

# 'Red flag' proposals to be linked to implicit spatial management of the South African sardine resource

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The new OMP for South African sardine is being developed assuming implicit spatial management, subject to opt out in some way if 'red flags' are raised. Implicit spatial management assumes the distribution of future directed sardine catches east and west of Cape Agulhas will be spread according to past behaviour. While explicit spatial management is simulated to perform well when 'red flags' are raised, there are concerns about the practical implementation of explicit spatial management. Thus alternative corrective measures are put forward which maintain implicit spatial management in all years. Two forms of corrective measures are recommended, one for 'preventative' red flags and one for 'penalty' red flags (which also includes 'benefit' green flags).

## Introduction

Implicit spatial management of the South African sardine resource, whereby the future spatial fishing patterns are assumed to follow those observed in the past, was originally proposed 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). This document considers further the underlying 'baseline' implicit spatial management assumptions, together with the performance under explicit spatial management and alternative ways of providing 'preventative' and 'penalty' red flags (linked to 'benefit' green flags).

## Method

de Moor (2018) tuned a Candidate Management Procedure (CMP1) to the sardine Operating Model (OM1) with the proportion of south component spawner biomass contributing to west component effective spawner biomass of  $p = 0.08$  and movement hypothesis Mover. All analyses performed herein are based on this OM1 and are compared against CMP1 (or CMP1-40, see below). All CMPs tested herein assume the same HCR format and constraints as CMP1.

While many of the alternatives considered in this document are compared against or tuned to the sardine risk level associated with CMP1 and OM1 of  $Risk_s < 0.2$ , this does not imply 'acceptance' of this risk level, i.e. of a 20% probability of future west component effective spawner biomass falling below the 2007 (lowest historical) level. A lower risk level may be appropriate (de Moor 2018, SPSWG aide memoire 12<sup>th</sup> September 2018). It rather simply provides a basis to compare between alternatives put forward in this document.

CMP1 assumes 'implicit' spatial management (de Moor and Butterworth 2018). This method caters for 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). However, given the established factories, varying vessel sizes and home ports, it may be unrealistic to assume industry would be able to take low

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proportions of the directed sardine catch west of Cape Agulhas. Four alternatives to CMP1 that allow for implicit spatial management, but bound the proportion of catch simulated to be taken west of Cape Agulhas are considered:

- i) CMP1-40 : implicit spatial management bounded by a minimum proportion of 0.4
- ii) CMP1-50 : implicit spatial management bounded by a minimum proportion of 0.5
- iii) CMP1-60 : implicit spatial management bounded by a minimum proportion of 0.6
- iv) CMP1-70 : implicit spatial management bounded by a minimum proportion of 0.7.

CMPs with fixed spatial splits (20%, 50% and 80% taken west of Cape Agulhas) in all years and regardless of the biomass estimated by the survey are investigated to consider the possible extreme benefits (or losses) from explicit spatial management.

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). Two forms of 'red flags' were proposed:

**Preventative Red Flags:** If the survey estimate of biomass west of Cape Agulhas during November  $y-1$  (or the average of the survey estimates of biomass west of Cape Agulhas during November  $y-1$  and  $y-2$ ) is less than a threshold. This was proposed with the idea of conserving the west coast biomass as the primary producer of recruitment to the whole population and as a source of forage for, in particular, endangered range-restricted west coast top predators.

**Penalty Red Flags:** If the realised proportion of catch west of Cape Agulhas during  $y-1$  (or the average of the realised proportion of catch west of Cape Agulhas during  $y-1$  and  $y-2$ ) is above a threshold. This was proposed with the idea of 'fish as in the past' (implicit spatial management) unless the realised future proportion of catch taken on the west coast is seen to be too high compared with past practice, with conservative measures following to correct.

When considering a preventative red flag, three thresholds have been explored, namely a survey estimate of biomass west of Cape Agulhas,  $B_{west}^{obs}$ , of 100 000t, 150 000t and 200 000t. These choices were loosely informed by considering the ratio of the effective west component spawner biomass to the survey estimated biomass west of Cape Agulhas (Figure 2). The former provides a basis to compare against the stock recruitment relationship, with the desire for this to not fall below the hinge point of the hockey stick stock recruitment relationship. The latter is a measurable quantity that can be used for management purposes. Figure 3 shows the distribution of the hinge point for OM1. The 25%ile, median and 75%ile of this distribution are 9 000t, 16 000t and 31 000t of effective west component spawning biomass. Thus, should such a 'red flag' be linked to 31 000t, there would still be 25% of cases for which recruitment would be impaired (according to the stock recruitment relationship) prior to the red flag being raised. While the hinge point differs for every simulation, and the ratio of effective west component spawner biomass to survey estimated biomass west of Cape Agulhas differs for each year and simulation, Table 1 shows some rough calculations to ball-park potential red flag thresholds for observed biomass west of Cape Agulhas. The thresholds for preventative red flags should also consider the range-restricted west coast predators. For example, 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.

The corrective measures (applying to year  $y$ ) investigated once the preventative red flag is raised (based on the survey estimated biomass in November  $y-1$ ) are as follows:

- i) explicit spatial management requiring the split of catch to be 40:60 (west:east) of Cape Agulhas;
- ii) implicit spatial management, but with a lower  $\beta$  control parameter in the HCR; and
- iii) implicit spatial management, but with the TAC being some proportion ( $<1$ ) of that calculated by the original HCR.

All measures were implemented by smoothing over a range  $\pm 10\%$  above and below the thresholds of 100, 150 and 200 000t. For example, for 150 000t, no corrective measure was implemented at 165 000t ( $150\ 000t + 10\%$ ), half the corrective measure was implemented at 150 000t, and the full corrective measure was implemented at 135 000t ( $150\ 000t - 10\%$ ).

The idea behind penalty red flags is to adjust the directed sardine catches in cases where the realised spatial distribution of the catches differs from that assumed by implicit spatial management. In order to test this, four operating models of different future spatial distributions or patterns of catches were used. The first is OM1, where the proportion of catch taken west of Cape Agulhas is dependent on the ratio of west component biomass to the total TAC, with the restriction that future catch is distributed with a minimum of 40% west of Cape Agulhas (Figure 5). Three alternatives model possible ways that future catches may not follow the baseline assumption:

OM-60: 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. This models a situation where the future distribution of catches do not move sufficiently eastward in years where this would have been expected according to the relationship based on past fishing behaviour.

OM-UL: 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). This models the situation where in future industry is slower to shift the distribution of catches away from the west coast compared to that observed historically, but that a greater shift can still be expected in years where the total directed sardine TAC is closer to the west component biomass.

OM-70: 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. This models the situation where fishing vessels fish close to their home port, regardless of the underlying spatial distribution of the catches, with approximately 70% of the TAC allocated to Right Holders based west of Cape Agulhas.

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.

Penalty red flags, raised if future catches are spread further to the west than expected based on past fishing behaviour, together with corresponding 'benefit' green flags, raised if future catches are spread further to the east than expected based on past fishing behaviour are implemented as follows.

- i) The proportion of the HCR-calculated TAC is initially set to 1.
- ii) When a penalty red flag is raised, the proportion of the TAC awarded is decreased by an amount (e.g. -0.10). The lowest possible proportion is 0, though this is never realised in simulations undertaken to date.

- iii) When a benefit green flag is raised, the proportion of the HCR-calculated TAC awarded is increased by an amount (e.g. +0.03). The maximum possible proportion tested is either 1.05 or 1.10.
- iv) The proportion is adjusted towards 1 each year prior to any further penalty being subtracted or benefit added. Different weights in this adjustment are tested.

Thus, for example, if the proportion is adjusted 50% towards 1 each year and the sequence of flags being raised is i) none, ii) red, iii) red, iv) green, v) none, with a penalty of -0.10 and a benefit of 0.03, then the sequence of annual proportions of the TAC awarded would be i) 1.00, ii)  $0.50*(1.00+1.00)-0.10=0.90$ , iii)  $0.5*(1.00+0.90)-0.10=0.85$ , iv)  $0.50*(1.00+0.85)+0.03 = 0.96$ , v)  $0.50*(1.00+0.96) = 0.98$ .

The cases tested based red and green flags (to impact the proportion of the TAC in year  $y$ ) on:

- a) the proportion of catch distributed west of Cape Agulhas during year  $y-1$ , or
- b) the proportion of catch distributed west of Cape Agulhas during year  $y-1$  and the November survey estimate of biomass west of Cape Agulhas in November  $y-1$ , or
- c) the proportion of catch distributed west of Cape Agulhas during year  $y-1$  and the November survey estimate of biomass west of Cape Agulhas in November  $y-2$ , or
- d) the proportion of the catch distributed west of Cape Agulhas during year  $y-1$  and the ratio of the proxy-November biomass west of Cape Agulhas in November  $y-2$  to the TAC in  $y-1$ . The proxy-November biomass west of Cape Agulhas is given by the survey estimate divided by the median survey bias of 0.70783.

## Results and discussion

### *Implicit spatial management*

The assumed distribution of catch between the west and south coasts of South Africa under the implicit spatial management of CMP1 is based on a relationship fit to historical data. That relationship predicts a decrease in the proportion of catch taken west of Cape Agulhas when the ratio of model estimated west coast biomass : total TAC decreases (de Moor and Butterworth 2018). Under CMP1, the proportion of catch west of Cape Agulhas is simulated to be 0.72 in median terms, with a 90% probability interval of [0.31,0.94] (Figure 1). It is important to note, when comparing with alternative explicit spatial management scenarios considered in this document, that this model of implicit spatial management predicts that the proportion of catch taken west of Cape Agulhas is typically less when the biomass west of Cape Agulhas is low (Tables 2 and 3). Under this baseline implicit spatial management scenario, 5% of years are simulated to have less than 30% of catch taken west of Cape Agulhas.

However, such low proportions of directed sardine catch west of Cape Agulhas hardly seem likely to be realised in practice, and this would lead to an increase in the risk to the sardine resource (Table 4). If, for example, the industry distributed at most 30% of their catches east of Cape Agulhas, the risk to the sardine resource increases from 0.20 under CMP1 to 0.26 for  $\beta = 0.174$  (Table 4). Figure 4 shows that the historical proportions of catch taken west of Cape Agulhas have a minimum of about 0.4. These low proportions occurred during occasions when the ratio of west component biomass to TAC was the lowest estimated. Retuning CMP1 to simulate a potentially more realistic range in this proportion, by bounding it to a minimum of 0.4 (CMP1-40) or 0.5 (CMP1-50) results in lower  $\beta$  control parameters and total catches (Table 5), but almost certainly a more realistic spatial distribution of catches (Figure 5). For CMP1-40, the proportion of catch

taken west of Cape Agulhas is simulated to be at 40% in 9% of cases, while for CMP1-50 this proportion is simulated to be at 50% in 15% of cases.

CMP1-40 was selected by the OMP Task Team as a reasonably achievable implicit spatial management scenario against which to compare other scenarios.

#### *Fixed explicit spatial management*

Tables 4 and 5 show a clear benefit, both in terms of higher catches and higher biomass, of taking less catch on the west coast. Even for the same control parameter  $\beta$ , taking less of the TAC on the west coast results in more biomass and therefore more catch overall (Table 4). If, instead of allowing for the flexibility in the catch split assumed by implicit spatial management, some fixed explicit spatial management option was sought, the catch would need to be split equally between the west and south coasts to maintain the same level of risk as CMP1 under OM1.

The same trend, in terms of there being a benefit in terms of total catch and resource biomass for lower proportions of catch taken west of Cape Agulhas, is seen if explicit spatial management is employed only during years for which the critical biomass metarule is used (i.e.  $B_{y-1}^{obs,S} < B_{crit}^S$ ) or the survey estimate of biomass west of Cape Agulhas is less than 200 000t (Appendix A).

#### *Preventative red flags*

Explicit spatial management is evidently an effective measure to reduce the risk to the resource, or alternatively take a greater amount of total catch for the same risk (Table 6, Appendix B). However, given concerns about the ability to implement explicit spatial management practically, corrective measures that maintain implicit spatial management were preferred (Table 6, Appendix B).

By reducing the HCR-calculated TAC by 50% once the preventative red flag is raised, it is possible to reduce the risk to the resource and reduce the probability of the west component biomass falling to a low level (Figure 6) while maintaining a similar amount of average and median catch as that simulated under CMP1-40 without preventative red flags (Table 6). This is achieved by allowing a greater catch when the west component biomass is higher (i.e. higher  $\beta$ ), and less catch when the west component biomass is low (Figure 7). The  $\beta$  control parameter decreases from 0.183 if the preventative red flag is raised at 200 000t to 0.155 if the preventative red flag is raised only at 100 000t. However, the proportion of times the TAC is reduced by 50% increases from 0.17 if the red flag is raised at 100 000t, to 0.28 at 150 000t and 0.37 at 200 000t.

#### *Penalty red flags*

Table 7 shows that the risk to the sardine resource, as well as the probability that the west component biomass falls below 150 000t increases substantially if future fishing patterns do not conform to those generated by the relationship based on past fishing behaviour.

