Comparisons of alternative single-area sardine TAC Management Procedures

C.L. de Moor*

Correspondence email: *carryn.demoor@uct.ac.za*

Introduction

The Small Pelagic Scientific Working Group has requested further testing of Candidate Management Procedures allocating a single-area sardine Total Allowable Catch (TAC) for possible update of Interim OMP-13 v2 for use in setting the 2014 initial sardine and anchovy TACs and Total Allowable Bycatches (TABs). This is planned as a temporary measure, while further testing continues in comparing Candidate MPs which allocate a single-area sardine TAC to those which allocate a two-area sardine TAC.

The harvest control rules are detailed in de Moor and Butterworth (2013a), and the simulation testing framework used for model projections is detailed in de Moor and Butterworth (2013b). Results are shown assuming either a single or two sardine stock operating model. When assuming a two sardine stock operating model, three different primary hypotheses of movement of "west" stock recruits to the "south" stock are considered (de Moor and Butterworth 2013c):

NoMove - no future movement

MoveB - future movement is based on a relationship with the ratio of "south" to "west" stock 1+ biomass

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.

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.

$risk_S^{west2}$ - 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.

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

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.

This document compares projections under a no catch scenario, Interim OMP-13 v2 (de Moor and Butterworth 2013d), and alternative values for the minimum sardine TAC (c_{mntac}^{S}) and the sardine Exceptional Circumstances threshold (B_{ec}^{S}). The effect of different assumed proportions of the single-area TAC caught west and south-east of Cape Agulhas is also explored.

Results

The choice that will need to be made by the Small Pelagic Scientific Working Group will be to recommend a particular management strategy (Operational Management Procedure) which needs to be robust to a range of uncertainty in the underlying operating models. These uncertainties include the number of sardine stocks and the future movement of sardine in the two-stock operating model. To assist in such decisions, the tables in this document have been arranged so that the implications of a particular management strategy on the resources can be seen for a range of alternative operating model hypotheses. However, to enable some comparison between alternative management strategies, the figures have been arranged so that, given a particular operating model hypothesis, the simulated implications of different management strategies can be seen.

Table 1 lists the risk to the resources under a no future catch scenario. The risk is low if a single stock hypothesis is assumed. However, given a two stock hypothesis, even with no future catch the risk of the “west” stock decreasing below its average level in recent years ($risk_S^{west2}$) remains above 90% if movement of “west” stock recruits to the “south” stock continues.

Under a future catch scenario with TACs and TABs calculated from Interim OMP-13 v2, the risk to the anchovy resource increases to 0.23-0.24 (Table 2), from 0.008 under a no catch scenario. The average projected anchovy catch is 288-292 000t (Table 2). Assuming a single sardine stock hypothesis, the risk to the total sardine resource increases from 0.047 (no catch) to 0.224 with an average projected directed catch of 156 000t (Table 2, Figure 4d). Assuming a two sardine stock hypothesis with no future movement of recruits from the “west” to “south” stocks, *NoMove*, the risk to the total sardine resource increases two fold, with an average projected directed catch of 180 000t, the majority of this taken on the west coast (Table 2, Figure 4a). Although there is a 47% chance that the “west” stock biomass would decrease below the average November 1991-1994 1+ biomass at least once during the projection period ($risk_S^{west}$, Table 2), Figure 1a shows that there is a greater chance of this threshold being breached in the first few years of the projection period. Assuming a two sardine stock hypothesis with future movement of recruits from the “west” to “south” stocks, *MoveB* and *MoveE*, the risk to the total sardine resource increases from 0.60-0.75 (no catch) to 0.96-0.98, with a much lower average projected directed catch of 31 000t. Figures 1b,c show that the “west” stock biomass is depleted during the projection period, with a subsequent depletion in the “south” stock biomass (Figures 2b,c) and thus catch (Figures 4b,c).

Minimum sardine TAC

Assuming a single sardine stock hypothesis, the risk to the total sardine resource decreases from 0.224 to 0.203 to 0.187 as the minimum sardine TAC is decreased from 90 to 70 and 50 000t (Table 2, Figure 7). There is a 2 000t decrease in average projected directed sardine catch for every 20 000t decrease in the minimum sardine TAC (Table 2, Figures 8d, 9d).

Assuming a two sardine stock hypothesis with *NoMove*, there is a small decrease in the risk to the sardine resources (Table 2, Figures 5, 6) with only a small change in the average projected catch from the south coast (Table 2, Figures 8a, 9a), primarily because higher directed sardine catches are projected.

Assuming a two sardine stock hypothesis with *MoveB* or *MoveE*, a decrease in the minimum sardine TAC results in a small decrease in the risk to the "south" sardine stock (Table 2). Although there is a decrease of about 3 000t in the sardine catch as the minimum sardine TAC decreases from 90 to 70 000t (Table 2, Figures 8b,c, 9b,c), this decrease is primarily from the south coast catch (Table 2) and thus the decline in the "west" stock continues with little difference in the risk to the "west" stock between the minimum sardine TAC scenarios (Table 2, Figure 5b,c).

Sardine Exceptional Circumstances threshold

Assuming a single stock hypothesis, the risk to the total sardine resource decreases from 0.224 to 0.149 as the sardine Exceptional Circumstances threshold increases from 300 to 700 000t, with a decrease in the average projected directed sardine catch from 156 to 145 000t (Table 3). Assuming a two sardine stock hypothesis with *NoMove*, the risk to the total sardine resource decreases, with $risk_S^{west}$ decreasing from 0.466 to 0.431 as the Exceptional Circumstances threshold increases from 300 to 700 000t. There is a small decrease in the average south coast catch (Table 3).

As expected, there is little difference in the median projections (Figures 12a, 13d); the difference is primarily seen in projections with the lowest 1+ biomass. The higher Exceptional Circumstances threshold halts the projected decline in the lower 5%ile of the projected single stock 1+ biomass (Figure 12b), or provides for a more rapid and greater increase in the lower 5%ile of the projected "west" stock biomass assuming *NoMove* (Figure 10a, lower panel). Note once again that assuming *NoMove*, the risk to the "west" stock resource is greatest in the former years of the projection period (Figure 10a). In these cases the lower 5%ile of catch decreases with increasing Exceptional Circumstances threshold (Figures 12b, 14d). The slower recovery in the total catch under *NoMove* for higher Exceptional Circumstances thresholds is the driver of the more rapid and greater increase in the projected "west" stock 1+ biomass.

Assuming a two stock hypothesis with *MoveB* or *MoveE*, the risk to the total sardine resource decreases from 0.96-0.98 to 0.94-0.97 as the sardine Exceptional Circumstances threshold increases from 300 to 700 000t (Table 3). There is a greater decrease in the "south" stock risk, with little change in the risk to the "west" stock (there remains a 98-99% change of the "west" stock 1+ biomass falling below its November 1991-1993 average). Given the more pessimistic projections under *MoveB* and *MoveE* compared to *NoMove*, the declaration of Exceptional Circumstances occurs more often and thus a difference in the projected average catch can be clearly seen in the median plots (Figure 13b,c); the projected catches of the lower 5%ile being low for all scenarios (Figure 14b,c). There is a decrease in total projected sardine catch from 31 to 26/27 000t, though some increase in the west coast catch, possibly due to the slower decline in the "west" stock in former years (Figures 10b,c).

Split of sardine catch west and south-east of Cape Agulhas

The simulation testing framework currently assumes that future catches of a single-area directed sardine TAC would be split between the "west" and "south" stocks according to a relationship with the ratio of the TAC to the observed 1+ biomass west of Cape Agulhas (Figure 15). Table 4 shows the results for some alternative assumptions, where the future proportion of catch from the "west" and "south" stocks is assumed constant. As expected, for all movement scenarios, the risk to the total sardine resource, and the "west" stock decreases with decreasing proportion of catch taken west of Cape Agulhas (Table 4, Figure 16).

Under *NoMove*, the risk to the total sardine population is lower than under a single-stock hypothesis when all of the catch is assumed taken from the "south" stock, though with a much lower average catch (Figures 18a, 19a, because the majority of the biomass remains west of Cape Agulhus under this movement hypothesis). However, if 20% or 40% of the catch is taken west of Cape Agulhas, the risk to the total sardine resource remains under 0.3 (in comparison to 0.224 for single stock hypothesis), with an average projected catch of 62 000t (20% west of Cape Agulhas) to 100 000t (40% west of Cape Agulhas) (Table 4, Figures 16a, 18a, 19a). Under this *NoMove* hypothesis, all these alternatives which ensure a fixed proportion of catch west and south-east of Cape Agulhas, have a lower average projected catch than the baseline (Figure 15) because the majority of the sardine are modelled to remain on the west coast (Figures 18a, 19a). The risk to the "south" stock remains at 100% for all scenarios, though the median long-term depletion is less for the baseline due to the higher proportion of catch from the west coast (Figure 17a).

Under *MoveB* and *MoveE*, the risk to the total sardine resource decreases below 0.9 when 80 to 100% of the catch is taken south-east of Cape Agulhas, though the risk to the "west" stock remains above 0.9 given the movement of recruits to the "south" stock (Table 4). Improved results, both in terms of average projected catch and estimated risk to the resources, in comparison to the baseline assumptions, based on the relationship observed historically (Figure 15), is obtained if 60% or more of the catch is taken south-east of Cape Agulhas (Table 4, Figures 16b,c - 19b,c).

Summary

The results in this document continue to show that the underlying operating model (single versus two stock hypothesis and the choice of future movement hypothesis) has a greater impact on the difference in projected trajectories and risk statistics, than does a change in a single sardine TAC Candidate Management Procedure. The candidate MPs simulation tested in this document include comparisons to Interim OMP-13 v2 and lower minimum sardine TAC or higher sardine Exceptional Circumstances thresholds.

