0.135 | 98 | 0.23 | 0.30 | 0.09 |
| | Opt5 | 20% | -0.10 | +0.10 | 1.1 | 0.192 | 0.136 | 99 | 0.24 | 0.29 | 0.09 |
| | Opt6 | 20% | -0.15 | +0.05 | 1.1 | 0.191 | 0.135 | 100 | 0.24 | 0.28 | 0.09 |
| | Opt7 | 20% | -0.20 | +0.05 | 1.1 | 0.187 | 0.132 | 98 | 0.23 | 0.31 | 0.07 |
| | Opt8 | 20% | -0.20 | +0.10 | 1.1 | 0.190 | 0.134 | 100 | 0.24 | 0.29 | 0.08 |
| | Opt9 | 20% | -0.15 | +0.02 | 1.1 | 0.189 | 0.134 | 98 | 0.23 | 0.30 | 0.08 |

**Table A.3.** Summary performance statistics for i) CMP5, ii) CMP5 together with a **preventative red flag of 50% of the HCR-calculated TAC when $B_{y-1}^{obs,S} < 150$**[7], and iii) the simultaneous implementation of a penalty (of -0.10 of HCR-calculated TAC) red flag when $\mathrm{p}(\mathrm{y}-1) \geq 1.2 \times \left[0.905035 \times \left(1 - exp\left\{-0.416847\left(B_{west,y-2}^{obs,S}/0.70783\right)/TAC_{y-1}\right\}\right)\right]$, with a benefit (of +0.03 of HCR-calculated TAC) green flag when $\mathrm{p}(\mathrm{y}-1) \leq \left[0.905035 \times \left(1 - exp\left\{-0.416847\left(B_{west,y-2}^{obs,S}/0.70783\right)/TAC_{y-1}\right\}\right)\right]/1.2$, and an annual 10% readjustment towards 1 (i.e. Opt1 of Table 4). The order of the application in scenarios where both preventative and penalty/benefit flags are raised is first the preventative and then the penalty/benefit. Where appropriate, medians and 90%iles are provided, and for some statistics the means are shown additionally in **bold**. All biomasses are given in thousands of tons. Penalty flags are applied from *2025-2035 only*.

