Further results from future projections of a single or two sardine stock operating model, with initial results using a two-area directed sardine TAC

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Introduction

de Moor and Butterworth (2013a) showed some initial projections for future average directed catch and risk to the resources, assuming a no catch scenario, Interim OMP-13 v2, or a similar Management Procedure (MP) with re-tuned control parameters. Results were shown assuming either a single or a two sardine stock operating model.

Risk to the resources is defined as follows:

$risk_A$ - the probability that total adult anchovy biomass falls below 10% of the average total adult anchovy biomass over November 1984 and November 1999 at least once during the projection period of 20 years.

$risk_S$ - the probability that total adult sardine biomass falls below the average total adult sardine biomass over November 1991 and November 1994 at least once during the projection period of 20 years.

$risk_S^j$ - the probability that adult sardine biomass of stock *j* falls below the average adult sardine biomass of stock *j* over November 1991 and November 1994 at least once during the projection period of 20 years.

$risk_S^{west\,2}$ - the probability that adult "west" stock sardine biomass falls below the average adult "west" stock sardine biomass over November 2004 and November 2011 at least once during the projection period of 20 years.

These statistics are thus designed to determine the chance of "something bad" happening even once over the projection period, rather than the average number of times "something bad" is projected to happen.

In this document further characteristics of the projections under a two sardine stock operating model are explored. All projections are based on the simulation testing framework described by de Moor and Butterworth (2013b). Updated results are shown for a no catch scenario, Interim OMP-13 v2 and a Candidate MP which calculates separate directed sardine TACs for the areas west and south of Cape Agulhas. The Candidate MP which calculates a two-area directed sardine TAC uses, for the most part, the same constraints for the full area/population as for Interim OMP-13 v2, which calculates a single area directed sardine TAC (de Moor and Butterworth 2013c).

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When assuming a two sardine stock operating model, three different primary hypotheses of movement of "west" stock recruits to the "south" stock are considered:

NoMove - no future movement

MoveB - future movement is based on a relationship with the ratio of "south" to "west" stock 1+ biomass (de Moor and Butterworth 2013a,b,e)

MoveE - future movement "switches" between increasing or decreasing towards an equilibrium proportion, based on whether a favourable or unfavourable environment exists on the south coast (de Moor and Butterworth 2013f)[1].

Results

Sardine single stock operating model

Table 1 shows the future risk to the resources and average projected directed catches assuming a single sardine stock hypothesis. This shows that Interim OMP-13 v2 results in a risk to the sardine resource of 22% (anchovy risk of 23%), compared to a risk of 5% (<1% for anchovy) under a no future catch scenario, and an average projected directed sardine catch of 156 000t (290 000t for anchovy).

As expected, the same results are obtained for both Interim OMP-13 v2 and the two-area candidate MP when using the same control parameters as for Interim OMP-13 v2, and applying the same control parameter, β, to the directed sardine TAC west and south of Cape Agulhas (Table 1).

An alternative two-area candidate MP which assumes no future directed ≥14cm sardine TAC west of Cape Agulhas results in a 37% decrease in average catch and a 33% decrease in risk to the total sardine population (Table 1).

Sardine two stock operating model: no catch scenario

Table 2 shows the future risk to the resources and average projected directed catches assuming a two sardine stock operating model, with different hypotheses for the movement of "west" stock recruits to the "south" stock. The hypotheses of movement considered here include *MoveB* and *MoveE* as well as the extreme *NoMove*. Some further extremes of only a favourable (increasing proportion moving) or unfavourable (decreasing proportion moving) south coast environment are also explored for comparative purposes.

[1] The model which was fit to the posterior median proportions of "west" stock recruits moving to the "south" stock has been used for these results.

In all cases the risk to the anchovy resource remains <1% as for the single sardine stock operating model under a no future catch scenario.

Assuming no future catch, the risk to the total sardine population increases from 18% under *NoMove* to 94% under a constant favourable south coast environment hypothesis. The primary reason for this difference is because the "west" stock has been estimated to be appreciably more productive than the "south" stock (de Moor and Butterworth 2013e). Thus in a situation where few recruits leave the "west" stock, the "west" spawning stock biomass (SSB) is able to recover to a level which provides maximum median recruitment (Figure 1a). In contrast, in a situation where most of the recruits leave the "west" stock, the SSB is generally depleted below this level and lower future "west" stock recruitment occurs. On the basis of the operating model used, which reflects the data available, a larger "south" stock SSB, resulting from a greater influx of "west" stock recruits, is not assumed to result in a higher median recruitment to the "south" stock.

The future projected SSB for the "west" and "south" stocks under a no catch scenario are shown in Figures 1 and 2 for *NoMove*, *MoveB* and *MoveE*. The expected increase/decrease of the "west"/"south" stocks from their current estimated abundance levels under *NoMove* is clearly demonstrated (Figures 1a, 2a). The "west" stock is projected to recover to levels of SSB at which maximum median recruitment is expected (i.e. even the lower 5% probability interval trajectory increase above the posterior median of the biomass below which median recruitment drops) (Figure 1a).

The future projected 1+ biomass for the "west" and "south" stocks under a no catch scenario are shown in Figures 3 and 4 for *NoMove*, *MoveB* and *MoveE*. These figures also demonstrate that under *NoMove*, the probability of future "west" stock 1+ biomass falling below the "west" stock risk threshold of average 91-94 biomass is very low after about 2015 (Figure 3a). In contrast, *MoveB* and *MoveE* predict that the median 1+ biomass of the "west" stock will remain below the median risk threshold over the 20 year projection period (which is the primary reason for the 95% risk levels in Table 2). It is worth noting that the median projected "west" stock 1+ biomass does increase a little over the projection period under *MoveB* (Figure 3b), whereas there is a slight oscillation in the "west" stock 1+ biomass, with less overall increase, when *MoveE* is assumed (Figure 3c).

Sardine two stock operating model: Interim OMP-13 v2

Assuming future harvesting according to Interim OMP-13 v2, if no future movement of "west" stock recruits to the "south" stock is assumed, the "west" stock is modelled to increase over the projection period, with median SSB levels from 2020 onwards above the median level above which median maximum recruitment can be expected (Figure 5a). The risk to the sardine resource is 37% (50% to the "west" stock) (Table 2); however, Figure 7a indicates the risk to be greater in the first half of the projection period and appreciably lower during the second half of the projection period.

Figures 5b,c, 6b,c, 7b,c and 8b,c indicate that if movement of "west" stock recruits to the "south" stock continues, then continued harvesting of sardine using the single-area TAC HCR formulae of Interim OMP-13 v2 will almost certainly soon heavily deplete the "west" stock, with the "south" stock showing the same behaviour though a little later in time (Table 2).

Although the trajectories of "south" SSB decrease over the projection period, given the low productivity of this stock, recruitment to the "south" stock remains at about its maximum median value (Figure 6).

Given the quicker recovery modelled for the "west" stock under *NoMove*, compared to the two movement hypotheses that allow future "west" stock recruits to move to the "south" stock, it is unsurprising that the total directed sardine catch is predicted to increase over the projection period under *NoMove*, and decrease under *MoveB* and *MoveE* (Figure 9). The average predicted total directed sardine catch is 165 000t under *NoMove*, but only 25-26 000t under *MoveB* and *MoveE*, with a median of <10 000t from 2017 (*MoveE*) or 2019 (*MoveB*) to 2032 (Table 2).

Sardine two stock operating model: two-area Candidate MP

Unlike with the single stock operating model, identical results are not obtained for both Interim OMP-13 v2 and the two-area candidate MP when using the same control parameters as for Interim OMP-13 v2, and applying the same control parameter, β, to the directed sardine TAC west and south of Cape Agulhas (Table 2). However, the results are similar. This is because in the latter case the assumption is made that all the catch from west of Cape Agulhas is taken from the "west" stock, while all the catch from south of Cape Agulhas is taken from the "south" stock (de Moor and Butterworth 2013b). In the single-area TAC (Interim OMP-13 v2), an assumption is made that the sardine catch taken from the "west"/"south" stock is proportional to the ratio of the directed sardine TAC to the "west" stock 1+ biomass (de Moor and Butterworth 2013b). Thus the split of the catch by stock differs, and over time this results in slightly different 1+ biomass trajectories and TACs (Figures 12-14 compared to 7-9, Figure 23). These results are slightly less pessimistic than those for the single-area Interim OMP-13 v2 (Table 2, Figures 10-14 compared to Figures 5-9), however these results are likely dependent on the underlying assumptions of how the catch is split by stock, rather than improved performance of the two-area Candidate MP with the same sardine control parameters.

Two alternatives to assuming the same control parameters as Interim OMP-13 v2 were tested. In one case, no future TAC would be set for directed sardine west of Cape Agulhas, while the same control parameter would be maintained for directed sardine south of Cape Agulhas, i.e. $\beta_1 = 0.0$[2] and $\beta_2 = 0.090$. In the second case, no future TAC would be set for directed sardine west of Cape Agulhas, but a higher control parameter would be used for directed sardine south of Cape Agulhas, i.e. $\beta_1 = 0.0$ and $\beta_2 = 0.25$.

The "west" stock has a greater chance of recovery under the Candidate MP than one in which $\beta_1 = \beta_2 = 0.090$ (Figures 15 and 17 compared to 10 and 12). The risk to the total sardine population is between 76% (*MoveB*) and 84% (*MoveE*). However, the median trajectories still decline over the projection period (Figures 15, 17 and 21). This is in comparison to the no catch scenario for which the median trajectories are predicted to increase over the next 20 years (Figure 3, Figure 21). The reason for this is because under this Candidate MP juvenile sardine are still caught on the west coast, primarily as bycatch with the anchovy directed fishery, while no juvenile sardine are caught under the no catch scenario. The average annual west coast bycatch for this 2-area Candidate MP with no directed sardine TAC on the west coast ranges from 13 400t (*MoveE*) (Table 4), 17 400t (*MoveB*) to 46 000t (*NoMove*) when the "west" stock is projected to increase over time. This is also demonstrated in the trajectories obtained if a lower anchovy control parameter α_{ns} is used (Figure 20 compared to Figure 17).

