

# Multiple sardine Operating Models and associated risk

C.L. de Moor\*

Correspondence email: [carryn.demoor@uct.ac.za](mailto:carryn.demoor@uct.ac.za)

A new Candidate Management Procedure (CMP), "CMP1", is tuned to updated baseline sardine and anchovy Operating Models (OMs), maintaining the same constraints as that for Interim OMP-18. Another CMP, "CMP2" is also shown, tuned to the sardine OM which assumes 60% of south coast spawner biomass contributes to west coast 'effective' spawner biomass. The performance statistics resulting from applying these two CMPs under eight alternative sardine OMs are shown.

## Introduction

Development of a new Operational Management Procedure (OMP) for South African sardine and anchovy has mostly progressed by considering a single sardine Operating Model only (e.g. de Moor 2018a). However, a Reference Set of Operating Models (OMs) has been proposed for sardine to incorporate alternative hypotheses on the proportion of south component spawner biomass that forms part of the west component 'effective' spawner biomass, and on the annually varying proportions of west component sardine that move to the south (de Moor 2017, de Moor et al. 2018).

Work thus far has focused on an Operating Model (OM1) with a proportion,  $p = 0.08$ , of south component spawner biomass that forms part of west component effective spawner biomass and using the MoveR hypothesis, in which future west-to-south movement is randomly drawn from that estimated in recent years.

## Method

### *Updated Operating Model*

The Operating Model used to simulation test Candidate Management Procedures (CMPs) for South African sardine and anchovy has been updated from that used to develop Interim OMP-18 with the following primary changes (de Moor 2018b):

- i) Final known catches by area, and TACs for 2017 and 2018 have been incorporated;
- ii) A new model for simulating recruitment to the south component is now used (de Moor 2018c).

A new Candidate Management Procedure ("CMP1"), maintaining all the same constraints as Interim OMP-18, was retuned for OM1. This retuning was done based on the following two assumptions:

- a) The anchovy risk - *the probability of anchovy spawner biomass being below a quarter of the historical minimum spawner biomass (1996) level over the 20 year projection period* - resulting from projecting OMP-14 anchovy HCRs using OM1 ( $Risk_A = 0.109$ ) was then used to tune the  $\alpha$  control parameter for CMP1.
- b) The  $\beta$  control parameter was selected so that the 20%ile of the projected sardine total biomass distribution under CMP1 was 68% of that projected under a no catch scenario (Table 1).

Another CMP ("CMP2"), also maintaining all the same constraints as Interim OMP-18, was retuned for OM2 which assumes

---

\* MARAM (Marine Resource Assessment and Management Group), Department of Mathematics and Applied Mathematics, University of Cape Town, Rondebosch, 7701, South Africa.

$p = 0.6$  and MoveR. The  $\beta$  control parameter was selected so that the 20%ile of the projected sardine total biomass distribution under CMP2 was 68% of that projected under a no catch scenario using OM2 (Table 1).

### *Alternative Operating Models*

The full suite of eight sardine OMs considered include values of 0%, 8%, 20% and 60% for the proportion of south component spawner biomass forming part of the west component effective spawner biomass and the two movement hypotheses MoveR and Moved (de Moor et al. 2018).

## **Results and discussion**

### *CMP1 under OM1*

CMP1 has substantially higher control parameter values than that of Interim OMP-18 with higher simulated catches and higher risks to the sardine ( $Risk_S$ ) and anchovy ( $Risk_A$ ) resources than that simulated using the old OM (Table 2).

There is no change in the projected anchovy dynamics from the previous OM to OMP1 under a no catch scenario, with a 2.5% risk (Table 2). This is because the primary change in OM1 that directly affects anchovy is the 2017 catches and 2018 TAC. However, as the OMP-14 anchovy HCRs result in a higher risk to the anchovy resource under OM1, compared to that under the previous OM, CMP1 has been tuned to this higher risk level of 10.9%. This results in a higher  $\alpha$  and higher projected catches, but with a lower projected final biomass, minimum biomass and depletion than that for Interim OMP-18. There is also a higher chance of the Critical Biomass metarule being employed. Figures 1 and 2 show the projected anchovy biomass and spawner biomass, respectively. While anchovy has a relatively lower risk threshold than sardine (a quarter of the historical minimum spawner biomass), it is worth noting that the spawner biomass is simulated to breach this threshold only after 5 years; the high variability in anchovy recruitment results in a wide projected distribution of future (spawner) biomass.

The first change to OM1 from the previous OM resulted in a CMP that was tuned to a lower  $\beta$  value. This was primarily as a result of finalising the split of 2017 catches on the west and south coasts, and finalising the 2018 TAC. The second change to OM1 resulted in a more positive outlook for the south component due to higher future recruitments to this component being projected (de Moor 2018c). The increase in sardine catches under CMP1 compared to Interim OMP-18 is thus primarily allocated to south coast catches (Table 2). The south component final biomass, minimum biomass and depletion are all higher than that projected under Interim OMP-18 with the previous OM. However, as the CMP is tuned based on total biomass (Table 1), there is some decrease in the projected final biomass, minimum biomass and depletion of the west component. The increase in south component biomass (from higher average recruitment) is also projected to result in the Critical Biomass metarule being employed less frequently. Figures 3 and 4 show the projected sardine biomass and effective spawner biomass, respectively. The sardine effective spawner biomass is projected to recover (in median terms by 53%) fairly rapidly under a no catch scenario, but under CMP1 a minimal increase (9% in median terms) is expected. At the end of the projection period under CMP1, the 20%ile of the west component spawner biomass distribution is 57% of that under a no future catch scenario (Table 1b).

*OM2 compared to OM1*

The population is projected to recover to a slightly higher biomass under OM2 (with  $p = 0.6$ ) compared to OM1 (Figure 5), with the median total biomass in 2036 being 976 000t for OM2 compared to 953 000t for OM1 and the 20%ile used in the “leftward shift” being 692 000t for OM2 and 663 000t for OM1. While the effective spawner biomass for the two OMs differ substantially for each component, there is little difference in the total effective spawner biomass (Figure 6). The sardine risk – *the probability of the sardine west component effective spawner biomass being below the 2007 level over the projection period* – increases from 7% under OM1 to 9% under OM2.

*CMP2 under OM2*

CMP2 was tuned assuming OM2 (Table 1), resulting in  $\beta = 0.208$ . While the ‘leftward shift’ tuning ensures the 20%ile of the distribution of total biomass at the end of the projection period is 68% of that under a no catch scenario, the 20%ile of the effective west component spawner biomass is 55% of that under a no catch scenario (Table 1b). This CMP results in a 32% chance ( $Risk_S$ ) of the west component spawner biomass being below the 2007 level over the projection period. This is an increase of 23% in  $Risk_S$  under fishing compared to a no fishing scenario. CMP1, in contrast, had an increase of 13% (Table 2). The sardine directed catch is simulated to be higher under CMP2 assuming OM2 than under CMP1 assuming OM1, with a slightly greater proportion of the catch taken on the south coast. Figures 7 and 8 show the projected sardine biomass and effective spawner biomass, respectively.