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, but that the

risk to the resource would be brought down to that possible under OM1's implicit spatial management should future fishing patterns differ from that informed by 'fish-as-in-the-past'. There is some trade-off between these ideals (Table 7), but having a relationship proportional to the median relationship assumed under OM1 (Figure 5) produced the best results (Table 7).

### Summary

- The OMP Task Team selected CMP1-40 to be used as an achievable implicit spatial management scenario against which to base further comparisons. However, should the industry consider it unviable that they could catch 60% of the directed sardine TAC east of Cape Agulhas in future years, this should be adjusted to CMP1-50 or CMP1-60.
- The proportion of the directed sardine catch taken west of Cape Agulhas in 2016 was 0.641 and in 2017 was 0.825.
- 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 opting out of this if 'red flags' are raised.
- The OMP Task Team recommends a preventative red flag with the corrective measure being 50% of the HCR-calculated TAC being awarded when the red flag of survey estimated biomass west of Cape Agulhas is below 150 000t (with  $\beta = 0.167$ ) or below 100 000t (with  $\beta = 0.155$ ).
- None of the penalty red flags tested thus far is 'ideal', in being able to simultaneously have no impact on the scenario of future catches mimicking that in the past, while also bringing the risk of scenarios with different future catch distribution scenarios down to that for the baseline, but nevertheless considerable progress has been made towards that goal, which in any case is very unlikely to be achievable perfectly. Given also time constraints, diminishing returns on further efforts, and the inevitability of the need to make some trade-off decisions, the OMP Task team initially offers the following penalty red flag (with its corresponding benefit green flag) scenario as the best compromise (red text of Table 7):

A penalty red flag is raised if the proportion of catch in  $y-1$  west of Cape Agulhas is above  $1.2 \times [0.905035 \times (1 - \exp\{-0.416847 (B_{west,y-2}^{obs,S}/0.70783)/TAC_{y-1}\})]$ <sup>1</sup>. The penalty when a red flag is raised is a decrease of 0.10 in the proportion of HCR-calculated TAC awarded. A green flag is raised if the proportion of catch in  $y-1$  west of Cape Agulhas is less than  $[0.905035 \times (1 - \exp\{-0.416847 (B_{west,y-2}^{obs,S}/0.70783)/TAC_{y-1}\})]/1.2$ . The benefit when a green flag is raised is an increase of 0.03 in the proportion of HCR-calculated TAC awarded. The benefit is subject to a maximum proportion of 1.10. The proportion is readjusted 10% towards 1 each year prior to any penalty or benefit being added.

- Table 8 gives the performance statistics when both the preventative and penalty (benefit) red flags are simulated to be implemented simultaneously.
- These preventative and penalty red flags will need to be rechecked once any further adjustments to the underlying baseline OMs for sardine and anchovy are effected.

### Acknowledgements

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<sup>1</sup> This is the median historical relationship.

## References

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**Table 1.** The survey estimate of biomass west of Cape Agulhas corresponding to a range of effective west component spawner biomass levels, assuming a fixed ratio of survey estimate : effective spawner biomass of 0.15, 0.25 or 0.35 (Figure 2).

Effective west component spawner biomass	Equivalent survey estimate of biomass west of Cape Agulhas		
	If ratio = 0.15	If ratio = 0.25	If ratio = 0.35
25 000t	167 000t	100 000t	71 000t
28 000t	187 000t	112 000t	80 000t
30 000t	200 000t	120 000t	86 000t
32 000t	213 000t	128 000t	91 000t

**Table 2.** The average, median and 90% probability distributions for total survey estimated sardine biomass,  $B_{y-1}^{S,obs}$ , and model predicted west component biomass,  $B_{west,y-1}^S$ , corresponding to cases where the proportion of catch taken west of Cape Agulhas is less than 50%, 40%, 30% and 20%. These results are calculated from 2018-2036 only, using CMP1 and OM1.

	% of all simulations	$B_{y-1}^{S,obs}$		$B_{west,y-1}^S$	
		Average	Median [90%ile]	Average	Median [90%ile]
<0.5	19.6%	768	644 [123,1794]	198	174 [40,439]
<0.4	11.0%	774	658 [110,1809]	162	143 [25,357]
<0.3	5.0%	776	655 [75,1822]	125	109 [10,294]
<0.2	2.0%	719	607 [47,1746]	90	81 [3,223]

**Table 3.** The average, median and 90% probability distributions for the proportion of catch taken west of Cape Agulhas when the total survey estimated sardine biomass,  $B_{y-1}^{S,obs}$ , is less than 200 or 300 000t, and when the model predicted west component biomass,  $B_{west,y-1}^S$ , is less than 100, 200 or 300 000t. These results are calculated from future projections over 2018-2036 only, using CMP1 and OM1.

	% of all simulations	Proportion of catch west of Cape Agulhas	
		Average	Median [90%ile]
$B_{y-1}^{S,obs} < 200$	10.0%	0.69	0.74 [0.24,0.96]
$B_{y-1}^{S,obs} < 300$	22.4%	0.70	0.75 [0.30,0.96]
$B_{west,y-1}^S < 100$	6.0%	0.40	0.37 [0.08,0.80]
$B_{west,y-1}^S < 200$	23.8%	0.51	0.51 [0.17,0.87]
$B_{west,y-1}^S < 300$	44.1%	0.57	0.58 [0.21,0.90]

**Table 4.** Some summary performance statistics for alternative CMPs with  $\beta = 0.174$ . 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.

Proportion:		CMP1	CMP1-40	CMP1-50	CMP1-60	CMP1-70	Fixed explicit spatial management		
		$\in(0;1)$	$\geq 0.4$	$\geq 0.5$	$\geq 0.6$	$\geq 0.7$	=0.2	=0.5	=0.8
Risk stats	$\beta$	0.174	0.174	0.174	0.174	0.174	0.174	0.174	0.174
	$Risk_S$	0.20	0.21	0.22	0.24	0.26	0.14	0.20	0.29
	$p(TAC^S < 20)$	0.02	0.03	0.03	0.03	0.04	0.02	0.03	0.04
Biomass statistics	$B_{tot,2036}^S$	<b>274</b> 213 [85,623]	<b>271</b> 229 [80,623]	<b>269</b> 229 [71,622]	<b>266</b> 225 [64,622]	<b>261</b> 221 [62,615]	<b>297</b> 249 [95,678]	<b>278</b> 235 [73,643]	<b>256</b> 216 [54,612]
	$B_{tot,min}^S$	102 [40,186]	101 [32,186]	99 [29,186]	98 [28,183]	95 [24,180]	112 [46,197]	103 [33,192]	93 [20,179]
	$B_{west,min}^S$	16 [3,48]	15 [1,47]	14 [0,46]	12 [0,45]	9 [0,43]	23 [5,63]	16 [0,53]	7 [0,41]
Catch statistics	$C_{tot}^S$	<b>103</b> 92 [31,200]	<b>103</b> 91 [31,200]	<b>102</b> 90 [30,200]	<b>101</b> 89 [27,200]	<b>100</b> 87 [24,200]	<b>106</b> 96 [31,200]	<b>103</b> 92 [31,200]	<b>98</b> 85 [20,200]
	Med $C_{tot}^S$ <sup>2</sup>	94 [65,139]	93 [65,139]	92 [63,138]	91 [59,137]	89 [52,134]	97 [65,145]	94 [65,143]	88 [37,132]
	$C_{west}^S$	<b>68</b> 58 [19,154]	<b>69</b> 59 [20,154]	<b>70</b> 60 [20,154]	<b>72</b> 62 [20,153]	<b>75</b> 66 [18,153]	<b>22</b> 20 [7,40]	<b>52</b> 46 [15,100]	<b>78</b> 68 [15,160]
	$C_{south}^S$	<b>36</b> 26 [3,104]	<b>34</b> 26 [3,99]	<b>32</b> 25 [3,92]	<b>29</b> 24 [3,80]	<b>24</b> 20 [3,60]	<b>84</b> 77 [5,160]	<b>51</b> 46 [5,100]	<b>20</b> 17 [4,40]
	$C_{west}^S / C_{tot}^S$	0.72 [0.31,0.94]	0.71 [0.40,0.94]	0.71 [0.50,0.94]	0.71 [0.60,0.94]	0.70 [0.69,0.94]	0.20 [0.20,0.82]	0.50 [0.50,0.82]	0.80 [0.78,0.82]
	$MAV_{tot}^S$	0.50 [0.26,0.50]	0.50 [0.26,0.50]	0.50 [0.26,0.50]	0.50 [0.26,0.50]	0.50 [0.28,0.50]	0.48 [0.27,0.50]	0.49 [0.27,0.50]	0.49 [0.28,0.50]
	$MAV_{west}^S$	0.38 [0.24,0.54]	0.37 [0.23,0.50]	0.38 [0.23,0.50]	0.40 [0.25,0.50]	0.43 [0.26,0.50]	0.49 [0.26,0.50]	0.44 [0.26,0.50]	0.50 [0.28,0.50]
$MAV_{south}^S$	0.72 [0.51,0.91]	0.70 [0.50,0.89]	0.67 [0.49,0.88]	0.63 [0.47,0.86]	0.55 [0.43,0.82]	0.48 [0.26,0.50]	0.50 [0.26,0.50]	0.50 [0.26,0.50]	

<sup>2</sup> This gives the median and 90%ile of the 1000 median (over 20 years for each simulation) catches.

**Table 5.** Some summary performance statistics for alternative CMPs tuned to  $Risk_S < 0.20$ . 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.

Proportion:		CMP1	CMP1-40	CMP1-50	CMP1-60	CMP1-70	Fixed explicit spatial management		
		$\in(0;1)$	$\geq 0.4$	$\geq 0.5$	$\geq 0.6$	$\geq 0.7$	=0.2	=0.5	=0.8
Risk statist	$\beta$	0.174	0.144	0.127	0.107	0.086	0.600	0.173	0.059
	$Risk_S$	0.200	0.200	0.200	0.200	0.200	0.180 <sup>3</sup>	0.200	0.200
	$p(TAC^S < 20)$	0.02	0.03	0.03	0.03	0.03	0.01	0.03	0.03
Bioma SS	$B_{tot,2036}^S$	<b>274</b> 213 [85,623]	<b>282</b> 241 [87,633]	<b>287</b> 246 [88,639]	<b>293</b> 252 [88,656]	300 258 [89,663]	<b>251</b> 199 [48,645]	<b>278</b> 236 [73,644]	<b>310</b> 265 [87,689]
	$B_{tot,min}^S$	102 [40,186]	108 [40,190]	111 [40,194]	115 [43,200]	118 [43,205]	72 [14,162]	103 [33,192]	119 [43,210]
	$B_{west,min}^S$	16 [3,48]	16 [1,49]	16 [1,49]	15 [1,49]	15 [0,50]	20 [1,59]	16 [0,53]	15 [0,53]
Catch statistics	$C_{tot}^S$	<b>103</b> 92 [31,200]	<b>94</b> 77 [31,200]	<b>88</b> 69 [31,200]	<b>80</b> 65 [31,197]	<b>73</b> 65 [30,161]	<b>149</b> 192 [31,200]	<b>103</b> 92 [31,200]	<b>64</b> 65 [28,113]
	Med $C_{tot}^S$	94 [65,139]	80 [65,118]	71 [64,105]	65 [63,97]	65 [60,80]	93 [99,200]	94 [65,142]	65 [58,65]
	$C_{west}^S$	<b>68</b> 58 [19,154]	<b>65</b> 56 [20,148]	<b>63</b> 55 [20,142]	<b>61</b> 54 [20,130]	<b>58</b> 53 [23,125]	<b>32</b> 40 [10,40]	<b>52</b> 46 [15,100]	<b>51</b> 52 [22,90]
	$C_{south}^S$	<b>36</b> 26 [3,104]	<b>29</b> 21 [2,87]	<b>25</b> 18 [2,73]	<b>20</b> 15 [2,56]	<b>15</b> 13 [2,37]	<b>116</b> 152 [5,160]	<b>51</b> 46 [5,100]	<b>13</b> 13 [5,23]
	$C_{west}^S / C_{tot}^S$	0.72 [0.31,0.94]	0.75 [0.40,0.95]	0.76 [0.50,0.95]	0.78 [0.60,0.96]	0.80 [0.70,0.97]	0.20 [0.20,0.82]	0.50 [0.50,0.82]	0.80 [0.80,0.82]
	$MAV_{tot}^S$	0.50 [0.26,0.50]	0.47 [0.26,0.50]	0.46 [0.23,0.50]	0.42 [0.18,0.50]	0.35 [0.07,0.50]	0.23 [0.00,0.50]	0.49 [0.27,0.50]	0.19 [0.00,0.50]
	$MAV_{west}^S$	0.38 [0.24,0.54]	0.37 [0.22,0.49]	0.36 [0.22,0.49]	0.36 [0.21,0.49]	0.32 [0.16,0.48]	0.05 [0.00,0.50]	0.44 [0.26,0.50]	0.19 [0.00,0.50]
	$MAV_{south}^S$	0.72 [0.51,0.91]	0.71 [0.50,0.91]	0.70 [0.50,0.92]	0.67 [0.46,0.90]	0.61 [0.38,0.86]	0.25 [0.00,0.50]	0.50 [0.26,0.50]	0.18 [0.00,0.50]

<sup>3</sup> The  $\beta$  value was already very high for a risk of 0.18 and thus higher values to attempt to match a risk of 0.2 were not considered further.

