Exceptional Circumstances Provisions for OMP-08: Initial Evaluations

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Introduction

OMP-08 was implemented for the South African sardine and anchovy resources in December 2007, with provisional rules governing the declaration of exceptional circumstances. It was agreed that the rules and thresholds for exceptional circumstances provisions would be finalised before June 2008. This document details initial tests and alternatives considered for these exceptional circumstance provisions.

Methods

The OMP is run under a number of alternative exceptional circumstances options in order to examine the effect of such exceptional circumstances provisions on the resource. The "Current OMP-08" used in this document refers to the OMP rules implemented in December 2007, with control parameters ($\beta = 0.096$, $\alpha_{ns} = 0.37$ and $\alpha_{ads} = 0.74$) having been adjusted in accordance with the recommended change in the anchovy risk threshold and move to the 'corner point' in Cunningham and Butterworth (2008). The 10% of simulations that resulted in the lowest simulated true biomass over the projection period under "Current OMP-08" were selected for clearer comparisons between the results of alternative options in the "lower tail", which provides better focus on cases where the status of a resource has become poor so that stronger measures may be needed to ensure recovery.

The rules used to calculate the directed sardine and anchovy TACs are listed in Appendix A (Cunningham and Butterworth 2007), while the rules used to test if exceptional circumstances are to be declared and the adjustment to the TACs if exceptional circumstances are declared are detailed in Appendix B. The rules in "Current OMP-08" and the variants considered are reflected in the control rule plots in Figure B1 of Appendix B. The variants involve either changing the threshold at which exceptional circumstances are declared, having the TAC drop faster if biomass is below this threshold, and ensuring continuity over thresholds given restrictions on the extent of inter annual TAC changes.

Results

The context to consider these results (as to the efficacy of exceptional circumstances rules) is that the MPs are designed to avoid the resource dropping below the thresholds in question, but if they do, remedial additional measures should be such as to see the resource recover rapidly to again be above such thresholds.

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Table 1 compares the key summary statistics for the sardine resource under "Current OMP-08" to a situation of no catch from 2008 to 2027 or the use of the OMP rules without any exceptional circumstances provisions. Table 2 presents such statistics for the anchovy resource. As expected, in the case of no exceptional circumstances provisions, the risk to the sardine or anchovy resource increases substantially, the average projected catch decreases and the resource in 2027 is in a poorer state compared to that projected under "Current OMP-08". This latter point is also highlighted in the 2027 biomass distributions of the resource, which show an appreciable portion of the area under the curves at low biomass values (Figures 1a and 2a).

Of concern (as mentioned in previous documents), is the frequency with which anchovy exceptional circumstances are declared (Table 2). The probability of declaring anchovy exceptional circumstances increases from 0.04 under a no catch scenario to 0.20 under "Current OMP-08", while the average number of years for which exceptional circumstances, if declared, are declared consecutively is 4.7 years under "Current OMP-08".

For sardine, exceptional circumstances are declared unnecessarily or are not declared when necessary only in a small number of cases (Table 1). For anchovy exceptional circumstances are seldom declared unnecessarily, while are not declared when necessary 8% of the time. Note that when considering the proportion of times exceptional circumstances are declared unnecessarily, or are not declared when necessary, the true biomass is compared to the exceptional circumstances threshold adjusted by the bias in the November survey (i.e., true = threshold*bias).

Tables 3 and 4 show that for the 10% of cases resulting in the lowest abundances for sardine and anchovy, there is relatively substantial recovery in median terms compared to the situations without exceptional circumstances provisions.

In order to evaluate the "efficacy" with which the exceptional circumstances rules allow the resources to recover, Figures 3a and 4a plot the biomass trajectories for sardine and anchovy respectively, for some the worse cases of the "Current OMP-08". The recovery for both resources is not immediate, frequently requiring a number of years of consecutive declaration of exceptional circumstances. Considering biomass trajectories around the lower 2½ percentile for sardine and 5 percentile for anchovy of the distribution of minimum projected 2008 to 2022 biomass shows a more rapid increase out of the region of exceptional circumstances for anchovy.

Alternative Thresholds

As expected, sardine exceptional circumstances are declared more/less frequently and the risk to the sardine resource is higher/lower for a lower/higher exceptional circumstances threshold than that currently used (Table 5, Figure 1b). Similarly for anchovy, where a decrease in the exceptional circumstances threshold results in the declaration of exceptional circumstances less often, but with a substantial increase in risk to the resource (Table 6, Figure 2b).

Faster Decrease in the TAC

Replacing the quadratic rule used to adjust the TAC with a cubic rule such that the TAC is decreased faster once exceptional circumstances are declared results in little change in the summary statistics for sardine (Table 5, Figure 1c) and a slight improvement to the risk for anchovy (Table 6, Figure 2c).