*CMP1 and CMP2 under all OMs*

For a given CMP, the average projected catch increases by 5 to 8% as  $p$  increases from 0 to 0.6 (Table 3). However,  $Risk_S$  increases by 49 to 65% as  $p$  increases from 0 to 0.6 (Table 3, Figure 9). When the movement hypothesis is changed from MoveR to MoveD, the catches increase slightly and  $Risk_S$  decreases (Table 3).

$Risk_S$  and total sardine catch resulting when weighting results from all OMs using two example weighting methods are given in Table 4.

**Key points for SPSWG discussion and next steps**

- The tuning of the CMP to anchovy risk assumes that the risk associated with OMP-14 (which was tuned using an OM conditioned on data up to 2011) is acceptable under OMs conditioned on data up to 2015. Is this an appropriate assumption? For CMP1, this results in an anchovy risk of 11%, which appears to be rather high given the low risk threshold, and is higher than that which resulted when this method was first applied without the 2018 TAC being finalised. However, is this sufficiently mitigated by:
  - i) The spawner biomass is only projected to breach the risk threshold after about 5 years; a new OMP should be developed before then.
  - ii) The OM assumes a Beverton Holt stock recruitment relationship fit to all years of recruitment and spawner biomass. A robustness test that assumes a Beverton Holt stock recruitment relationship fit to data from 2000 onwards only may result in a lower anchovy risk. However, one cannot predict how long the current “higher recruitment regime” will last.

- The tuning of the CMP for the sardine control parameter,  $\beta$ , is based upon the 'leftward shift' method which forces the 20%ile of total biomass at the end of the 20 year projection period to be 68% of that under a no catch scenario. This method has been employed during the development of previous OMPs. However, OMP-18 development has used a new risk threshold based on the west component effective spawner biomass, rather than total biomass. This can create some confusion between the 'equivalent' CMPs tuned using the leftward shift method (using total biomass) and resulting different  $Risk_S$  levels (based on effective west component spawner biomass). The 'leftward shift' method results in relative high probabilities (20% for CMP1 and 32% for CMP2) of the future west component effective spawner biomass falling below that estimated in 2007, which was the historically lowest level for  $p = 0.08$ . Is this an appropriate risk level?
- It is worth noting, as has been seen in previous projection analyses, that the natural mortality assumed for sardine, together with a plus group, may result in over-optimistic projections for sardine biomass. The total survey estimate of biomass in 2016 (converted to total biomass through the distribution for survey bias to a median of 365 000t with 90% probability interval (PI) of [316 000t,426 000t]) was much lower than that simulated under OM1 and OM2 (Figures 3,7). 80% of that 'observed distribution' was less than the lower simulated 5%ile! The total survey estimate of biomass in 2017 (converted to a median of 473 000t with 90% PI of [409 000t, 551 000t]), while mostly above the 5%ile of that simulated, was still much lower in median terms than that simulated. As information from recruit surveys in 2016 and 2017 have already been used in the OMs (de Moor 2018b), this may indicate the OMs accumulate more biomass than in reality.
- It is possible to tune a single CMP to a combined reference set of the eight OMs. This, however, requires an agreed weighting of all the OMs. Weightings thus far have only been provided by 4 members and one observer of the PWG, and require input and/or comment from the PWG prior to finalisation.

### Acknowledgements

The SWG-PEL OMP Task Team members are thanked for their comments on initial analyses.

### References

- de Moor CL. 2017. A summary of the operating models being used to simulation test OMP-18 for South African sardine and anchovy. MARAM International Stock Assessment Workshop, December 2017, Cape Town. Document MARAM/IWS/2017/Sardine/P6.
- de Moor CL. 2018a. Interim OMP-18. DAFF: Branch Fisheries Document FISHERIES/2018/AUG/SWG-PEL/24.
- de Moor CL. 2018b. Simulation testing framework used during OMP-18 development. DAFF: Branch Fisheries Document FISHERIES/2018/SEP/SWG-PEL/27.
- de Moor CL. 2018c. Recruitment to the south component of South African sardine. DAFF: Branch Fisheries Document FISHERIES/2018/SEP/SWG-PEL/25.
- de Moor CL, Bergh M, Butterworth DS, Coetzee JC and van der Lingen CD. 2018. Density dependent movement of South African sardine. DAFF: Branch Fisheries Document FISHERIES/2018/MAR/SWG-PEL/02.

**Table 1a.** The ratio of the lower percentiles of the distribution of sardine biomass at the end of the projection period under a catch compared to a no future catch scenario. Results are shown for CMP1 tuned assuming OM1 ( $p = 0.08$  and Mover) and CMP2 tuned assuming OM2 ( $p = 0.6$  and Mover).

		Total				West Component		South Component	
		OMP-08	OMP-14	$\beta = 0.173$	$\beta = 0.174$	$\beta = 0.173$	$\beta = 0.174$	$\beta = 0.173$	$\beta = 0.174$
CMP1 with OM1	10%ile	0.50	0.59	0.64	0.64	0.67	0.67	0.59	0.59
	20%ile	<b>0.68</b>	<b>0.68</b>	0.69	0.68	0.71	0.71	0.65	0.65
	30%ile	0.72	0.73	0.71	0.71	0.73	0.73	0.68	0.68
	40%ile	0.73	0.76	0.73	0.73	0.76	0.76	0.70	0.70
	50%ile	0.72	0.78	0.74	0.74	0.76	0.76	0.71	0.71
		OMP-08	OMP-14	$\beta = 0.207$	$\beta = 0.208$	$\beta = 0.207$	$\beta = 0.208$	$\beta = 0.207$	$\beta = 0.208$
CMP2 with OM2	10%ile	0.50	0.59	0.65	0.65	0.72	0.72	0.58	0.58
	20%ile	<b>0.68</b>	<b>0.68</b>	0.69	0.68	0.73	0.73	0.63	0.63
	30%ile	0.72	0.73	0.71	0.71	0.75	0.75	0.67	0.67
	40%ile	0.73	0.76	0.73	0.73	0.77	0.77	0.68	0.68
	50%ile	0.72	0.78	0.73	0.73	0.77	0.77	0.69	0.69

**Table 1b.** The ratio of the lower percentiles of the distribution of sardine effective biomass at the end of the projection period under catch compared to a no future catch scenario, assuming OM1 ( $p = 0.08$  and Mover) and OM2 ( $p = 0.6$  and Mover).