The total directed ≥14cm sardine catch is lower under *NoMove*, for this two-area no west coast catch Candidate MP compared to the two-area Candidate MP with the same β control parameter west and south of Cape Agulhas. In contrast, some recovery in the "west" stock, which under the movement hypotheses *MoveB* and *MoveE*, feeds the "south" stock, the average catch under this two-area, no west coast catch Candidate MP is similar to, or higher than that attainable under a two-area Candidate MP with $\beta_1 = \beta_2 = 0.090$ (Table 2, and comparing the medians of Figures 14 and 19, Figure 23).

The Candidate MP which allows a higher fishing mortality on the south coast, while maintaining a zero TAC west of Cape Agulhas, ($\beta_1 = 0.0$ and $\beta_2 = 0.25$), results in a higher average annual catch for a similar risk level (Table 2).

[2] In this case the HCRs where constraints were applied for smoothing or maximum decrease from the previous year's TAC, were modified from those of de Moor and Butterworth (2013c) to maintain a zero TAC west of Cape Agulhas.

Summary

Tables 3 and 4 shows the full list of primary summary statistics for the no catch scenario, Interim OMP-13 v2 and the 2-area Candidate MP which assumes no directed ≥14cm sardine catch west of Cape Agulhas, given either the single or two sardine stock operating model.

References

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Table 1. The risk to the resources and average annual directed catch for projections assuming a **single sardine stock operating model,** "New". This operating model was updated from that used to develop Interim OMP-13v2 (de Moor and Butterworth 2013), but for comparative purposes results given for Interim OMP-13 v2 use the previous operating model ("Old"), which assumed a lower fixed variability about the stock recruitment relationship ($\sigma^S_{j=1,r}$). Statistics are shown for a no catch scenario, Interim OMP-13v2 (single area sardine TAC), and a candidate two-area sardine TAC MP.

Single stock Operating Model	Management Procedure	$\sigma^S_{j=1,r}$	β		α_{ns}	$risk_A$	$risk_S$	$\bar{C}^A$	$\bar{C}^S$
"New"	No Catch	0.45*	N/A		N/A	0.008	0.047	0	0
"Old"	Interim OMP-13 v2 (Single-area TAC)	0.40	0.090		0.871	0.247	0.209	275	154
"New"		0.45*	0.090		0.871	0.226[3]	0.224	290	156
			β_{west}	β_{south}					
"New"	Two-area TAC	0.45	0.090	0.090	0.871	0.226	0.224	290	156
"New"		0.45*	0	0.090	0.871	0.229	0.150	290	98

* Further summary statistics for these options are given in Table 3.

[3] Note that the statistics for Interim OMP-13 v2 for a single sardine stock operating model with $\sigma^S_{j=1,r} = 0.45$ are slightly updated from de Moor and Butterworth (2013a) because the increase in the directed sardine TAC mid-year in years for which Exceptional Circumstances are declared, was not correctly allocated between areas/stocks in initial results.

Table 2. The risk to the resources and average annual directed catch for projections assuming a **two sardine stock operating model** assuming a fixed value of $k^S_{\mathrm{cov}E} = 1$ for the multiplicative bias associated with the coverage of the "south" stock recruits by the recruit survey in comparison to the "west" stock recruits during the same survey. Statistics are shown for a no catch scenario, Interim OMP-13 v2 (single area sardine TAC), and a candidate two-area sardine TAC MP. Results are shown for alternative hypotheses of future movement of "west" recruits to the "south" stock: no future movement (*NoMove*), future movement is related to the ratio of "south" to "west" stock 1+ biomass (*MoveB*), and future movement is determined by switching between favourable and unfavourable environmental south coast states (*MoveE*). For the no catch scenario, results are also shown for the two extremes of only a favourable ("Fav Env") or unfavourable ("Unfav Env") environment for sardine on the south coast.

Management Procedure	Two stock movement model	β		α_{ns}	$risk_A$	$risk_S$	$risk_S^{west}$	$risk_S^{south}$	$risk_S^{west2}$	$\bar{C}^A$	$\bar{C}^S$	$\bar{C}^S_{west}$	$\bar{C}^S_{south}$
No Catch	NoMove	N/A		N/A	0.008	0.183	0.328	0.997	0.068	0	0	0	0
	Unfav Env	N/A		N/A	0.008	0.542	0.889	0.247	0.797	0	0	0	0
	MoveB	N/A		N/A	0.008	0.593	0.952	0.134	0.904	0	0	0	0
	MoveE*	N/A		N/A	0.008	0.748	0.948	0.416	0.908	0	0	0	0
	Fav Env	N/A		N/A	0.008	0.935	0.991	0.790	0.979	0	0	0	0
Interim OMP-13 v2 (single-area TAC)	NoMove	0.090		0.871	0.238	0.368	0.507	0.998	0.225	288	165	163	2
	MoveE*	0.090		0.871	0.241	0.962	0.992	0.938	0.976	292	26	14	12
	MoveB	0.090		0.871	0.240	0.993	0.999	0.979	0.999	292	25	14	12
Two-Area TAC		β_{west}	β_{south}										
	NoMove	0.090	0.090	0.871	0.237	0.334	0.466	0.998	0.165	288	177	174	3
	MoveE	0.090	0.090	0.871	0.242	0.918	0.977	0.855	0.952	292	40	15	26
	MoveB	0.090	0.090	0.871	0.245	0.941	0.991	0.828	0.981	292	45	15	29
	NoMove	0	0.090	0.871	0.244	0.241	0.361	1.000	0.092	288	8	0	8
	MoveE*	0	0.090	0.871	0.247	0.842	0.954	0.703	0.916	291	41	0	41
	MoveB	0	0.090	0.871	0.250	0.764	0.965	0.497	0.921	291	53	0	53
	MoveE	0	0.090	0.400	0.100	0.839	0.954	0.687	0.914	256	41	0	41
	MoveB	0	0.090	0.400	0.093	0.749	0.962	0.455	0.915	256	54	0	54
	NoMove	0	0.250	0.871	0.244	0.262	0.361	1.000	0.092	288	9	0	9
	MoveB	0	0.250	0.871	0.248	0.786	0.962	0.538	0.915	291	77	0	77
	MoveE	0	0.250	0.871	0.247	0.854	0.954	0.724	0.916	291	59	0	59

* Further summary statistics for these options are given in Table 4.

Table 3. Key summary statistics for the sardine and anchovy resources under a no-catch scenario, Interim OMP-13 v2 and a Candidate 2-area MP which sets no directed ≥14cm sardine TAC west of Cape Agulhas, assuming a **single sardine stock operating model**:

- the probability that adult sardine biomass falls below the average adult sardine biomass over November 1991 to November 1994 (the "risk threshold", $Risk^{S}$) **at least once during the projection period** of 20 years, $risk^{S}$;
- the probability that adult anchovy biomass falls below 10% of the average adult anchovy biomass between November 1984 and November 1999 **at least once during the projection period** of 20 years, $risk^{A}$;
- the probability of breaching the sardine/anchovy risk threshold **in any one year, averaged over years,** during the projection period ($risk^{*S/A}$);
- average minimum biomass over the projection period as a proportion of carrying capacity ($K^{S/A}$) and as a proportion of the risk threshold;
- average biomass at the end of the projection period as a proportion of carrying capacity, as a proportion of the risk threshold, and as a proportion of biomass at the beginning of the projection period;
- average directed catch (in thousands of tons), $\overline{C}^{S}/\overline{C}^{A}$, and average anchovy catch during the additional season, $\overline{C}^{A}_{ad}$;
- average sardine bycatch comprising juvenile sardine bycatch with anchovy, round herring and large sardine (in thousands of tons), $\overline{C}^{S}_{by}$;
- average proportional annual change in directed catch, AAV^{S}/AAV^{A};
- posterior median annual rate of increase of number of moulters of penguins on Robben Island, ROI^{prop}_{y}, over the first few years y of the projection period, where $prop$ indicates the year from which the proportion of observed biomass west of Cape Agulhas was drawn.
- posterior median ratio of the number of moulters of penguins on Robben Island, P^{prop}_{y}, after y years of the projection period to the current (2012) number, where $prop$ indicates the year from which the proportion of observed biomass west of Cape Agulhas was drawn.
- proportion of times Exceptional Circumstances are/not declared ($EC^{declared}/EC^{NOTdeclared}$) when true biomass is/not below the corresponding threshold ($B^{A/S}_{y} <$ or $\geq Threshold$);
- proportion of times the directed TAC decreases below the minimum TAC (i.e., Exceptional Circumstances are declared), $TAC^{A/S}_{y} < c^{A/S}_{mntac}$; and

- average number of years for which Exceptional Circumstances, if declared, are declared consecutively, $EC^{A/S}_{consec}$.