A lower minimum sardine TAC will decrease the risk to the sardine resource if a single sardine stock exists, or if there is no future movement between a "west" and "south" sardine stock. The average decrease in catch is projected to be small. However, should movement of "west" stock recruits to the "south" stock continue, a change in minimum sardine TAC (with much of this modelled to be caught from the west coast) does little to change the pessimistic projections for sardine.

In the short term (up to 2020), the depletion of the "west" stock is less for a higher sardine Exceptional Circumstances threshold under *MoveB* and *MoveE*, though there is little difference in the long term. Some examples of directed sardine TACs under Interim OMP-13 v2 and higher sardine Exceptional Circumstances thresholds are given in Table 5 using the past 8 years of observations. Some examples are also given for these alternative Exceptional Circumstances thresholds, but with a less conservative (i.e. linear rather than quadratic) Exceptional Circumstances rule.

Moving fishing pressure from the west to the south coast, however, has the most optimistic projections for the "west" stock. (By definition, there would no difference to a single stock hypothesis if more catch were taken west or south-east of Cape Agulhas.) If movement of "west" stock recruits to the "south" stock continues, then in addition to the higher projected 1+ biomass, there would also be a prolonged period before any decrease in the median catch, for a higher proportion of catch south-east of Cape Agulhas. If there is no future movement of "west" stock recruits to the "south" stock then the projected catch in the near future would be lower for a higher proportion of the catch taken south-east of Cape Agulhas, but the "west" 1+ biomass increases further.

References

de Moor, C.L. and Butterworth, D.S. 2013a. Draft Two-Area Harvest Control Rules for OMP-13. DAFF: Branch Fisheries Document FISHERIES/2013/OCT/SWG-PEL/30. 16pp.

de Moor, C.L. and Butterworth, D.S. 2013b. The simulation testing framework used during the development of OMP-13. DAFF: Branch Fisheries Document FISHERIES/2013/OCT/SWG-PEL/26. 27pp.

de Moor, C.L. and Butterworth, D.S. 2013c. Further results from future projections of a single or two sardine stock operating model, with initial results using a two-area directed sardine TAC. DAFF: Branch Fisheries Document FISHERIES/2013/OCT/SWG-PEL/31rev. 26pp.

de Moor, C.L., and Butterworth, D.S. 2013d. Interim OMP-13 v2. DAFF: Branch Fisheries Document FISHERIES/2013/JUL/SWG-PEL/15. 18pp

de Moor, C.L., Butterworth, D.S., and Coetzee, J.C. 2013. Proposals to Split Sardine Catch West and East of Cape Agulhas. DAFF: Branch Fisheries Document FISHERIES/2013/SEP/SWG-PEL/24. 8pp

Table 1. The risk to the resources and average annual directed catch for projections assuming **no future catch**. Results are shown for a single sardine operating model (with variability about the stock recruitment relationship $\sigma^{S}_{j=1,r} = 0.45$) and three alternatives of 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. The alternative hypotheses of future movement of "west" recruits to the "south" stock are: 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*).

Management Procedure	Single Stock or Two stock movement model	β	α_{ns}	$risk_A$	$risk_S$	$risk_S^{west}$	$risk_S^{south}$	$risk_S^{west2}$	$\overline{C}^{A}$	$\overline{C}^{S}$	$\overline{C}^{S}_{west}$	$\overline{C}^{S}_{south}$
No Catch	Single Stock	N/A	N/A	0.008	0.047				0	0		
	NoMove	N/A	N/A	0.008	0.183	0.328	0.997	0.068	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

Table 2. The risk to the resources and average annual directed catch for projections assuming **a single area sardine TAC Management Procedure, with different minimum sardine TACs**. Results are shown for a single sardine operating model (with variability about the stock recruitment relationship $\sigma^S_{j=1,r} = 0.45$) and three alternatives of a two sardine stock operating model assuming a fixed value of $k^S_{\text{cov}E} = 1$ 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. The alternative hypotheses of future movement of "west" recruits to the "south" stock are: 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*).

Management Procedure	Single Stock or Two stock movement model	β	α_{ns}	$risk_A$	$risk_S$	$risk_S^{west}$	$risk_S^{south}$	$risk_S^{west2}$	$\overline{C}^A$	$\overline{C}^S$	$\overline{C}^S_{west}$	$\overline{C}^S_{south}$
Single area TAC min of 90 000t (Interim OMP-13 v2)	Single Stock	0.090	0.871	0.226	0.224				290	156		
	NoMove[1]	0.090	0.871	0.237	0.361	0.466	1.000	0.200	288	180	161	20
	MoveE[1]	0.090	0.871	0.240	0.955	0.987	0.934	0.970	292	31	15	16
	MoveB[1]	0.090	0.871	0.243	0.981	0.998	0.957	0.996	292	31	15	16
Single area TAC min of 70 000t	Single Stock	0.090	0.871	0.226	0.203				290	154		
	NoMove	0.090	0.871	0.237	0.343	0.453	1.000	0.189	288	179	161	18
	MoveE	0.090	0.871	0.241	0.952	0.986	0.919	0.970	292	30	15	14
	MoveB	0.090	0.871	0.243	0.979	0.998	0.942	0.996	292	29	15	14
Single area TAC min of 50 000t	Single Stock	0.090	0.871	0.226	0.187				290	152		
	NoMove	0.090	0.871	0.237	0.326	0.448	1.000	0.181	288	179	161	18
	MoveE	0.090	0.871	0.242	0.946	0.985	0.903	0.970	292	26	16	10
	MoveB	0.090	0.871	0.241	0.975	0.998	0.919	0.996	292	28	16	12

[1] These results are different from those in de Moor and Butterworth (2013). The reason for the difference is because de Moor and Butterworth (2013) results used model predicted November 1+ biomass instead of simulated survey 1+ biomass in the relationship, $p_w^{catch}(y) = 1.0 - 0.89 \times \{TAC(y)/B_w^{obs}(y-1)\}/(0.89 + \{TAC(y)/B_w^{obs}(y-1)\})$, used to calculate the proportional split of sardine catch east and west of Cape Agulhas. This relationship is only used for the scenario of a single area sardine TAC with a two sardine stock operating model. As the simulated survey biomass is less than the model predicted biomass (due to survey bias), this results in a smaller proportion of the catch predicted to be taken west of Cape Agulhas in the future.

Table 3. The risk to the resources and average annual directed catch for projections assuming **a single area sardine TAC Management Procedure, with different sardine Exceptional Circumstances thresholds**. Results are shown for a single sardine operating model (with variability about the stock recruitment relationship $\sigma^S_{j=1,r} = 0.45$) and three alternatives of a two sardine stock operating model assuming a fixed value of $k^S_{\text{cov}E} = 1$ 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. The alternative hypotheses of future movement of "west" recruits to the "south" stock are: 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*).

Management Procedure	Single Stock or Two stock movement model	β	α_{ns}	$risk_A$	$risk_S$	$risk_S^{west}$	$risk_S^{south}$	$risk_S^{west2}$	$\overline{C}^A$	$\overline{C}^S$	$\overline{C}^S_{west}$	$\overline{C}^S_{south}$
Single area TAC B^S_{EC} = 300 000t (Interim OMP-13 v2)	Single Stock	0.090	0.871	0.226	0.224				290	156		
	NoMove	0.090	0.871	0.237	0.361	0.466	1.000	0.200	288	180	161	20
	MoveE	0.090	0.871	0.240	0.955	0.987	0.934	0.970	292	31	15	16
	MoveB	0.090	0.871	0.243	0.981	0.998	0.957	0.996	292	31	15	16
Single area TAC B^S_{EC} = 400 000t	Single Stock	0.090	0.871	0.226	0.206				290	154		
	NoMove	0.090	0.871	0.237	0.348	0.462	1.000	0.194	288	180	162	19
	MoveE	0.090	0.871	0.241	0.951	0.987	0.915	0.970	292	29	15	13
	MoveB	0.090	0.871	0.244	0.981	0.998	0.934	0.997	292	29	15	13
Single area TAC B^S_{EC} = 500 000t	Single Stock	0.090	0.871	0.227	0.184				290	151		
	NoMove	0.090	0.871	0.236	0.332	0.454	1.000	0.178	288	180	162	18
	MoveE	0.090	0.871	0.242	0.947	0.986	0.896	0.970	292	28	16	12
	MoveB	0.090	0.871	0.244	0.979	0.998	0.909	0.996	292	27	16	12
Single area TAC B^S_{EC} = 600 000t	Single Stock	0.090	0.871	0.228	0.165				290	148		
	NoMove	0.090	0.871	0.237	0.315	0.442	1.000	0.168	288	179	162	17
	MoveE	0.090	0.871	0.242	0.944	0.985	0.876	0.968	292	27	16	11
	MoveB	0.090	0.871	0.242	0.975	0.998	0.880	0.996	292	26	16	10
Single area TAC B^S_{EC} = 700 000t	Single Stock	0.090	0.871	0.228	0.149				290	145		
	NoMove	0.090	0.871	0.237	0.305	0.431	1.000	0.160	288	178	161	17
	MoveE	0.090	0.871	0.243	0.939	0.983	0.859	0.967	292	27	17	10
	MoveB	0.090	0.871	0.243	0.970	0.998	0.842	0.996	292	26	16	10

Table 4. The risk to the resources and average annual directed catch for projections assuming **a single area sardine TAC Management Procedure, with different model assumptions of the split of sardine catch east and west of Cape Agulhas**. Results are shown for three alternatives of 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[2]. The alternative hypotheses of future movement of "west" recruits to the "south" stock are: 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*).