Continuous TAC

Keeping the TAC continuous over the range of biomass near the exceptional circumstances threshold results in an increase in risk to both resources (Tables 5 and 6) and a greater proportion of the biomass in 2027 at lower levels (Figures 1c and 2c). Since Cunningham and Butterworth (2008) recommend that OMP-08 be tuned keeping $risk_S < 0.18$ and $risk_A < 0.28$, changing the exceptional circumstances provisions such that the rules are continuous will most likely necessitate further changes in the rule or increase in the threshold to keep the risk below these thresholds.

Summary

This document has provided a first look at the impact of the exceptional circumstances provisions included in the rules for directed sardine and anchovy TACs in OMP-08. Some alternatives rules and thresholds to those considered in the "Current OMP-08" have been considered.

In summary, sardine exceptional circumstances are not declared too often under "Current OMP-08", but when declared more than once are often declared for 4 consecutive years. These initial results do not show an appreciable decrease to this average if the TAC is decreased faster using a cubic instead of a quadratic rule, but this will be further investigated. This may be related to the resource being towards the lower end of the assumed stock-recruitment curve in such circumstances. A further alternative yet to be considered for the sardine resource is that in the case of sardine exceptional circumstances being declared, only a portion of the TAC is provided at the beginning of the year with a possible mid-year increase in the TAC if recruitment is above average.

As mentioned above, anchovy exceptional circumstances are simulated to be declared rather frequently. Lowering the exceptional circumstances threshold does decrease this probability slightly, but is accompanied by a large increase in risk to the resource. This implies that although a minimum constraint of 150 000t is applied to the anchovy TAC, it is not unlikely that the TAC will fall below this minimum in the medium term future.

References

Cunningham, C.L. and Butterworth, D.S. 2007. Development and Testing of OMP-08. MCM Document MCM/2007/26NOV/SWG-PEL/01. 40pp.

Cunningham, C.L. and Butterworth, D.S. 2008. Re-evaluation of Risk Thresholds for Sardine and Anchovy. MCM Document MCM/2008/SWG-PEL/01. 7pp.

Table 1. Key summary statistics for the sardine resource: 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, $risk_S$; average directed catch (in thousands of tons), $\overline{C}^S$; average proportional annual change in directed catch, AAV^S; average biomass at the end of the projection period as a proportion of carrying capacity, as a proportion of the risk threshold (lower 5%ile given in brackets), and as a proportion of biomass at the beginning of the projection period; and average minimum biomass over the projection period as a proportion of carrying capacity and as a proportion of the risk threshold. Statistics are calculated from all simulations and from the 10% of simulations corresponding to the lowest projected biomass under "Current" OMP-08.

	All Simulations			Lowest 10%		
	No Catch	Current OMP-08	No EC rules	No Catch	Current OMP-08	No EC rules
$risk_S$	0.027	0.178	0.451	0.027	0.178	0.451
$\overline{C}^S$ (2008-2027)	0	190	165	0	79	64
AAV^S (2008-2027)	0	0.24	0.24	0	0.40	0.18
$\overline{B^S_{2027} / K^S_{non-peak}}$	0.93	0.70	0.44	0.62	0.18	0.03
$\overline{B^S_{2027} / Risk^S}$	17.34 (2.35)	10.77 (0.82)	7.01 (0.00)	10.08 (1.15)	1.88 (0.05)	0.16 (0.00)
$\overline{B^S_{2027} / B^S_{2007}}$	9.65	5.84	3.85	6.49	1.29	0.12
$\overline{B^S_{\min} / K^S_{non-peak}}$	0.33	0.26	0.17	0.18	0.06	0.01
$\overline{B^S_{\min} / Risk^S}$	2.24	1.78	1.20	1.35	0.39	0.07
Proportion of times Exceptional Circumstances are declared (2008-2027)	0.003[1]	0.035	N/A			N/A
Mean number of times Exceptional Circumstances are declared for 2 or more consecutive years in a 20 year projection period	0.008	0.119	N/A			N/A
Probability that Exceptional Circumstances are declared in the following year, given the declaration of Exceptional Circumstances in any year	0.121	0.172	N/A			N/A
Average number of years for which Exceptional Circumstances, if declared, are declared consecutively	2.375	3.924	N/A			N/A
Proportion of times Exceptional Circumstances are declared and true biomass is below the corresponding threshold	0.000	0.010	N/A			N/A
Proportion of times Exceptional Circumstances are declared and true biomass is above the corresponding threshold[2]	0.003	0.024	N/A			N/A
Proportion of times Exceptional Circumstances are not declared when true biomass is below the corresponding threshold[3]	0.000	0.001	N/A			N/A

[1] References to the declaration of exceptional circumstances under the no catch option refer to the number of times the simulated observed biomass drops below the current exceptional circumstance threshold of 250 000t.
[2] This reports the proportion of times exceptional circumstances are declared unnecessarily.
[3] This reports the proportion of times exceptional circumstances are not declared when they should have been.