	Sardine	No Catch	Interim OMP-13v2	2-Area MP	Anchovy	No Catch	Interim OMP-13v2	2-Area MP
Key Control Parameters	β		0.090	0.0; 0.090	α_{ns}		0.871	0.871
Risk Statistics	$risk^S$	0.047	0.224	0.150	$risk^A$	0.008	0.224	0.229
	$risk^{*S}$	0.008	0.073	0.052	$risk^{*A}$	0.002	0.039	0.040
Biomass Statistics	$\overline{B^S_{\min}/K^S}$	0.50	0.39	0.42	$\overline{B^A_{\min}/K^A}$	0.26	0.10	0.10
	$\overline{B^S_{\min}/Risk^S}$	1.94	1.49	1.62	$\overline{B^A_{\min}/Risk^A}$	9.21	3.67	3.66
	$\overline{B^S_{2032}/K^S}$	0.99	0.76	0.84	$\overline{B^A_{2032}/K^A}$	1.20	0.56	0.56
	$\overline{B^S_{2032}/Risk^S}$	4.13	3.11	3.50	$\overline{B^A_{2032}/Risk^A}$	49.27	22.92	22.86
	$\overline{B^S_{2032}/B^S_{2011}}$	2.08	1.54	1.74	$\overline{B^A_{2032}/B^A_{2011}}$	4.55	1.82	1.81
Catch Statistics	$\overline{C}^S$ ('13-'32)	0	156	90	$\overline{C}^A$ ('13-'32)	0	290	290
	$\overline{C}^S_{by}$	0	33	33				
	$\overline{C}^S$ ('13-'15)	0	125	89	$\overline{C}^A$ ('13-'15)	0	339	339
	AAV^S ('13-'32)	0.00	0.31	0.53	AAV^A ('13-'32)	0.00	0.21	0.21
	AAV^S ('13-'15)	0.00	0.61	0.61	AAV^A ('13-'15)	0.00	0.13	0.13

Table 3 (continued).

Exceptional Circumstances	$p\left(EC^{declared}, B_y^S < Threshold\right)$	0.00	0.01	0.01	$p\left(EC^{declared}, B_y^A < Threshold\right)$	0.02	0.24	0.24
	$p\left(EC^{declared}, B_y^S \geq Threshold\right)$	0.01	0.05	0.10	$p\left(EC^{declared}, B_y^A \geq Threshold\right)$	0.01	0.02	0.02
	$p\left(EC^{NOTdeclared}, B_y^S < Threshold\right)$	0.00	0.00	0.00	$p\left(EC^{NOTdeclared}, B_y^A < Threshold\right)$	0.01	0.04	0.04
	$p\left(EC^{NOTdeclared}, B_y^S \geq Threshold\right)$	0.99	0.94	0.89	$p\left(EC^{NOTdeclared}, B_y^A \geq Threshold\right)$	0.96	0.70	0.70
	$p\left(TAC_y^S < c_{mntac}^S\right)$	N/A	0.06	0.05	$p\left(TAC_y^A < c_{mntac}^A\right)$	N/A	0.26	0.26
	EC_{consec}^S	N/A	1.37	1.34	EC_{consec}^A	N/A	3.42	3.44
Penguin Statistics	Robben Island Penguins							
	ROI_5^{84-99}	0.01	0.00	0.00	ROI_5^{00-11}	-0.08	-0.10	-0.09
	ROI_{10}^{84-99}	0.01	-0.01	0.00	ROI_{10}^{00-11}	-0.06	-0.07	-0.07
	ROI_{20}^{84-99}	0.00	-0.01	-0.01	ROI_{20}^{00-11}	-0.04	-0.05	-0.04
	P_5^{84-99}	1.07	1.00	1.02	P_5^{00-11}	0.60	0.51	0.54
	P_{10}^{84-99}	1.09	0.92	0.95	P_{10}^{00-11}	0.40	0.29	0.32
	P_{20}^{84-99}	0.96	0.76	0.83	P_{20}^{00-11}	0.18	0.10	0.12

Table 4. As for Table 3, but assuming a **two sardine stock operating model**, with movement hypothesis *MoveE*. The upper table gives results for the full sardine and anchovy populations while the lower table gives results for the "west" and "south" sardine stocks and catch west/south of Cape Agulhas.

	Sardine	No Catch	Interim OMP-13v2	2-Area MP	Anchovy	No Catch	Interim OMP-13v2	2-Area MP
Key Control Parameters	β		0.090	0.0; 0.090	α_{ns}		0.871	0.871
Risk Statistics	$risk^S$	0.748	0.962	0.842	$risk^A$	0.008	0.241	0.247
	$risk^{*S}$	0.503	0.856	0.648	$risk^{*A}$	0.002	0.041	0.042
Biomass Statistics	$\overline{B^S_{\min}/K^S}$	0.12	0.03	0.08	$\overline{B^A_{\min}/K^A}$	0.26	0.09	0.09
	$\overline{B^S_{\min}/Risk^S}$	0.67	0.18	0.44	$\overline{B^A_{\min}/Risk^A}$	9.21	3.48	3.52
	$\overline{B^S_{2032}/K^S}$	0.39	0.07	0.25	$\overline{B^A_{2032}/K^A}$	1.20	0.54	0.55
	$\overline{B^S_{2032}/Risk^S}$	2.44	0.41	1.62	$\overline{B^A_{2032}/Risk^A}$	49.27	22.16	22.34
	$\overline{B^S_{2032}/B^S_{2011}}$	1.40	0.24	0.91	$\overline{B^A_{2032}/B^A_{2011}}$	4.55	1.76	1.77
Catch Statistics	$\overline{C}^S$ ('13-'32)	0	26	41	$\overline{C}^A$ ('13-'32)	0	292	291
	$\overline{C}^S_{by}$	0	5	15				
	$\overline{C}^S$ ('13-'15)	0	80	74	$\overline{C}^A$ ('13-'15)	0	345	344
	AAV^S ('13-'32)	0.00	1.95	0.82	AAV^A ('13-'32)	0.00	0.17	0.21
	AAV^S ('13-'15)	0.00	0.52	0.82	AAV^A ('13-'15)	0.00	0.13	0.13
Exceptional Circumstances	$p\left(EC^{declared}, B^S_y < Threshold\right)$	0.13	0.58	0.35	$p\left(EC^{declared}, B^A_y < Threshold\right)$	0.02	0.26	0.25
	$p\left(EC^{declared}, B^S_y \geq Threshold\right)$	0.20	0.13	0.41	$p\left(EC^{declared}, B^A_y \geq Threshold\right)$	0.01	0.02	0.02
	$p\left(EC^{NOTdeclared}, B^S_y < Threshold\right)$	0.01	0.03	0.00	$p\left(EC^{NOTdeclared}, B^A_y < Threshold\right)$	0.01	0.05	0.04
	$p\left(EC^{NOTdeclared}, B^S_y \geq Threshold\right)$	0.66	0.26	0.24	$p\left(EC^{NOTdeclared}, B^A_y \geq Threshold\right)$	0.96	0.68	0.68
	$p\left(TAC^S_y < c^S_{mntac}\right)$	N/A	0.71	0.49	$p\left(TAC^A_y < c^A_{mntac}\right)$	N/A	0.28	0.27
	EC^S_{consec}	N/A	6.05	4.11	EC^A_{consec}	N/A	3.39	3.42

Penguin Statistics	Robben Island Penguins							
	ROI_5^{84-99}	-0.06	-0.11	-0.15	ROI_5^{00-11}	-0.13	-0.15	
	ROI_{10}^{84-99}	-0.07	-0.09	-0.09	ROI_{10}^{00-11}	-0.09	-0.09	
	ROI_{20}^{84-99}	-0.05	-0.05	-0.05	ROI_{20}^{00-11}	-0.05	-0.05	
	P_5^{84-99}	0.68	0.43	0.23	P_5^{00-11}	0.33	0.25	
	P_{10}^{84-99}	0.35	0.09	0.05	P_{10}^{00-11}	0.10	0.05	
	P_{20}^{84-99}	0.10	0.00	0.00	P_{20}^{00-11}	0.01	0.00	

		Sardine "west" stock or area			Sardine "south" stock or area		
		No Catch	Interim OMP-13v2	2-Area MP	No Catch	Interim OMP-13v2	2-Area MP
Key Control Parameters	β		0.090	0.0		0.090	0.090
Risk Statistics	$risk^S$	0.948	0.992	0.954	0.416	0.938	0.703
	$risk^{*S}$	0.722	0.937	0.786	0.141	0.579	0.359
Biomass Statistics	$\overline{B^S_{\min}/K^S}$	0.03	0.01	0.03	2.02	0.70	1.24
	$\overline{B^S_{\min}/Risk^S}$	0.26	0.04	0.20	1.53	0.53	0.93
	$\overline{B^S_{2032}/K^S}$	0.21	0.02	0.14	6.20	1.58	4.12
	$\overline{B^S_{2032}/Risk^S}$	1.75	0.17	1.16	4.65	1.17	3.08
	$\overline{B^S_{2032}/B^S_{2011}}$	3.59	0.18	1.77	0.97	0.25	0.66
Catch Statistics	$\overline{C}^S$ ('13-'32)	0	14	0	0	12	41
	$\overline{C}^S_{by}$	0	5	13	0	<1	1
	$\overline{C}^S$ ('13-'15)	0	45	0	0	36	74
	AAV^S ('13-'32)	0.00	1.20	0.00	0.00	10.32	0.72
	AAV^S ('13-'15)	0.00	0.54	0.00	0.00	0.49	0.58