| Operating Model | Preventative red flag? | Penalty/benefit flags? | $\beta$ | $Risk_S$ | $p(B_w^S < 150)$ | $C_{tot}^S$ | $C_{west}^S$ | $C_{south}^S$ | $MAV_{tot}^S$ | $MAV_{west}^S$ | $MAV_{south}^S$ | p(prevent flag) | p(Red flag) | p(Green flag) | p(Red flag x2) | p(both red) | Min (TAC prop) | $p(B_w^{obs,S} < 336)$ | $avg\ \#\ years\ B_w^{obs,S} < 336$ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| OM5 | x | x | 0.175 | 0.182 | 0.128 | **104** 93 [31,200] | **70** 61 [22,155] | **34** 25 [5,100] | 0.49 [0.26,0.50] | 0.37 [0.23,0.51] | 0.67 [0.47,0.84] | - | - | - | - | - | 1 | 0.62 | 3.41 |
| | √ | x | 0.200 | **0.164** | **0.114** | **103** 94 [16,200] | **70** 61 [13,158] | **33** 23 [2,101] | 0.57 [0.30,0.75] | 0.48 [0.28,0.69] | 0.80 [0.54,0.94] | 0.23 | - | - | - | - | 1 | 0.61 | 3.30 |
| | √ | √ | 0.200 | 0.163 | 0.113 | **100** 90 [15,200] | **68** 59 [12,154] | **32** 21 [2,96] | 0.57 [0.30,0.75] | 0.49 [0.27,0.69] | 0.80 [0.54,0.94] | 0.23 | 0.17 | 0.24 | 0.04 | 0.11 | 0.49 | 0.61 | 3.29 |
| OM-60 | x | x | 0.175 | 0.196 | 0.138 | **104** 92 [31,200] | **72** 62 [22,154] | **31** 24 [5,80] | 0.49 [0.26,0.50] | 0.38 [0.25,0.50] | 0.64 [0.44,0.81] | - | - | - | - | - | 1 | 0.62 | 3.48 |
| | √ | x | 0.200 | 0.175 | 0.121 | **102** 93 [16,200] | **71** 63 [13,158] | **30** 22 [2,80] | 0.58 [0.29,0.75] | 0.50 [0.28,0.69] | 0.78 [0.51,0.93] | 0.24 | - | - | - | - | 1 | 0.61 | 3.32 |
| | √ | √ | 0.200 | 0.169 | 0.118 | **98** 88 [14,200] | **70** 61 [12,153] | **29** 20 [2,79] | 0.57 [0.30,0.75] | 0.50 [0.28,0.70] | 0.78 [0.52,0.93] | 0.24 | 0.20 | 0.19 | 0.05 | 0.12 | 0.48 | 0.61 | 3.30 |
| OM-UL | x | x | 0.175 | 0.198 | 0.149 | **104** 92 [31,200] | **78** 67 [24,177] | **26** 17 [4,86] | 0.49 [0.27,0.50] | 0.39 [0.24,0.50] | 0.66 [0.44,0.85] | - | - | - | - | - | 1 | 0.63 | 3.50 |
| | √ | x | 0.200 | 0.178 | 0.123 | **102** 93 [16,200] | **77** 68 [13,180] | **25** 15 [2,85] | 0.58 [0.31,0.75] | 0.50 [0.28,0.71] | 0.77 [0.50,0.94] | 0.24 | - | - | - | - | 1 | 0.62 | 3.35 |
| | √ | √ | 0.200 | 0.169 | 0.119 | **95** 84 [14,200] | **73** 63 [12,162] | **22** 13 [1,78] | 0.58 [0.31,0.76] | 0.52 [0.28,0.73] | 0.77 [0.48,0.94] | 0.24 | 0.28 | 0.08 | 0.09 | 0.13 | 0.43 | 0.61 | 3.32 |
| OM-70 | x | x | 0.175 | 0.206 | 0.145 | **103** 92 [31,200] | **71** 62 [21,140] | **32** 27 [5,65] | 0.49 [0.27,0.50] | 0.44 [0.24,0.50] | 0.50 [0.34,0.64] | - | - | - | - | - | 1 | 0.62 | 3.51 |
| | √ | x | 0.200 | 0.180 | 0.124 | **102** 93 [15,200] | **71** 63 [11,140] | **31** 27 [3,68] | 0.58 [0.30,0.75] | 0.52 [0.28,0.75] | 0.67 [0.39,0.81] | 0.24 | - | - | - | - | 1 | 0.61 | 3.32 |
| | √ | √ | 0.200 | 0.175 | 0.122 | **100** 89 [15,200] | **69** 60 [10,144] | **30** 25 [3,68] | 0.57 [0.30,0.75] | 0.53 [0.27,0.75] | 0.67 [0.38,0.81] | 0.24 | 0.17 | 0.25 | 0.04 | 0.12 | 0.55 | 0.61 | 3.30 |

[7] The corrective measure is implemented smoothly over a linear range from full implementation at 135 000t (150 000t–10%) to no corrective measure at 165 000t (150 000t+10%).

**Table A.4.** Summary performance statistics for i) CMP5, ii) CMP5 together with a **preventative red flag of 50% of the HCR-calculated TAC when $B_{y-1}^{obs,S} < 100$**[8], and iii) the simultaneous implementation of a penalty (of -0.10 of HCR-calculated TAC) red flag when $\mathrm{p}(\mathrm{y}-1) \geq 1.2 \times \left[0.905035 \times \left(1 - exp\left\{-0.416847\left(B_{west,y-2}^{obs,S}/0.70783\right)/TAC_{y-1}\right\}\right)\right]$, with a benefit (of +0.03 of HCR-calculated TAC) green flag when $\mathrm{p}(\mathrm{y}-1) \leq \left[0.905035 \times \left(1 - exp\left\{-0.416847\left(B_{west,y-2}^{obs,S}/0.70783\right)/TAC_{y-1}\right\}\right)\right]/1.2$, and an annual 10% readjustment towards 1 (i.e. Opt1 of Table 4). The order of the application in scenarios where both preventative and penalty/benefit flags are raised is first the preventative and then the penalty/benefit. Where appropriate, medians and 90%iles are provided, and for some statistics the means are shown additionally in **bold**. All biomasses are given in thousands of tons. Penalty flags are applied from *2025-2035 only*.