Management Procedure	Single Stock or Two stock movement model	β	α_{ns}	$risk_A$	$risk_S$	$risk_S^{west}$	$risk_S^{south}$	$risk_S^{west2}$	$\overline{C}^{A}$	$\overline{C}^{S}$	$\overline{C}^{S}_{west}$	$\overline{C}^{S}_{south}$
Single area TAC Catch split based on relationship of TAC:B[West] (Interim OMP-13 v2)	NoMove	0.090	0.871	0.237	0.361	0.466	1.000	0.200	288	180	161	20
	MoveE	0.090	0.871	0.240	0.955	0.987	0.934	0.970	292	31	15	16
	MoveB	0.090	0.871	0.243	0.981	0.998	0.957	0.996	292	31	15	16
Single area TAC 80% catch west of Cape Agulhas	NoMove	0.090	0.871	0.237	0.398	0.515	1.000	0.245	288	165	142	22
	MoveE	0.090	0.871	0.240	0.972	0.990	0.951	0.978	292	20	12	7
	MoveB	0.090	0.871	0.236	0.992	0.998	0.983	0.999	292	20	13	7
Single area TAC 60% catch west of Cape Agulhas	NoMove	0.090	0.871	0.240	0.341	0.415	1.000	0.146	288	136	112	24
	MoveE	0.090	0.871	0.242	0.947	0.982	0.926	0.966	292	30	14	16
	MoveB	0.090	0.871	0.244	0.974	0.995	0.938	0.992	292	32	15	16
Single area TAC 40% catch west of Cape Agulhas	NoMove	0.090	0.871	0.241	0.290	0.335	1.000	0.087	288	100	77	23
	MoveE	0.090	0.871	0.242	0.913	0.969	0.883	0.944	292	43	13	30
	MoveB	0.090	0.871	0.244	0.933	0.983	0.840	0.972	292	50	17	33
Single area TAC 20% catch west of Cape Agulhas	NoMove	0.090	0.871	0.243	0.242	0.254	1.000	0.044	288	62	40	22
	MoveE	0.090	0.871	0.246	0.877	0.948	0.823	0.915	291	58	9	49
	MoveB	0.090	0.871	0.243	0.833	0.957	0.698	0.929	291	74	13	60
Single area TAC 0% catch west of Cape Agulhas	NoMove	0.090	0.871	0.245	0.207	0.193	1.000	0.018	288	22	0	22
	MoveE	0.090	0.871	0.247	0.817	0.926	0.738	0.879	291	78	0	78
	MoveB	0.090	0.871	0.246	0.684	0.924	0.526	0.844	291	102	0	102

[2] These alternatives do not affect the single stock operating model.

Table 5. A comparison of the sardine TACs (rounded to the nearest thousand tons) generated under OMP-08 ($\beta = 0.097$, $\alpha_{ns} = 0.78$) compared to Interim OMP-13 v2 ($\beta = 0.090$, $\alpha_{ns} = 0.871$) and the same HCRs as Interim OMP-13 v2, but with different sardine Exceptional Circumstances thresholds, B^S_{ec}, for a given set of historic observations. The historic observations are as follows:

$B^S_{y,N}$ - November survey estimate of sardine 1+ biomass in year y (in thousands of tons)

$N^S_{y,r}$ - May survey estimate of sardine recruitment in year y (in billions)

Comparisons are also shown for a linear, rather than quadratic, decline in the TAC once Exceptional Circumstances are declared.

		2006	2007	2008	2009	2010	2011	2012	2013
$B^S_{y-1,N}$		1048.991	712.557	252.201	384.080	501.575	508.392	1037.060	345.054
$N^S_{y,r}$		2.874	9.564	2.937	3.852	9.207	35.569	5.469	12.124
Quadratic	OMP-08 ($B^S_{ec} = 300$)	204	150	34	90	90	90	101	90
	Interim OMP-13v2 ($B^S_{ec} = 300$)	204	163[3]	34[4]	90	90	90	93[5]	90
	$B^S_{ec} = 400$	204	147[6]	14	52	90	90	93	57
	$B^S_{ec} = 500$	204	129[6]	6	28	90	90	93	29
	$B^S_{ec} = 600$	204	111[6]	3	16	46	63[7]	93	16
	$B^S_{ec} = 700$	189[6]	92[6]	1	9	29	40[7]	93	9
Linear	$B^S_{ec} = 300$	204	163	71	90	90	90	93	90
	$B^S_{ec} = 400$	204	147	46	85	90	90	93	74
	$B^S_{ec} = 500$	204	129	31	62	90	90	93	53
	$B^S_{ec} = 600$	204	111	20	47	70	72	93	39
	$B^S_{ec} = 700$	189	92	13	36	56	57	93	29

[3] Differs from OMP-08 due to linear smoothing.

[4] Differs from OMP-08 due to R_{crit} value.

[5] Differs from OMP-08 due to β value.

[6] Linear smoothing applied.

[7] A conservative initial sardine TAC is recommended in December, but given the above average recruitment, the maximum of 220% of the initial sardine TAC is recommended mid-year.

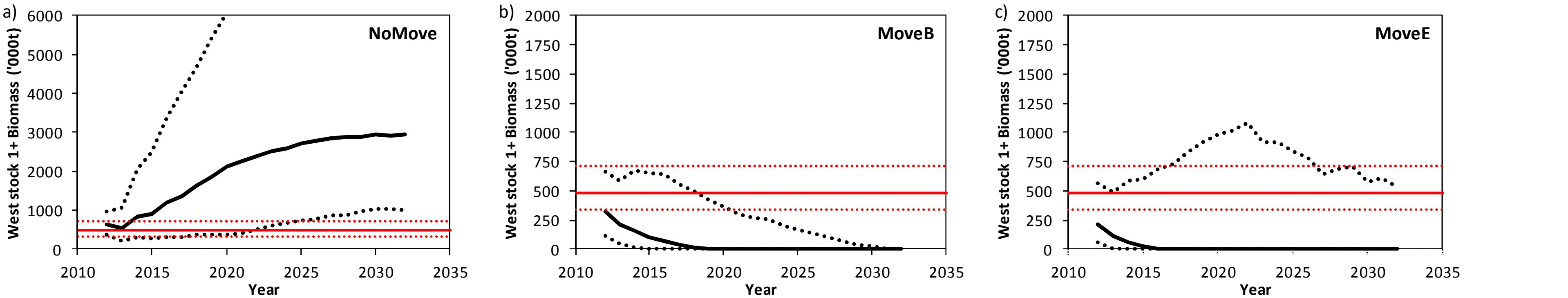

Figure 1. Future median and 90% probability intervals of projected **"west" 1+ biomass** assuming a **two sardine stock** operating model and **Interim OMP-13 v2**. Trajectories are shown for different hypothesis of future movement of "west" stock recruits to the "south" stock: a) *NoMove*, b) *MoveB*, 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).[8]

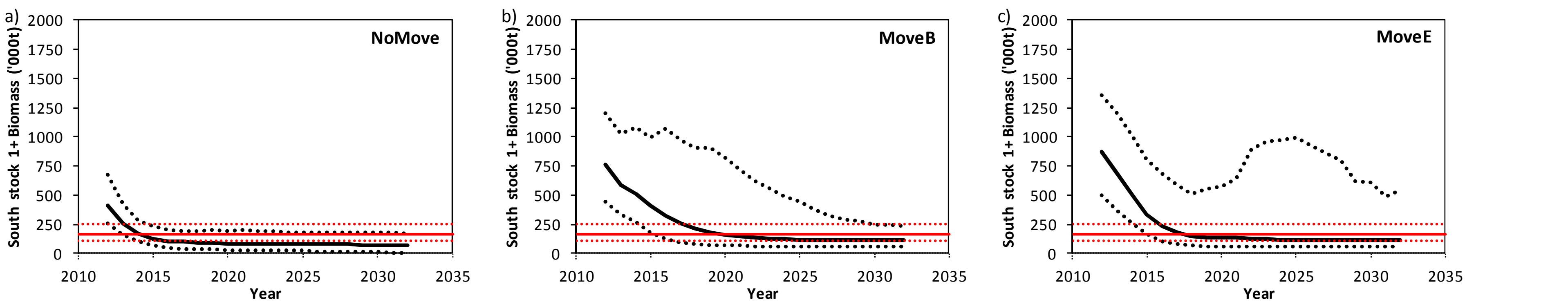

Figure 2. Future median and 90% probability intervals of projected **"south" stock 1+ biomass** assuming a **two sardine stock** operating model and **Interim OMP-13 v2**. Trajectories are shown for different hypothesis of future movement of "west" stock recruits to the "south" stock: a) *NoMove*, b) *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[8].

[8] These results are different from those in de Moor and Butterworth (2013). The reason for the difference is because de Moor and Butterworth (2013) results used model predicted November 1+ biomass instead of simulated survey 1+ biomass in the relationship, $p_w^{catch}(y) = 1.0 - 0.89 \times \{TAC(y)/B_w^{obs}(y-1)\}/(0.89 + \{TAC(y)/B_w^{obs}(y-1)\})$, used to calculate the proportional split of sardine catch east and west of Cape Agulhas. This relationship is only used for the scenario of a single area sardine TAC with a two sardine stock operating model. As the simulated survey biomass is less than the model predicted biomass (due to survey bias), this results in a smaller proportion of the catch predicted to be taken west of Cape Agulhas in the future.

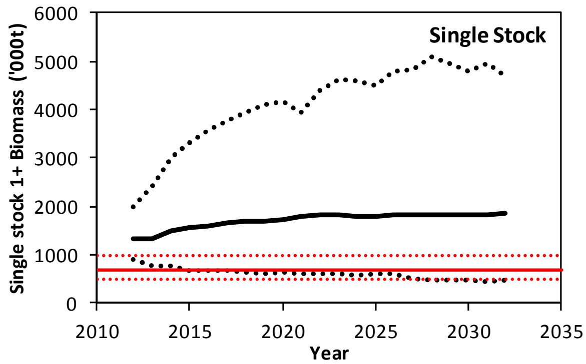

Figure 3. Future median and 90% probability intervals of projected **total 1+ biomass** assuming a **single sardine stock** operating model and **Interim OMP-13 v2**. The posterior median, 5%ile and 95%ile of the distribution of average 91-94 1+ biomass is shown in the red horizontal lines.