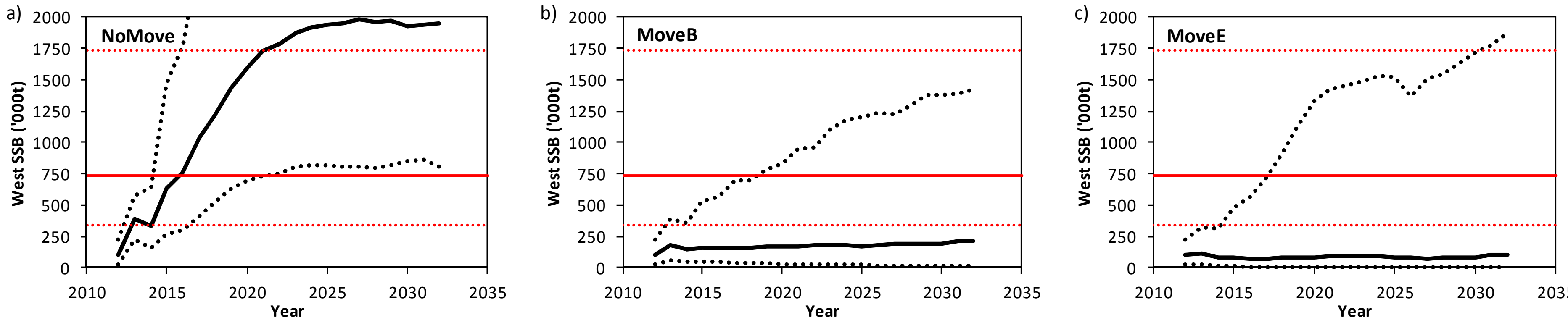

Figure 1. Future median and 90% probability intervals of projected **"west" stock** spawning stock biomass (**SSB**) assuming a two sardine stock operating model and **no future catch**. Trajectories are shown for different hypothesis of future movement of "west" stock recruits to the "south" stock: a) no future movement (*NoMove*), b) movement is related to the ratio of "south" to "west" stock 1+ biomass (*MoveB*), and c) movement is related to changes in the south coast environment (*MoveE*). The posterior median, 5%ile and 95%ile of the distribution of biomass below which median recruitment drops is shown in the red horizontal lines.

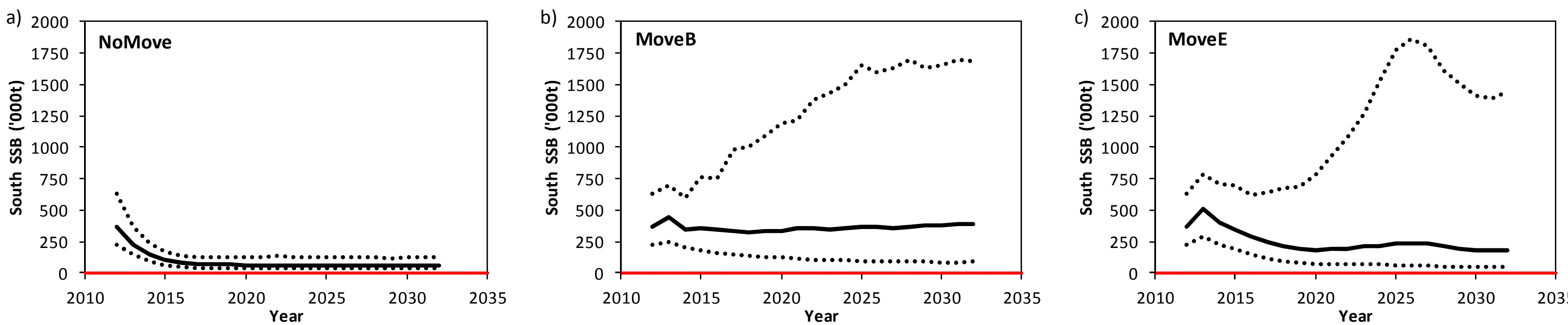

Figure 2. Future median and 90% probability intervals of projected **"south" stock** spawning stock biomass (**SSB**) assuming a two sardine stock operating model and **no future catch**. Trajectories are shown for different hypothesis of future movement of "west" stock recruits to the "south" stock: a) *NoMove*, b) *MoveB*, and c) *MoveE*. The posterior median, 5%ile and 95%ile of the distribution of biomass below which median recruitment drops is shown in the red horizontal lines.

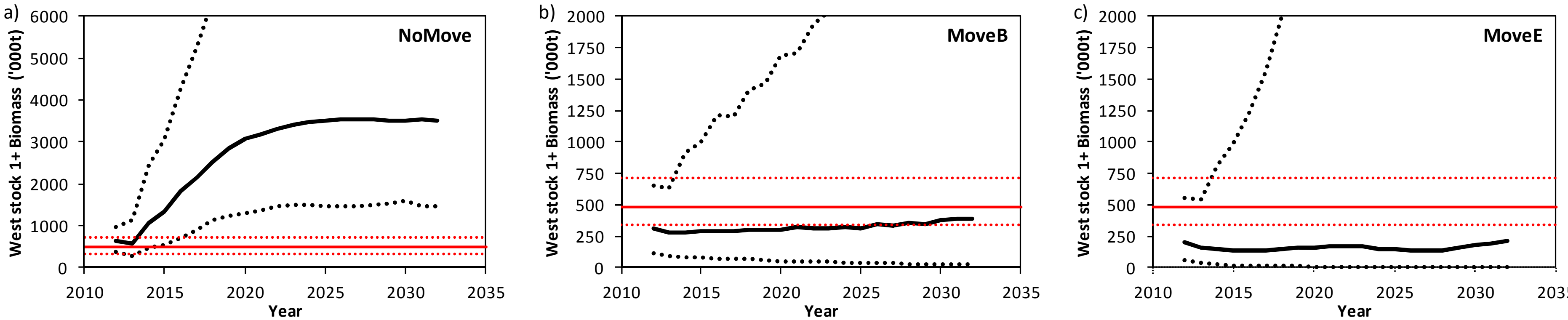

Figure 3. Future median and 90% probability intervals of projected **"west" 1+ biomass** assuming a **two sardine stock** operating model and **no future catch**. Trajectories are shown for different hypothesis of future movement of "west" stock recruits to the "south" stock: a) *NoMove*, b) *MoveB*, and c) *MoveE*. The posterior median, 5%ile and 95%ile of the distribution of average 91-94 1+ biomass is shown in the red horizontal lines. Note that the vertical scale on Figure a) is different to that of b) and c).

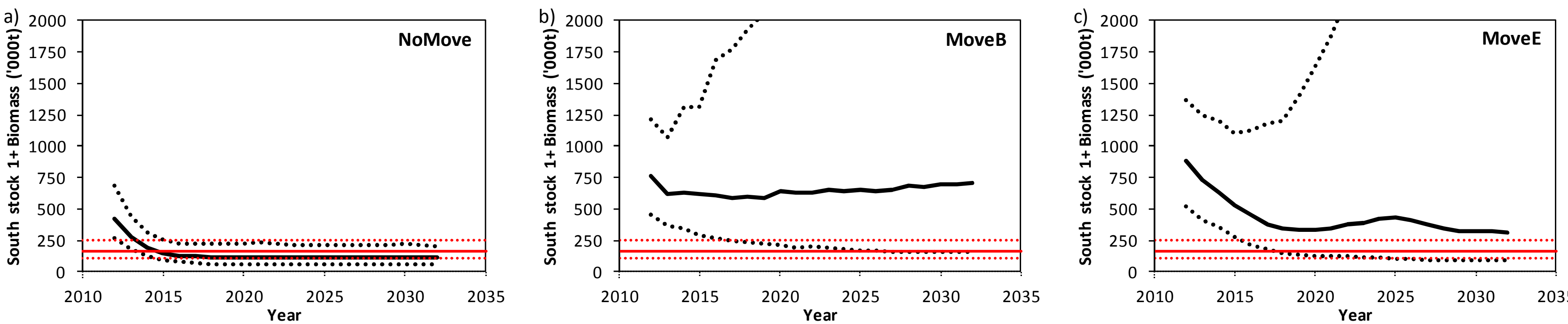

Figure 4. Future median and 90% probability intervals of projected **"south" stock 1+ biomass** assuming a **two sardine stock** operating model and **no future catch**. Trajectories are shown for different hypothesis of future movement of "west" stock recruits to the "south" stock: a) *NoMove*, b) *MoveB*, and c) *MoveE*. The posterior median, 5%ile and 95%ile of the distribution of average 91-94 1+ biomass is shown in the red horizontal lines.

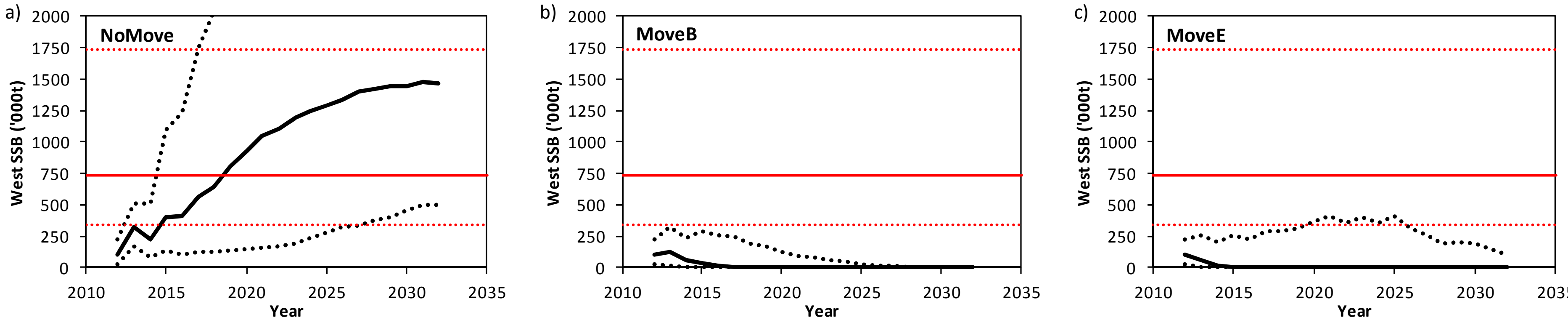

Figure 5. Future median and 90% probability intervals of projected **"west" stock** spawning stock biomass (**SSB**) assuming a two sardine stock operating model and **Interim OMP-13 v2**. Trajectories are shown for different hypothesis of future movement of "west" stock recruits to the "south" stock: a) *NoMove*, b) *MoveB*, and c) *MoveE*. The posterior median, 5%ile and 95%ile of the distribution of biomass below which median recruitment drops is shown in the red horizontal lines.