		Total			West Component	South Component
		OMP-08	OMP-14	$\beta = 0.174$	$\beta = 0.174$	$\beta = 0.174$
CMP1 with OM1	10%ile	0.50	0.59	0.53	0.53	0.52
	20%ile	<b>0.68</b>	<b>0.68</b>	0.57	0.57	0.56
	30%ile	0.72	0.73	0.59	0.59	0.59
	40%ile	0.73	0.76	0.61	0.61	0.62
	50%ile	0.72	0.78	0.63	0.63	0.64
		OMP-08	OMP-14	$\beta = 0.208$	$\beta = 0.208$	$\beta = 0.208$
CMP2 with OM2	10%ile	0.50	0.59	0.52	0.54	0.50
	20%ile	<b>0.68</b>	<b>0.68</b>	0.54	0.55	0.53
	30%ile	0.72	0.73	0.59	0.58	0.57
	40%ile	0.73	0.76	0.60	0.60	0.60
	50%ile	0.72	0.78	0.61	0.62	0.62

**Table 2.** Key summary performance statistics for Interim OMP-18 and CMP1. 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.

		OM without (i) and (ii) listed on page 1		OM1		OM2	
		No Catch	Interim OMP-18	No Catch	CMP1	No Catch	CMP2
Risk statistics	$\beta$	-	0.144	-	0.174	-	0.208
	$Risk_S$	0.076	0.198	0.068	0.200	0.086	0.320
	$p(TAC^S < 20)$	-	0.05	-	0.02	-	0.01
Biomass statistics	$B_{tot,2036}^S$	<b>379</b> 320 [141,805]	<b>253</b> 206 [58,593]	<b>418</b> 366 [170,824]	<b>274</b> 213 [85,623]	<b>429</b> 373 [177,873]	<b>281</b> 229 [90,657]
	$B_{west,2036}^S$	<b>183</b> 136 [29,506]	<b>126</b> 86 [12,375]	<b>182</b> 136 [29,506]	<b>120</b> 82 [14,362]	<b>188</b> 141 [31,513]	<b>125</b> 84 [15,378]
	$B_{south,2036}^S$	<b>195</b> 164 [68,426]	<b>127</b> 104 [29,313]	<b>235</b> 205 [93,471]	<b>154</b> 131 [44,334]	<b>240</b> 211 [95,477]	<b>156</b> 130 [42,353]
	$B_{tot,2036}^S/B_{tot,2015}^S$	4.2 [1.3,21.3]	2.6 [0.6,14.8]	4.4 [1.5,21.4]	2.7 [0.8,14.4]	4.5 [1.5,22.0]	2.8 [0.8,15.0]
	$B_{west,2036}^S/B_{west,2015}^S$	3.0 [0.6,19.3]	1.9 [0.2,13.1]	3.0 [0.6,20.4]	1.8 [0.3,12.9]	3.2 [0.6,21.0]	1.9 [0.3,14.2]
	$B_{south,2036}^S/B_{south,2015}^S$	0.9 [0.4,2.4]	0.6 [0.2,1.7]	1.1 [0.5,2.7]	0.7 [0.2,1.9]	1.2 [0.5,2.7]	0.7 [0.2,1.9]
	$B_{tot,min}^S$	157 [92,233]	90 [30,166]	173 [111,254]	102 [40,186]	179 [116,258]	100 [43,186]
	$B_{west,min}^S$	31 [8,71]	18 [3,51]	30 [8,71]	16 [3,48]	31 [9,72]	17 [4,48]
	$B_{south,min}^S$	78 [37,134]	39 [9,88]	98 [54,161]	53 [15,108]	100 [55,167]	50 [15,108]
	$C_{tot}^S$	<b>1</b> 0 [0,28]	<b>87</b> 71 [21,200]	<b>2</b> 0 [0,31]	<b>103</b> 92 [31,200]	<b>2</b> 0 [0,31]	<b>116</b> 103 [31,200]
Med $C_{tot}^S$ <sup>1</sup>	0 [0,0]	72 [54,111]	0 [0,0]	94 [65,139]	0 [0,0]	106 [71,168]	
$C_{west}^S$	<b>1</b> 0 [0,24]	<b>62</b> 54 [15,146]	<b>1</b> 0 [0,26]	<b>68</b> 58 [19,154]	<b>1</b> 0 [0,26]	<b>74</b> 64 [22,161]	
$C_{south}^S$	<b>0</b> 0 [0,4]	<b>25</b> 17 [1,80]	<b>0</b> 0 [0,5]	<b>36</b> 26 [3,104]	<b>0</b> 0 [0,5]	<b>42</b> 32 [4,116]	
$C_{west}^S/C_{tot}^S$	0.00 [0.00,0.87]	0.77 [0.35,0.98]	0.00 [0.00,0.82]	0.72 [0.31,0.94]	0.00 [0.00,0.82]	0.69 [0.30,0.93]	
$ByC_{tot}^S$	<b>0.3</b> 0.0 [0.0,0.0]	<b>18.0</b> 10.6 [1.4,59.2]	<b>0.3</b> 0.0 [0.0,5.2]	<b>20.5</b> 11.2 [1.4,70.7]	<b>0.3</b> 0.0 [0.0,5.2]	<b>21.2</b> 11.8 [1.4,72.5]	
$ByC_{west}^S$	<b>0.3</b> 0.0 [0.0,0.0]	<b>18.0</b> 10.6 [1.4,59.2]	<b>0.3</b> 0.0 [0.0,5.2]	<b>20.5</b> 11.1 [1.3,70.7]	<b>0.3</b> 0.0 [0.0,5.2]	<b>21.2</b> 11.8 [1.4,72.5]	
$ByC_{south}^S$	<b>0.0</b> 0.0 [0.0,0.0]	<b>0.0</b> 0.0 [0.0,0.0]	<b>0.0</b> 0.0 [0.0,0.0]	<b>0.0</b> 0.0 [0.0,0.1]	<b>0.0</b> 0.0 [0.0,0.0]	<b>0.0</b> 0.0 [0.0,0.1]	
$MAV_{tot}^S$ <sup>2</sup>	-	0.50 [0.27,0.50]	-	0.50 [0.26,0.50]	-	0.48 [0.23,0.50]	
$MAV_{west}^S$	-	0.39 [0.25,0.53]	-	0.38 [0.24,0.54]	-	0.38 [0.23,0.54]	
$MAV_{south}^S$	-	0.79 [0.53,1.00]	-	0.72 [0.51,0.91]	-	0.71 [0.48,0.88]	
Critical Biomass statistics	$p(B_y^{Sobs} < B_{crit}^S, B_y < B_{crit}^S/k_N^S)$	-	0.16	-	0.10	-	0.09
	$p(B_y^{Sobs} < B_{crit}^S, B_y \geq B_{crit}^S/k_N^S)$	-	0.16	-	0.16	-	0.16
	$p(B_y^{Sobs} \geq B_{crit}^S, B_y < B_{crit}^S/k_N^S)$	-	0.08	-	0.06	-	0.06
	$p(B_y^{Sobs} \geq B_{crit}^S, B_y \geq B_{crit}^S/k_N^S)$	-	0.60	-	0.68	-	0.69

<sup>1</sup> This gives the median and 90%ile of the 1000 median (over 20 years for each simulation) catches.