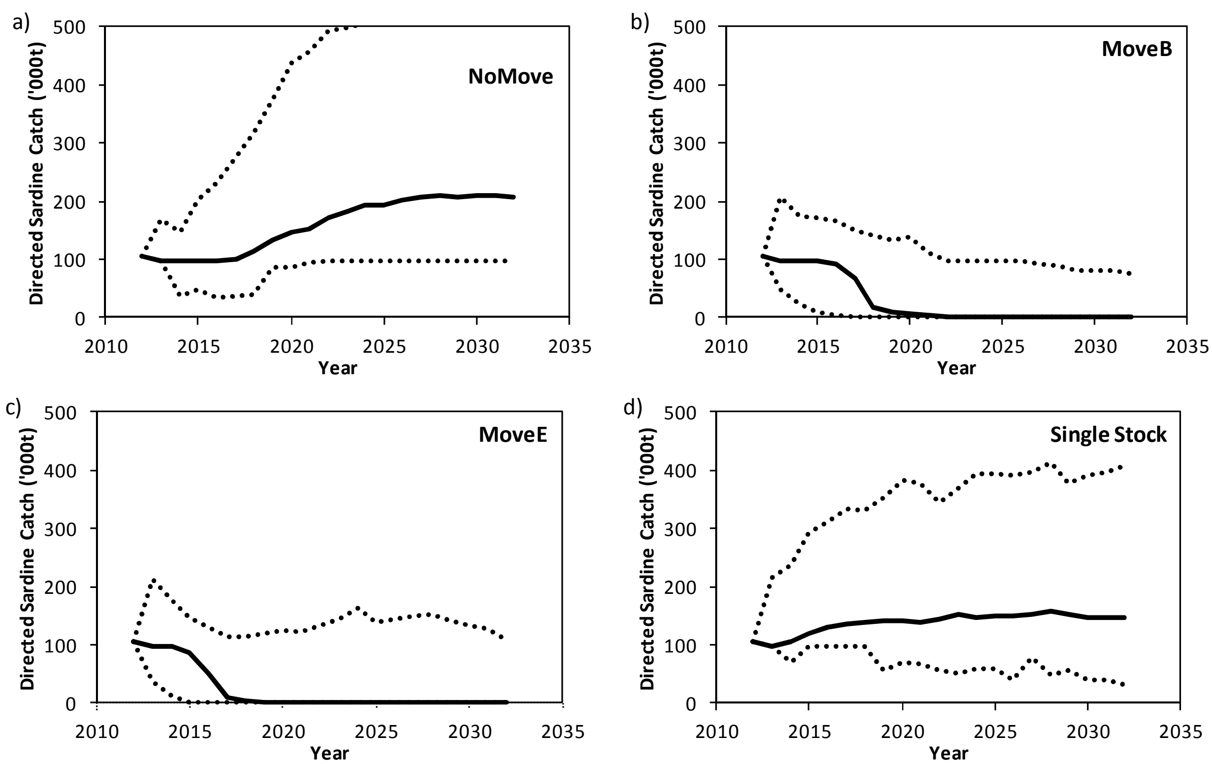

Figure 4. Future median and 90% probability intervals of projected total **directed ≥14cm sardine catch** assuming a **two sardine stock** operating model (a-c) and d) a **single sardine stock** operating model, and **Interim OMP-13 v2**. Trajectories are shown for different hypotheses of future movement of “west” stock recruits to the “south” stock: a) *NoMove*, b) *MoveB*, and c) *MoveE*.

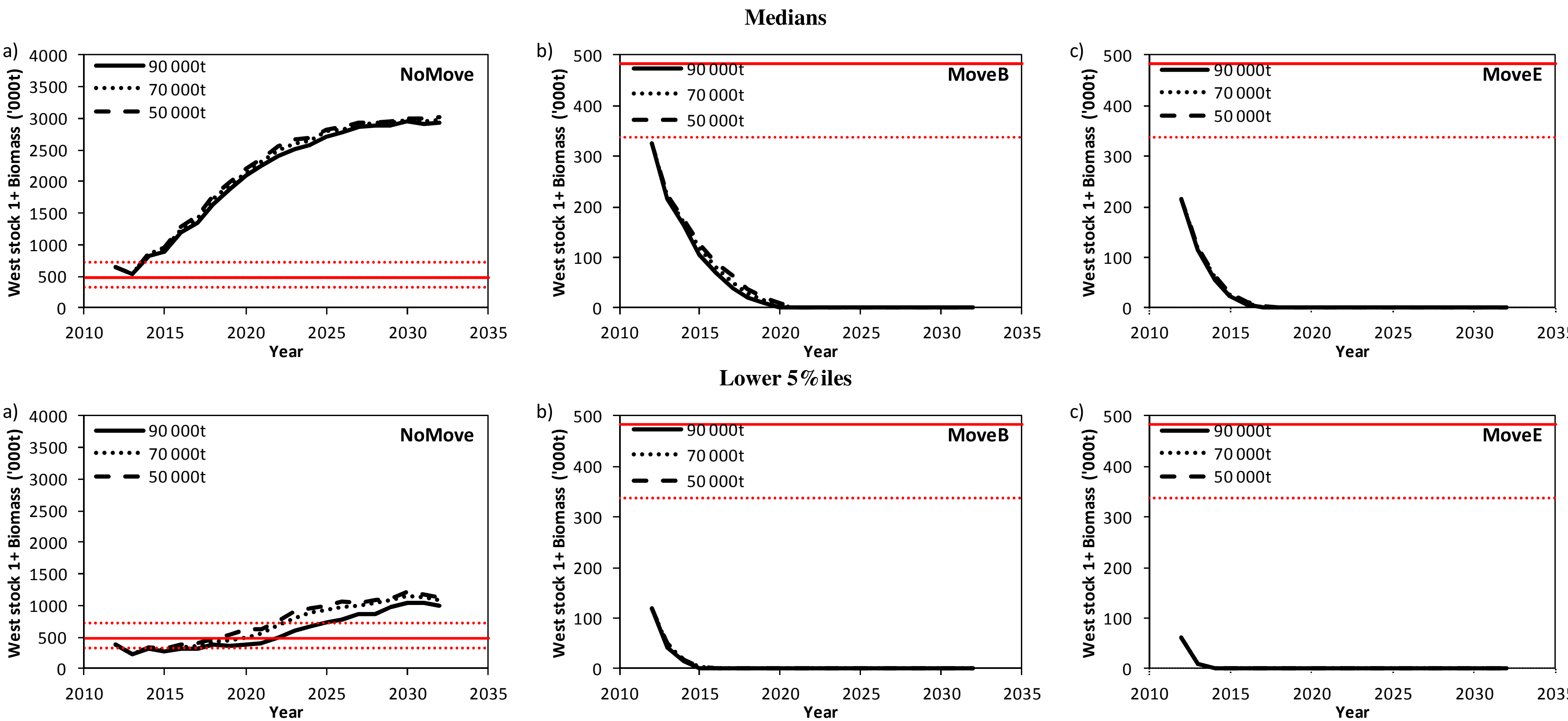

Figure 5. Future median (upper row) and lower 5%ile (lower row) projected **"west" 1+ biomass** assuming a **two sardine stock** operating model and different minimum sardine TAC values. Trajectories are shown for different hypothesis of future movement of "west" stock recruits to the "south" stock: 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).

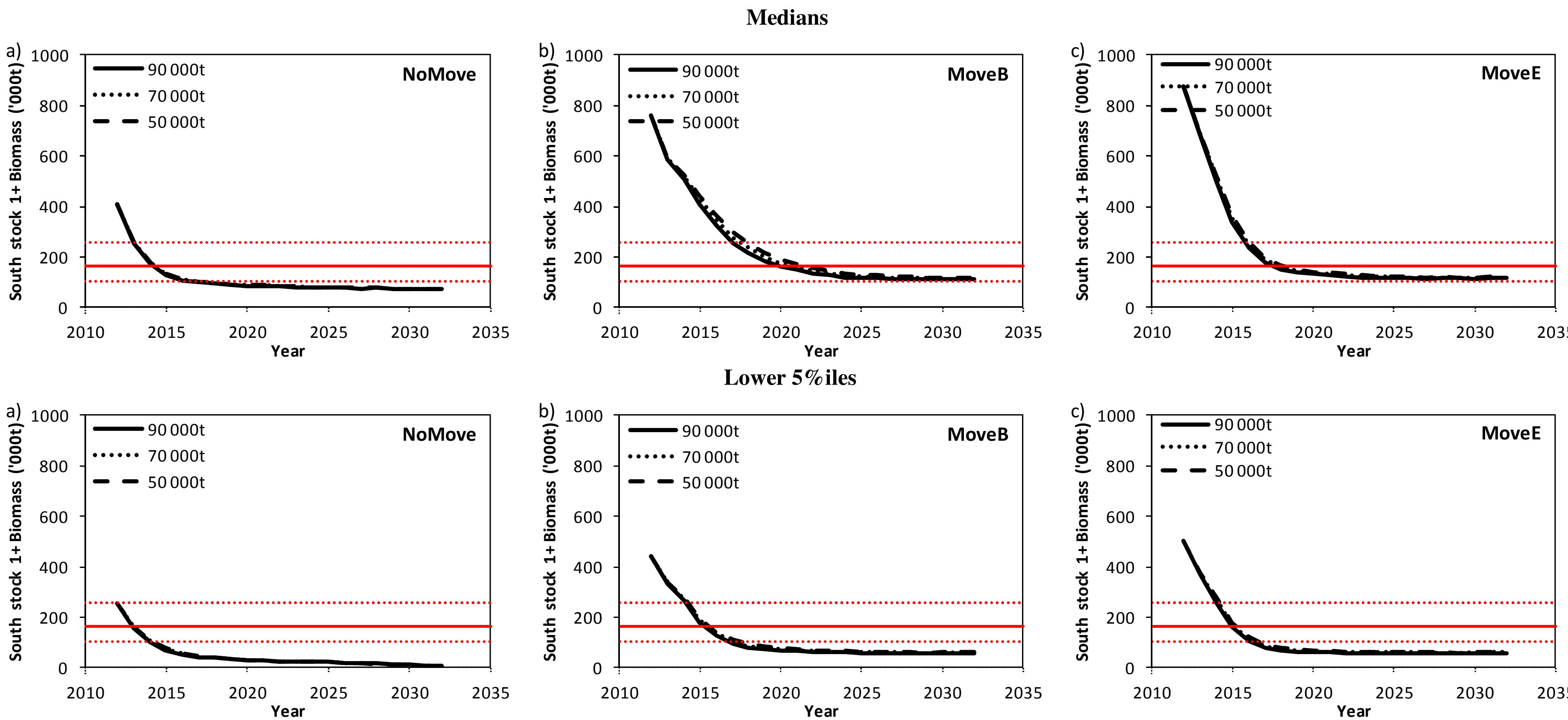

Figure 6. Future median (upper row) and lower 5%ile (lower row) projected **"south" 1+ biomass** assuming a **two sardine stock** operating model and different minimum sardine TAC values. Trajectories are shown for different hypothesis of future movement of "west" stock recruits to the "south" stock: 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.