| Operating Model | Preventative red flag? | Penalty/benefit flags? | $\beta$ | $Risk_S$ | $p(B_w^S < 150)$ | $C_{tot}^S$ | $C_{west}^S$ | $C_{south}^S$ | $MAV_{tot}^S$ | $MAV_{west}^S$ | $MAV_{south}^S$ | p(prevent flag) | p(Red flag) | p(Green flag) | p(Red flag x2) | p(both red) | Min (TAC prop) | $p(B_w^{obs,S} < 336)$ | $avg\ \#\ years\ B_w^{obs,S} < 336$ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| OM5 | x | x | 0.175 | 0.182 | 0.128 | **104** 93 [31,200] | **70** 61 [22,155] | **34** 25 [5,100] | 0.49 [0.26,0.50] | 0.37 [0.23,0.51] | 0.67 [0.47,0.84] | - | - | - | - | - | 1 | 0.62 | 3.41 |
| | √ | x | 0.186 | **0.167** | **0.117** | **103** 94 [19,200] | **70** 61 [15,157] | **33** 23 [3,99] | 0.50 [0.28,0.75] | 0.44 [0.27,0.64] | 0.75 [0.52,0.91] | 0.14 | - | - | - | - | 1 | 0.61 | 3.33 |
| | √ | √ | 0.186 | 0.165 | 0.116 | **100** 89 [17,200] | **68** 60 [14,152] | **31** 21 [2,95] | 0.50 [0.27,0.75] | 0.45 [0.27,0.64] | 0.76 [0.52,0.91] | 0.14 | 0.18 | 0.24 | 0.05 | 0.06 | 0.49 | 0.61 | 3.32 |
| OM-60 | x | x | 0.175 | 0.196 | 0.138 | **104** 92 [31,200] | **72** 62 [22,154] | **31** 24 [5,80] | 0.49 [0.26,0.50] | 0.38 [0.25,0.50] | 0.64 [0.44,0.81] | - | - | - | - | - | 1 | 0.62 | 3.48 |
| | √ | x | 0.186 | 0.178 | 0.124 | **102** 93 [18,200] | **72** 63 [15,157] | **30** 23 [2,80] | 0.50 [0.29,0.75] | 0.45 [0.26,0.65] | 0.74 [0.50,0.90] | 0.14 | - | - | - | - | 1 | 0.62 | 3.36 |
| | √ | √ | 0.186 | 0.172 | 0.120 | **98** 87 [16,200] | **69** 61 [14,150] | **28** 21 [2,78] | 0.50 [0.28,0.75] | 0.45 [0.26,0.66] | 0.74 [0.49,0.90] | 0.14 | 0.22 | 0.19 | 0.06 | 0.07 | 0.49 | 0.61 | 3.33 |
| OM-UL | x | x | 0.175 | 0.198 | 0.149 | **104** 92 [31,200] | **78** 67 [24,177] | **26** 17 [4,86] | 0.49 [0.27,0.50] | 0.39 [0.24,0.50] | 0.66 [0.44,0.85] | - | - | - | - | - | 1 | 0.63 | 3.50 |
| | √ | x | 0.186 | 0.184 | 0.126 | **102** 92 [18,200] | **77** 68 [15,180] | **25** 15 [2,85] | 0.50 [0.29,0.75] | 0.46 [0.26,0.65] | 0.75 [0.49,0.92] | 0.14 | - | - | - | - | 1 | 0.62 | 3.40 |
| | √ | √ | 0.186 | 0.173 | 0.121 | **95** 83 [16,200] | **72** 63 [14,159] | **22** 13 [2,78] | 0.51 [0.28,0.75] | 0.47 [0.26,0.68] | 0.73 [0.46,0.92] | 0.14 | 0.30 | 0.07 | 0.10 | 0.08 | 0.47 | 0.62 | 3.36 |
| OM-70 | x | x | 0.175 | 0.206 | 0.145 | **103** 92 [31,200] | **71** 62 [21,140] | **32** 27 [5,65] | 0.49 [0.27,0.50] | 0.44 [0.24,0.50] | 0.50 [0.34,0.64] | - | - | - | - | - | 1 | 0.62 | 3.51 |
| | √ | x | 0.186 | 0.185 | 0.128 | **102** 93 [18,200] | **71** 63 [13,140] | **31** 27 [4,66] | 0.50 [0.29,0.75] | 0.50 [0.27,0.71] | 0.59 [0.36,0.75] | 0.14 | - | - | - | - | 1 | 0.62 | 3.37 |
| | √ | √ | 0.186 | 0.178 | 0.124 | **99** 89 [17,200] | **69** 61 [12,143] | **30** 26 [4,66] | 0.50 [0.28,0.75] | 0.49 [0.26,0.71] | 0.59 [0.36,0.79] | 0.14 | 0.19 | 0.27 | 0.06 | 0.07 | 0.52 | 0.61 | 3.35 |

[8] The corrective measure is implemented smoothly over a linear range from full implementation at 90 000t (100 000t–10%) to no corrective measure at 110 000t (100 000t+10%).