<sup>2</sup> Median and 90%ile of  $AAV_y^b = |C_{tot,y}^{S,b} - C_{tot,y-1}^{S,b}|/C_{tot,y-1}^{S,b}$

Table 2 (continued).

		OM without (i) and (ii) listed on page 1		OM1		OM2	
		No Catch	Interim OMP-18	No Catch	CMP1	No Catch	CMP2
Risk statistics	$\alpha$	-	0.914	-	1.379	-	1.379
	$Risk_A$	0.026	0.082	0.026	0.109	0.026	0.109
Biomass statistics	$B_{2036}^A$	<b>1333</b> 960 [70,3678]	<b>807</b> 410 [25,2895]	<b>1333</b> 960 [70,3678]	<b>723</b> 310 [18,2807]	<b>1333</b> 960 [70,3678]	<b>723</b> 312 [18,2807]
	$B_{2036}^A/B_{2015}^A$	0.7 [0.1,2.7]	0.3 [0.0,2.1]	0.7 [0.1,2.7]	0.2 [0.0,2.0]	0.7 [0.1,2.7]	0.2 [0.0,2.0]
	$B_{min}^A$	447 [51,1130]	178 [18,729]	447 [51,1130]	138 [15,677]	447 [51,1130]	138 [15,679]
Catch statistics	$C^A$	<b>10</b> 0 [0,217]	<b>226</b> 248 [0,350]	<b>10</b> 0 [0,217]	<b>237</b> 303 [0,350]	<b>11</b> 0 [0,217]	<b>237</b> 302 [0,350]
	Med $C^A$	0 [0,0]	247 [6,350]	0 [0,0]	306 [2,350]	0 [0,0]	305 [2,350]
	$MAV^A$	-	0.22 [0.00,0.63]	-	0.14 [0.00,0.78]	-	0.14 [0.00,0.78]
Critical Biomass statistics	$p(B_y^{Aobs} < B_{crit}^A, B_y < B_{crit}^A/k_N^A)$	-	0.28	-	0.33	-	0.33
	$p(B_y^{Aobs} < B_{crit}^A, B_y \geq B_{crit}^A/k_N^A)$	-	0.02	-	0.02	-	0.02
	$p(B_y^{Aobs} \geq B_{crit}^A, B_y < B_{crit}^A/k_N^A)$	-	0.02	-	0.02	-	0.02
	$p(B_y^{Aobs} \geq B_{crit}^A, B_y \geq B_{crit}^A/k_N^A)$	-	0.68	-	0.63	-	0.63

**Table 3.** Key performance statistics for CMP1 ( $\beta = 0.174$ ) and CMP2 ( $\beta = 0.208$ ), run under eight alternative OMs. The red values indicate those which were tuned to a total biomass depletion consistent with former OMPs. Where appropriate, medians [90% probability intervals] are provided, and for some statistics the means are additionally provided in bold.

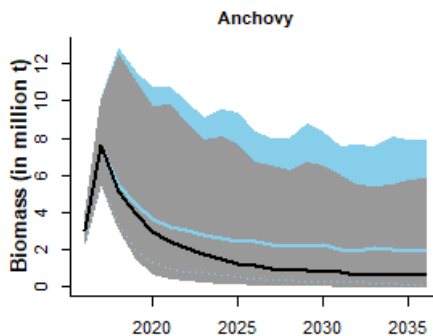
Operating Model	CMP1				CMP2				
	$Risk_S$	$C_{tot}^S$	$C_{west}^S$	$MAV_{tot}^S$	$Risk_S$	$C_{tot}^S$	$C_{west}^S$	$MAV_{tot}^S$	
MoveR	$p = 0.0$	0.199	<b>101 90</b> [26,200]	<b>66 57</b> [14,153]	0.50 [0.25,0.50]	0.204	<b>110 100</b> [27,200]	<b>69 60</b> [14,157]	0.50 [0.23,0.50]
	$p = 0.08$	<b>0.200</b>	<b>103 92</b> [31,200]	<b>68 58</b> [19,154]	<b>0.50</b> [0.26,0.50]	0.210	<b>113 100</b> [31,200]	<b>71 61</b> [18,158]	0.50 [0.24,0.50]
	$p = 0.2$	0.222	<b>105 94</b> [31,200]	<b>69 59</b> [20,156]	0.50 [0.27,0.50]	0.237	<b>114 100</b> [31,200]	<b>72 63</b> [20,159]	0.49 [0.24,0.50]
	$p = 0.6$	0.296	<b>107 97</b> [31,200]	<b>71 61</b> [22,158]	0.49 [0.26,0.50]	<b>0.320</b>	<b>116 103</b> [31,200]	<b>74 64</b> [22,161]	<b>0.48</b> [0.23,0.50]
MoveD	$p = 0.0$	0.174	<b>102 91</b> [31,200]	<b>68 58</b> [16,153]	0.50 [0.26,0.50]	0.179	<b>111 100</b> [31,200]	<b>71 62</b> [16,157]	0.50 [0.25,0.50]
	$p = 0.08$	0.175	<b>104 93</b> [31,200]	<b>69 59</b> [20,155]	0.49 [0.26,0.50]	0.183	<b>114 100</b> [31,200]	<b>73 63</b> [20,158]	0.50 [0.25,0.50]
	$p = 0.2$	0.193	<b>106 95</b> [31,200]	<b>71 61</b> [21,156]	0.49 [0.25,0.50]	0.207	<b>115 101</b> [31,200]	<b>74 64</b> [21,160]	0.49 [0.24,0.50]
	$p = 0.6$	0.276	<b>107 97</b> [31,200]	<b>72 62</b> [23,157]	0.48 [0.25,0.50]	0.296	<b>117 104</b> [31,200]	<b>75 66</b> [23,160]	0.49 [0.24,0.50]

**Table 4a.** Example weightings provided to each OM (obtained from Table 4b), and two summary performance statistics are provided for CMP1 and CMP2 over all OMs using these weightings.

