Further results towards the selection of "Draft OMP-13"

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de Moor and Butterworth (2012a) presented results for a "Base MP" variant which contained mostly the same constraint parameters as OMP-08, except for a lower maximum total anchovy TAC. That "Base MP" variant was tuned to risk levels ($risk^S < 0.21$ and $risk^A < 0.18$) which corresponded to a similar extent of leftward shift of the biomass distribution from a no catch to a catch scenario as that simulated under OMP-08. However, when used to determine the acceptable level of risk for anchovy, this approach resulted in a counter-intuitive result of lesser acceptable levels of catch from a resource now estimated to be more productive than was previously the case. This document further explores a method to determine an acceptable level of risk for anchovy and provides comparative results for different trade-off curves for the same "Base MP" tuned to different levels of anchovy risk, as well as for a few key alternative MP variants. The Harvest Control Rules are described in de Moor and Butterworth (2012b) and the simulation testing framework used for all alternatives is described in de Moor and Butterworth (2012c).

Sardine-Anchovy Trade Off

The unique reason for a joint sardine and anchovy MP is the unavoidable juvenile sardine bycatch when targeting anchovy; thus keeping all other factors constant, the higher the anchovy catch the higher the juvenile sardine bycatch and thus the lower the adult sardine catch in future years. The trade off between the projected average (over 20 years of 1000 simulations) directed >14cm sardine catch and average anchovy catch is shown in Figure 1 for the last three sardine-anchovy OMPs. The risk threshold definitions for sardine and anchovy have remained unchanged from the last two OMPs:

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

$risk^A$ - 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.

Note that although the definitions remain unchanged, the simulated true biomass used in the definitions of the risk threshold will change from one assessment to the next given updated estimation of, among other parameters, bias in the November surveys. However, the extents of these changes have decreased from one assessment to the next. Each trade-off curve plotted in Figure 1 was obtained by restricting the risk for both sardine and anchovy to an acceptable level.

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Selection of Risk Levels

Given changes in the perceived level of productivity of a resource resulting from the inclusion of revised and new data in an assessment (Figure 2), de Moor and Butterworth (2010) have developed an objective method of determining an acceptable level of risk for a new MP. Figure 3 shows the projected distributions of sardine and anchovy 1+ biomass in 2027 under OMP-08 and a no catch scenario. Under the method developed, an acceptable level of risk for a new MP would result in a distribution with a similar "leftward shift" from the no catch scenario to that under OMP-08 in Figure 3. Although impossible to match the level of depletion ("leftward shift") at all percentiles, past choices have focussed primarily on the 20th percentile, while still trying to obtain similar levels of depletion at other lower percentiles. However, applying this method directly for the new "Base MP" resulted in the counter-intuitive results for anchovy summarised above (de Moor and Butterworth 2012a).

Underlying Operating Models

The recent sardine assessment (de Moor and Butterworth 2012d), although updated to account for alternative time series of data, has retained the same level of juvenile and adult natural mortality and Hockey Stick stock-recruitment curve as that used in the 2007 assessment (de Moor and Butterworth 2007) (see Figure 4). In contrast, the anchovy assessment (de Moor and Butterworth 2012e) has been based on a Beverton Holt stock-recruitment curve, while the 2007 assessment used a Hockey Stick stock-recruitment curve with a fixed inflection point of $0.2K^A$. The fixed inflection point was chosen for former assessments because of insufficient data to obtain a precise estimate of the inflection point. The updated assessment, however, shows this choice of curve to fit the data very poorly. In addition, the revised base case assessment has been based on a higher level of natural mortality compared to that used in the 2007 assessment because maintaining the same level of natural mortality as before resulted in an unrealistic ratio for the estimated bias for the May recruit relative to the November survey. Figure 5 shows that the stock-recruitment relationship estimated by the model maintaining the same assumptions as the last assessment (i.e., Hockey Stick curve with fixed inflection point and $\overline{M}_j^A = \overline{M}_{ad}^A = 0.9$) as well as that for the new base case assessment (i.e., Beverton Holt curve with $\overline{M}_j^A = \overline{M}_{ad}^A = 1.2$), compared to the relationship estimated in the 2007 assessment. What is noticeable in comparing these curves is that although the updated Beverton Holt curve estimates higher recruitment at higher spawner biomass levels, at low spawner biomass levels (which correspond to the regions where risk is a concern) the Beverton Holt curve estimates lower recruitment than the Hockey Stick curve with fixed inflection point. Thus these changes in key resource productivity assumptions necessitate a "re-think" on the method used to determine an acceptable level of risk for anchovy.

Bridging the Gap

In an attempt to build a bridge between the current method of determining an acceptable level of risk and a new method for anchovy, a new MP was run with all constraints maintained as the same as that for OMP-08 (i.e., with a maximum anchovy TAC of 600 000t), and the anchovy operating model used was that which assumed a Hockey Stick stock-recruitment curve with a fixed inflection point at $0.2K^A$ and $\overline{M}_j^A = \overline{M}_{ad}^A = 0.9$. The base case sardine operating model was used. Using the method which aims to match the leftward shift of the biomass distribution from a no catch to a MP scenario to be similar from one OMP to the next results in the trade-off curve given in Figure 6 which is obtained by constraining ($risk^S < 0.21$ and $risk^A < 0.125$). Table 1 shows that the point on the curve corresponding to a maximum average sardine catch at the maximum average anchovy catch satisfies the requirement for a similar level of leftward shift of the biomass distribution for both sardine and anchovy from one OMP to the next. Other points on this curve, corresponding to a higher average sardine and a lower average anchovy catch, also satisfy this requirement (although they are less "risky" for anchovy). These results are broadly what one would expect, in that the corner point of this curve equates to lower average directed sardine catch than under OMP-08 (corresponding to that expected from Figure 4, given the now reduced asymptotic level of expected recruitment which that shows), and a slightly higher average directed anchovy catch than under OMP-08.