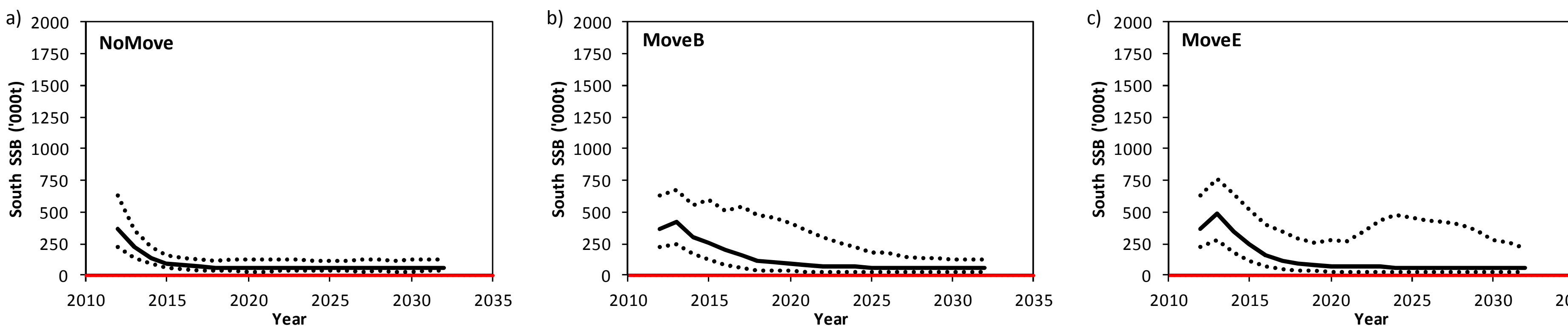

Figure 6. Future median and 90% probability intervals of projected **"south" stock** spawning stock biomass (**SSB**) assuming a two sardine stock operating model and **Interim OMP-13 v2**. Trajectories are shown for different hypothesis of future movement of "west" stock recruits to the "south" stock: a) *NoMove*, b) *MoveB*, and c) *MoveE*. The posterior median, 5%ile and 95%ile of the distribution of biomass below which median recruitment drops is shown in the red horizontal lines.

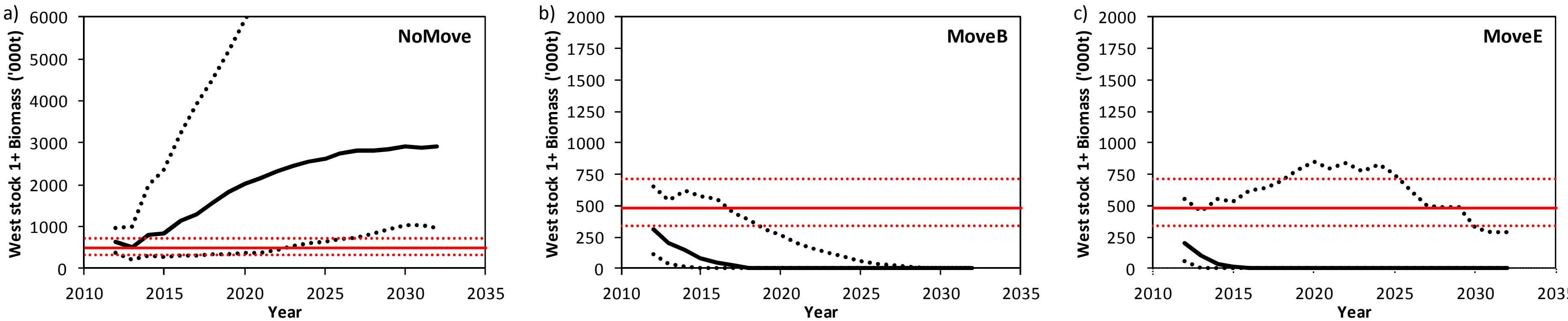

Figure 7. Future median and 90% probability intervals of projected **"west" 1+ biomass** assuming a **two sardine stock** operating model and **Interim OMP-13 v2**. Trajectories are shown for different hypothesis of future movement of "west" stock recruits to the "south" stock: a) *NoMove*, b) *MoveB*, and c) *MoveE*. The posterior median, 5%ile and 95%ile of the distribution of average 91-94 1+ biomass is shown in the red horizontal lines. Note that the vertical scale on Figure a) is different to that of b) and c).

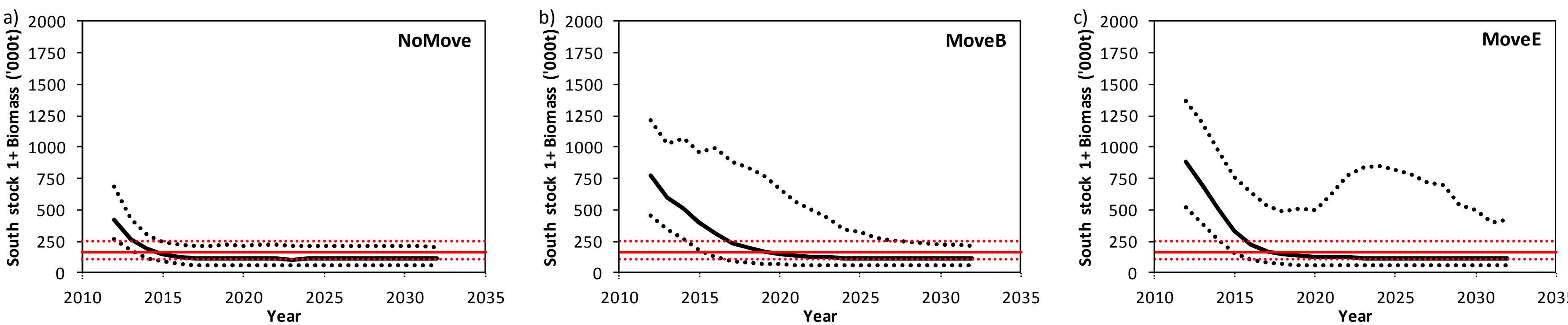

Figure 8. Future median and 90% probability intervals of projected **"south" stock 1+ biomass** assuming a **two sardine stock** operating model and **Interim OMP-13 v2**. Trajectories are shown for different hypothesis of future movement of "west" stock recruits to the "south" stock: a) *NoMove*, b) *MoveB*, and c) *MoveE*. The posterior median, 5%ile and 95%ile of the distribution of average 91-94 1+ biomass is shown in the red horizontal lines.

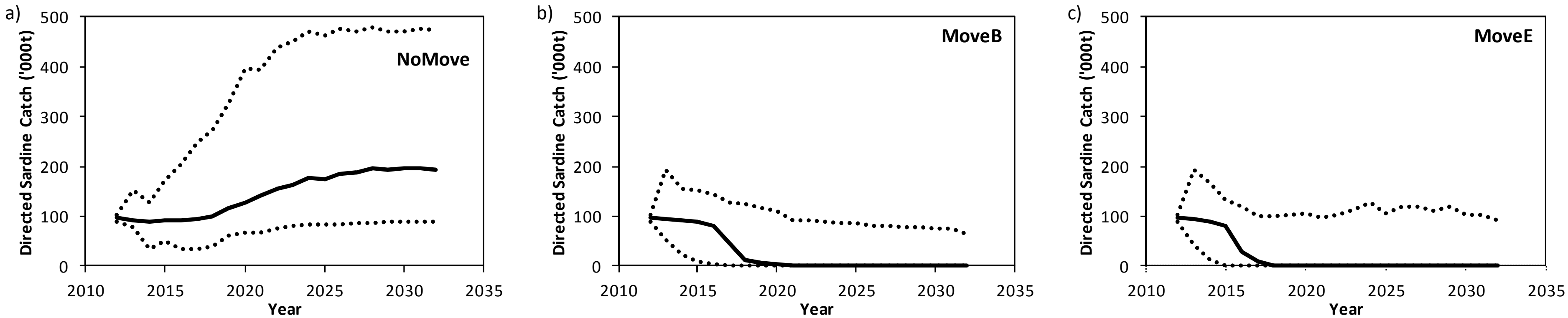

Figure 9. Future median and 90% probability intervals of projected total **directed ≥14cm sardine catch** assuming a **two sardine stock** operating model and **Interim OMP-13 v2**. Trajectories are shown for different hypothesis of future movement of "west" stock recruits to the "south" stock: a) *NoMove*, b) *MoveB*, and c) *MoveE*.