**Table 6.** Summary performance statistics for CMP1-40 and alternative CMPs using different explicit and implicit spatial management scenarios once the **preventative red flag** of a low survey estimated sardine biomass west of Cape Agulhas is raised. 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.

	Corrective Measure once red flag raised:	N/A (CMP1-40)	Explicit Prop=0.4	Implicit 0.50*TAC	Explicit Prop=0.4	Implicit 0.50*TAC	Implicit 0.50*TAC	Implicit 0.50*TAC
Red Flag at $B_{y-1}^{obs,S} < 200^4$	$\beta$	0.144	0.144	0.144	0.189	0.189	0.183	0.254
	$Risk_S$	0.200	0.182	0.167	0.200	0.182	0.180	0.200
	$p(B_w^S < 150)$	0.141	0.129	0.122	0.140	0.129	0.128	0.138
	$C_{tot}^S$	<b>94 77</b>	<b>94 78</b>	<b>83 65</b>	<b>108 99</b>	<b>94 80</b>	<b>93 78</b>	<b>107 100</b>
		[31,200]	[31,200]	[12,200]	[31,200]	[12,200]	[12,200]	[13,200]
Red Flag at $B_{y-1}^{obs,S} < 150^5$	$\beta$	0.144	0.144	0.144	0.179	0.179	0.167	0.226
	$Risk_S$	0.200	0.186	0.175	0.200	0.184	0.181	0.200
	$p(B_w^S < 150)$	0.141	0.132	0.126	0.141	0.131	0.129	0.139
	$C_{tot}^S$	<b>94 77</b>	<b>94 78</b>	<b>86 69</b>	<b>105 94</b>	<b>96 83</b>	<b>92 79</b>	<b>106 100</b>
		[31,200]	[31,200]	[14,200]	[31,200]	[14,200]	[14,200]	[14,200]
Red Flag at $B_{y-1}^{obs,S} < 100^6$	$\beta$	0.144	0.144	0.144	0.166	0.166	0.155	0.196
	$Risk_S$	0.200	0.191	0.182	0.200	0.189	0.185	0.200
	$p(B_w^S < 150)$	0.141	0.135	0.129	0.141	0.133	0.131	0.138
	$C_{tot}^S$	<b>94 77</b>	<b>94 78</b>	<b>89 73</b>	<b>101 88</b>	<b>96 83</b>	<b>93 78</b>	<b>104 96</b>
		[31,200]	[31,200]	[16,200]	[31,200]	[16,200]	[16,200]	[16,200]

<sup>4</sup> The corrective measure is implemented smoothly over a linear range from full implementation at 180 000t (200 000t – 10%) to no corrective measure at 220 000t (200 000t + 10%).

<sup>5</sup> The corrective measure is implemented smoothly over a linear range from full implementation at 165 000t (150 000t – 10%) to no corrective measure at 130 000t (150 000t + 10%).

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

**Table 7.** Summary performance statistics for CMP1-40 and alternative CMPs using different corrective measures once a **penalty red flag** is raised. These measures also include a benefit if a ‘green flag’ is raised. All alternatives use  $\beta = 0.144$ . Where appropriate, medians and 90%iles are provided, and for some statistics the means are additionally shown 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.

Operating Model	OM1	OM-60	OM-UL	OM-70	OM1	OM-60	OM-UL	OM-70	OM1	OM-60	OM-UL	OM-70
Red flag threshold	N/A				$p(y-1) \geq 0.85$				$p(y-1) \geq 0.75 \ \& \ (B_{west,y-2}^{obs,S}/0.7)/TAC(y-1) < 3$			
Green flag threshold	(CMP1-40, with no penalty red or green flags)				$p(y-1) \leq 0.75$				$p(y-1) \leq 0.65 \ \& \ (B_{west,y-2}^{obs,S}/0.7)/TAC(y-1) > 5$			
Penalty if red flag					-0.06				-0.10			
Benefit if green flag (Max)					+0.02 (1.1)				+0.02			
$Risk_S$	0.200	0.212	0.220	0.219	0.199	0.211	0.199	0.229	0.199	0.210	0.213	0.218
$p(B_w^S < 150)$	0.141	0.150	0.155	0.154	0.141	0.149	0.142	0.161	0.141	0.149	0.150	0.154
$C_{tot}^S$	94	93	93	93	91	91	77	97	93	92	88	93
p(Red flag)	N/A	N/A	N/A	N/A	0.25	0.24	0.73	0.02	0.05	0.05	0.14	0.00
p(Green flag)	N/A	N/A	N/A	N/A	0.52	0.53	0.18	0.96	0.19	0.17	0.06	0.02
p(TAC<HCR)	N/A	N/A	N/A	N/A	0.48	0.47	0.87	0.06	0.30	0.29	0.56	0.06
p(TAC>HCR)	N/A	N/A	N/A	N/A	0.44	0.45	0.12	0.91	0.44	0.42	0.14	0.18
Red flag threshold	$p(y-1) \geq 1.2 \times [0.905035 \times (1 - \exp\{-0.416847 (B_{west,y-2}^{obs,S}/0.70783)/TAC_{y-1}\})]$											
Green flag threshold	$p(y-1) \leq [0.905035 \times (1 - \exp\{-0.416847 (B_{west,y-2}^{obs,S}/0.70783)/TAC_{y-1}\})]/1.2$											
Penalty if red flag	-0.10; 50% readjustment				-0.10; 30% readjustment				-0.10; 10% readjustment			
Benefit if green flag (Max)	+0.05 (1.1); 50% readjustment				+0.05 (1.1); 30% readjustment				+0.05 (1.1); 10% readjustment			
$Risk_S$	0.199	0.208	0.213	0.216	0.199	0.207	0.211	0.214	0.197	0.203	0.204	0.212
$p(B_w^S < 150)$	0.141	0.147	0.150	0.152	0.141	0.146	0.148	0.152	0.140	0.144	0.145	0.150
$C_{tot}^S$	93	91	89	93	92	91	87	92	91	89	83	91
p(Red flag)	0.21	0.28	0.43	0.24	0.21	0.28	0.42	0.24	0.20	0.27	0.40	0.23
p(Green flag)	0.22	0.18	0.07	0.30	0.22	0.18	0.06	0.30	0.22	0.18	0.05	0.32
p(TAC<HCR)	0.47	0.59	0.82	0.43	0.53	0.65	0.85	0.50	0.60	0.71	0.86	0.56
p(TAC>HCR)	0.39	0.29	0.08	0.46	0.35	0.24	0.06	0.42	0.29	0.18	0.05	0.35
Red flag threshold	$p(y-1) \geq 1.2 \times [0.905035 \times (1 - \exp\{-0.416847 (B_{west,y-2}^{obs,S}/0.70783)/TAC_{y-1}\})]$											
Green flag threshold	$p(y-1) \leq [0.905035 \times (1 - \exp\{-0.416847 (B_{west,y-2}^{obs,S}/0.70783)/TAC_{y-1}\})]/1.2$											
Penalty if red flag	-0.05; 10% readjustment				-0.10; 10% readjustment				-0.10; 10% readjustment			
Benefit if green flag (Max)	+0.02 (1.1); 10% readjustment				+0.02 (1.1); 10% readjustment				+0.03 (1.1); 10% readjustment			
$Risk_S$	0.198	0.207	0.212	0.214	0.195	0.201	0.203	0.209	<b>0.196</b>	<b>0.202</b>	<b>0.204</b>	<b>0.210</b>
$p(B_w^S < 150)$	0.140	0.146	0.150	0.151	0.139	0.143	0.145	0.147	<b>0.139</b>	<b>0.144</b>	<b>0.145</b>	<b>0.148</b>
$C_{tot}^S$	92	91	88	92	89	88	83	89	<b>90</b>	<b>88</b>	<b>83</b>	<b>90</b>
p(Red flag)	0.21	0.28	0.43	0.24	0.20	0.26	0.39	0.22	<b>0.20</b>	<b>0.26</b>	<b>0.39</b>	<b>0.23</b>
p(Green flag)	0.22	0.22	0.06	0.31	0.21	0.17	0.06	0.34	<b>0.21</b>	<b>0.18</b>	<b>0.06</b>	<b>0.33</b>
p(TAC<HCR)	0.62	0.73	0.86	0.60	0.69	0.76	0.87	0.68	<b>0.66</b>	<b>0.75</b>	<b>0.87</b>	<b>0.64</b>
p(TAC>HCR)	0.26	0.16	0.05	0.32	0.20	0.13	0.04	0.23	<b>0.22</b>	<b>0.15</b>	<b>0.04</b>	<b>0.27</b>

**Table 8a.** Summary performance statistics for CMP1-40, together with preventative red flags of 0.5\* the HCR-calculated TAC when a preventative red flag is raised. Statistics are given for a preventative red flag threshold of 150 000t of survey estimated biomass west of Cape Agulhas. Results additionally show the simultaneous implementation of a penalty (of -0.10 of HCR-calculated TAC) red flag when  $p(y - 1) \geq 1.2 \times [0.905035 \times (1 - \exp\{-0.416847 (B_{west,y-2}^{obs,S}/0.70783)/TAC_{y-1}\})]$ , with a benefit (of +0.03 of HCR-calculated TAC) green flag when  $p(y - 1) \leq [0.905035 \times (1 - \exp\{-0.416847 (B_{west,y-2}^{obs,S}/0.70783)/TAC_{y-1}\})]/1.2$ . The order of the application in scenarios where both preventative and penalty flags are raised is first the preventative and then the penalty. 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. Penalty flags are applied from 2025-2035 only, as is the scenario in the final column which considers if a simple continuous reduction to the TAC can obtain the same conservative benefits.

	Operating model:	OM1	OM1	OM-60	OM-UL	OM-70	OM1	OM-60	OM-UL	OM-70	OM1	OM-60	OM-UL	OM-70
		CMP1-40	Preventative Red Flag only					Preventative and penalty flags				90% of HCR-calculated TAC in all years		
Preventative flag $B_{y-1}^{obs,S} < 150$	$\beta$	0.144	0.167	0.167	0.167	0.167	0.167	0.167	0.167	0.167	0.144	0.144	0.144	0.144
	$Risk_S$	0.200	0.181	0.190	0.198	0.193	0.179	0.185	0.186	0.191	0.185	0.197	0.205	0.201
	$p(B_w^S < 150)$	0.141	0.129	0.134	0.140	0.137	0.128	0.132	0.134	0.135	0.131	0.140	0.144	0.143
	$C_{tot}^S$	<b>94 77</b>	<b>92 79</b>	<b>92 78</b>	<b>91 77</b>	<b>92 78</b>	<b>90 75</b>	<b>89 74</b>	<b>82 67</b>	<b>91 76</b>	<b>88 72</b>	<b>88 72</b>	<b>87 71</b>	<b>88 72</b>
		[31,200]	[14,200]	[14,200]	[13,200]	[13,200]	[13,200]	[13,200]	[11,198]	[13,200]	[26,180]	[26,180]	[26,180]	[26,180]
	$C_{west}^S$	<b>65 56</b>	<b>65 56</b>	<b>66 58</b>	<b>73 63</b>	<b>64 56</b>	<b>63 55</b>	<b>64 56</b>	<b>67 58</b>	<b>64 55</b>	<b>62 53</b>	<b>63 54</b>	<b>70 59</b>	<b>61 52</b>
		[20,148]	[12,154]	[11,153]	[12,181]	[10,140]	[11,149]	[11,148]	[10,160]	[9,143]	[18,141]	[19,141]	[20,163]	[18,126]
	$C_{south}^S$	<b>29 21</b>	<b>28 18</b>	<b>26 18</b>	<b>18 7</b>	<b>28 22</b>	<b>26 17</b>	<b>24 17</b>	<b>15 5</b>	<b>27 22</b>	<b>26 18</b>	<b>24 18</b>	<b>18 8</b>	<b>27 21</b>
		[2,87]	[1,90]	[1,80]	[0,74]	[2,60]	[1,86]	[1,74]	[0,65]	[2,64]	[2,81]	[2,72]	[0,69]	[5,56]
	p(Red flag)	-	-	-	-	-	0.18	0.20	0.37	0.15	-	-	-	-
	p(Green flag)	-	-	-	-	-	0.23	0.19	0.06	0.31	-	-	-	-
	p(TAC<HCR)	-	-	-	-	-	0.62	0.67	0.86	0.52	-	-	-	-
	p(TAC>HCR)	-	-	-	-	-	0.26	0.21	0.05	0.38	-	-	-	-
	p(prevent flag)	-	-	-	-	-	0.25	0.25	0.25	0.25	-	-	-	-
	p(both red)	-	-	-	-	-	0.19	0.21	0.25	0.20	-	-	-	-
min(TAC prop)	-	-	-	-	-	0.52	0.44	0.43	0.42	-	-	-	-	

**Table 8b.** As per Table 8a, but with a preventative red flag threshold of 100 000t of survey estimated biomass west of Cape Agulhas.