A MP variant with a maximum anchovy TAC of 350 000t is also shown in Figure 6. Note that the anchovy risk level of $risk^A < 0.20$ used to construct this trade-off curve is not determined by the "leftward shift" criterion, but rather by the maximum possible anchovy TAC. Table 1 shows that even a point on the right hand side of this trade-off curve is more conservative in terms of depletion of the resource under the MP variant than that simulated under OMP-08. Finally, a MP variant with a maximum anchovy TAC of 450 000t was also evaluated, constrained by $risk^A < 0.14$, such that the corner point satisfies the requirement that the leftward shift of the biomass distribution of the resource under the MP variant compared to a no-catch scenario remain similar from one OMP to the next, and corresponds in turn to a similar level of leftward shift estimated to be achieved under OMP-08 (Figure 6, Table 1).

It would therefore seem reasonable to tune a new MP with a maximum anchovy TAC of 350 000t, tested under an alternative operating model, to an anchovy risk level of 0.20, or even slightly higher given the conservative nature of the results in Table 1.

A New "Base MP"

Figure 7 shows the trade-off curves for a new MP, with a maximum anchovy TAC of 350 000t, tuned to $risk^S < 0.21$ and a range of anchovy risk levels. Following the above analysis, the "Base MP" is chosen at the corner point of the curve for which $risk^A < 0.20$. A coarse range of the alternative control parameter for the final anchovy TAC, α_{ads}, was also tested. A higher value for α_{ads} corresponds to a higher average anchovy catch during the additional season, but a lower average total anchovy catch for the same risk level. The leftward shift from a no catch to a catch scenario for the lower percentiles of the biomass distributions are given in Table 2 for corner points on all of these trade-off curves, and the projected distributions of sardine and anchovy 1+ biomass in 2032 under the "Base MP" variant are plotted against the no catch scenario in Figure 8.

Figure 9 shows the change in average directed large sardine and anchovy catch for different values of the control parameters, α_{ns} and β. Given the relatively flat (horizontal) natural of the trade-off curve, it is probable that the favoured choice for both species would be the 'corner point' ($\beta = 0.089$, $\alpha = 0.331$) which maximises the large sardine catch with little decrease in the average expected anchovy catch.

Performance Statistics

In addition to ensuring the risk to the sardine and anchovy resources is satisfied by any MP variant, de Moor and Coetzee (2012) produced a list of performance statistics against which to evaluate alternative MP variants. Table 3 lists these key performance statistics for the "Base MP" variant compared to a no-catch scenario. Under the "Base MP" variant, the sardine resource is projected to increase to about 50% more than its level in November 2011, which is triple the risk threshold defined by the average November 1991 to 1994 1+ biomass. The average >14cm directed catch is projected to be 153 000t and the average total <14cm bycatch[1] to be 38 000t. The anchovy resource is projected to increase (on average) to four fold its level in November 2011. However, this average is high due to the skew distribution for the anchovy abundance; the median will be lower. The average anchovy catch is projected to be 252 000t, with an average of 70 000t being caught during the September to December additional season.

Table 4 lists some further performance statistics, though these are not discussed in detail here as many of them apply to Exceptional Circumstances which will be fully tested during 2013.

Alternative Candidate MPs

The following alternatives to the Harvest Control Rules have been tested (where catches are given in thousands of tons):

i) A lower minimum sardine TAC: $c^S_{mntac} = 85$ compared to $c^S_{mntac} = 90$ for the "Base MP" variant.

ii) A lower minimum sardine TAC: $c^S_{mntac} = 80$ compared to $c^S_{mntac} = 90$ for the "Base MP" variant.

iii) A lower minimum sardine TAC: $c^S_{mntac} = 75$ compared to $c^S_{mntac} = 90$ for the "Base MP" variant.

iv) A higher maximum anchovy TAC: $c^A_{mxtac} = 450$ compared to $c^A_{mxtac} = 350$ for the "Base MP" variant.

v) An additional season which extends from October to December compared to September to December for the "Base MP" variant

The trade-off curves for these alternatives are plotted in Figure 10. The same risk levels of $risk^S < 0.21$ and $risk^A < 0.20$, as used for "Base MP" attain similar levels of "leftward shift" of the projected biomass distributions after 20 years from a no catch scenario to the alternative MP variants compared to the "Base MP" (Table 5). Lower minimum sardine TACs result in slightly higher average directed sardine catch compared to the "Base MP", both in the short and medium term. The average variation of this catch (taking into account both increases and decreases in catch) is also higher in these alternatives compared to "Base MP". A higher maximum total anchovy TAC results in an increase in the average normal season anchovy catch. Extending the normal season to include September slightly increases the average directed sardine catch and slightly decreases the average total anchovy catch.

[1] Note this is the model projected bycatch, not TAB, with the former frequently being assumed to be less than the latter during simulation testing, due to a drop-off in the juvenile sardine : anchovy ratio during the year.

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Table 1. The ratio of the percentiles of the distribution of sardine and anchovy biomass in 2032 under the a new MP using the anchovy operating model with a Hockey Stick stock-recruitment curve with a fixed inflection point and $\overline{M}_j^A = \overline{M}_{ad}^A = 0.9$ for the points marked on the trade-off curves in Figure 6, with $risk_S < 0.21$. Shaded cells represent cases for which the predicted MP : no catch ratio is more pessimistic than that which applied for OMP-08. The ratios corresponding to OMP-04 are given for interest. The key MP control parameters, β and α_{ns}, and corresponding levels of risk and average anticipated directed catch (in thousands of tons) for both sardine and anchovy are also given.