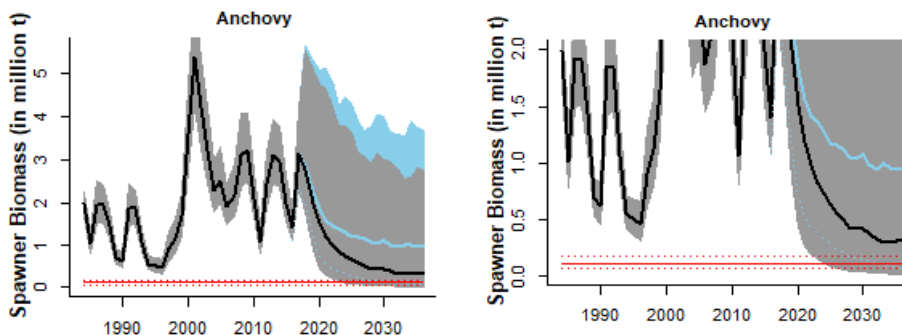
		Alt 1	Alt 2	Alt 3	Alt 4	Alt 5	Mean	Median
MoveR	$p = 0.0$	0.025	0.003	0.003	0.023	0.080	0.027	0.025
	$p = 0.08$	0.250	0.073	0.010	0.248	0.200	0.156	0.227
	$p = 0.2$	0.175	0.100	0.075	0.135	0.080	0.113	0.113
	$p = 0.6$	0.050	0.075	0.163	0.045	0.040	0.075	0.057
MoveD	$p = 0.0$	0.025	0.008	0.008	0.028	0.120	0.038	0.028
	$p = 0.08$	0.250	0.218	0.030	0.303	0.300	0.220	0.283
	$p = 0.2$	0.175	0.300	0.225	0.165	0.120	0.197	0.198
	$p = 0.6$	0.05	0.225	0.488	0.055	0.060	0.176	0.068
				CMP1	$Risk_S$	0.215	0.204	
					$C_{tot}^S$	<b>105 94</b>	<b>105 94</b>	
				CMP2	$Risk_S$	0.228	0.216	
					$C_{tot}^S$	<b>115 101</b>	<b>114 100</b>	

**Table 4b.** Example weightings provided for alternative  $p$  values and alternative movement hypotheses.

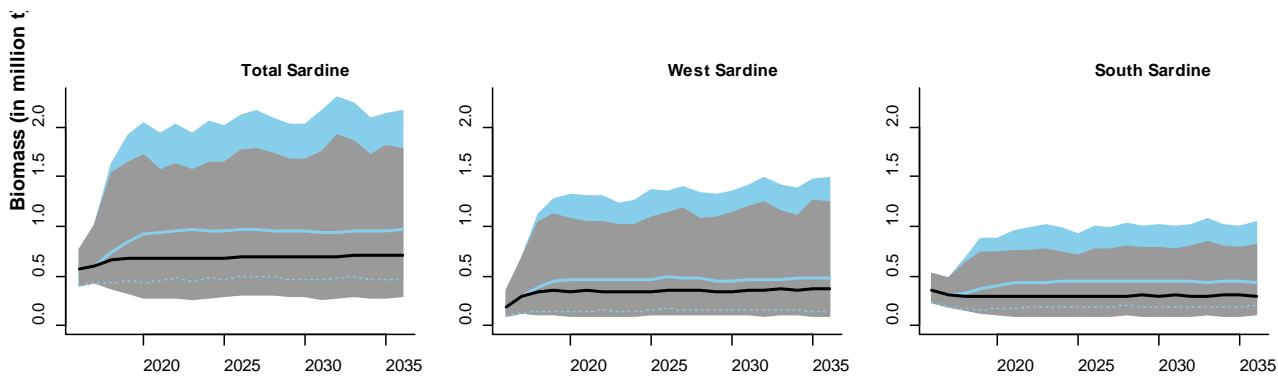
	Alt 1	Alt 2	Alt 3	Alt 4	Alt 5
$p = 0.0$	0.05	0.01	0.01	0.05	0.20
$p = 0.08$	0.50	0.29	0.04	0.55	0.50
$p = 0.2$	0.35	0.40	0.30	0.30	0.20
$p = 0.6$	0.10	0.30	0.65	0.10	0.10
MoveR	0.50	0.25	0.25	0.45	0.40
MoveD	0.50	0.75	0.75	0.55	0.60



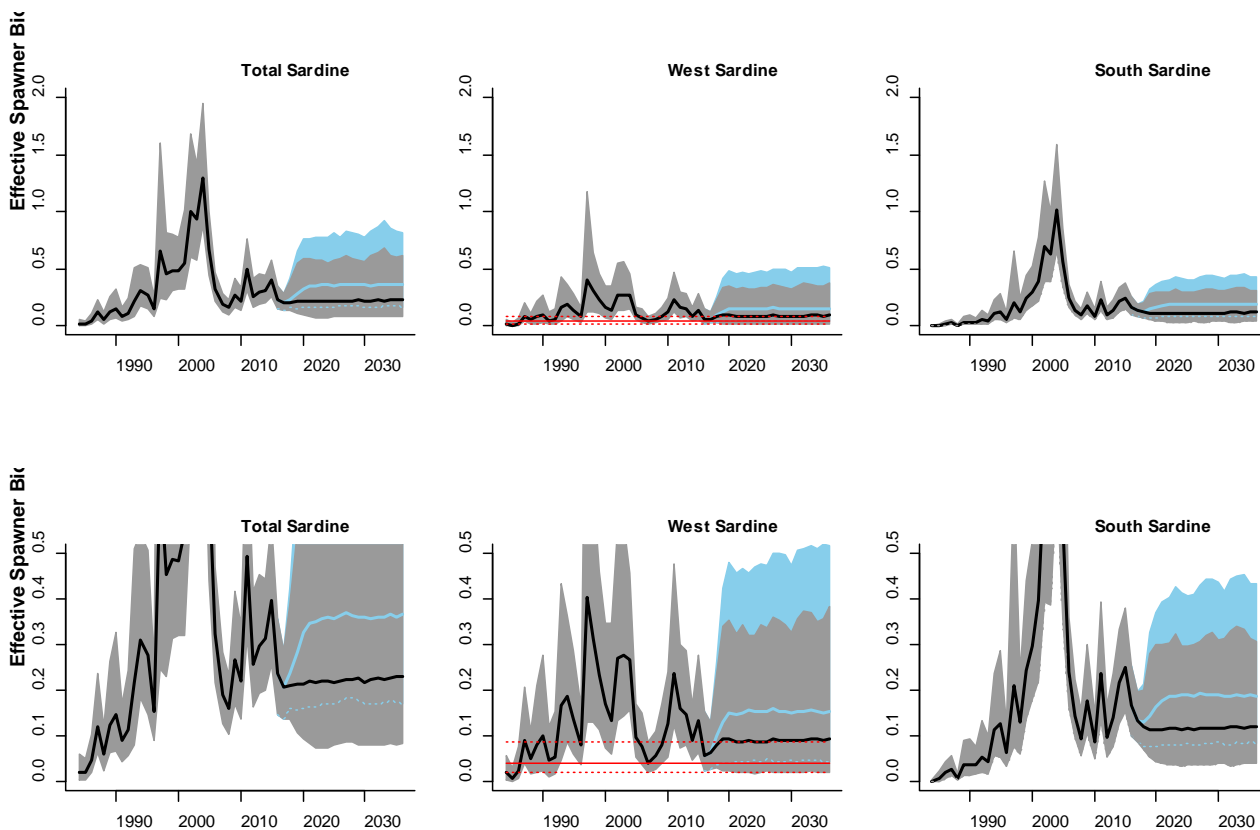
**Figure 1.** The median and 90%iles of anchovy biomass for CMP1 (grey) compared to a no future catch scenario (blue), with future projections based on OM1.