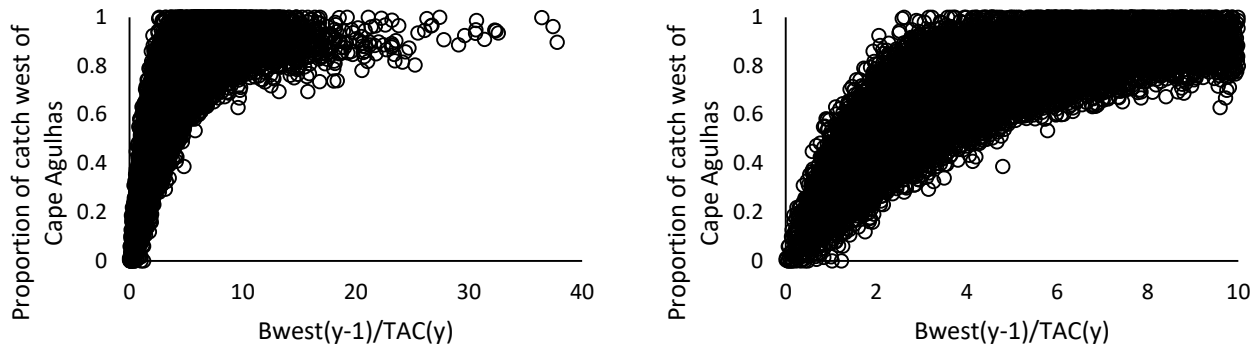
	Operating model:	OM1	OM1	OM-60	OM-UL	OM-70	OM1	OM-60	OM-UL	OM-70
		CMP1-40	Preventative Red Flag only				Preventative and penalty flags			
Preventative flag $B_{y-1}^{obs,s} < 100$	$\beta$	0.144	0.155	0.155	0.155	0.155	0.155	0.155	0.155	0.155
	$Risk_S$	0.200	0.185	0.194	0.203	0.198	0.182	0.188	0.189	0.194
	$p(B_w^S < 150)$	0.141	0.131	0.137	0.142	0.139	0.129	0.134	0.136	0.137
	$C_{tot}^S$	<b>94 77</b>	<b>93 78</b>	<b>92 78</b>	<b>92 77</b>	<b>92 77</b>	<b>89 74</b>	<b>88 73</b>	<b>82 67</b>	<b>91 75</b>
		[31,200]	[16,200]	[16,200]	[16,200]	[16,200]	[16,200]	[15,200]	[13,190]	[15,200]
	$C_{west}^S$	<b>65 56</b>	<b>65 57</b>	<b>66 58</b>	<b>73 65</b>	<b>64 56</b>	<b>63 55</b>	<b>64 56</b>	<b>67 58</b>	<b>63 55</b>
		[20,148]	[14,151]	[14,151]	[14,176]	[11,140]	[13,146]	[12,145]	[12,157]	[11,141]
	$C_{south}^S$	<b>29 21</b>	<b>28 19</b>	<b>26 19</b>	<b>18 8</b>	<b>28 22</b>	<b>26 17</b>	<b>24 17</b>	<b>15 5</b>	<b>27 22</b>
		[2,87]	[1,88]	[1,79]	[0,73]	[3,60]	[1,84]	[1,73]	[0,64]	[3,63]
	p(Red flag)	-	-	-	-	-	0.19	0.22	0.39	0.17
	p(Green flag)	-	-	-	-	-	0.22	0.18	0.06	0.32
	p(TAC<HCR)	-	-	-	-	-	0.66	0.72	0.87	0.57
	p(TAC>HCR)	-	-	-	-	-	0.23	0.17	0.04	0.34
	p(prevent flag)	-	-	-	-	-	0.15	0.15	0.16	0.16
p(both red)	-	-	-	-	-	0.12	0.14	0.16	0.13	
min(TAC prop)	-	-	-	-	-	0.50	0.44	0.40	0.44	

**Table 8c.** As per Table 8a, but with penalty flags and alternative operating models, as well as the scenario in the final column applied from 2018-2035.

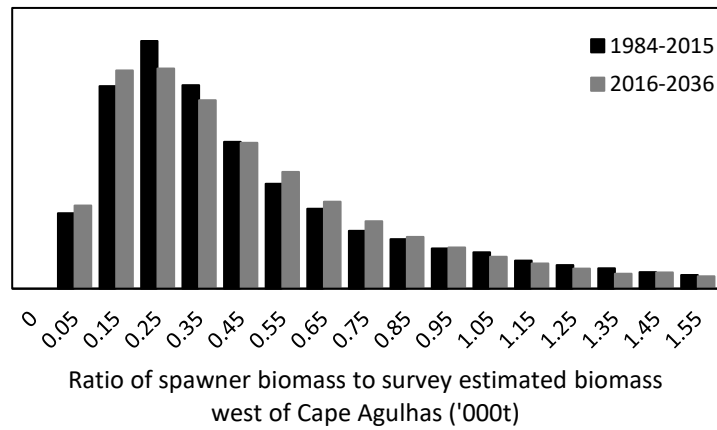
	Operating model:	OM1	OM1	OM-60	OM-UL	OM-70	OM1	OM-60	OM-UL	OM-70	OM1	OM-60	OM-UL	OM-70
		CMP1-40	Preventative Red Flag only				Preventative and penalty flags				90% of HCR-calculated TAC in all years			
Preventative flag $B_{y-1}^{obs,s} < 150$	$\beta$	0.144	0.167	0.167	0.167	0.167	0.167	0.167	0.167	0.167	0.144	0.144	0.144	0.144
	$Risk_S$	0.200	0.181	0.196	0.209	0.202	0.176	0.185	0.186	0.197	0.181	0.194	0.202	0.198
	$p(B_w^S < 150)$	0.141	0.129	0.139	0.147	0.142	0.126	0.133	0.134	0.140	0.129	0.138	0.142	0.141
	$C_{tot}^S$	<b>94 77</b>	<b>92 79</b>	<b>92 77</b>	<b>91 76</b>	<b>91 77</b>	<b>87 73</b>	<b>85 71</b>	<b>73 65</b>	<b>90 74</b>	<b>85 70</b>	<b>85 69</b>	<b>85 69</b>	<b>85 69</b>
		[31,200]	[14,200]	[13,200]	[12,200]	[13,200]	[13,195]	[12,191]	[9,166]	[12,204]	[26,180]	[26,180]	[26,180]	[26,180]
	$C_{west}^S$	<b>65 56</b>	<b>65 56</b>	<b>67 58</b>	<b>78 65</b>	<b>64 54</b>	<b>62 54</b>	<b>63 55</b>	<b>67 59</b>	<b>63 52</b>	<b>61 52</b>	<b>62 54</b>	<b>69 58</b>	<b>60 51</b>
		[20,148]	[12,154]	[11,153]	[12,190]	[9,140]	[11,154]	[10,144]	[9,153]	[8,142]	[18,138]	[18,138]	[19,160]	[18,126]
	$C_{south}^S$	<b>29 21</b>	<b>28 18</b>	<b>25 18</b>	<b>13 3</b>	<b>27 23</b>	<b>25 16</b>	<b>22 15</b>	<b>7 0</b>	<b>27 22</b>	<b>25 17</b>	<b>23 17</b>	<b>16 7</b>	<b>25 20</b>
		[2,87]	[1,90]	[1,77]	[0,62]	[4,60]	[1,82]	[1,67]	[0,39]	[4,61]	[2,77]	[2,68]	[0,63]	[4,54]
	p(Red flag)	-	-	-	-	-	0.17	0.20	0.37	0.15	-	-	-	-
	p(Green flag)	-	-	-	-	-	0.22	0.18	0.04	0.32	-	-	-	-
	p(TAC<HCR)	-	-	-	-	-	0.70	0.77	0.94	0.57	-	-	-	-
	p(TAC>HCR)	-	-	-	-	-	0.22	0.14	0.01	0.38	-	-	-	-
	p(prevent flag)	-	-	-	-	-	0.27	0.28	0.28	0.28	-	-	-	-
p(both red)	-	-	-	-	-	0.05	0.07	0.11	0.06	-	-	-	-	
min(TAC prop)	-	-	-	-	-	0.39	0.35	0.32	0.41	-	-	-	-	

**Table 8d.** As per Table 8c, but with a preventative red flag threshold of 100 000t of survey estimated biomass west of Cape Agulhas.

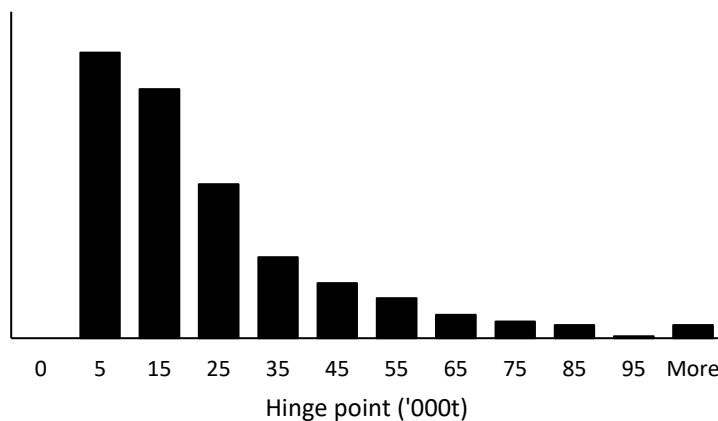
	Operating model:	OM1	OM1	OM-60	OM-UL	OM-70	OM1	OM-60	OM-UL	OM-70
		CMP1-40	Preventative Red Flag only				Preventative and penalty flags			
0.34preventative flag $B_{y-1}^{obs,S} < 100$	$\beta$		0.155	0.155	0.155	0.155	0.155	0.155	0.155	0.155
	$Risk_S$		0.185	0.200	0.216	0.206	0.179	0.187	0.188	0.200
	$p(B_w^S < 150)$		0.131	0.141	0.150	0.146	0.128	0.135	0.136	0.140
	$C_{tot}^S$		<b>93 78</b>	<b>92 77</b>	<b>91 76</b>	<b>92 77</b>	<b>87 72</b>	<b>84 69</b>	<b>73 65</b>	<b>89 73</b>
			[16,200]	[16,200]	[16,200]	[16,200]	[15,191]	[14,187]	[11,164]	[14,200]
	$C_{west}^S$		<b>65 57</b>	<b>67 59</b>	<b>78 65</b>	<b>64 54</b>	<b>62 54</b>	<b>63 55</b>	<b>66 58</b>	<b>62 51</b>
			[14,151]	[13,151]	[15,187]	[11,140]	[12,143]	[12,140]	[10,150]	[10,140]
	$C_{south}^S$		<b>28 19</b>	<b>25 18</b>	<b>13 3</b>	<b>27 23</b>	<b>25 16</b>	<b>21 15</b>	<b>7 0</b>	<b>27 22</b>
			[1,88]	[1,74]	[0,61]	[5,60]	[1,81]	[1,65]	[0,38]	[4,60]
	p(Red flag)		-	-	-	-	0.19	0.22	0.38	0.17
	p(Green flag)		-	-	-	-	0.22	0.17	0.04	0.34
	p(TAC<HCR)		-	-	-	-	0.72	0.80	0.94	0.62
	p(TAC>HCR)		-	-	-	-	0.20	0.12	0.01	0.33
	p(prevent flag)		-	-	-	-	0.17	0.17	0.17	0.18
p(both red)		-	-	-	-	0.04	0.05	0.08	0.05	
min(TAC prop)		-	-	-	-	0.39	0.35	0.32	0.41	



**Figure 1.** The future simulated proportion of catch taken west of Cape Agulhas for CMP1, plotted against the ratio of the west component biomass to the total TAC for CMP1 using OM1. The right plot repeats the left one with a smaller range for the horizontal axis.

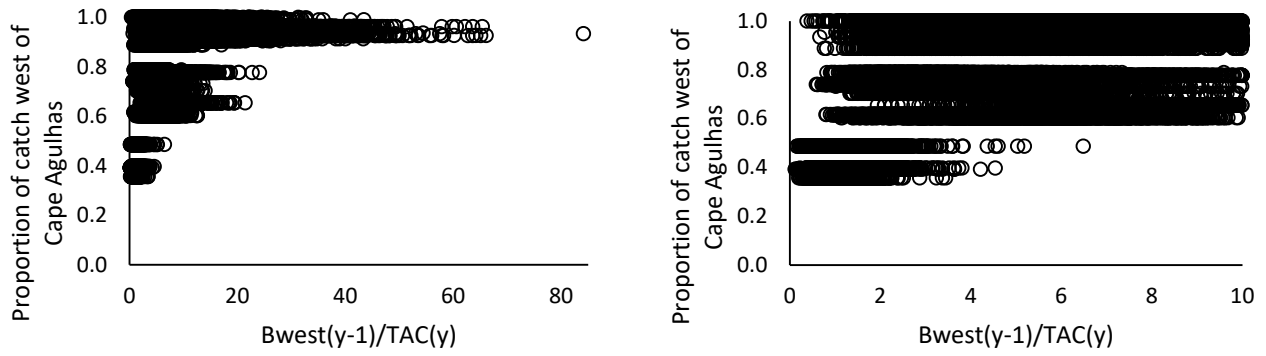


**Figure 2.** Histogram of the ratio of effective west component spawner biomass : survey estimated biomass west of Cape Agulhas.