	OMP-04/No-catch	OMP-08/No-catch	New MP/No-catch									
			$c_{mxtac}^A = 600$, $risk_A < 0.13$				$c_{mxtac}^A = 350$, $risk_A < 0.20$			$c_{mxtac}^A = 450$, $risk_A < 0.14$		
β	0.147	0.097	0.065	0.067	0.07	0.078	0.068	0.082	0.086	0.066	0.07	0.078
α_{ns}	0.738	0.780	0.811	0.777	0.753	0.585	0.834	0.522	0.419	0.848	0.778	0.600
$risk_S$		0.178	0.207	0.209	0.209	0.209	0.209	0.209	0.209	0.209	0.209	0.209
$risk_A$		0.097	0.129	0.114	0.109	0.068	0.113	0.048	0.031	0.137	0.113	0.072
$\overline{C}^A$		381	389	384	381	352	341	320	303	378	372	349
$\overline{C}^A$ (ad season only)			95	95	94	90	84	87	84	92	93	90
$\overline{C}^S$		190	125	127	131	140	129	145	149	126	131	140
Sardine												
10%ile	0.59	0.50	0.56	0.57	0.56	0.57	0.56	0.53	0.54	0.55	0.55	0.54
20%ile	0.68	0.68	0.65	0.65	0.64	0.65	0.65	0.64	0.63	0.64	0.64	0.63
30%ile	0.69	0.72	0.71	0.71	0.71	0.71	0.71	0.70	0.70	0.71	0.71	0.70
40%ile	0.71	0.73	0.75	0.75	0.75	0.75	0.74	0.74	0.74	0.74	0.74	0.74
median	0.72	0.72	0.77	0.76	0.76	0.76	0.77	0.76	0.75	0.76	0.76	0.76
Anchovy												
10%ile	0.25	0.30	0.31	0.31	0.33	0.42	0.34	0.47	0.55	0.31	0.32	0.41
20%ile	0.37	0.36	0.35	0.36	0.37	0.45	0.39	0.49	0.55	0.35	0.37	0.44
30%ile	0.45	0.40	0.41	0.42	0.42	0.51	0.46	0.55	0.60	0.40	0.42	0.50
40%ile	0.56	0.43	0.45	0.46	0.46	0.53	0.51	0.57	0.62	0.45	0.46	0.53
median	0.58	0.47	0.50	0.51	0.52	0.57	0.57	0.61	0.64	0.51	0.52	0.57

Table 2. The ratio of the percentiles of the distribution of sardine and anchovy biomass in 2032 under the new MP using the base case anchovy operating model (a Beverton Holt stock-recruitment relationship with $\overline{M}_j^A = \overline{M}_{ad}^A = 1.2$) and for the corner points on the trade-off curves in Figure 7, with $risk_S < 0.21$ and a range of anchovy risk levels and final anchovy TAC control parameter, α_{ads}, values. The **red bold** column corresponds to the "Base MP". Shaded cells for sardine represent cases for which the predicted MP : no catch ratio is more pessimistic than that which applied for OMP-08. Shaded cells for anchovy represent cases for which the predicted MP : no catch ratio is more pessimistic than the "Base MP". The ratios corresponding to OMP-04 are given for interest. The key MP control parameters, β and α_{ns}, and corresponding levels of risk and average anticipated directed catch (in thousands of tons) for both sardine and anchovy are also given.

	OMP-04/No-catch	OMP-08/No-catch	New MP/No-catch									
			$\alpha_{ads} = 1.5\times\alpha_{ns}$				$\alpha_{ads} = 2\times\alpha_{ns}$			$\alpha_{ads} = 2.5\times\alpha_{ns}$		
$risk_A$:			**< 0.20**	< 0.25	< 0.28	< 0.30	< 0.20	< 0.25	< 0.30	< 0.20	< 0.25	< 0.30
β	0.147	0.097	**0.089**	0.087	0.086	0.085	0.092	0.088	0.087	0.093	0.090	0.088
α_{ns}	0.738	0.780	**0.331**	0.47	0.536	0.574	0.274	0.381	0.476	0.240	0.322	0.419
$risk_S$		0.178	**0.207**	0.209	0.209	0.209	0.209	0.206	0.208	0.208	0.208	0.208
$risk_A$		0.097	**0.198**	0.246	0.279	0.299	0.198	0.247	0.295	0.198	0.247	0.298
$\overline{C}^A$		381	**252**	262	264	265	245	257	261	240	251	258
$\overline{C}^A$ (ad season only)			**70**	70	70	69	73	75	76	76	78	80
$\overline{C}^S$		190	**153**	151	149	148	157	152	151	158	154	152
Sardine												
10%ile	0.59	0.50	**0.55**	0.55	0.54	0.53	0.55	0.55	0.55	0.54	0.55	0.55
20%ile	0.68	0.68	**0.64**	0.63	0.63	0.63	0.63	0.64	0.63	0.63	0.64	0.64
30%ile	0.69	0.72	**0.71**	0.70	0.70	0.71	0.71	0.71	0.71	0.71	0.71	0.71
40%ile	0.71	0.73	**0.75**	0.75	0.75	0.75	0.75	0.75	0.75	0.75	0.75	0.75
median	0.72	0.72	**0.76**	0.76	0.76	0.76	0.76	0.76	0.76	0.76	0.76	0.76
Anchovy												
10%ile	0.25	0.30	**0.21**	0.15	0.14	0.13	0.22	0.15	0.13	0.21	0.15	0.13
20%ile	0.37	0.36	**0.31**	0.22	0.18	0.17	0.32	0.22	0.17	0.32	0.22	0.17
30%ile	0.45	0.40	**0.37**	0.27	0.22	0.20	0.37	0.27	0.20	0.36	0.27	0.20
40%ile	0.56	0.43	**0.40**	0.32	0.27	0.26	0.42	0.31	0.25	0.43	0.32	0.25
median	0.58	0.47	**0.43**	0.35	0.31	0.30	0.44	0.37	0.30	0.45	0.38	0.31

Table 3. Key summary statistics for the sardine and anchovy resources under a no-catch scenario and the “Base MP” variant:

- 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,
- $risk_A$; 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 ; and

The statistics under some alternative MP variants are also given: i) a minimum sardine TAC of 85 000t, ii) 80 000t, iii) 75 000t, iv) a maximum total anchovy TAC of 450 000t and v) an additional season from October to December.