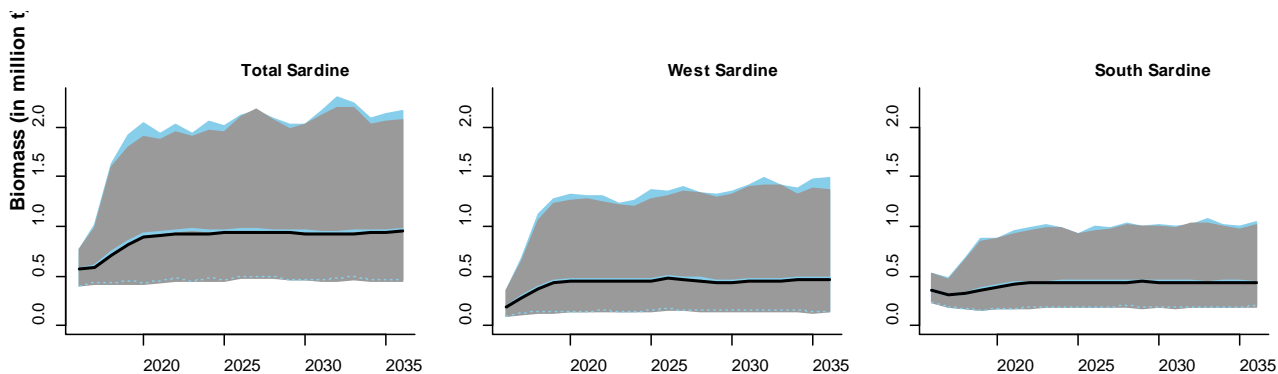
**Figure 2.** The median and 90%iles of anchovy spawner biomass for CMP1 (grey) compared to a no future catch scenario (blue), with future projections based on OM1. The right plot is a repeat of the left plot, but over a smaller vertical axis range to more clearly show the anchovy risk threshold (red).



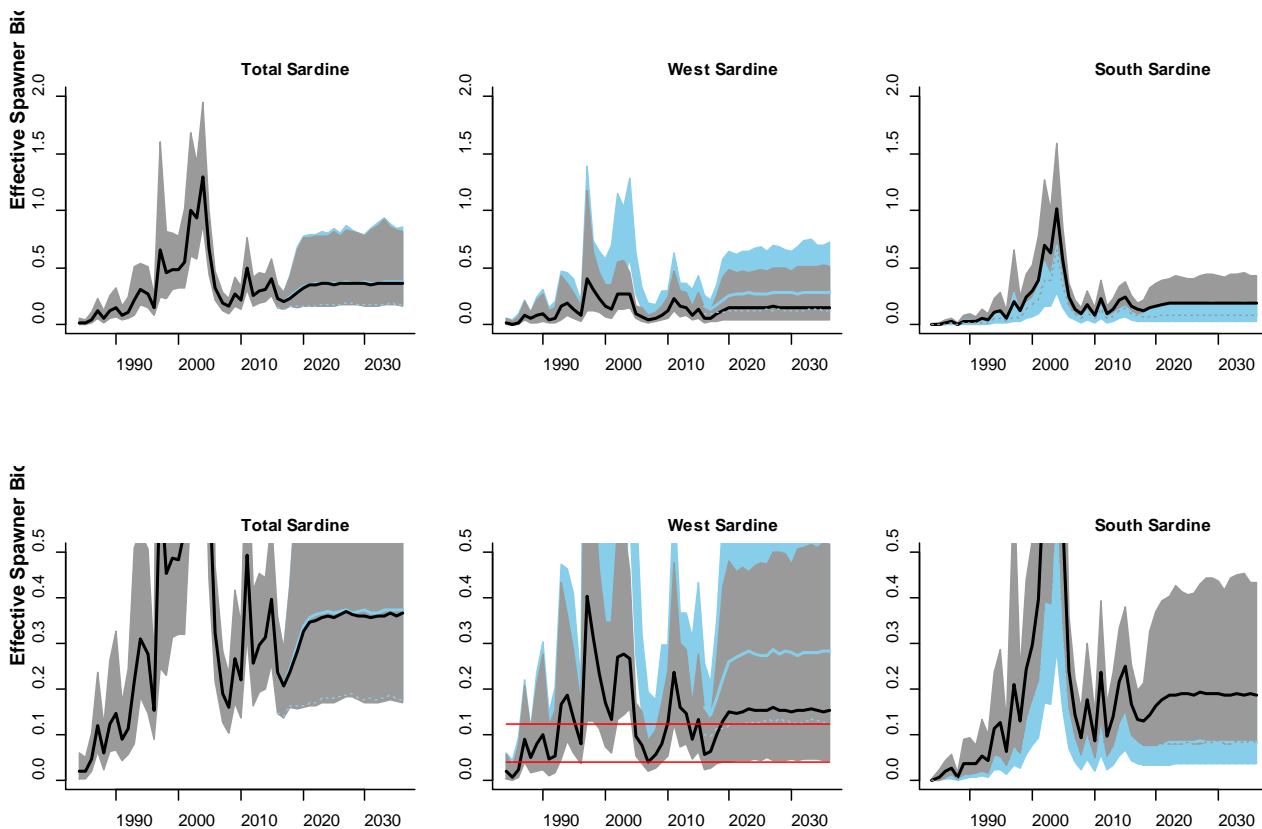
**Figure 3.** The median and 90%iles of sardine biomass for CMP1 (grey) compared to a no future catch scenario (blue), with future projections based on OM1.