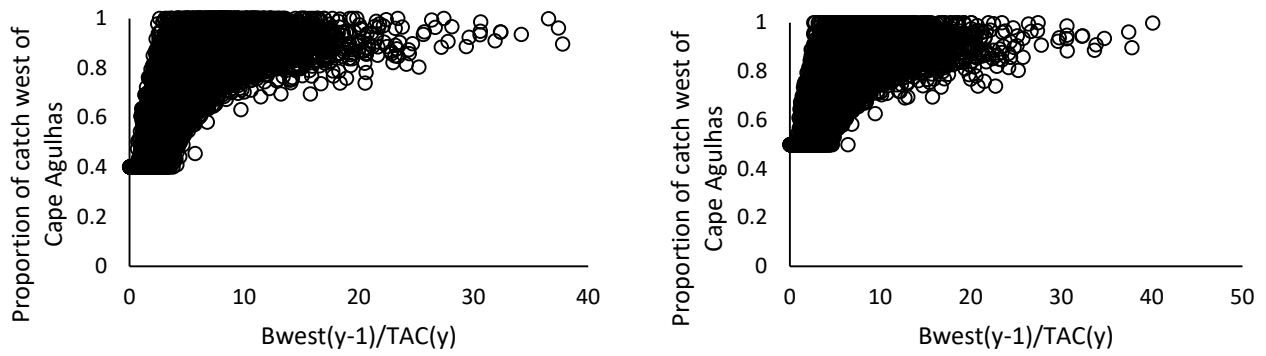


**Figure 3.** Histogram of the hinge point of west component effective spawning biomass in the hockey stick stock recruitment relationship for OM1.

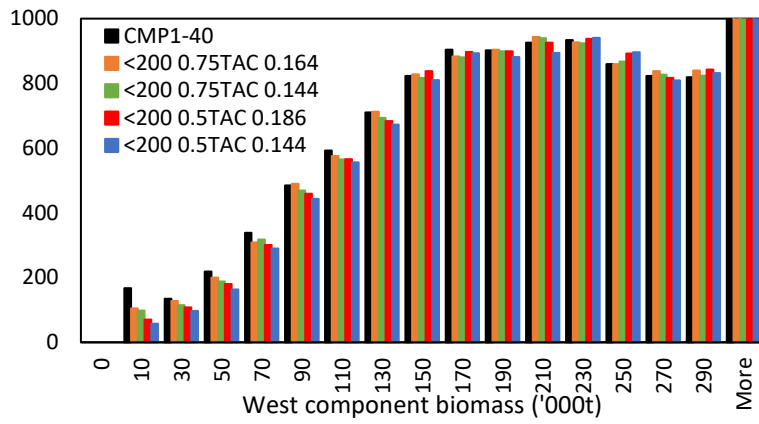
0.62



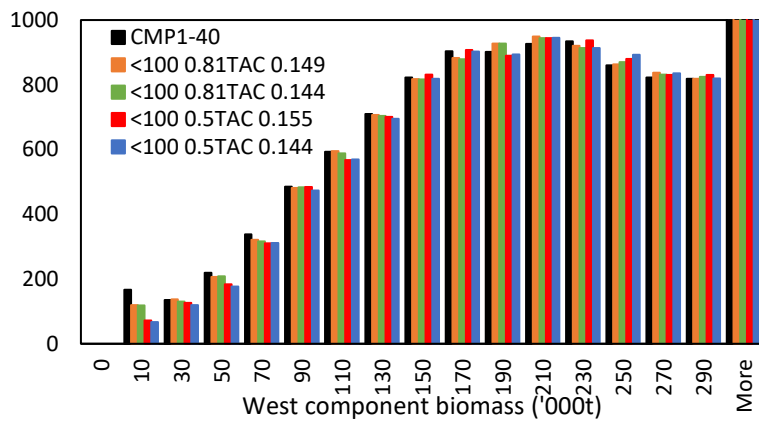
**Figure 4.** The *historical* proportion of catch taken west of Cape Agulhas, plotted against the ratio of the model predicted west component biomass to the total historical TAC. The right plot is a repeat of the left one, over a smaller range for the horizontal axis.



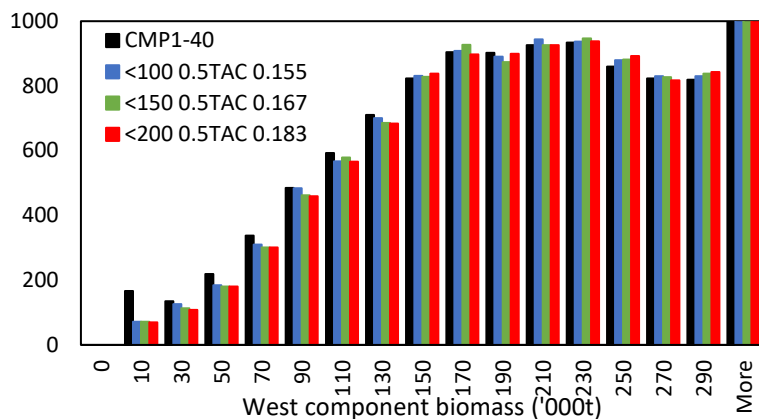
**Figure 5.** The future simulated proportion of catch taken west of Cape Agulhas, plotted against the ratio of the west component biomass to the total TAC for (left) CMP1-40 and (right) CMP1-50.



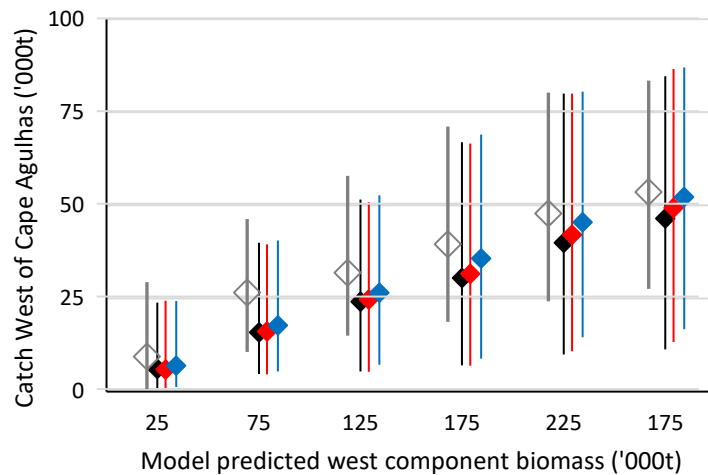
**Figure 6a.** Histograms (focussing on the lower end of the range) for the model predicted west component biomass under CMP1-40 compared to four alternative implicit spatial management scenarios using a preventative red flag of survey estimated biomass west of Cape Agulhas of 200 000t.



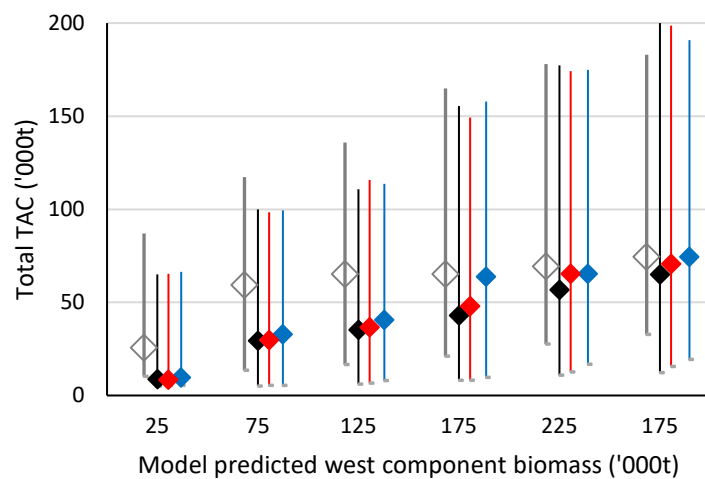
**Figure 6b.** Histograms (focussing on the lower end of the range) for the model predicted west component biomass under CMP1-40 compared to four alternative implicit spatial management scenarios using a preventative red flag of survey estimated biomass west of Cape Agulhas of 100 000t.



**Figure 6c.** Histograms (focussing on the lower end of the range) for the model predicted west component biomass under CMP1-40 compared to alternative implicit spatial management scenarios which decrease the TAC by 50% once a preventative red flag of survey estimated biomass west of Cape Agulhas of less than 100 000t, 150 000t or 200 000t is raised.



**Figure 7a.** The median and 90%ile of **directed sardine catch taken west of Cape Agulhas** between 2025 and 2036 for the scenarios of CMP1-40 (grey), and preventative red flags with a corrective measure of 50% of the HCR calculated TAC when the red flag is raised at a threshold of 200 000t (black,  $\beta = 0.183$ ), 150 000t (red,  $\beta = 0.167$ ) or 100 000t (blue,  $\beta = 0.155$ ).



**Figure 7b.** The median and 90%ile of the **total directed sardine TAC** between 2025 and 2036 for the scenarios of CMP1-40 (grey), and preventative red flags with a corrective measure of 50% of the HCR calculated TAC when the red flag is raised at a threshold of 200 000t (black,  $\beta = 0.183$ ), 150 000t (red,  $\beta = 0.167$ ) or 100 000t (blue,  $\beta = 0.155$ ).

## Appendix A: Explicit spatial management options

### *Explicit spatial management together with the Critical Biomass metarule*

CMPs with fixed spatial splits (20%, 40%, 50%, 55%, 60%, 80% of directed sardine catch taken west of Cape Agulhas) once the observed total biomass falls below the Critical Biomass threshold ( $B_{crit}^S$ ) have been investigated.  $B_{crit}^S$  is a level below which the TAC is rapidly reduced given concern for the resource status, and has been proposed as one possible trigger to switch from implicit to explicit spatial management.

The Critical Biomass metarule is simulated to be used in 35% of cases under CMP1 (de Moor 2018). The performance statistics for cases with explicit spatial management when  $B_{y-1}^{S,obs} < B_{crit}^S$ , are therefore between the performance statistics of CMP1 and those of the options with fixed explicit spatial management in all years (Tables A.1, A.2). The same trends are evident however, in that for lower proportions of catch taken west of Cape Agulhas, there is a benefit in terms of total catch and resource biomass (Tables A.1, A.2). Explicit spatial management of 55% of catch taken west of Cape Agulhas when  $B_{y-1}^{S,obs} < B_{crit}^S$  corresponds closely to the control parameter and risk associated with CMP1 (Table A.1). Explicit spatial management of 60% of catch taken west of Cape Agulhas when  $B_{y-1}^{S,obs} < B_{crit}^S$  corresponds closely to the control parameter and risk associated with CMP1-40 (Table A.1).

### *Explicit spatial management with low survey estimated biomass west of Cape Agulhas*

CMPs with fixed spatial splits (40%, 50%, 60% 80% of directed sardine catch taken west of Cape Agulhas) once the survey estimated biomass west of Cape Agulhas falls below a threshold of 200 000t have also been investigated.

The same pattern of increasing risk for higher proportions of catch taken west of Cape Agulhas - this time in cases when the biomass surveyed west of Cape Agulhas is below a threshold of 200 000t - is seen (Table A.2). If the proportion taken west of Cape Agulhas is explicitly set to 0.40 when the observed biomass west of Cape Agulhas is less than 200 000t, and 0.40 is also assumed to be the minimum during the remaining implicit spatial management years, then the  $\beta$  control parameter is 0.188 with an average (median) total catch of 107 (98) thousand tons. This compares against CMP1-40 with  $\beta = 0.144$  and an average (median) total catch of 94 (77) thousand tons.

**Table A.1.** Summary performance statistics for CMP1 assuming implicit spatial management, and assuming explicit spatial management (proportions of 0.2, 0.4, 0.5, 0.55, 0.6 and 0.8 taken west of Cape Agulhas) during the years for which the Critical Biomass metarules are employed. 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. The **red** values indicate where similarity with CMP1 was sought.