Sardine	No Catch	Base MP	$c^S_{mntac}=85$	$c^S_{mntac}=80$	$c^S_{mntac}=75$	$c^A_{mxtac}=450$	Oct-Dec	Anchovy	No Catch	Base MP	$c^S_{mntac}=85$	$c^S_{mntac}=80$	$c^S_{mntac}=75$	$c^A_{mxtac}=450$	Oct-Dec
β		0.089	0.093	0.095	0.097	0.089	0.091	α		0.331	0.331	0.331	0.331	0.330	0.315
$risk_S$	0.031	0.207	0.208	0.208	0.209	0.207	0.209	$risk_A$	0.02	0.198	0.199	0.199	0.199	0.199	0.197
$\overline{B^S_{\min}/K^S}$	0.54	0.41	0.41	0.41	0.41	0.41	0.41	$\overline{B^A_{\min}/K^A}$	0.22	0.11	0.11	0.11	0.11	0.11	0.11
$\overline{B^S_{\min}/Risk^S}$	2.03	1.57	1.56	1.56	1.56	1.57	1.56	$\overline{B^A_{\min}/Risk^A}$	7.57	3.87	3.87	3.87	3.87	3.84	3.92
$\overline{B^S_{2032}/K^S}$	0.99	0.75	0.74	0.74	0.74	0.75	0.74	$\overline{B^A_{2032}/K^A}$	1.17	0.67	0.67	0.67	0.67	0.66	0.67
$\overline{B^S_{2032}/Risk^S}$	4.04	3.01	3.00	3.00	2.99	3.01	3.00	$\overline{B^A_{2032}/Risk^A}$	48.19	26.71	26.72	26.73	26.73	26.25	27.04
$\overline{B^S_{2032}/B^S_{2011}}$	1.99	1.46	1.45	1.45	1.45	1.45	1.45	$\overline{B^A_{2032}/B^A_{2011}}$	7.59	4.20	4.20	4.20	4.20	4.13	4.25
$\overline{C}^S$ ('13-'32)	0	153	157	158	159	153	155	$\overline{C}^A$ ('13-'32)	0	252	252	252	252	260	250
$\overline{C}^S_{by}$	0	38	38	38	38	38	37	$\overline{C}^A_{ad}$ ('13-'32)	0	70	70	70	70	70	70
$\overline{C}^S$ ('13-'15)	0	124	126	126	127	124	126	$\overline{C}^A$ ('13-'15)	0	241	241	241	241	246	239
								$\overline{C}^A_{ad}$ ('13-'15)	0	56	56	56	56	56	56
AAV^S ('13-'32)	0.00	0.20	0.22	0.25	0.28	0.20	0.20	AAV^A ('13-'32)	0.00	0.30	0.30	0.30	0.30	0.31	0.30
AAV^S ('13-'15)	0.00	0.04	0.07	0.12	0.17	0.04	0.04	AAV^A ('13-'15)	0.00	0.09	0.09	0.09	0.09	0.09	0.08

Table 4. Further summary statistics for the sardine and anchovy resources under a no-catch scenario and the "Base MP" variant: Proportion of times Exceptional Circumstances are/not declared ($EC^{declared}/EC^{NOTdeclared}$) when true biomass is/not below the corresponding threshold ($B_y^{A/S} <$ or $\geq Threshold$); proportion of times the directed TAC decreases below the minimum TAC (i.e., Exceptional Circumstances are declared), $TAC_y^{A/S} < c_{mntac}^{A/S}$; average number of years for which Exceptional Circumstances, if declared, are declared consecutively, $EC_{consec}^{A/S}$.

Sardine	No Catch	Base MP	Anchovy	No Catch	Base MP
$p\left(EC^{declared}, B_y^S < Threshold\right)$	0.00	0.01	$p\left(EC^{declared}, B_y^A < Threshold\right)$	0.02	0.14
$p\left(EC^{declared}, B_y^S \geq Threshold\right)$	0.01	0.05	$p\left(EC^{declared}, B_y^A \geq Threshold\right)$	0.01	0.01
$p\left(EC^{NOTdeclared}, B_y^S < Threshold\right)$	0.00	0.00	$p\left(EC^{NOTdeclared}, B_y^A < Threshold\right)$	0.01	0.03
$p\left(EC^{NOTdeclared}, B_y^S \geq Threshold\right)$	0.99	0.95	$p\left(EC^{NOTdeclared}, B_y^A \geq Threshold\right)$	0.96	0.82
$TAC_y^S < c_{mntac}^S$	0	0.05	$TAC_y^A < c_{mntac}^A$	0	0.15
EC_{consec}^S	0	1	EC_{consec}^A	0	3

Table 5. The ratio of the percentiles of the distribution of sardine and anchovy biomass in 2032 under the new MP using the base case anchovy operating model (a Beverton Holt stock-recruitment relationship with $\bar{M}_j^A = \bar{M}_{ad}^A = 1.2$) and for the corner points on the trade-off curves in Figure 10, with $risk_S < 0.21$ and $risk_A < 0.20$. The **red bold** column corresponds to the "Base MP". Shaded cells for sardine represent cases for which the predicted MP : no catch ratio is more pessimistic than that which applied for OMP-08. Shaded cells for anchovy represent cases for which the predicted MP : no catch ratio is more pessimistic than the "Base MP". The ratios corresponding to OMP-04 are given for interest. The key MP control parameters, β and α_{ns}, and corresponding levels of risk and average anticipated directed catch (in thousands of tons) for both sardine and anchovy are also given.

	OMP-04/No-catch	OMP-08/No-catch	New MP/No-catch					
			Base MP	$c_{mntac}^S = 85$	$c_{mntac}^S = 80$	$c_{mntac}^S = 75$	$c_{mxtac}^A = 450$	Oct-Dec Ad Season
β	0.147	0.097	**0.089**	0.093	0.095	0.097	0.089	0.091
α_{ns}	0.738	0.780	**0.331**	0.331	0.331	0.331	0.330	0.315
$risk_S$		0.178	**0.207**	0.208	0.208	0.209	0.207	0.209
$risk_A$		0.097	**0.198**	0.199	0.199	0.199	0.199	0.197
$\bar{C}^A$		381	**252**	252	252	252	260	250
$\bar{C}^A$ (ad season only)			**70**					
$\bar{C}^S$		190	**153**	157	158	159	153	155
Sardine								
10%ile	0.59	0.50	**0.55**	0.55	0.55	0.56	0.55	0.54
20%ile	0.68	0.68	**0.64**	0.63	0.64	0.63	0.64	0.64
30%ile	0.69	0.72	**0.71**	0.71	0.71	0.71	0.71	0.71
40%ile	0.71	0.73	**0.75**	0.75	0.74	0.74	0.75	0.75
median	0.72	0.72	**0.76**	0.76	0.75	0.75	0.76	0.76
Anchovy								
10%ile	0.25	0.30	**0.21**	0.22	0.22	0.22	0.22	0.22
20%ile	0.37	0.36	**0.31**	0.31	0.31	0.31	0.31	0.31
30%ile	0.45	0.40	**0.37**	0.37	0.37	0.37	0.36	0.38
40%ile	0.56	0.43	**0.40**	0.41	0.41	0.41	0.40	0.41
median	0.58	0.47	**0.43**	0.43	0.43	0.43	0.43	0.43