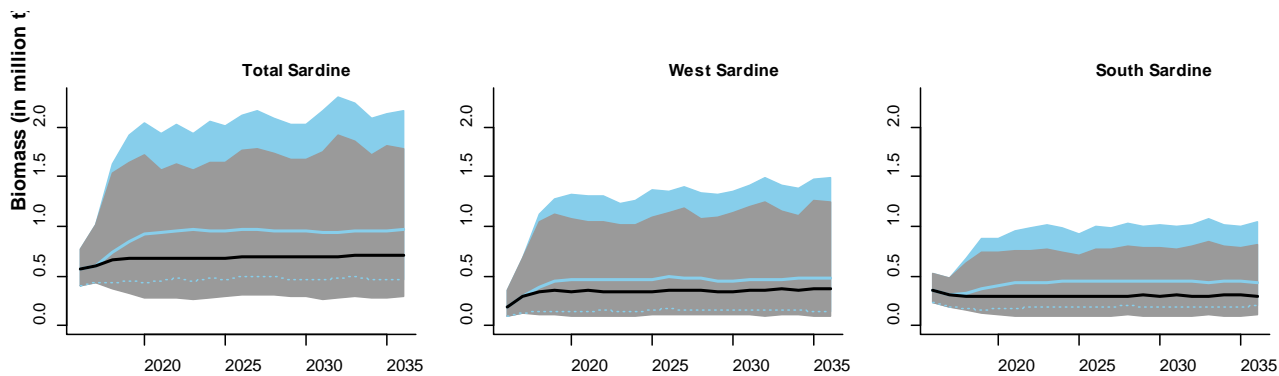
**Figure 4.** The median and 90%iles of sardine effective spawner biomass for CMP1 (grey) compared to a no future catch scenario (blue), with future projections based on OM1. The lower plots are a repeat of the upper plots, but over a smaller vertical axis range to more clearly show the sardine risk threshold (red).



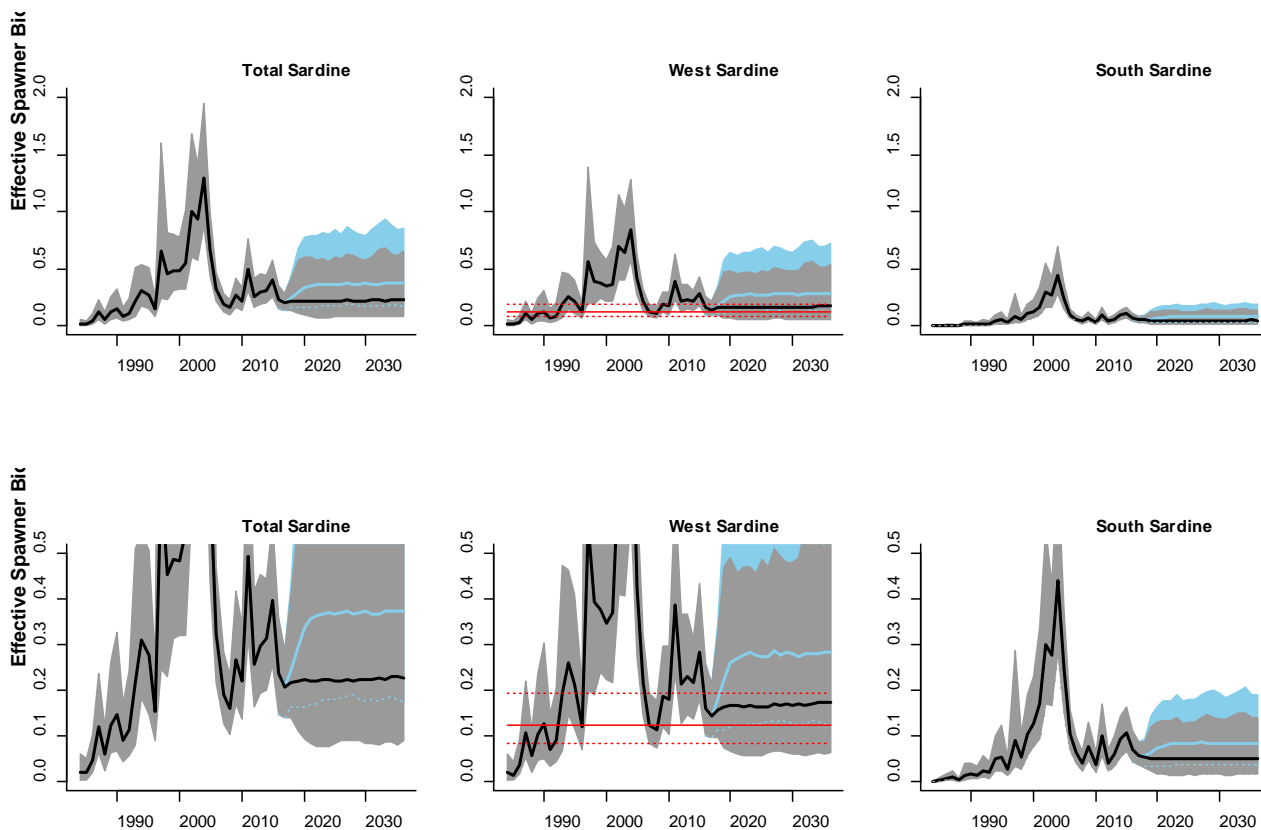
**Figure 5.** The median and 90%iles of sardine biomass for a no future catch scenario based on OM1 ( $p = 0.08$ , grey) and OM2 ( $p = 0.6$ , blue).