Proportion:		CMP1	Explicit spatial management with $B_{y-1}^{obs,S} < B_{crit}^S$					
		∈(0;1)	=0.2	=0.4	=0.5	=0.55	=0.6	=0.8
Risk stats	$\beta$	<b>0.174</b>	<b>0.174</b>	<b>0.174</b>	<b>0.174</b>	<b>0.174</b>	<b>0.174</b>	<b>0.174</b>
	$Risk_S$	0.20	0.18	0.19	0.20	0.20	0.20	0.21
	$p(TAC^S < 20)$	0.02	0.02	0.02	0.02	0.02	0.02	0.03
Biomass statistics	$B_{tot,2036}^S$	<b>274</b> 213 [85,623]	<b>278</b> 234 [86,626]	<b>276</b> 232 [85,625]	<b>275</b> 231 [84,624]	<b>274</b> 231 [82,624]	<b>273</b> 231 [81,624]	<b>271</b> 229 [77,623]
	$B_{tot,min}^S$	102 [40,186]	105 [42,188]	103 [39,188]	103 [38,188]	103 [38,188]	102 [36,188]	101 [32,187]
	$B_{west,min}^S$	16 [3,48]	18 [3,50]	17 [3,49]	17 [2,49]	16 [2,48]	16 [248]	15 [1,48]
Catch statistics	$C_{tot}^S$	<b>103</b> 92 [31,200]	<b>104</b> 93 [31,200]	<b>104</b> 92 [31,200]	<b>104</b> 92 [31,200]	<b>103</b> 92 [31,200]	<b>103</b> 92 [31,200]	<b>102</b> 91 [30,200]
	Med $C_{tot}^S$	94 [65,139]	95 [65,140]	94 [65,139]	94 [65,139]	94 [65,139]	94 [65,139]	93 [64,139]
	$C_{west}^S$	<b>68</b> 58 [19,154]	<b>63</b> 57 [6,155]	<b>65</b> 57 [13,154]	<b>66</b> 56 [15,154]	<b>66</b> 56 [16,154]	<b>67</b> 57 [17,154]	<b>68</b> 58 [19,154]
	$C_{south}^S$	<b>36</b> 26 3,104]	<b>42</b> 36 [5,103]	<b>39</b> 32 [5,103]	<b>38</b> 30 [5,103]	<b>37</b> 29 [5,103]	<b>37</b> 26 [5,103]	<b>34</b> 21 [4,104]
	$C_{west}^S/C_{tot}^S$	0.72 [0.31,0.94]	0.61 [0.20,0.92]	0.61 [0.33,0.92]	0.61 [0.33,0.91]	0.61 [0.33,0.91]	0.60 [0.33,0.91]	0.79 [0.32,0.91]
	$MAV_{tot}^S$	0.50 [0.26,0.50]	0.50 [0.26,0.50]	0.50 [0.26,0.50]	0.50 [0.26,0.50]	0.50 [0.26,0.50]	0.50 [0.26,0.50]	0.50 [0.26,0.50]
	$MAV_{west}^S$	0.38 [0.24,0.54]	0.50 [0.31,0.80]	0.45 [0.25,0.63]	0.42 [0.26,0.57]	0.41 [0.27,0.54]	0.44 [0.26,0.52]	0.40 [0.23,0.51]
	$MAV_{south}^S$	0.72 [0.51,0.91]	0.57 [0.38,0.83]	0.57 [0.40,0.82]	0.59 [0.42,0.83]	0.61 [0.43,0.83]	0.62 [0.44,0.83]	0.74 [0.50,0.90]

Proportion:		CMP1	Explicit spatial management with $B_{y-1}^{obs,S} < B_{crit}^S$					
		∈(0;1)	=0.2	=0.4	=0.5	=0.55	=0.6	=0.8
Risk stats	$\beta$	0.174	0.266	0.206	0.186	0.176	0.167	0.136
	$Risk_S$	<b>0.200</b>	<b>0.200</b>	<b>0.200</b>	<b>0.200</b>	<b>0.200</b>	<b>0.200</b>	<b>0.200</b>
	$p(TAC^S < 20)$	0.02	0.02	0.02	0.02	0.02	0.02	0.03
Biomass statistics	$B_{tot,2036}^S$	<b>274</b> 213 [85,623]	<b>255</b> 210 [66,603]	<b>266</b> 222 [78,615]	<b>271</b> 228 [81,620]	<b>273</b> 231 [82,623]	<b>276</b> 233 [83,626]	<b>285</b> 243 [86,635]
	$B_{tot,min}^S$	102 [40,186]	87 [31,171]	97 [34,179]	100 [37,185]	102 [37,187]	104 [38,189]	109 [41,192]
	$B_{west,min}^S$	16 [3,48]	17 [3,48]	17 [2,49]	17 [2,48]	16 [2,48]	16 [2,49]	16 [1,49]
Catch statistics	$C_{tot}^S$	<b>103</b> 92 [31,200]	<b>126</b> 123 [31,200]	<b>112</b> 100 [31,200]	<b>107</b> 97 [31,200]	<b>104</b> 93 [31,200]	<b>101</b> 88 [31,200]	<b>91</b> 73 [31,200]
	Med $C_{tot}^S$	94 [65,139]	125 [79,198]	101 [66,163]	98 [65,148]	95 [65,140]	91 [65,134]	75 [65,111]
	$C_{west}^S$	<b>68</b> 58 [19,154]	<b>69</b> 65 [7,162]	<b>67</b> 60 [13,158]	<b>67</b> 57 [15,156]	<b>66</b> 56 [16,154]	<b>66</b> 57 [17,153]	<b>64</b> 54 [20,145]
	$C_{south}^S$	<b>36</b> 26 3,104]	<b>58</b> 52 [5,129]	<b>45</b> 38 [5,115]	<b>40</b> 32 [5,108]	<b>38</b> 29 [5,104]	<b>35</b> 26 [5,101]	<b>27</b> 16 [3,86]
	$C_{west}^S/C_{tot}^S$	0.72 [0.31,0.94]	0.51 [0.20,0.87]	0.57 [0.30,0.90]	0.59 [0.32,0.91]	0.60 [0.32,0.91]	0.61 [0.33,0.92]	0.80 [0.37,0.93]
	$MAV_{tot}^S$	0.50 [0.26,0.50]	0.48 [0.17,0.50]	0.49 [0.25,0.50]	0.50 [0.26,0.50]	0.50 [0.27,0.50]	0.50 [0.27,0.50]	0.47 [0.24,0.50]
	$MAV_{west}^S$	0.38 [0.24,0.54]	0.50 [0.28,0.78]	0.45 [0.24,0.63]	0.42 [0.26,0.57]	0.41 [0.27,0.54]	0.44 [0.26,0.52]	0.38 [0.23,0.50]
	$MAV_{south}^S$	0.72 [0.51,0.91]	0.50 [0.32,0.71]	0.55 [0.39,0.80]	0.59 [0.43,0.82]	0.61 [0.43,0.83]	0.63 [0.45,0.84]	0.73 [0.50,0.90]

**Table A.2.** Summary performance statistics for i) CMP1-40 assuming implicit spatial management *limited to a minimum of 40% taken west of Cape Agulhas*, ii) assuming explicit spatial management (proportions of 0.4, 0.5, 0.55, 0.6 and 0.8 taken west of Cape Agulhas) during the years for which the Critical Biomass metarules are employed, and iii) assuming explicit spatial management when the survey estimate of biomass west of Cape Agulhas is less than 200 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. The **red** values indicate where similarity with CMP1-40 was sought.

Proportion:		CMP1-40 ≥0.4	Explicit spatial management with $B_{y-1}^{obs,S} < B_{crit}^S$					Explicit spatial management with $B_{west,y-1}^{obs,S} < 200$			
			Prop=0.4	Prop=0.5	Prop=0.55	Prop=0.6	Prop=0.8	Prop=0.4	Prop=0.5	=0.6	=0.8
Risk stats	$\beta$	<b>0.174</b>	<b>0.174</b>	<b>0.174</b>	<b>0.174</b>	<b>0.174</b>	<b>0.174</b>	<b>0.174</b>	<b>0.174</b>	<b>0.174</b>	<b>0.174</b>
	$Risk_S$	0.21	0.20	0.21	0.21	0.21	0.19	0.19	0.21	0.22	0.25
	$p(TAC^S < 20)$	0.03	0.02	0.03	0.03	0.03	0.02	0.02	0.03	0.03	0.04
Biomass statistics	$B_{tot,2036}^S$	<b>271</b> 229 [80,623]	<b>273</b> 231 [80,624]	<b>272</b> 230 [77,624]	<b>271</b> 230 [72,624]	<b>271</b> 229 [72,624]	<b>275</b> 232 [82,625]	<b>275</b> 232 [82,625]	<b>272</b> 230 [72,624]	<b>269</b> 229 [68,624]	<b>264</b> 225 [63,623]
	$B_{tot,min}^S$	101 [32,186]	102 [35,188]	101 [34,188]	101 [33,188]	100 [31,188]	102 [38,189]	102 [38,189]	101 [33,188]	100 [29,188]	97 [26,182]
	$B_{west,min}^S$	15 [1,47]	16 [1,49]	16 [1,48]	15 [1,48]	15 [0,48]	17 [1,51]	17 [1,51]	16 [0,49]	14 [0,48]	11 [0,45]
Catch statistics	$C_{tot}^S$	<b>103</b> 91 [31,200]	<b>103</b> 92 [31,200]	<b>103</b> 91 [31,200]	<b>103</b> 91 [31,200]	<b>103</b> 91 [31,200]	<b>103</b> 92 [31,200]	<b>103</b> 92 [31,200]	<b>103</b> 91 [31,200]	<b>102</b> 90 [29,200]	<b>100</b> 88 [24,200]
	Med $C_{tot}^S$	93 [65,139]	94 [65,139]	93 [65,139]	93 [65,139]	93 [64,139]	94 [65,139]	94 [65,139]	94 [65,139]	93 [61,138]	90 [53,136]
	$C_{west}^S$	<b>69</b> 59 [20,154]	<b>65</b> 58 [13,154]	<b>66</b> 58 [15,154]	<b>67</b> 58 [17,154]	<b>67</b> 59 [18,154]	<b>64</b> 56 [13,155]	<b>64</b> 56 [13,155]	<b>66</b> 56 [15,154]	<b>67</b> 60 [17,154]	<b>71</b> 63 [18,153]
	$C_{south}^S$	<b>34</b> 26 [3,99]	<b>38</b> 32 [5,99]	<b>37</b> 30 [5,99]	<b>36</b> 29 [5,99]	<b>35</b> 26 [5,99]	<b>40</b> 38 [5,99]	<b>40</b> 38 [5,99]	<b>37</b> 32 [5,98]	<b>35</b> 26 [5,98]	<b>29</b> 17 [4,97]
	$C_{west}^S / C_{tot}^S$	0.71 [0.40,0.94]	0.61 [0.40,0.91]	0.60 [0.40,0.91]	0.60 [0.40,0.91]	0.60 [0.40,0.91]	0.54 [0.40,0.91]	0.54 [0.40,0.91]	0.53 [0.40,0.91]	0.60 [0.40,0.91]	0.80 [0.40,0.91]
	$MAV_{tot}^S$	0.50 [0.26,0.50]	0.50 [0.26,0.50]	0.50 [0.26,0.50]	0.50 [0.26,0.50]	0.50 [0.26,0.50]	0.50 [0.27,0.50]	0.50 [0.27,0.50]	0.50 [0.26,0.50]	0.50 [0.26,0.50]	0.50 [0.27,0.50]
	$MAV_{west}^S$	0.37 [0.23,0.50]	0.45 [0.23,0.61]	0.40 [0.26,0.55]	0.39 [0.27,0.52]	0.42 [0.25,0.51]	0.50 [0.25,0.64]	0.50 [0.25,0.64]	0.43 [0.26,0.55]	0.44 [0.25,0.51]	0.37 [0.20,0.50]
	$MAV_{south}^S$	0.70 [0.50,0.89]	0.53 [0.39,0.81]	0.58 [0.42,0.82]	0.59 [0.42,0.82]	0.61 [0.44,0.82]	0.50 [0.39,0.81]	0.50 [0.39,0.81]	0.54 [0.41,0.80]	0.57 [0.42,0.80]	0.68 [0.50,0.84]

Table A.2 (continued).