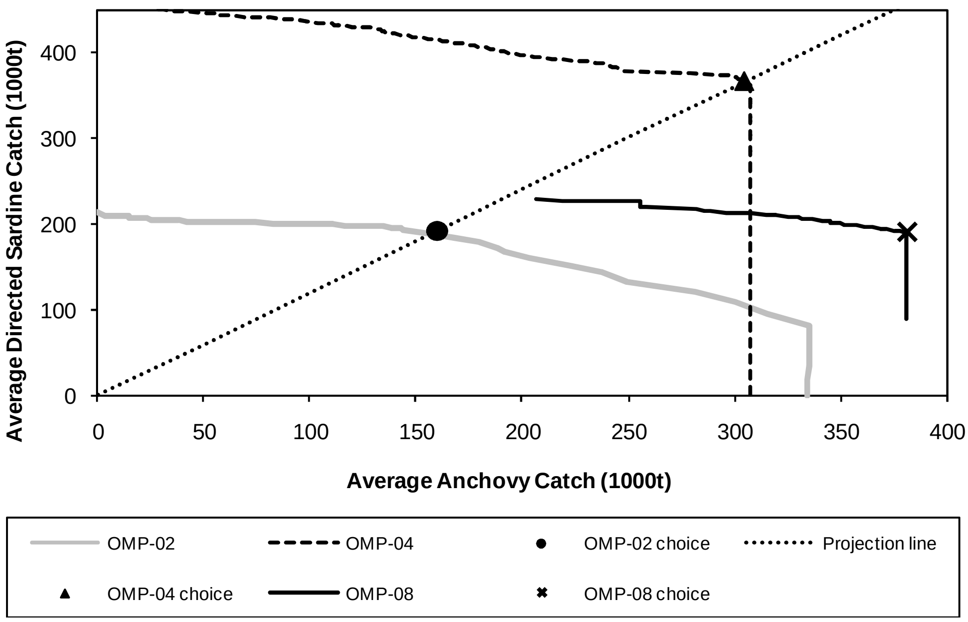

Figure 1. Trade-off curves for OMP-02, OMP-04 and OMP-08.

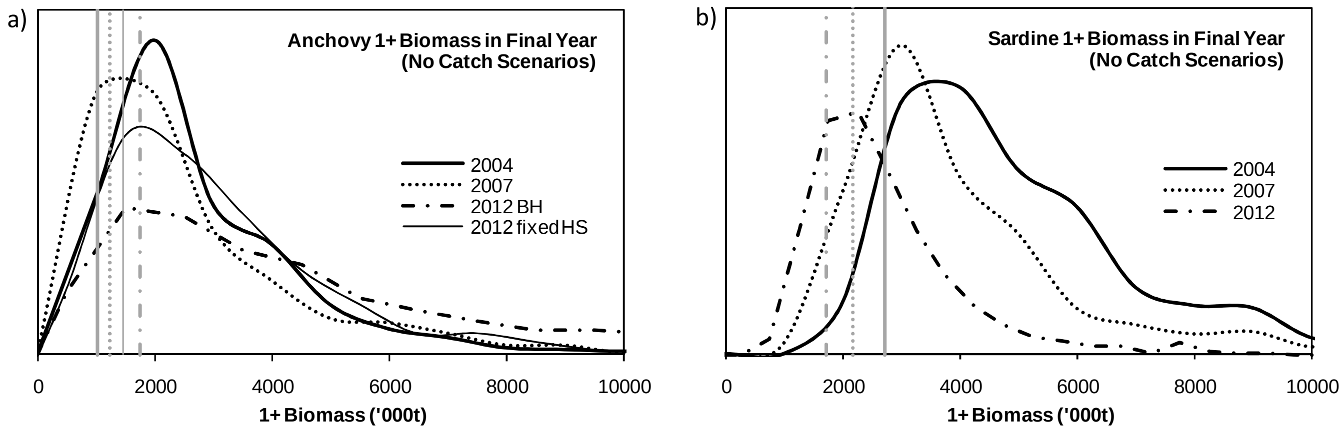

Figure 2. Comparison of a) anchovy and b) sardine 1+ biomass distributions in the final projection year under a no catch scenario for the last three full assessments. The vertical grey lines indicate the lower 20 percentile of each distribution. For anchovy, the distribution under the operating model assuming a Hockey Stick stock recruitment curve with a fixed inflection point and $\overline{M}_j^A = \overline{M}_{ad}^A = 0.9$, rather than a Beverton Holt stock recruitment curve with $\overline{M}_j^A = \overline{M}_{ad}^A = 1.2$ is also shown.

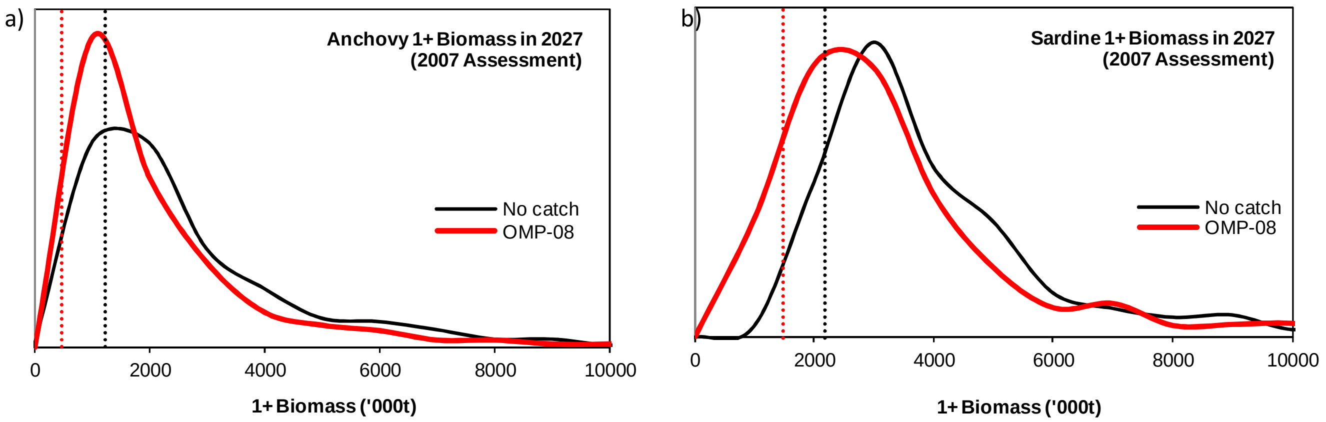

Figure 3. Comparison of a) anchovy and b) sardine 1+ biomass distributions in the final projection year under a no catch scenario and OMP-08, using the 2007 base case operating models.