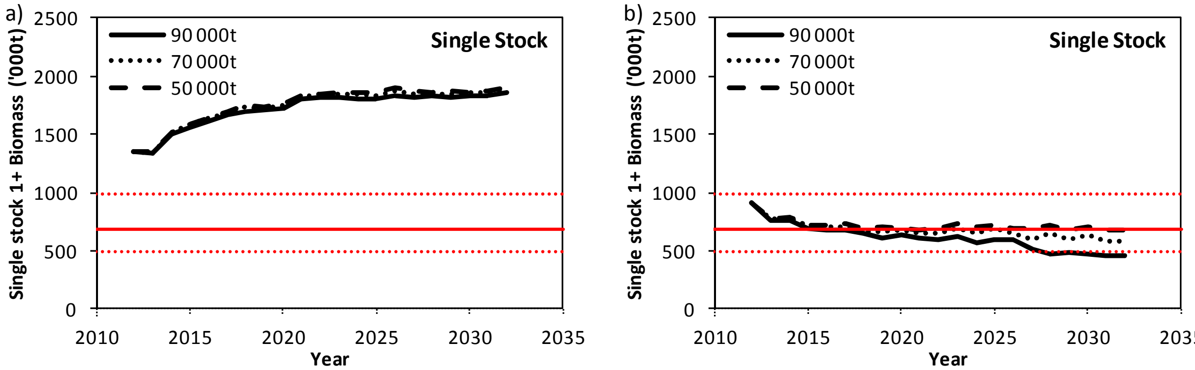

Figure 7. Future a) median and b) lower 5%ile projected **total 1+ biomass** assuming a **single sardine stock** operating model and different minimum sardine TAC values. The posterior median, 5%ile and 95%ile of the distribution of average 91-94 1+ biomass is shown in the red horizontal lines.

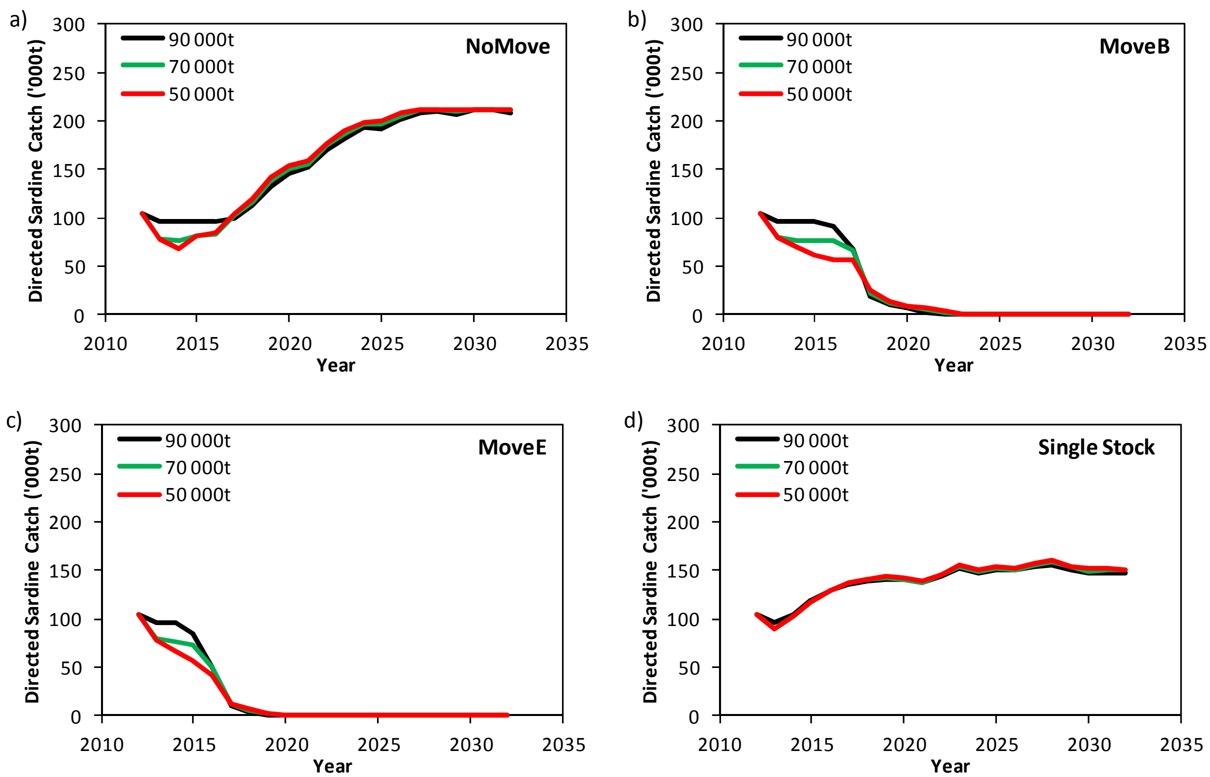

Figure 8. Future **median** projected total **directed ≥14cm sardine catch** assuming a **two sardine stock** operating model (a-c) and d) a **single sardine stock** operating model, and different minimum sardine TAC values. Trajectories are shown for different hypotheses of future movement of "west" stock recruits to the "south" stock: a) *NoMove*, b) *MoveB*, and c) *MoveE*.

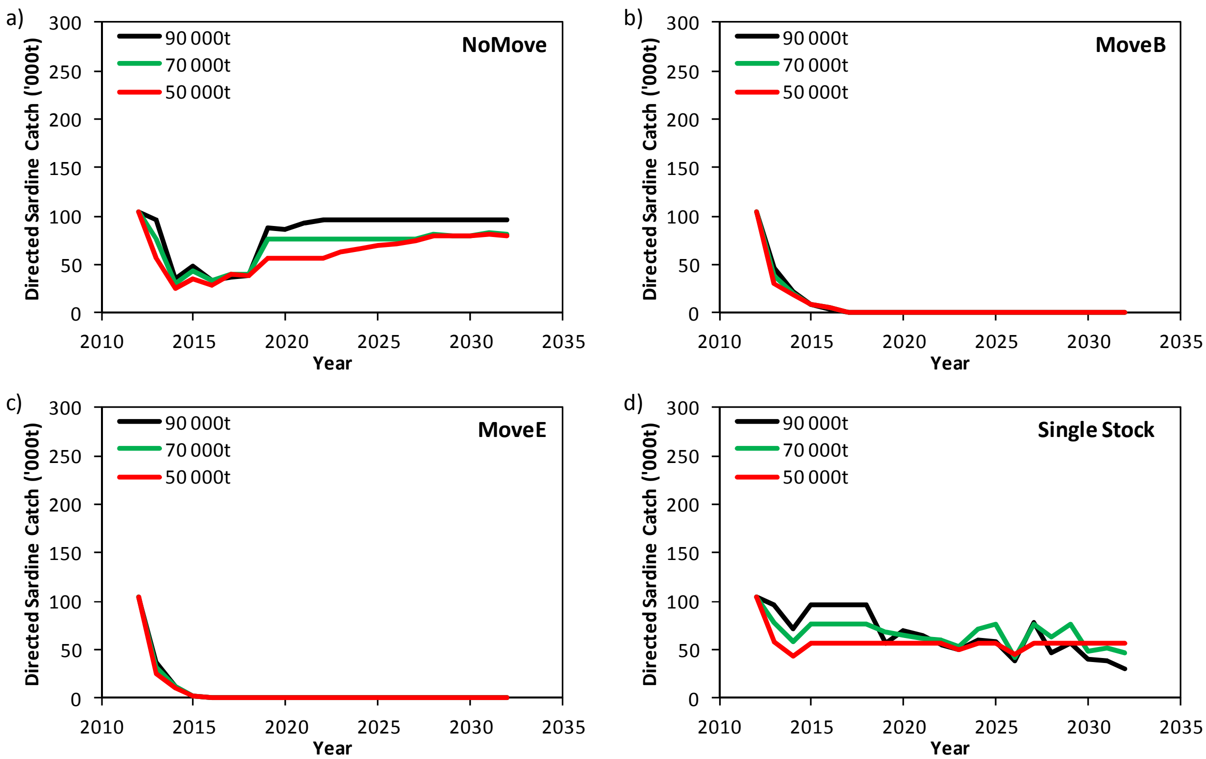

Figure 9. Future **lower 5%ile** of projected total **directed ≥14cm sardine catch** assuming a **two sardine stock** operating model (a-c) and d) a **single sardine stock** operating model, and different minimum sardine TAC values. Trajectories are shown for different hypotheses of future movement of "west" stock recruits to the "south" stock: a) *NoMove*, b) *MoveB*, and c) *MoveE*.