Proportion:		CMP1-40 ≥0.4	Explicit spatial management with $B_{y-1}^{obs,S} < B_{crit}^S$					Explicit spatial management with $B_{west,y-1}^{obs,S} < 200$			
			Prop=0.4	Prop=0.5	Prop=0.55	Prop=0.6	Prop=0.8	Prop=0.4	Prop=0.5	=0.6	=0.8
Risk stats	$\beta$	0.144	0.175	0.157	0.150	0.144	0.121	0.188	0.157	0.136	0.086
	$Risk_S$	<b>0.200</b>	<b>0.200</b>	<b>0.200</b>	<b>0.200</b>	<b>0.200</b>	<b>0.200</b>	<b>0.200</b>	<b>0.200</b>	<b>0.200</b>	<b>0.200</b>
	$p(TAC^S < 20)$	0.03	0.02	0.02	0.03	0.03	0.03	0.02	0.03	0.03	0.03
Biomass statistics	$B_{tot,2036}^S$	<b>282</b> 241 [87,633]	<b>273</b> 231 [80,624]	<b>278</b> 236 [83,629]	<b>280</b> 240 [84,631]	<b>282</b> 241 [85,633]	<b>289</b> 247 [88,642]	<b>270</b> 226 [76,622]	<b>278</b> 236 [80,629]	<b>284</b> 243 [79,636]	<b>301</b> 257 [85,663]
	$B_{tot,min}^S$	108 [40,190]	102 [35,188]	106 [37,189]	107 [37,190]	108 [38,191]	112 [41,196]	99 [33,186]	106 [37,191]	109 [38,193]	117 [43,205]
	$B_{west,min}^S$	16 [1,49]	16 [1,49]	16 [1,49]	16 [1,50]	16 [1,50]	16 [1,49]	16 [1,50]	16 [1,50]	16 [1,50]	15 [0,51]
Catch statistics	$C_{tot}^S$	<b>94</b> 77 [31,200]	<b>104</b> 92 [31,200]	<b>98</b> 84 [31,200]	<b>96</b> 80 [31,200]	<b>94</b> 77 [31,200]	<b>85</b> 66 [31,200]	<b>107</b> 98 [31,200]	<b>98</b> 84 [31,200]	<b>91</b> 73 [31,200]	<b>73</b> 65 [28,162]
	Med $C_{tot}^S$	80 [65,118]	94 [65,140]	86 [65,127]	83 [65,122]	79 [65,117]	68 [63,102]	98 [65,149]	86 [65,127]	75 [63,112]	65 [58,80]
	$C_{west}^S$	<b>65</b> 56 [20,148]	<b>65</b> 58 [13,154]	<b>64</b> 56 [16,151]	<b>64</b> 55 [17,150]	<b>64</b> 55 [19,148]	<b>62</b> 53 [23,139]	<b>65</b> 57 [13,156]	<b>64</b> 54 [16,151]	<b>62</b> 54 [18,145]	<b>57</b> 52 [22,115]
	$C_{south}^S$	<b>29</b> 21 [2,87]	<b>38</b> 32 [5,100]	<b>34</b> 27 [5,92]	<b>32</b> 25 [5,89]	<b>30</b> 23 [5,87]	<b>24</b> 14 [3,74]	<b>42</b> 39 [5,104]	<b>34</b> 32 [5,92]	<b>28</b> 25 [5,82]	<b>16</b> 13 [2,47]
	$C_{west}^S / C_{tot}^S$	0.75 [0.40,0.95]	0.60 [0.40,0.91]	0.63 [0.40,0.92]	0.64 [0.40,0.93]	0.65 [0.40,0.93]	0.80 [0.40,0.94]	0.52 [0.40,0.91]	0.56 [0.40,0.92]	0.60 [0.44,0.93]	0.80 [0.55,0.95]
	$MAV_{tot}^S$	0.47 [0.26,0.50]	0.50 [0.27,0.50]	0.49 [0.26,0.50]	0.48 [0.26,0.50]	0.48 [0.25,0.50]	0.45 [0.22,0.50]	0.50 [0.26,0.50]	0.49 [0.26,0.50]	0.46 [0.24,0.50]	0.35 [0.07,0.50]
	$MAV_{west}^S$	0.37 [0.22,0.49]	0.45 [0.23,0.61]	0.40 [0.26,0.54]	0.39 [0.27,0.51]	0.42 [0.25,0.51]	0.36 [0.20,0.50]	0.50 [0.26,0.63]	0.43 [0.26,0.55]	0.44 [0.25,0.51]	0.30 [0.14,0.50]
	$MAV_{south}^S$	0.71 [0.50,0.91]	0.53 [0.39,0.82]	0.58 [0.41,0.83]	0.59 [0.43,0.84]	0.61 [0.44,0.85]	0.71 [0.50,0.90]	0.50 [0.38,0.79]	0.54 [0.41,0.83]	0.57 [0.41,0.84]	0.59 [0.38,0.86]

## Appendix B: Additional results for preventative red flags

Tables B.1 to B.3 give performance statistics for the following alternative CMPs:

- CMP1-40: as defined in the main text.
- No Dir Catch: sardine bycatch only, no directed sardine catch.
- Explicit Prop=0.4: Continues using the same HCR formula when the red flag is raised, but catch is split 40:60 (west:east) during years for which the red flag is raised.
- Implicit  $x$ \*TAC: Continues using implicit spatial management when the red flag is raised, but the total TAC becomes a proportion ( $x < 1$ ) of the TAC during years for which the red flag is raised.
- Implicit  $\beta=x$ : Continues using implicit spatial management when the red flag is raised, but a different  $\beta$  control parameter is used in the HCR formula during years for which the red flag is raised.

In all preventative red flag cases considered, the red flag is raised and affects the TAC in year  $y$  only, based on the survey estimate of biomass west of Cape Agulhas in November of year  $y-1$ .

Two new performance statistics are included in the tables:

$p(B_w^S < 150)$  – the probability that the west component biomass falls below 150 000t during the projection period, and  
 Low :  $C_{tot}^S$  – the average total catch from the 10% of simulations corresponding to the CMP1-40 projected lowest west component spawner biomass.

- Explicit spatial management performs well in that  $Risk_S$  and  $p(B_w^S < 150)$  are lowered for the same  $\beta$ , and that for the same  $Risk_S$ , higher total catches than under CMP1-40 could be expected, though the west coast catch remains similar.
- The Implicit  $x$ \*TAC alternatives outperform the Implicit  $\beta=x$  cases. This is likely due to no change in the TAC for low values of survey estimated biomass under the Implicit  $\beta=x$  cases; a lower  $\beta$  does not alter the Critical Biomass metarule.
- $Risk_S$  and  $p(B_w^S < 150)$  increase as the red flag threshold is decreased from a survey estimate of biomass west of Cape Agulhas of 200 000t to 100 000t.

**Table B.1.** Summary performance statistics for a no directed catch scenario, CMP1-40 and alternative CMPs using different explicit and implicit spatial management scenarios once the **red flag** of a survey estimated sardine biomass west of Cape Agulhas being less than **200 000t is raised**. 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. The **red** values indicate similarity between CMPs.

Prop≥0.4		No Dir Catch	CMP1-40	Corrective measure, 'red flag' at $B_{west,y-1}^{obs,S} < 200$										
Corrective Measure once red flag raised:		N/A	N/A	Explicit Prop=0.4	Implicit 0.75*TAC	Implicit 0.50*TAC	Implicit 0*TAC	Explicit Prop=0.4	Implicit $\beta = 0.137$	Implicit 0.75*TAC	Implicit 0.50*TAC	Implicit 0*TAC	Implicit 0.50*TAC	Implicit 0.75*TAC
Risk stats	$\beta$	0	<b>0.144</b>	<b>0.144</b>	<b>0.144</b>	<b>0.144</b>	<b>0.144</b>	<b>0.189</b>	0.150	<b>0.189</b>	<b>0.189</b>	<b>0.189</b>	0.183	0.164
	$Risk_{\zeta}$	0.096	<b>0.200</b>	0.182	0.183	0.167	0.136	<b>0.200</b>	<b>0.200</b>	<b>0.200</b>	0.182	0.144	0.180	0.190
	$p(TAC^S < 20)$	-	0.03	0.02	0.03	0.04	0.06	0.02	0.03	0.03	0.04	0.06	0.04	0.03
	$p(B_w^S < 150)$	0.079	0.141	0.129	0.130	0.122	0.102	0.140	0.141	0.139	0.129	0.105	0.128	0.134
Biomass statistics	$B_{tot,2036}^S$	<b>391 340</b> [156,801]	<b>282 241</b> [87,633]	<b>286 244</b> [89,634]	<b>290 247</b> [98,637]	<b>298 254</b> [103,640]	<b>313 267</b> [117,663]	<b>270 227</b> [74,620]	<b>281 240</b> [87,632]	<b>276 233</b> [86,622]	<b>285 239</b> [94,623]	<b>302 256</b> [111,639]	<b>286 240</b> [96,626]	<b>284 241</b> [95,627]
	$B_{tot,min}^S$	158 [92,237]	108 [40,190]	110 [42,192]	115 [50,195]	122 [59,203]	132 [73,213]	99 [33,185]	107 [40,189]	107 [43,189]	114 [51,196]	126 [65,205]	116 [52,196]	111 [47,193]
	$B_{west,min}^S$	26 [7,67]	16 [1,49]	18 [1,51]	17 [2,50]	19 [3,51]	22 [6,54]	16 [1,49]	16 [1,49]	16 [2,48]	18 [3,49]	22 [5,53]	18 [3,49]	17 [2,49]
Catch statistics	$C_{tot}^S$	<b>5 0</b> [0,65]	<b>94 77</b> [31,200]	<b>94 78</b> [31,200]	<b>88 71</b> [20,200]	<b>83 65</b> [12,200]	<b>73 65</b> [0,200]	<b>108 99</b> [31,200]	<b>95 78</b> [31,200]	<b>100 86</b> [21,200]	<b>94 80</b> [12,200]	<b>83 72</b> [0,200]	<b>93 78</b> [12,200]	<b>94 77</b> [21,200]
	Med $C_{tot}^S$	0 [0,0]	80 [65,118]	80 [65,118]	72 [49,112]	67 [34,110]	65 [0,111]	99 [65,150]	80 [65,119]	87 [55,141]	81 [40,141]	77 [0,142]	79 [39,137]	79 [52,126]
	Low : $C_{tot}^S$	<b>5 0</b>	<b>76 65</b>	<b>77 65</b>	<b>71 65</b>	<b>66 53</b>	<b>56 31</b>	<b>85 70</b>	<b>76 65</b>	<b>80 65</b>	<b>75 60</b>	<b>64 31</b>	<b>74 60</b>	<b>75 65</b>
	$C_{west}^S$	<b>4 0</b> [0,26]	<b>65 56</b> [20,148]	<b>60 51</b> [13,148]	<b>63 54</b> [16,148]	<b>60 51</b> [10,149]	<b>52 50</b> [0,150]	<b>65 55</b> [13,156]	<b>65 56</b> [20,149]	<b>68 58</b> [16,156]	<b>65 55</b> [11,156]	<b>57 53</b> [0,158]	<b>65 54</b> [11,156]	<b>65 56</b> [16,153]
	$C_{south}^S$	<b>1 0</b> [0,5]	<b>29 21</b> [2,87]	<b>35 30</b> [5,90]	<b>25 17</b> [1,81]	<b>23 13</b> [1,78]	<b>20 9</b> [0,79]	<b>43 39</b> [5,107]	<b>29 21</b> [3,88]	<b>32 23</b> [2,95]	<b>29 19</b> [1,95]	<b>26 13</b> [0,96]	<b>28 18</b> [1,93]	<b>29 20</b> [1,89]
	$C_{west}^S / C_{tot}^S$	-	0.75 [0.40,0.95]	0.59 [0.40,0.93]	0.77 [0.40,0.96]	0.80 [0.43,0.97]	0.77 <sup>7</sup> [0.00,1.00]	0.53 [0.40,0.90]	0.74 [0.40,0.95]	0.73 [0.40,0.95]	0.77 [0.40,0.96]	0.72 <sup>6</sup> [0.00,1.00]	0.77 [0.40,0.96]	0.76 [0.40,0.95]
	$MAV_{tot}^S$	-	0.47 [0.26,0.50]	0.48 [0.25,0.50]	0.50 [0.31,0.62]	0.59 [0.37,0.75]	0.89 [0.23,1.00]	0.50 [0.26,0.50]	0.48 [0.26,0.50]	0.54 [0.31,0.62]	0.63 [0.36,0.75]	0.88 [0.20,1.00]	0.62 [0.36,0.75]	0.52 [0.32,0.62]
	$MAV_{west}^S$	-	0.37 [0.22,0.49]	0.50 [0.30,0.65]	0.43 [0.26,0.58]	0.50 [0.29,0.69]	0.65 [0.21,1.00]	0.50 [0.29,0.65]	0.37 [0.23,0.49]	0.44 [0.26,0.57]	0.51 [0.30,0.69]	0.65 [0.19,1.00]	0.51 [0.30,0.68]	0.43 [0.26,0.58]
	$MAV_{south}^S$	-	0.71 [0.50,0.91]	0.54 [0.40,0.84]	0.79 [0.57,0.97]	0.87 [0.63,1.00]	1.00 [0.51,1.00]	0.50 [0.38,0.78]	0.71 [0.50,0.90]	0.79 [0.54,0.95]	0.88 [0.66,1.00]	1.00 [0.46,1.00]	0.87 [0.66,1.00]	0.80 [0.55,0.95]

<sup>7</sup> These medians and 5%iles are skewed downward, as  $C_{west}^S / C_{tot}^S$  was assumed to = 0 whenever  $C_{tot}^S = 0$ , i.e. whenever the red flag was raised.

**Table B.2.** Summary performance statistics for a no directed catch scenario, CMP1-40 and alternative CMPs using different explicit and implicit spatial management scenarios once the **red flag** of a survey estimated sardine biomass west of Cape Agulhas being less than **150 000t is raised**. 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. The **red** values indicate similarity between CMPs.