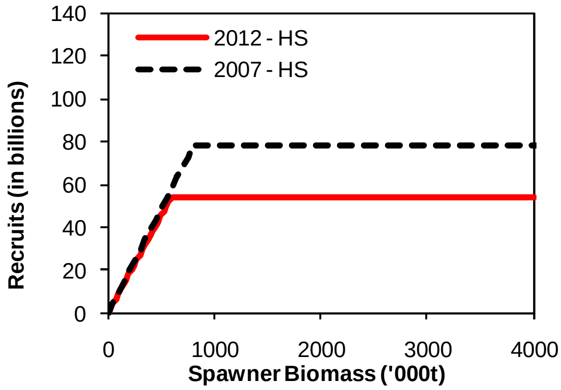

Figure 4. Model predicted sardine recruitment (in November) plotted against spawner biomass from November 1984 to November 2010 for the Hockey Stick stock recruitment relationship and $\overline{M}_j^S = 1.0, \overline{M}_{ad}^S = 0.8$. The corresponding curve estimated using data up to November 2006 is also plotted.

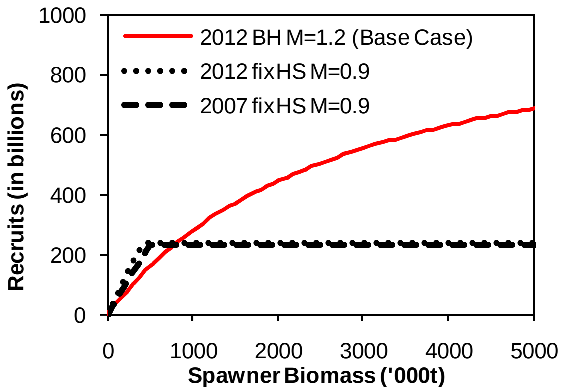

Figure 5. Model predicted anchovy recruitment (in November) plotted against spawner biomass from November 1984 to November 2010 for the Beverton Holt stock recruitment relationship with $\overline{M}_j^A = \overline{M}_{ad}^A = 1.2$ and for the Hockey Stick stock recruitment curve with inflection point fixed at $0.2K^A$ and $\overline{M}_j^A = \overline{M}_{ad}^A = 0.9$. The corresponding curve estimated using data up to November 2006 is also plotted.

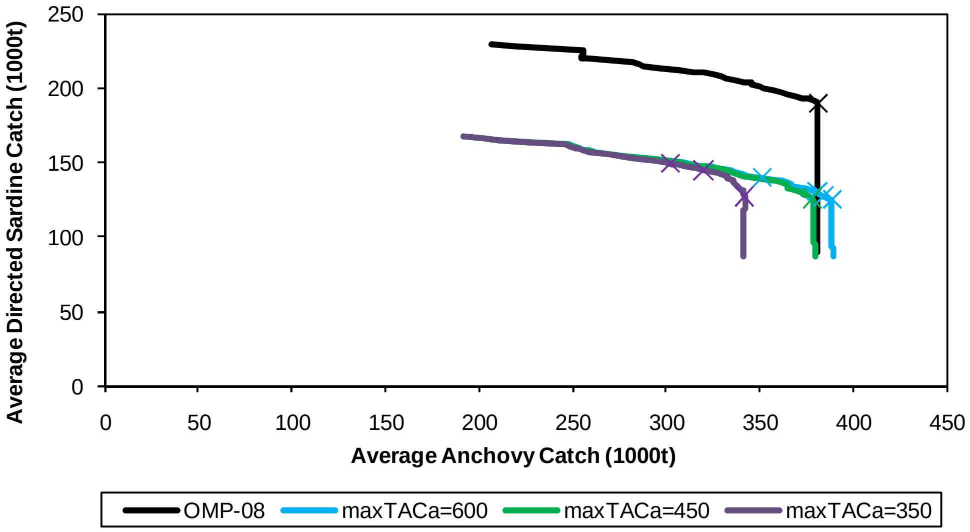

Figure 6. Trade-off curves for OMP-08 and the new MP tested using an anchovy operating model with similar assumptions to that used when simulation testing OMP-08, i.e. a Hockey Stick stock recruitment curve with inflection point fixed at $0.2K^A$ and a juvenile and adult natural mortality rate of 0.9 $year^{-1}$. The trade-off curve for OMP-08 was determined by limiting $risk_S < 0.18$ and $risk_A < 0.10$, while the trade-off curves for the new MP are determined by points satisfying $risk_S < 0.21$ and i) $risk_A < 0.13$ when $c_{mxtac}^A = 600$, ii) $risk_A < 0.14$ when $c_{mxtac}^A = 450$, and iii) $risk_A < 0.20$ when $c_{mxtac}^A = 350$.