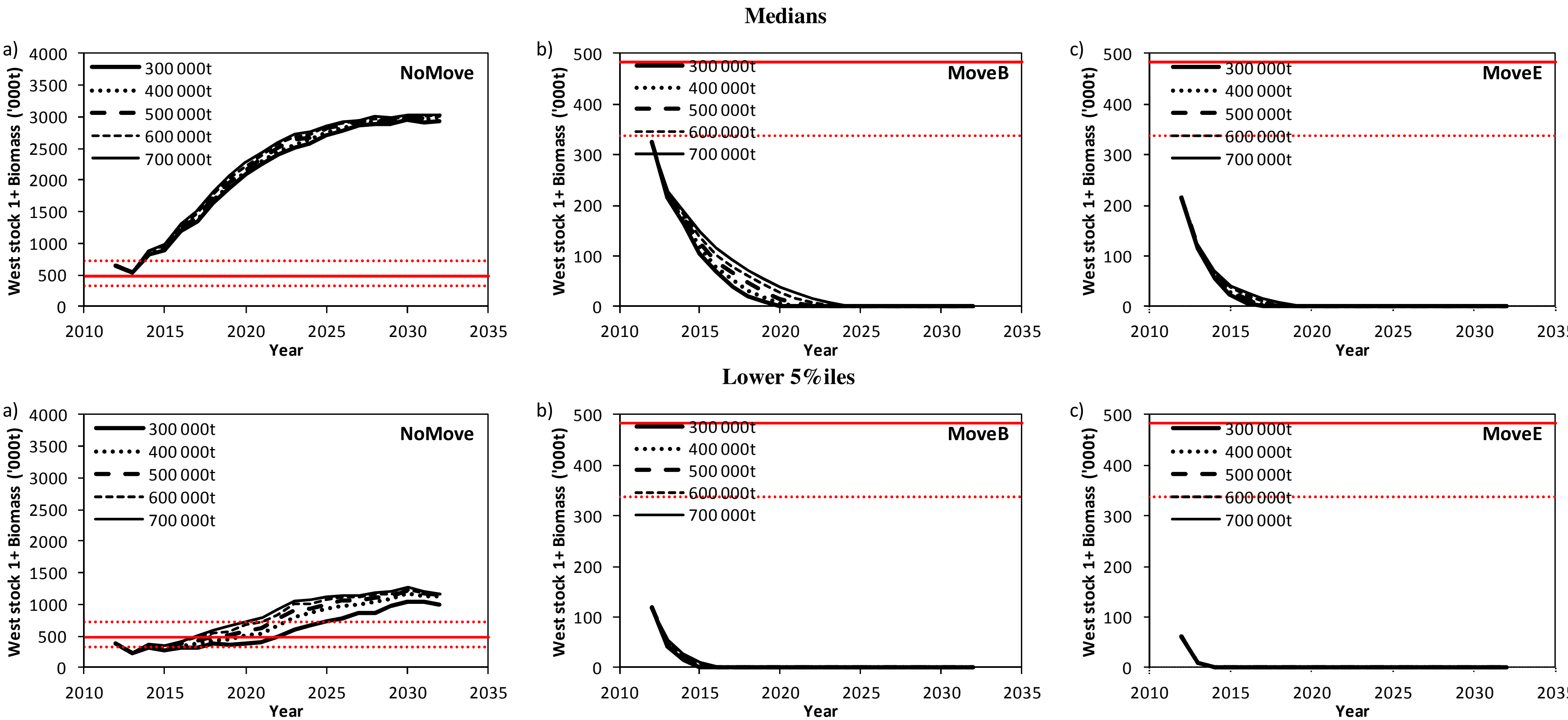

Figure 10. Future median (upper row) and lower 5%ile (lower row) projected **"west" 1+ biomass** assuming a **two sardine stock** operating model and different sardine Exceptional Circumstances thresholds. Trajectories are shown for different hypothesis of future movement of "west" stock recruits to 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).

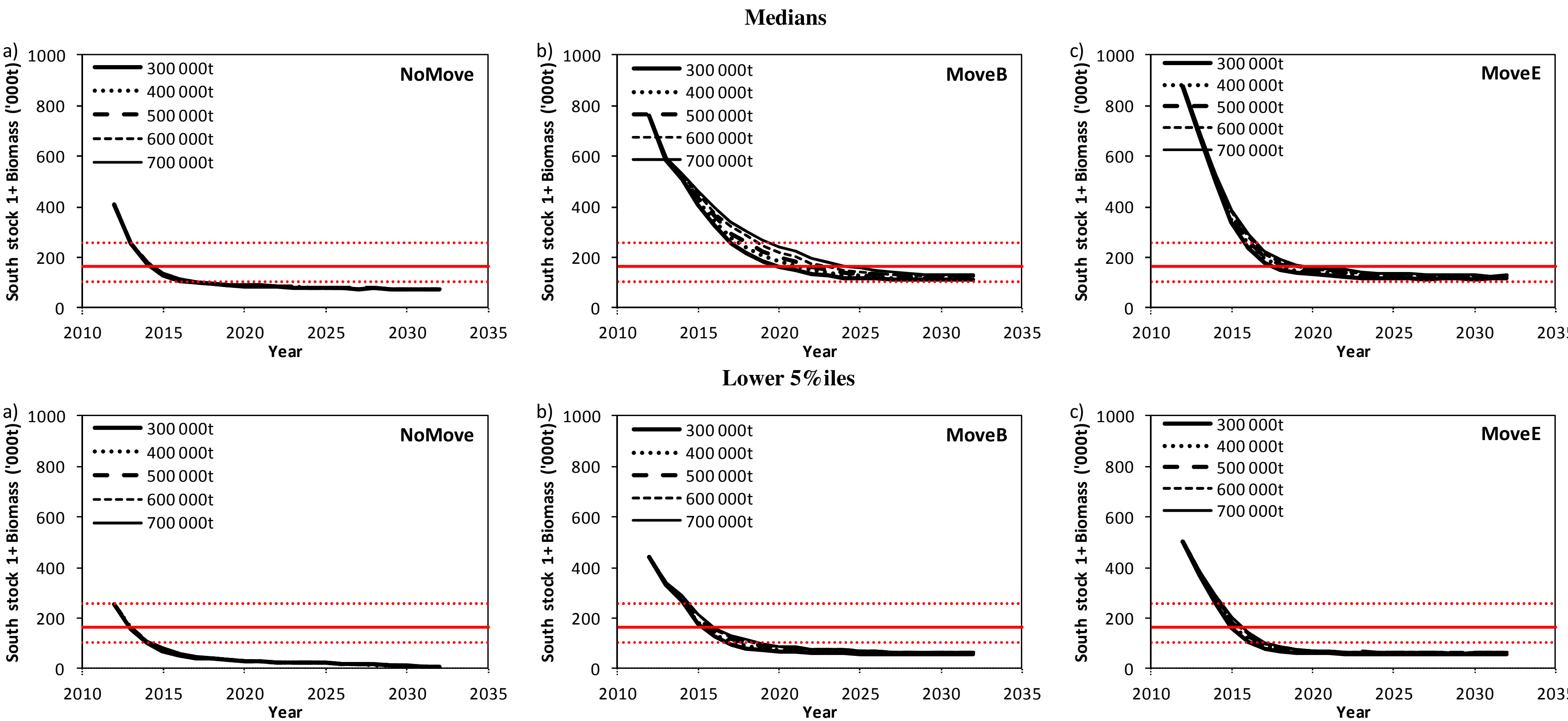

Figure 11. Future median (upper row) and lower 5%ile (lower row) projected **"south" 1+ biomass** assuming a **two sardine stock** operating model and different sardine Exceptional Circumstances thresholds. Trajectories are shown for different hypothesis of future movement of "west" stock recruits to 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.

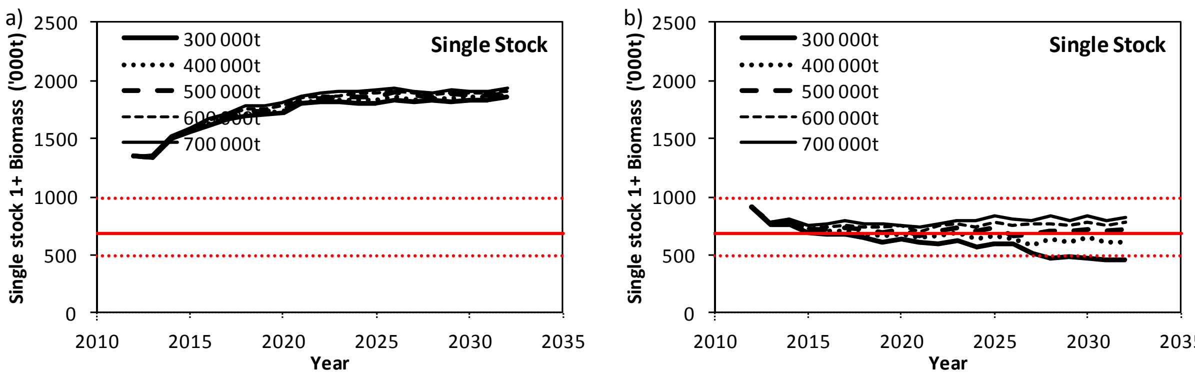

Figure 12. Future a) median and b) lower 5%ile projected **total 1+ biomass** assuming a **single sardine stock** operating model and different sardine Exceptional Circumstances thresholds. The posterior median, 5%ile and 95%ile of the distribution of average 91-94 1+ biomass is shown in the red horizontal lines.