Prop≥0.4		No Dir Catch	CMP1-40	Corrective measure, 'red flag' at $B_{west,y-1}^{obs,S} < 150$										
Corrective Measure once red flag raised:		N/A	N/A	Explicit Prop=0.4	Implicit 0.78*TAC	Implicit 0.50*TAC	Implicit 0*TAC	Explicit Prop=0.4	Implicit $\beta = 0.129$	Implicit 0.78*TAC	Implicit 0.50*TAC	Implicit 0*TAC	Implicit 0.50*TAC	Implicit 0.78*TAC
Risk stats	$\beta$	0	<b>0.144</b>	<b>0.144</b>	<b>0.144</b>	<b>0.144</b>	<b>0.144</b>	<b>0.179</b>	0.150	<b>0.179</b>	<b>0.179</b>	<b>0.179</b>	0.167	0.155
	$Risk_{\zeta}$	0.096	<b>0.200</b>	0.186	0.187	0.175	0.146	<b>0.200</b>	<b>0.200</b>	<b>0.200</b>	0.184	0.154	0.181	0.191
	$p(TAC^S < 20)$	-	0.03	0.02	0.03	0.04	0.05	0.02	0.03	0.03	0.04	0.06	0.04	0.03
	$p(B_w^S < 150)$	0.079	0.141	0.132	0.133	0.126	0.109	0.141	0.141	0.140	0.131	0.112	0.129	0.135
Biomass statistics	$B_{tot,2036}^S$	<b>391 340</b> [156,801]	<b>282 241</b> [87,633]	<b>285 243</b> [88,634]	<b>288 245</b> [97,634]	<b>294 250</b> [102,637]	<b>305 260</b> [112,648]	<b>272 229</b> [80,623]	<b>281 240</b> [87,632]	<b>276 232</b> [87,624]	<b>283 237</b> [95,624]	<b>296 251</b> [106,637]	<b>287 241</b> [96,627]	<b>284 241</b> [94,630]
	$B_{tot,min}^S$	158 [92,237]	108 [40,190]	110 [42,191]	113 [48,194]	119 [58,200]	128 [68,209]	101 [37,187]	107 [41,189]	106 [43,188]	113 [51,192]	122 [63,203]	116 [53,196]	111 [46,192]
	$B_{west,min}^S$	26 [7,67]	16 [1,49]	17 [1,50]	17 [2,50]	18 [3,50]	21 [5,52]	16 [1,49]	16 [1,49]	16 [1,48]	18 [3,49]	20 [5,52]	18 [3,49]	17 [2,49]
Catch statistics	$C_{tot}^S$	<b>5 0</b> [0,65]	<b>94 77</b> [31,200]	<b>94 78</b> [31,200]	<b>90 74</b> [23,200]	<b>86 69</b> [14,200]	<b>79 68</b> [0,200]	<b>105 94</b> [31,200]	<b>95 79</b> [31,200]	<b>100 87</b> [23,200]	<b>96 83</b> [14,200]	<b>88 82</b> [0,200]	<b>92 79</b> [14,200]	<b>93 78</b> [23,200]
	Med $C_{tot}^S$	0 [0,0]	80 [65,118]	80 [65,118]	75 [55,112]	71 [41,111]	70 [17,112]	96 [65,142]	80 [65,119]	88 [59,137]	84 [47,135]	83 [18,136]	79 [45,127]	79 [57,120]
	Low : $C_{tot}^S$	<b>5 0</b>	<b>76 65</b>	<b>77 65</b>	<b>73 65</b>	<b>69 65</b>	<b>62 65</b>	<b>83 67</b>	<b>76 65</b>	<b>80 65</b>	<b>76 65</b>	<b>69 65</b>	<b>74 65</b>	<b>75 65</b>
	$C_{west}^S$	<b>4 0</b> [0,26]	<b>65 56</b> [20,148]	<b>61 54</b> [13,148]	<b>64 55</b> [17,148]	<b>62 54</b> [12,148]	<b>57 54</b> [0,149]	<b>66 57</b> [13,155]	<b>66 57</b> [20,149]	<b>68 59</b> [17,155]	<b>66 57</b> [12,155]	<b>60 58</b> [0,156]	<b>65 56</b> [12,154]	<b>65 56</b> [17,151]
	$C_{south}^S$	<b>1 0</b> [0,5]	<b>29 21</b> [2,87]	<b>33 26</b> [5,89]	<b>26 18</b> [2,83]	<b>24 15</b> [1,81]	<b>22 13</b> [0,81]	<b>39 33</b> [5,102]	<b>29 21</b> [3,88]	<b>32 23</b> [2,94]	<b>30 20</b> [1,94]	<b>28 17</b> [0,95]	<b>28 18</b> [1,90]	<b>28 20</b> [2,88]
	$C_{west}^S / C_{tot}^S$	-	0.75 [0.40,0.95]	0.66 [0.40,0.93]	0.76 [0.40,0.96]	0.79 [0.41,0.97]	0.77 <sup>e</sup> [0.00,1.00]	0.61 [0.40,0.92]	0.74 [0.40,0.95]	0.73 [0.40,0.95]	0.76 [0.40,0.96]	0.73 <sup>e</sup> [0.00,1.00]	0.77 [0.40,0.96]	0.75 [0.40,0.95]
	$MAV_{tot}^S$	-	0.47 [0.26,0.50]	0.48 [0.25,0.50]	0.50 [0.28,0.61]	0.52 [0.34,0.75]	0.70 [0.31,1.00]	0.50 [0.27,0.50]	0.48 [0.26,0.50]	0.50 [0.29,0.61]	0.56 [0.32,0.75]	0.72 [0.28,1.00]	0.55 [0.33,0.75]	0.50 [0.28,0.61]
	$MAV_{west}^S$	-	0.37 [0.22,0.49]	0.47 [0.25,0.50]	0.41 [0.24,0.55]	0.48 [0.28,0.67]	0.56 [0.25,1.00]	0.48 [0.27,0.63]	0.37 [0.22,0.49]	0.42 [0.25,0.55]	0.48 [0.28,0.67]	0.56 [0.26,1.00]	0.48 [0.28,0.67]	0.41 [0.24,0.55]
	$MAV_{south}^S$	-	0.71 [0.50,0.91]	0.59 [0.42,0.86]	0.77 [0.55,0.95]	0.85 [0.60,1.00]	1.00 [0.60,1.00]	0.57 [0.41,0.83]	0.71 [0.50,0.91]	0.77 [0.54,0.94]	0.85 [0.59,1.00]	1.00 [0.57,1.00]	0.85 [0.60,1.00]	0.77 [0.54,0.95]

**Table B.3.** Summary performance statistics for a no directed catch scenario, CMP1-40 and alternative CMPs using different explicit and implicit spatial management scenarios once the **red flag** of a survey estimated sardine biomass west of Cape Agulhas being less than **100 000t is raised**. 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. The **red** values indicate similarity between CMPs.

Prop≥0.4 Corrective Measure once red flag raised:		No Dir Catch N/A	CMP1-40 N/A	Corrective measure, 'red flag' at $B_{west,y-1}^{obs,S} < 100$										
				Explicit Prop=0.4	Implicit 0.81*TAC	Implicit 0.50*TAC	Implicit 0*TAC	Explicit Prop=0.4	Implicit $\beta = 0.126$	Implicit 0.81*TAC	Implicit 0.50*TAC	Implicit 0*TAC	Implicit 0.50*TAC	Implicit 0.81*TAC
Risk stats	$\beta$	0	<b>0.144</b>	<b>0.144</b>	<b>0.144</b>	<b>0.144</b>	<b>0.144</b>	<b>0.166</b>	0.150	<b>0.166</b>	<b>0.166</b>	<b>0.166</b>	0.155	0.149
	$Risk_{\zeta}$	0.096	<b>0.200</b>	0.191	0.192	0.182	0.161	<b>0.200</b>	<b>0.200</b>	<b>0.200</b>	<b>0.200</b>	0.189	0.167	0.194
	$p(TAC^S < 20)$	-	0.03	0.02	0.03	0.03	0.04	0.02	0.02	0.03	0.03	0.03	0.04	0.03
	$p(B_w^S < 150)$	0.079	0.141	0.135	0.136	0.129	0.117	0.141	0.141	0.141	0.133	0.120	0.131	0.137
Biomass statistics	$B_{tot,2036}^S$	<b>391 340</b> [156,801]	<b>282 241</b> [87,633]	<b>284 242</b> [87,634]	<b>285 243</b> [94,634]	<b>290 246</b> [97,634]	<b>297 250</b> [104,648]	<b>276 234</b> [81,627]	<b>281 240</b> [87,632]	<b>278 235</b> [87,627]	<b>283 239</b> [93,627]	<b>291 244</b> [99,637]	<b>286 242</b> [95,630]	<b>284 241</b> [93,632]
	$B_{tot,min}^S$	158 [92,237]	108 [40,190]	109 [41,191]	111 [45,192]	117 [52,196]	123 [63,200]	104 [38,187]	107 [41,188]	106 [42,189]	112 [48,191]	119 [60,195]	114 [50,195]	110 [43,191]
	$B_{west,min}^S$	26 [7,67]	16 [1,49]	17 [1,50]	17 [2,50]	18 [3,50]	20 [4,51]	16 [1,49]	16 [1,49]	16 [1,48]	17 [2,49]	19 [4,50]	17 [3,49]	16 [2,49]
Catch statistics	$C_{tot}^S$	<b>5 0</b> [0,65]	<b>94 77</b> [31,200]	<b>94 78</b> [31,200]	<b>92 76</b> [26,200]	<b>89 73</b> [16,200]	<b>85 73</b> [0,200]	<b>101 88</b> [31,200]	<b>95 79</b> [31,200]	<b>99 85</b> [26,200]	<b>96 83</b> [16,200]	<b>92 83</b> [0,200]	<b>93 78</b> [16,200]	<b>93 78</b> [26,200]
	Med $C_{tot}^S$	0 [0,0]	80 [65,118]	80 [65,118]	78 [60,115]	75 [55,115]	74 [48,115]	90 [65,133]	82 [65,119]	86 [62,130]	84 [56,129]	84 [48,131]	80 [55,122]	79 [61,118]
	Low : $C_{tot}^S$	<b>5 0</b>	<b>76 65</b>	<b>77 65</b>	<b>74 65</b>	<b>71 65</b>	<b>68 65</b>	<b>81 65</b>	<b>76 65</b>	<b>79 65</b>	<b>76 65</b>	<b>72 65</b>		<b>75 65</b>
	$C_{west}^S$	<b>4 0</b> [0,26]	<b>65 56</b> [20,148]	<b>63 55</b> [13,148]	<b>64 56</b> [19,148]	<b>63 55</b> [14,148]	<b>61 56</b> [0,149]	<b>66 58</b> [13,153]	<b>66 57</b> [20,149]	<b>67 58</b> [19,153]	<b>66 58</b> [14,153]	<b>63 58</b> [0,154]	<b>65 57</b> [14,151]	<b>65 56</b> [19,149]
	$C_{south}^S$	<b>1 0</b> [0,5]	<b>29 21</b> [2,87]	<b>31 23</b> [4,88]	<b>28 20</b> [2,85]	<b>26 18</b> [1,84]	<b>25 16</b> [0,84]	<b>35 27</b> [5,97]	<b>29 21</b> [3,88]	<b>31 23</b> [2,94]	<b>30 20</b> [1,93]	<b>28 19</b> [0,93]	<b>28 19</b> [1,88]	<b>28 20</b> [2,87]
	$C_{west}^S / C_{tot}^S$	-	0.75 [0.40,0.95]	0.71 [0.40,0.94]	0.76 [0.40,0.95]	0.77 [0.40,0.96]	0.77 <sup>6</sup> [0.00,1.00]	0.68 [0.40,0.93]	0.74 [0.40,0.95]	0.73 [0.40,0.95]	0.75 [0.40,0.95]	0.74 <sup>6</sup> [0.00,1.00]	0.77 [0.40,0.96]	0.75 [0.40,0.95]
	$MAV_{tot}^S$	-	0.47 [0.26,0.50]	0.47 [0.25,0.50]	0.50 [0.26,0.59]	0.50 [0.28,0.75]	0.50 [0.29,1.00]	0.50 [0.27,0.50]	0.48 [0.26,0.50]	0.50 [0.27,0.59]	0.50 [0.30,0.75]	0.50 [0.29,1.00]	0.50 [0.29,0.75]	0.50 [0.27,0.59]
	$MAV_{west}^S$	-	0.37 [0.22,0.49]	0.43 [0.24,0.58]	0.39 [0.23,0.52]	0.43 [0.26,0.61]	0.46 [0.25,1.00]	0.43 [0.25,0.58]	0.37 [0.22,0.50]	0.39 [0.23,0.53]	0.44 [0.26,0.62]	0.47 [0.26,1.00]	0.44 [0.26,0.62]	0.39 [0.23,0.53]
	$MAV_{south}^S$	-	0.71 [0.50,0.91]	0.65 [0.46,0.88]	0.75 [0.52,0.94]	0.81 [0.56,0.99]	0.93 [0.58,1.00]	0.64 [0.44,0.87]	0.71 [0.50,0.91]	0.74 [0.53,0.93]	0.81 [0.56,0.98]	0.94 [0.57,1.00]	0.81 [0.56,0.99]	0.75 [0.53,0.94]