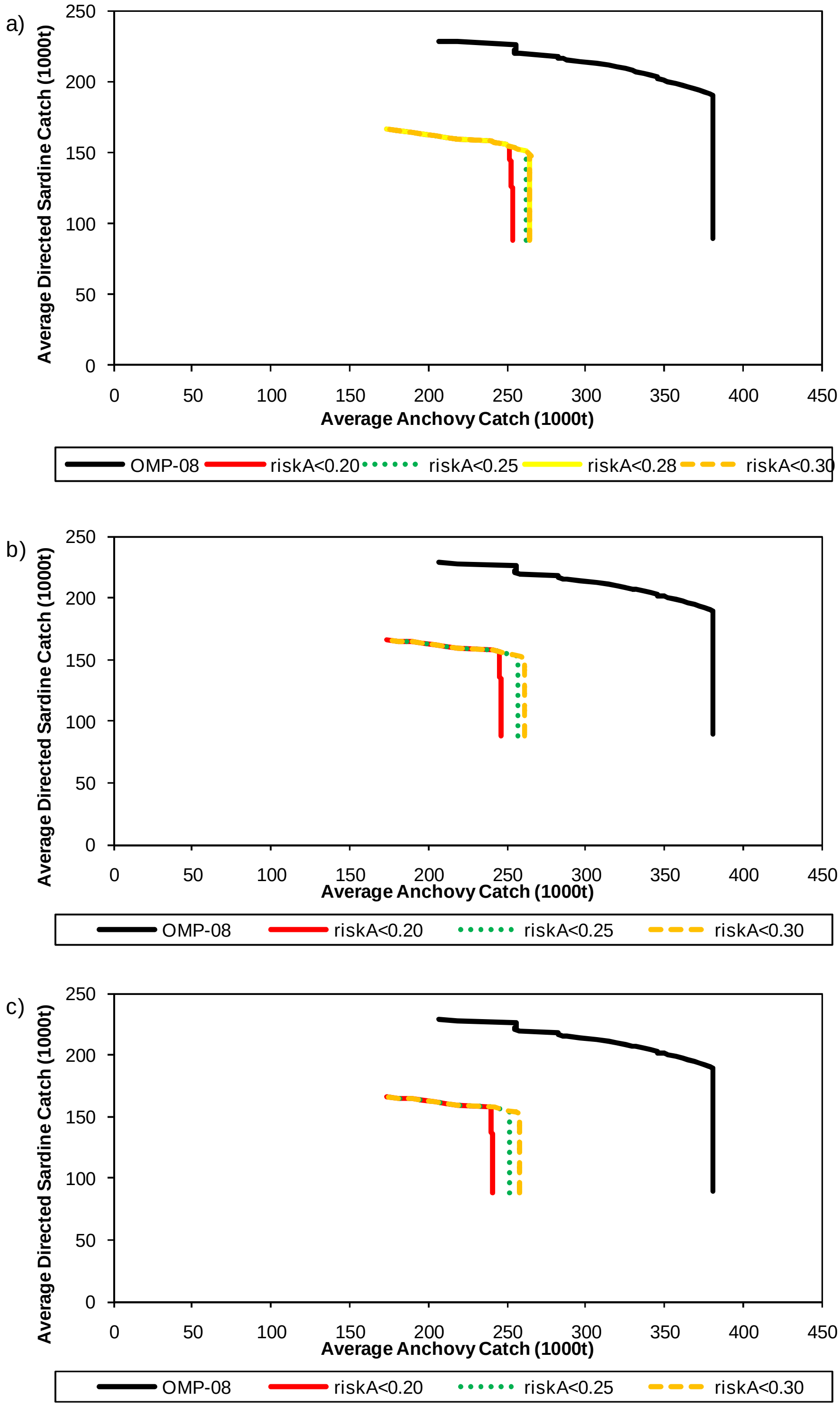

Figure 7. Trade-off curves for OMP-08 and the new MP with $c^{A}_{mxtac} = 350$, tested using the base case anchovy operating model, i.e. a Beverton-Holt stock recruitment curve and a juvenile and adult natural mortality rate of 1.2 *year*$^{-1}$. The trade-off curve for OMP-08 was determined by limiting $risk_S < 0.18$ and $risk_A < 0.10$, while the trade-off curves for the new MP are determined by points satisfying $risk_S < 0.21$ and a range of anchovy risk levels. Trade-off curves are given assuming a) $\alpha_{ads} = 1.5 \times \alpha_{ns}$, b) $\alpha_{ads} = 2 \times \alpha_{ns}$, and c) $\alpha_{ads} = 2.5 \times \alpha_{ns}$.

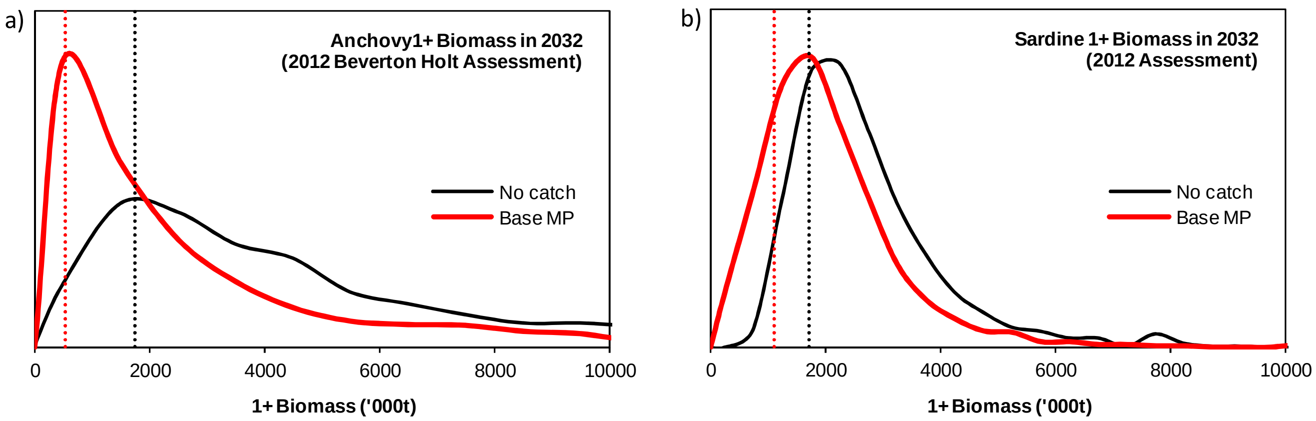

Figure 8. Comparison of a) anchovy and b) sardine 1+ biomass distributions in the final projection year under a no catch scenario and the “Base MP”.