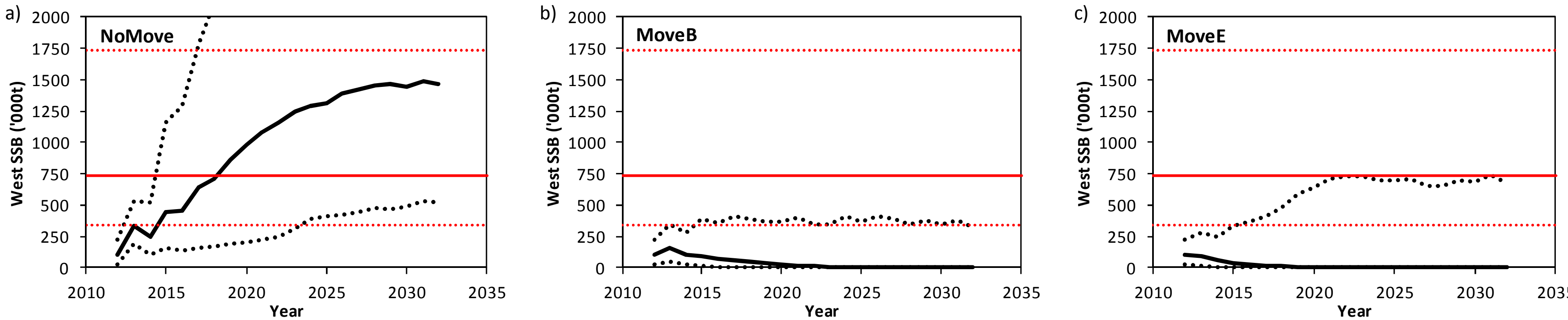

Figure 10. Future median and 90% probability intervals of projected **"west" stock** spawning stock biomass (**SSB**) assuming a two sardine stock operating model and **2-area Candidate MP with** $\beta_1 = \beta_2 = 0.090$. Trajectories are shown for different hypothesis of future movement of "west" stock recruits to the "south" stock: a) *NoMove*, b) *MoveB*, and c) *MoveE*. The posterior median, 5%ile and 95%ile of the distribution of biomass below which median recruitment drops is shown in the red horizontal lines.

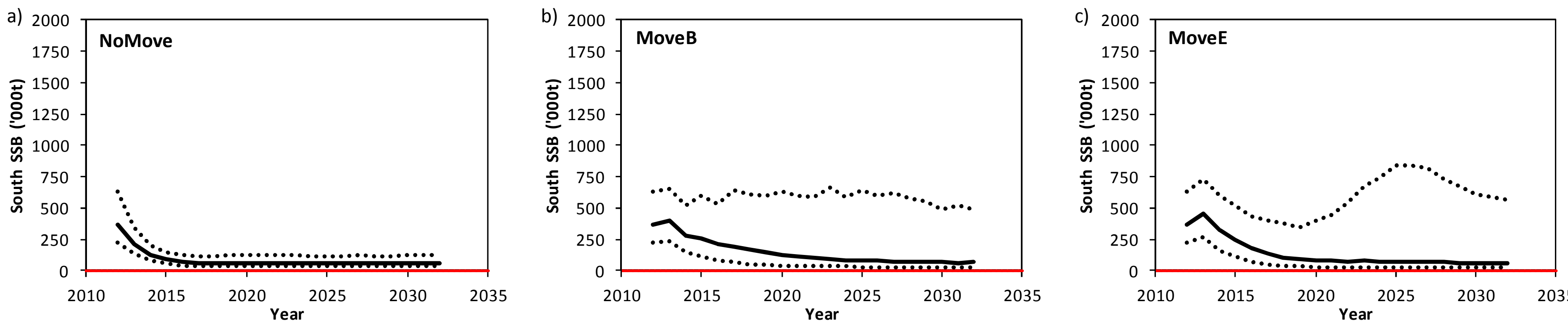

Figure 11. Future median and 90% probability intervals of projected **"south" stock** spawning stock biomass (**SSB**) assuming a two sardine stock operating model and **2-area Candidate MP with** $\beta_1 = \beta_2 = 0.090$. Trajectories are shown for different hypothesis of future movement of "west" stock recruits to the "south" stock: a) *NoMove*, b) *MoveB*, and c) *MoveE*. The posterior median, 5%ile and 95%ile of the distribution of biomass below which median recruitment drops is shown in the red horizontal lines.

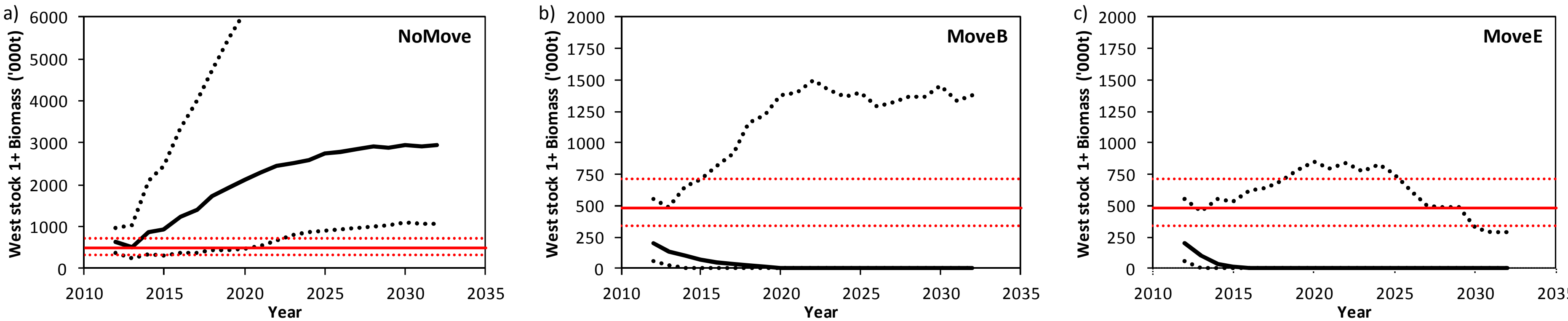

Figure 12. Future median and 90% probability intervals of projected **"west" 1+ biomass** assuming a **two sardine stock** operating model and **2-area Candidate MP with** $\beta_1 = \beta_2 = 0.090$. Trajectories are shown for different hypothesis of future movement of "west" stock recruits to the "south" stock: a) *NoMove*, b) *MoveB*, and c) *MoveE*. The posterior median, 5%ile and 95%ile of the distribution of average 91-94 1+ biomass is shown in the red horizontal lines. Note that the vertical scale on Figure a) is different to that of b) and c).

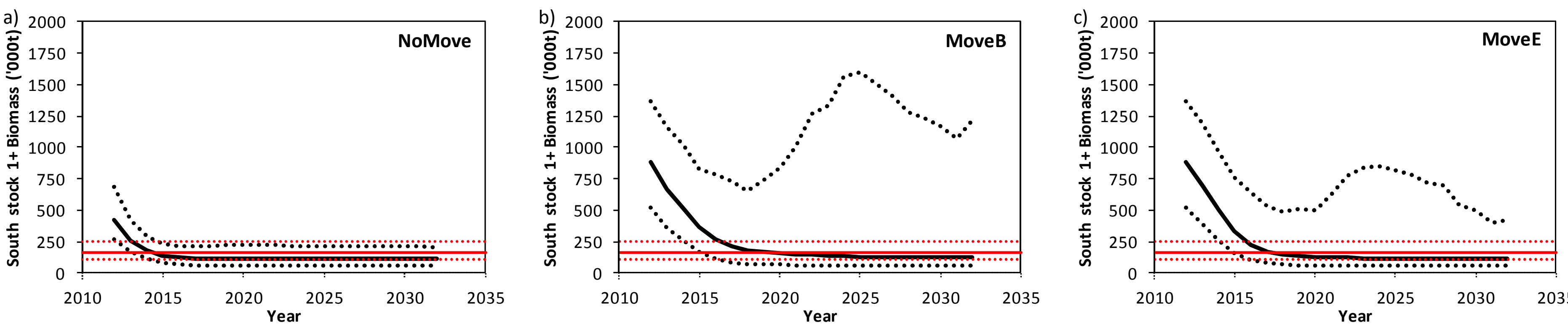

Figure 13. Future median and 90% probability intervals of projected **"south" stock 1+ biomass** assuming a **two sardine stock** operating model and **2-area Candidate MP with** $\beta_1 = \beta_2 = 0.090$. Trajectories are shown for different hypothesis of future movement of "west" stock recruits to the "south" stock: a) *NoMove*, b) *MoveB*, and c) *MoveE*. The posterior median, 5%ile and 95%ile of the distribution of average 91-94 1+ biomass is shown in the red horizontal lines.

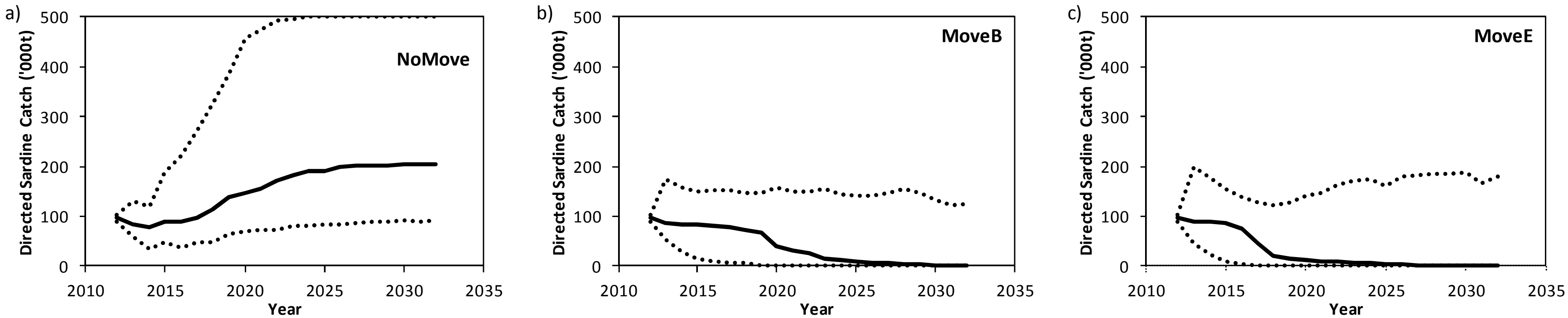

Figure 14. Future median and 90% probability intervals of projected total **directed ≥14cm sardine catch** assuming a **two sardine stock** operating model and **2-area Candidate MP with** $\beta_1 = \beta_2 = 0.090$. Trajectories are shown for different hypothesis of future movement of "west" stock recruits to the "south" stock: a) *NoMove*, b) *MoveB*, and c) *MoveE*.