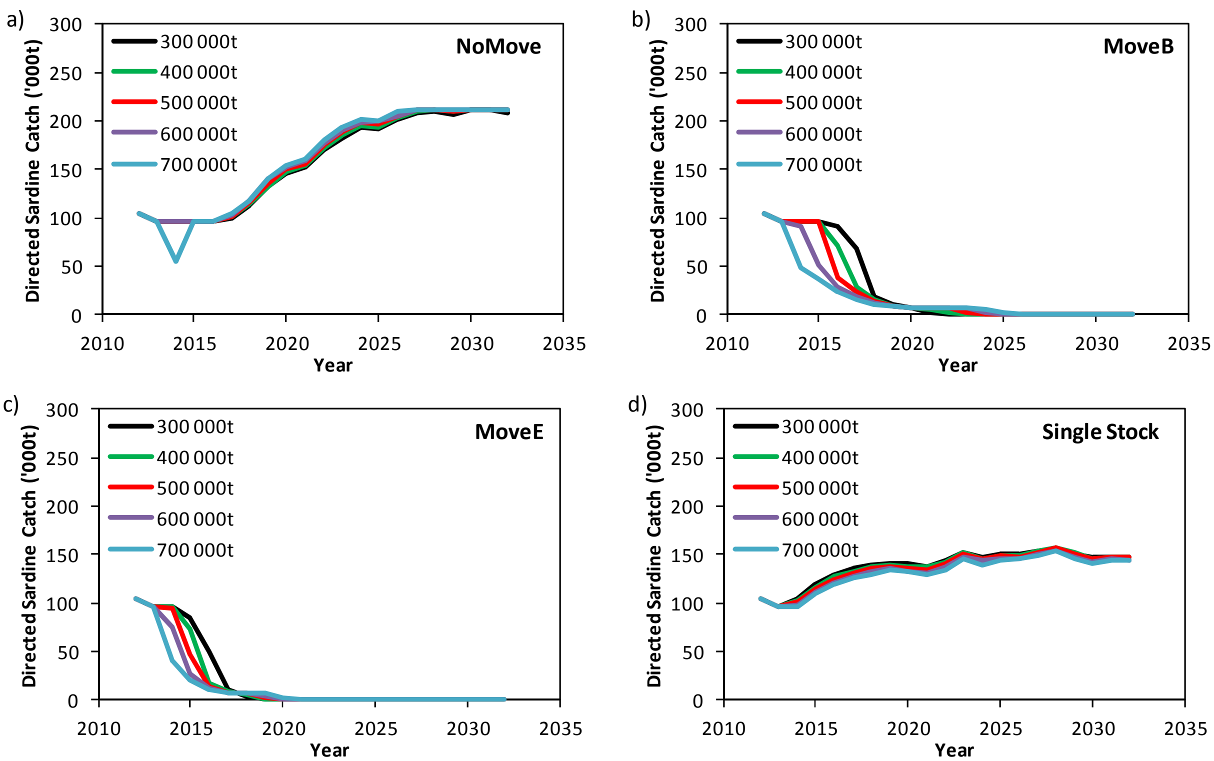

Figure 13. Future **median** projected total **directed ≥14cm sardine catch** assuming a **two sardine stock** operating model (a-c) and d) a **single sardine stock** operating model, and different sardine Exceptional Circumstances thresholds. Trajectories are shown for different hypotheses of future movement of "west" stock recruits to the "south" stock: a) *NoMove*, b) *MoveB*, and c) *MoveE*.

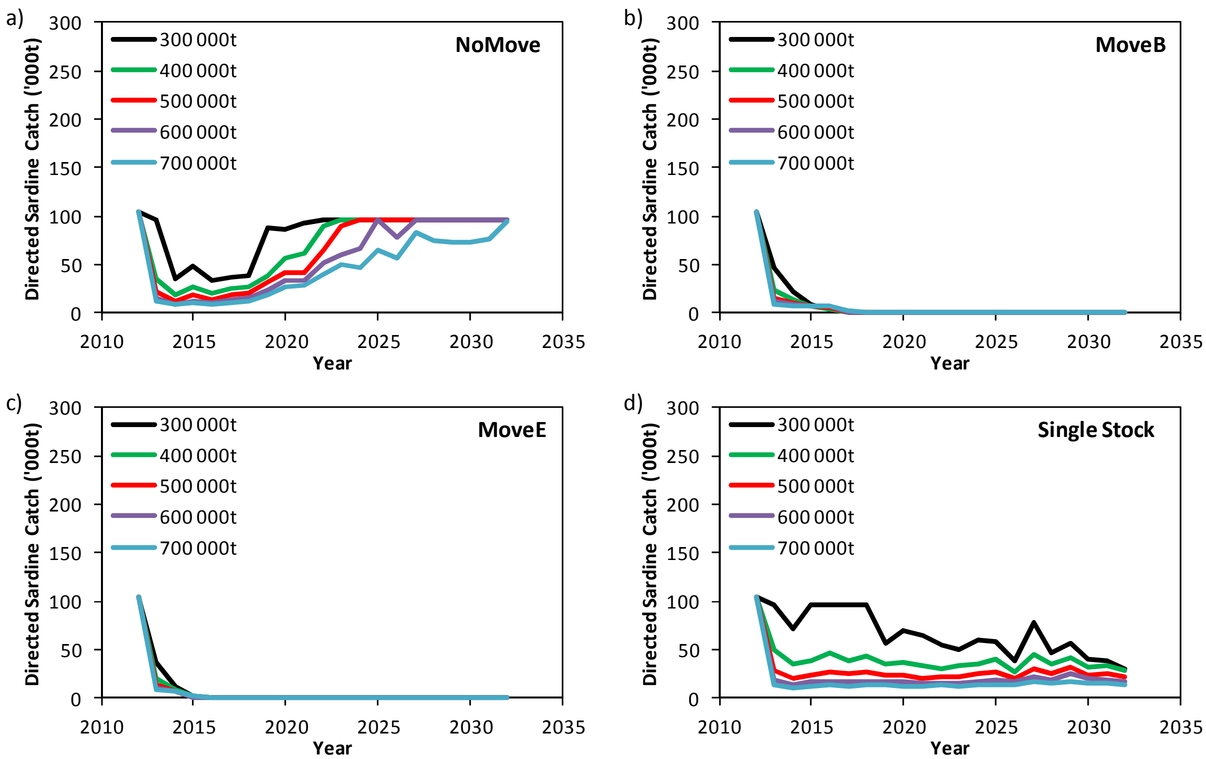

Figure 14. Future **lower 5%ile** of projected total **directed ≥14cm sardine catch** assuming a **two sardine stock** operating model (a-c) and d) a **single sardine stock** operating model, and different sardine Exceptional Circumstances thresholds. Trajectories are shown for different hypotheses of future movement of "west" stock recruits to the "south" stock: a) *NoMove*, b) *MoveB*, and c) *MoveE*.

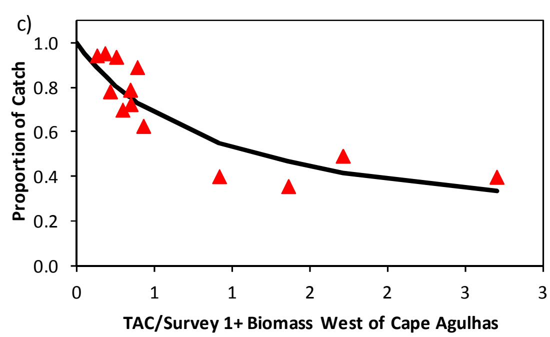

Figure 15. (Figure 6c of de Moor *et al.* 2013) The proportion of directed sardine catch and sardine bycatch with round herring caught west of Cape Agulhas over the most recent assessment years (1999-2011) plotted against the ratio of the directed sardine TAC in the same year to the survey estimated 1+ biomass west of Cape Agulhas in November of the previous year. The fitted relationship $p_w^{catch}(y) = 1 + 0.89 \times \{TAC(y)/B(y)\}/(0.89 + \{TAC(y)/B(y)\})$ is also plotted.