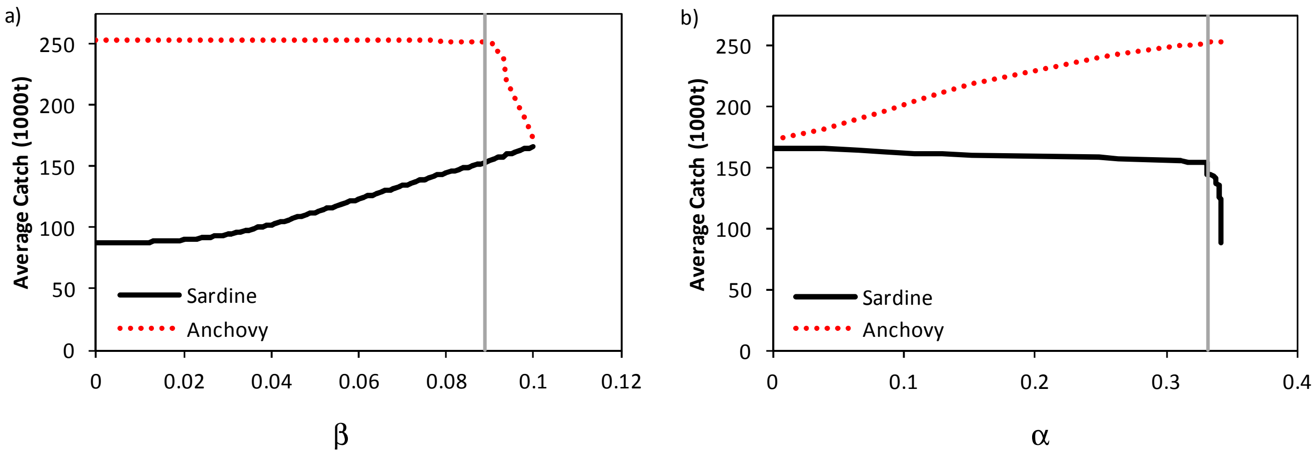

Figure 9. The average directed sardine and anchovy catches (as shown on the Trade-off curve in Figure 7a for $risk_A < 0.20$) plotted against a) the sardine control parameter, β and b) the anchovy control parameter, α. The grey vertical lines indicate a value of a) $\beta = 0.089$ and b) $\alpha = 0.331$ corresponding to the corner point of the new “Base MP” variant.

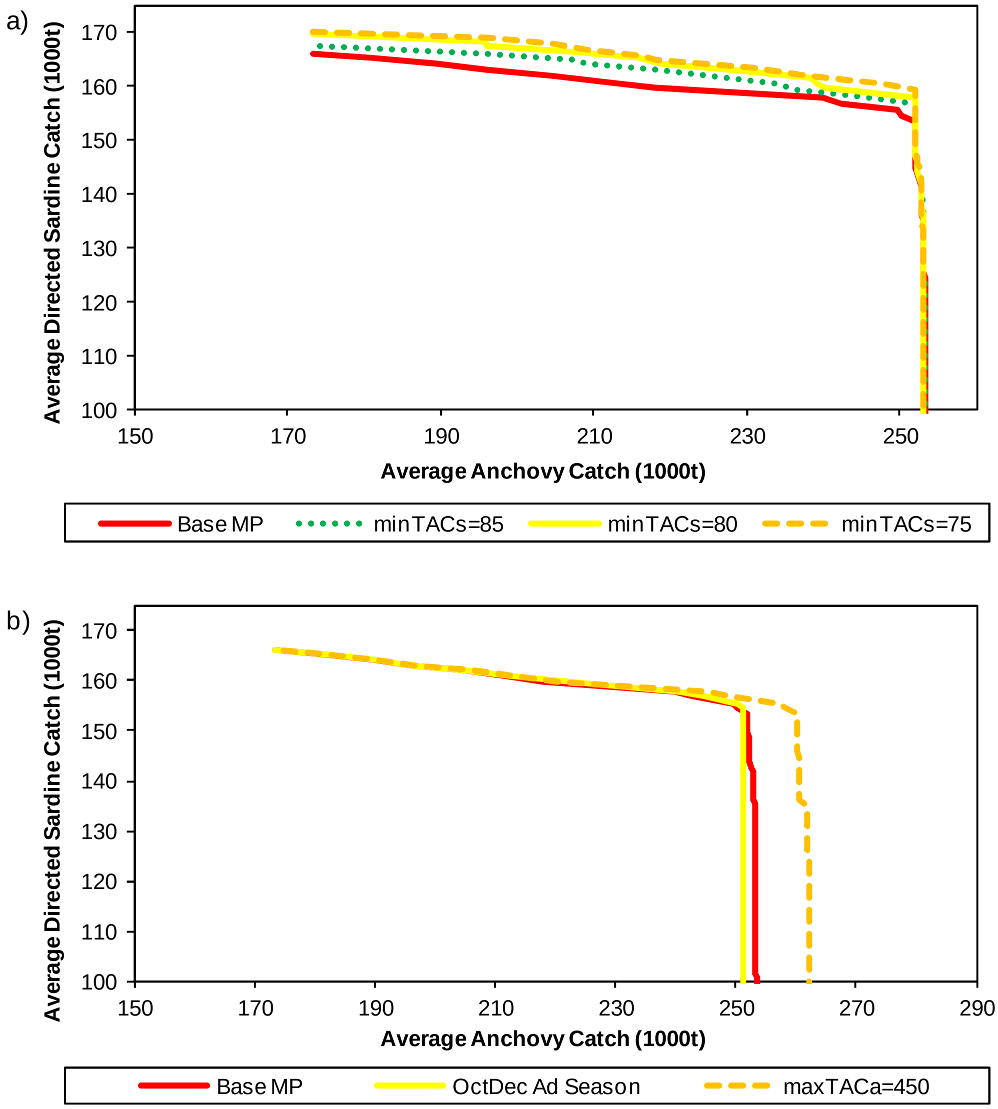

Figure 10. Trade-off curves for the "Base MP" and a) alternative minimum directed large sardine TACs, 75, 80 and 85 000t compared to 90 000 in "Base MP" and b) a maximum total anchovy TAC of 450 000t, compared to 350 000t in "Base MP", and an additional season from October to December, compared to September to December in "Base MP". The trade-off curves are all determined by limiting $risk_S < 0.21$ and $risk_A < 0.20$. Note, to aid comparison between trade-off curves, the axes do not intersect at zero in these figures.