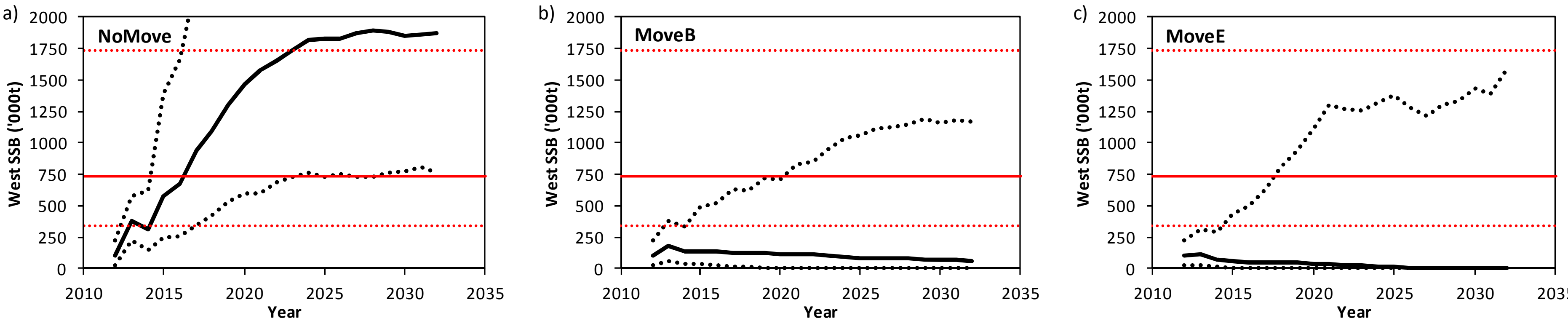

Figure 15. Future median and 90% probability intervals of projected **"west" stock** spawning stock biomass (**SSB**) assuming a two sardine stock operating model and **2-area Candidate MP with** $\beta_1 = 0.0, \quad \beta_2 = 0.090$. Trajectories are shown for different hypothesis of future movement of "west" stock recruits to the "south" stock: a) *NoMove*, b) *MoveB*, and c) *MoveE*. The posterior median, 5%ile and 95%ile of the distribution of biomass below which median recruitment drops is shown in the red horizontal lines.

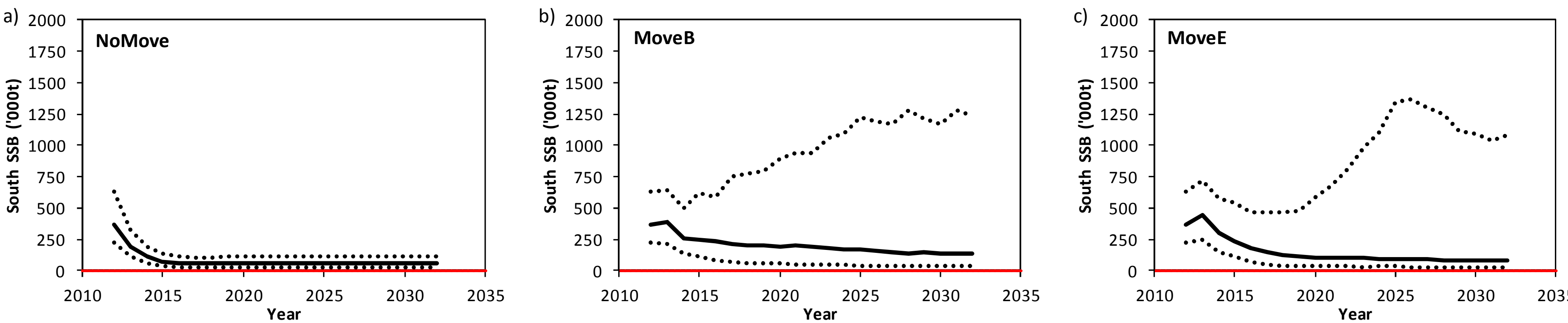

Figure 16. Future median and 90% probability intervals of projected **"south" stock** spawning stock biomass (**SSB**) assuming a two sardine stock operating model and **2-area Candidate MP with** $\beta_1 = 0.0, \quad \beta_2 = 0.090$. Trajectories are shown for different hypothesis of future movement of "west" stock recruits to the "south" stock: a) *NoMove*, b) *MoveB*, and c) *MoveE*. The posterior median, 5%ile and 95%ile of the distribution of biomass below which median recruitment drops is shown in the red horizontal lines.

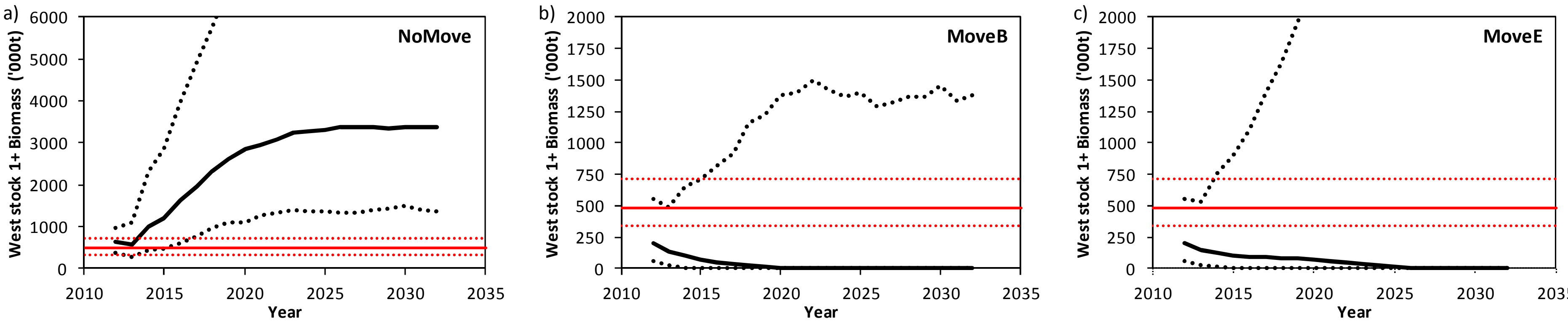

Figure 17. Future median and 90% probability intervals of projected **"west" 1+ biomass** assuming a **two sardine stock** operating model and **2-area Candidate MP with** $\beta_1 = 0.0, \quad \beta_2 = 0.090$. Trajectories are shown for different hypothesis of future movement of "west" stock recruits to the "south" stock: a) *NoMove*, b) *MoveB*, and c) *MoveE*. The posterior median, 5%ile and 95%ile of the distribution of average 91-94 1+ biomass is shown in the red horizontal lines. Note that the vertical scale on Figure a) is different to that of b) and c).

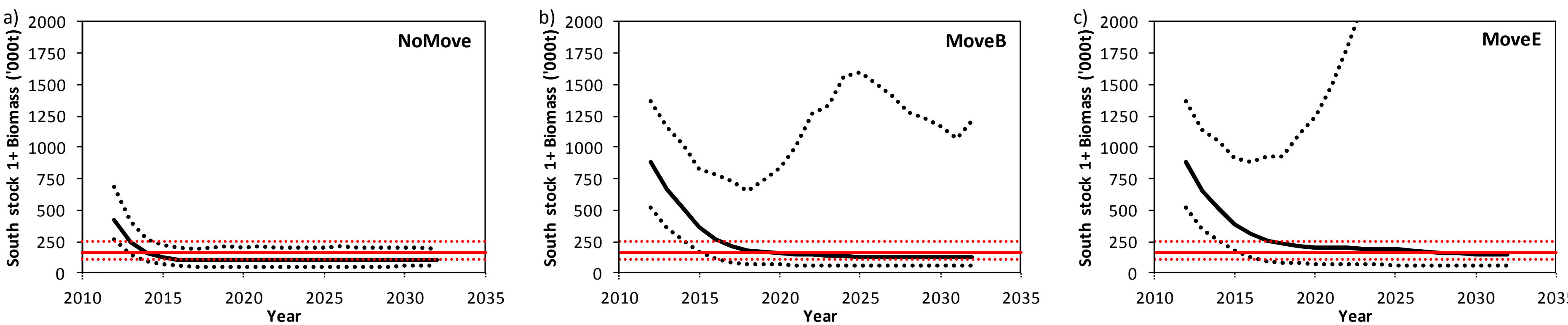

Figure 18. Future median and 90% probability intervals of projected **"south" stock 1+ biomass** assuming a **two sardine stock** operating model and **2-area Candidate MP with** $\beta_1 = 0.0, \quad \beta_2 = 0.090$. Trajectories are shown for different hypothesis of future movement of "west" stock recruits to the "south" stock: a) *NoMove*, b) *MoveB*, and c) *MoveE*. The posterior median, 5%ile and 95%ile of the distribution of average 91-94 1+ biomass is shown in the red horizontal lines.