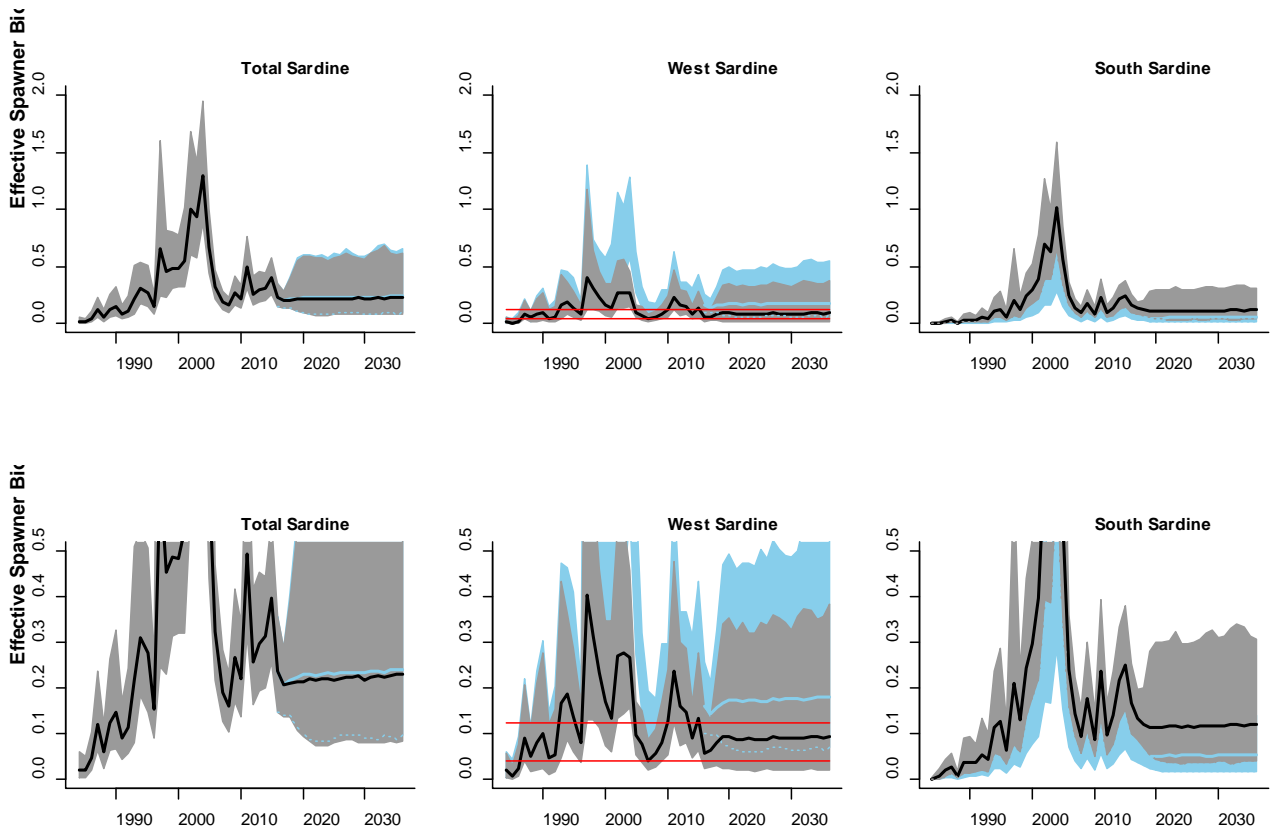
**Figure 6.** The median and 90%iles of sardine effective spawner biomass for a no future catch scenario based on OM1 ( $p = 0.08$ , grey) and OM2 ( $p = 0.6$ , blue). The lower plots are a repeat of the upper plots, but over a smaller vertical axis range. The two red lines denote the median 2007 effective west component spawner biomass under  $p = 0.08$  (~41 000t) and  $p = 0.6$  (~126 000t).



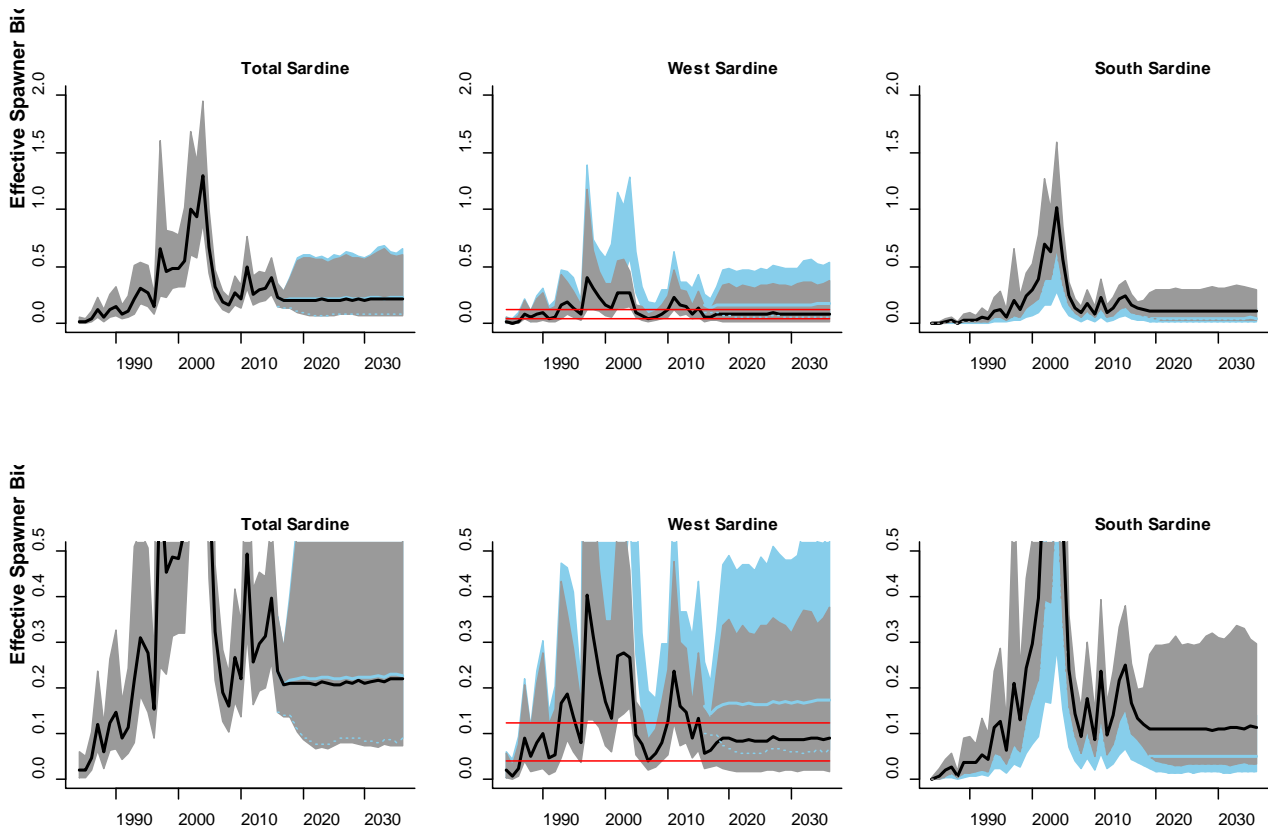
**Figure 7.** The median and 90%iles of sardine biomass for CMP2 (grey) compared to a no future catch scenario (blue), with future projections based on OM2.



**Figure 8.** The median and 90%iles of sardine effective spawner biomass for CMP2 (grey) compared to a no future catch scenario (blue), with future projections based on OM2. The lower plots are a repeat of the upper plots, but over a smaller vertical axis range to more clearly show the sardine risk threshold (red).



**Figure 9a.** The median and 90%iles of sardine effective spawner biomass for CMP1 under OM1 (grey) and OM2 (blue). The lower plots are a repeat of the upper plots, but over a smaller vertical axis range. The two red lines denote the median 2007 effective west component spawner biomass under  $p = 0.08$  (~41 000t) and  $p = 0.6$  (~126 000t).



**Figure 9a.** The median and 90%iles of sardine effective spawner biomass for CMP2 under OM1 (grey) and OM2 (blue). The lower plots are a repeat of the upper plots, but over a smaller vertical axis range. The two red lines denote the median 2007 effective west component spawner biomass under  $p = 0.08$  (~41 000t) and  $p = 0.6$  (~126 000t).