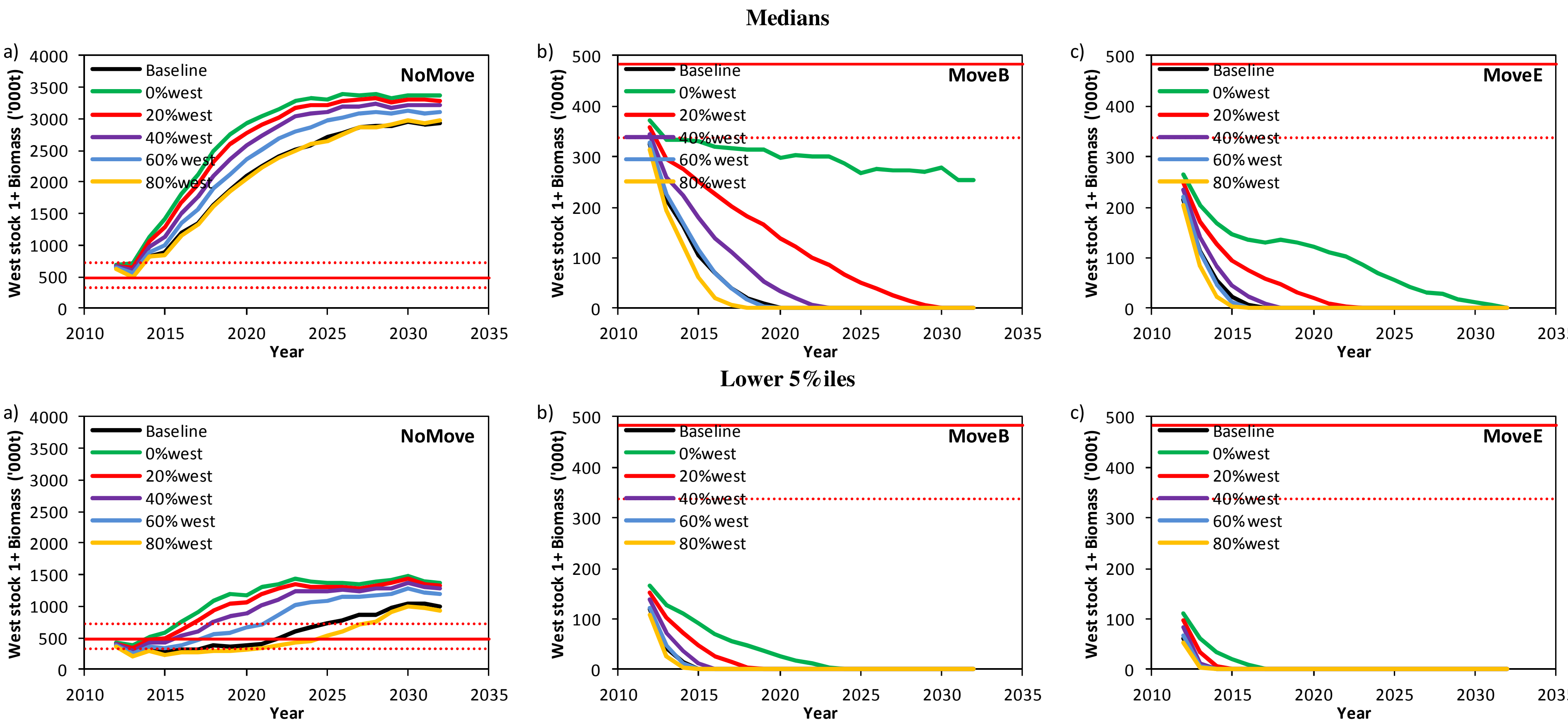

Figure 16. Future median (upper row) and lower 5%ile (lower row) projected **"west" 1+ biomass** assuming a **two sardine stock** operating model and different assumptions of the proportion of sardine caught west and south-east of Cape Agulhas . Trajectories are shown for different hypothesis of future 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).

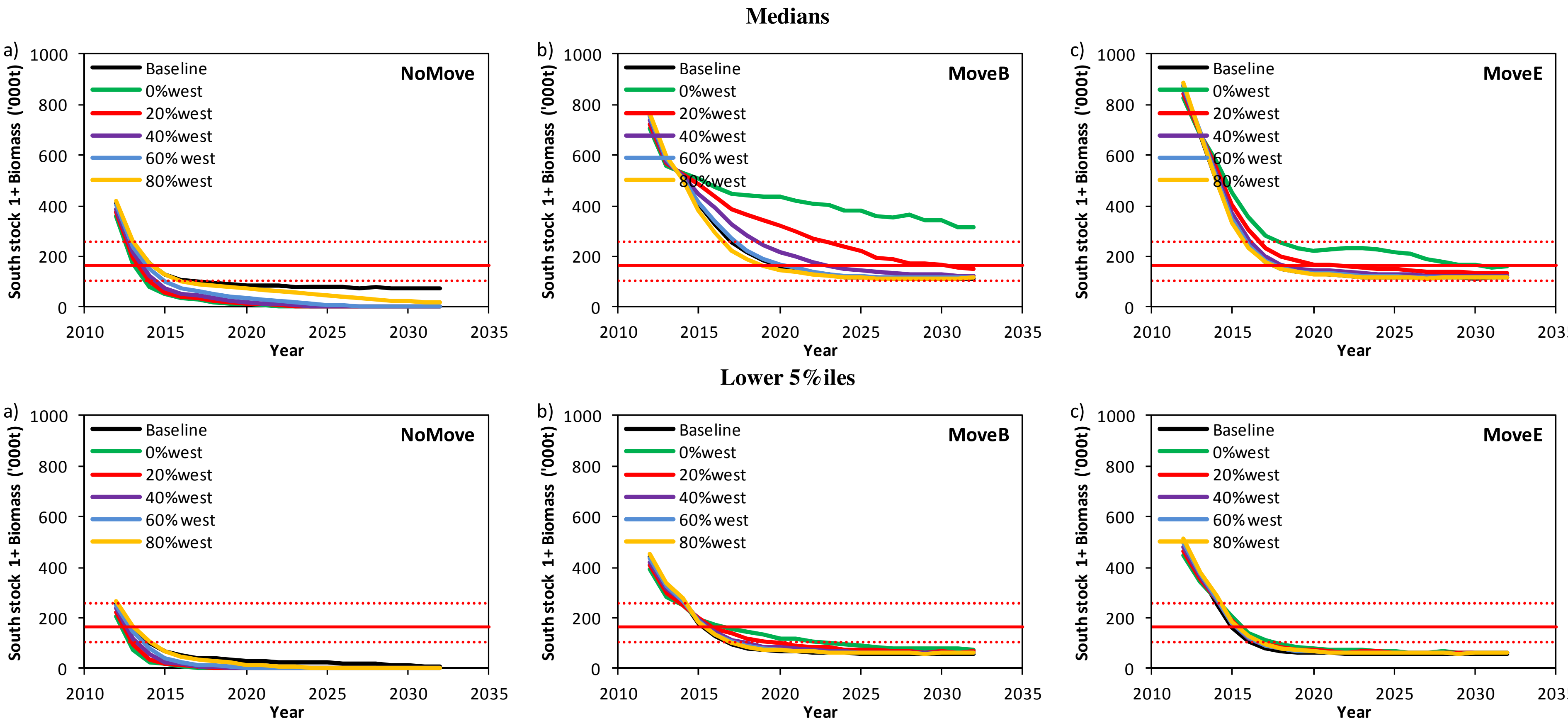

Figure 17. Future median (upper row) and lower 5%ile (lower row) projected **"south" 1+ biomass** assuming a **two sardine stock** operating model and different assumptions of the proportion of sardine caught west and south-east of Cape Agulhas. Trajectories are shown for different hypothesis of future 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.

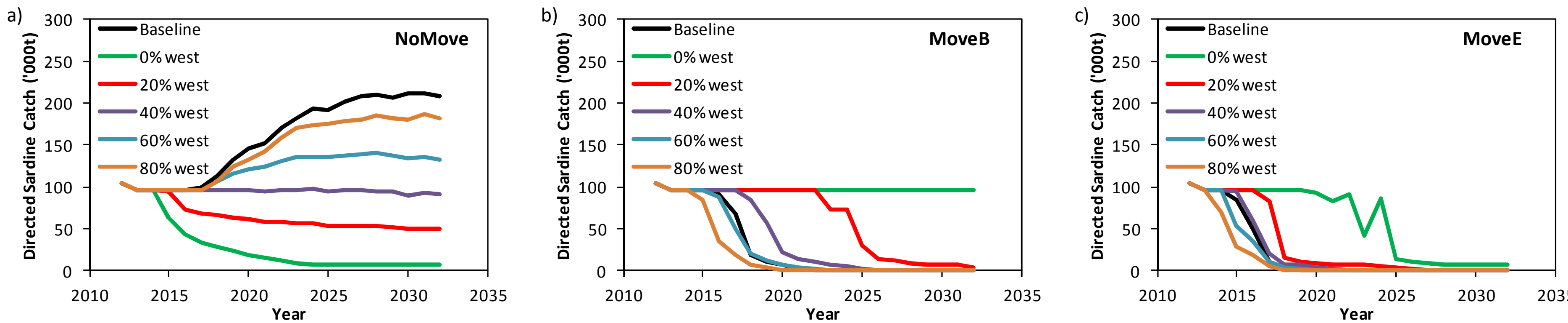

Figure 18. Future **median** projected total **directed ≥14cm sardine catch** assuming a **two sardine stock** operating model, and different assumptions of the proportion of sardine caught west and south-east of Cape Agulhas. Trajectories are shown for different hypotheses of future movement of "west" stock recruits to the "south" stock: a) *NoMove*, b) *MoveB*, and c) *MoveE*.

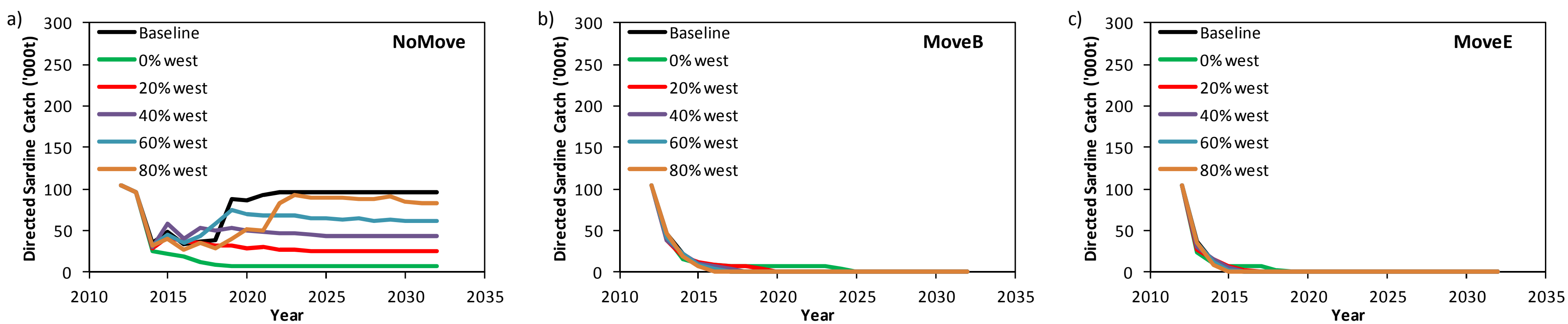

Figure 19. Future **lower 5%ile** of projected total **directed ≥14cm sardine catch** assuming a **two sardine stock** operating model, and different assumptions of the proportion of sardine caught west and south-east of Cape Agulhas. Trajectories are shown for different hypotheses of future movement of "west" stock recruits to the "south" stock: a) *NoMove*, b) *MoveB*, and c) *MoveE*.