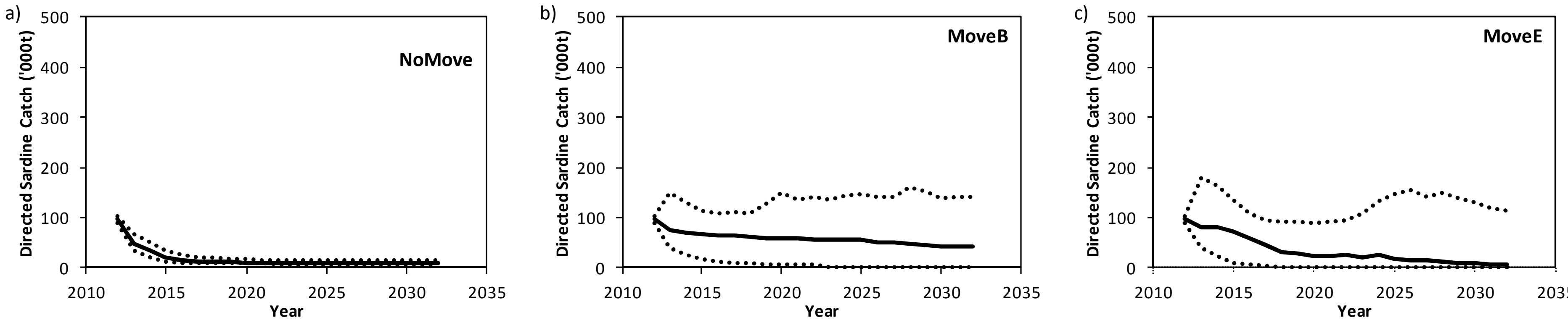

Figure 19. Future median and 90% probability intervals of projected total **directed ≥14cm sardine catch** assuming a **two sardine stock** operating model and **2-area Candidate MP with** $\beta_1 = 0.0, \quad \beta_2 = 0.090$. Trajectories are shown for different hypothesis of future movement of "west" stock recruits to the "south" stock: a) *NoMove*, b) *MoveB*, and c) *MoveE*.

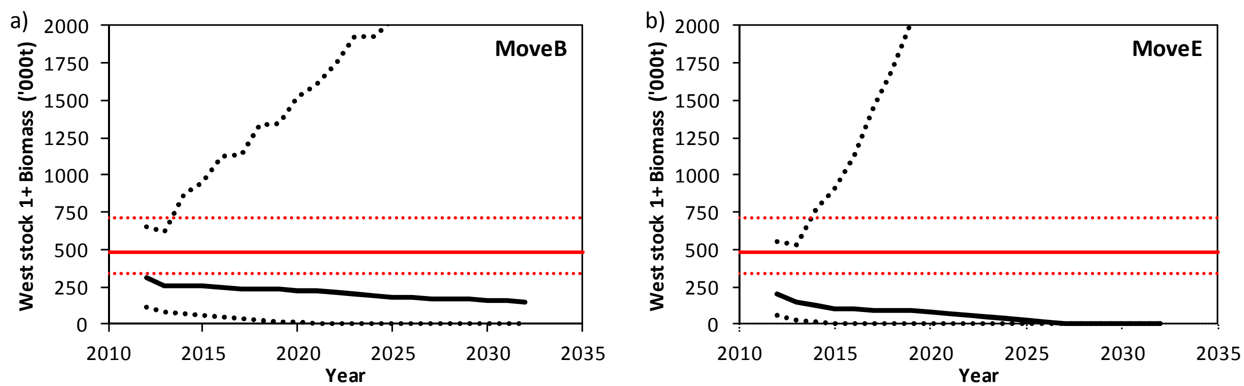

Figure 20. Future median and 90% probability intervals of projected **"west" 1+ biomass** assuming a **two sardine stock** operating model and **2-area Candidate MP with** $\beta_1 = 0.0, \quad \beta_2 = 0.090$ **and** $\alpha_{ns} = 0.4$. Trajectories are shown for different hypothesis of future movement of "west" stock recruits to the "south" stock: a) *NoMove*, b) *MoveB*, and c) *MoveE*. The posterior median, 5%ile and 95%ile of the distribution of average 91-94 1+ biomass is shown in the red horizontal lines.

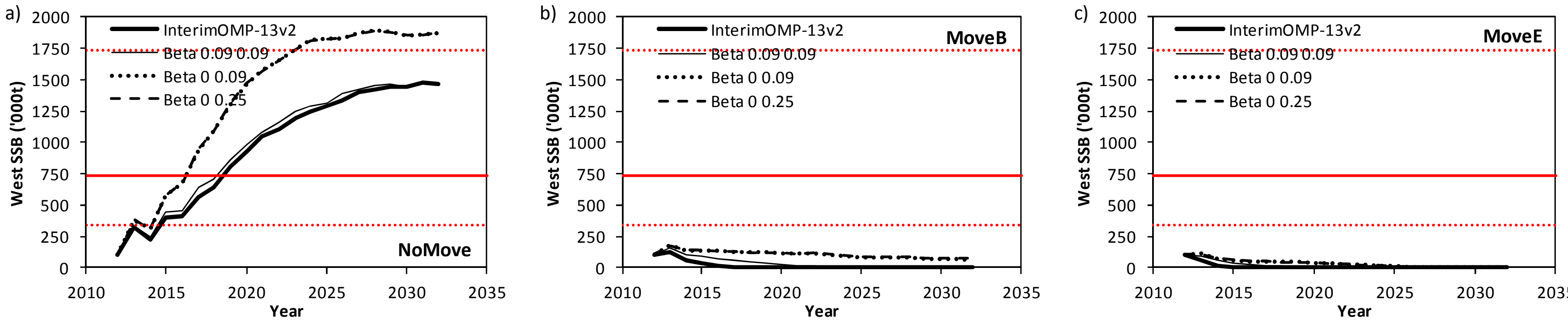

Figure 21. Future median projected **"west" SSB** assuming a **two sardine stock** operating model and different catch scenarios. Trajectories are shown for different hypothesis of future movement of "west" stock recruits to the "south" stock: a) *NoMove*, b) *MoveB*, and c) *MoveE*. The posterior median, 5%ile and 95%ile of the distribution of average 91-94 1+ biomass is shown in the red horizontal lines. Note that the vertical scale on Figure a) is different to that of b) and c).

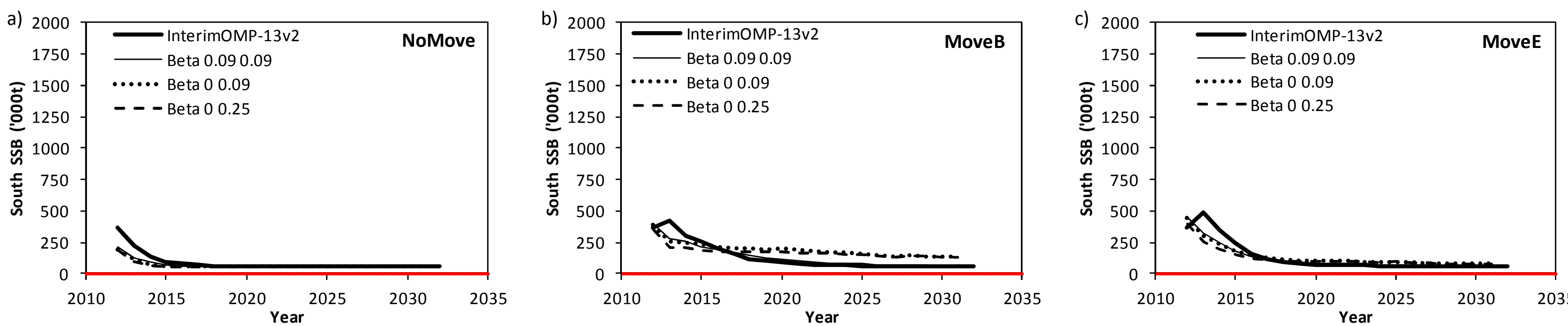

Figure 22. Future median projected **"south" SSB** assuming a **two sardine stock** operating model and different catch scenarios. Trajectories are shown for different hypothesis of future movement of "west" stock recruits to the "south" stock: a) *NoMove*, b) *MoveB*, and c) *MoveE*. The posterior median, 5%ile and 95%ile of the distribution of average 91-94 1+ biomass is shown in the red horizontal lines.

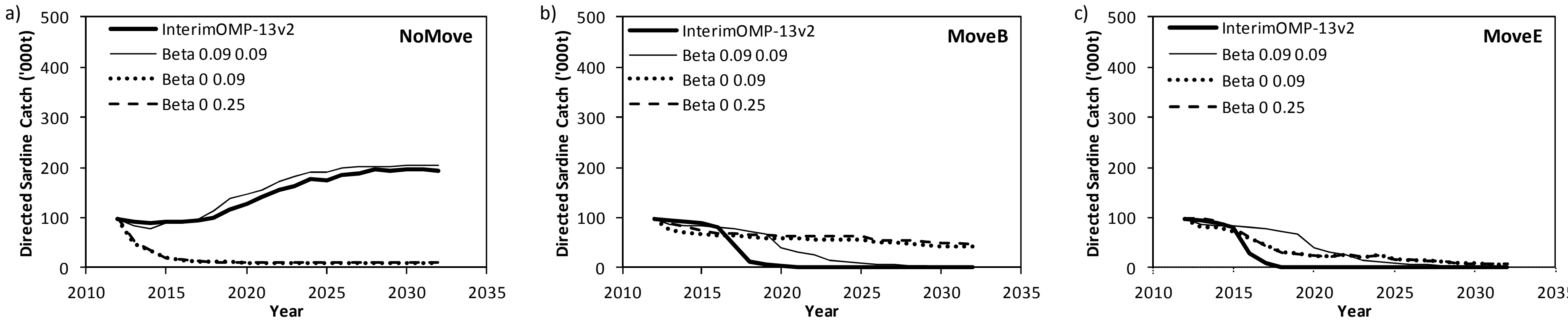

Figure 23. Future median projected total **directed ≥14cm sardine catch** assuming a **two sardine stock** operating model and different catch scenarios. Trajectories are shown for different hypothesis of future movement of "west" stock recruits to the "south" stock: a) *NoMove*, b) *MoveB*, and c) *MoveE*.