Table 2. Key summary statistics for the anchovy resource: 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 directed catch (in thousands of tons), $\overline{C}^A$, average proportional annual change in directed catch, AAV^A, average biomass at the end of the projection period as a proportion of carrying capacity, as a proportion of the risk threshold (lower 5%ile given in brackets), as a proportion of biomass at the beginning of the projection period, and average minimum biomass over the projection period as a proportion of carrying capacity and as a proportion of the risk threshold. Statistics are calculated from all simulations and from the 10% of simulations corresponding to the lowest projected biomass under "Current" OMP-08.

	All Simulations			Lowest 10%		
	No Catch	Current OMP-08	No EC rules	No Catch	Current OMP-08	No EC rules
$Risk_A$	0.037	0.278	0.49	0.037	0.278	0.49
$\overline{C}^A$ (2008-2027)	0	263	240	0	161	126
AAV^A (2008-2027)	0	0.40	0.38	0	0.52	0.47
$\overline{B^A_{2027}/K^A}$	0.96	0.61	0.42	0.63	0.31	0.00
$\overline{B^A_{2027}/Risk^A}$	2.57 (0.25)	1.71 (0.07)	1.26 (0.00)	2.09 (0.04)	1.00 (0.01)	0.02 (0.00)
$\overline{B^A_{2027}/B^A_{2007}}$	1.61	1.04	0.76	1.41	0.61	0.01
$\overline{B^A_{\min}/K^A}$	0.26	0.11	0.09	0.06	0.01	0.00
$\overline{B^A_{\min}/Risk^A}$	0.57	0.26	0.22	0.16	0.03	0.00
Proportion of times Exceptional Circumstances are declared (2008-2027)	0.038[4]	0.201	N/A			N/A
Mean number of times Exceptional Circumstances are declared for 2 or more consecutive years in a 20 year projection period	0.166	0.762	N/A			N/A
Probability that Exceptional Circumstances are declared in the following year, given the declaration of Exceptional Circumstances in any year	0.219	0.190	N/A			N/A
Average number of years for which Exceptional Circumstances, if declared, are declared consecutively	3.500	4.706	N/A			N/A
Proportion of times Exceptional Circumstances are declared and true biomass is below the corresponding threshold	0.033	0.191	N/A			N/A
Proportion of times Exceptional Circumstances are declared and true biomass is above the corresponding threshold	0.005	0.010	N/A			N/A
Proportion of times Exceptional Circumstances are not declared when true biomass is below the corresponding threshold	0.038	0.084	N/A			N/A

[4] References to the declaration of exceptional circumstances under the no catch option refer to the number of times the simulated observed biomass drops below the current exceptional circumstance threshold of 400 000t.

Table 3a. Median and lower 5%ile of the sardine biomass in 2027 calculated using OMP-08 with exceptional circumstances provisions as a ratio of the maximum of i) that calculated using OMP-08 without exceptional circumstances provisions or ii) 10% of the exceptional circumstances threshold[5]. Results are presented for the 10% of simulations corresponding to the lowest projected biomass under "Current OMP-08", excluding cases where exceptional circumstances are declared between 2023 and 2027 (which may have biased results, given the lack of subsequent time for recovery in such cases).

	"Current" OMP-08	Lower EC Threshold	Higher EC Threshold	Cubic Rule	Continuous Rule
EC Threshold	250 000t	200 000t	300 000t	250 000t	250 000t
Lower 5%ile	1.00	0.45	1.03	1.00	1.00
Median	22.77	14.33	35.86	23.12	13.98

Table 3b. As for Table 3a, except that results are presented for the 5% of simulations corresponding to the lowest projected biomass under "Current OMP-08", here including cases where exceptional circumstances are declared between 2023 and 2027.

	"Current" OMP-08	Lower EC Threshold	Higher EC Threshold	Cubic Rule	Continuous Rule
EC Threshold	250 000t	200 000t	300 000t	250 000t	250 000t
Lower 5%ile	1.00	1.00	1.03	1.00	1.00
Median	22.77	16.72	35.88	23.29	15.80

Table 4a. Median and lower 5%ile of the anchovy biomass in 2027 calculated using OMP-08 with exceptional circumstances provisions as a ratio of the maximum of i) that calculated using OMP-08 without exceptional circumstances provisions or ii) 10% of the exceptional circumstances threshold[6]. Results are presented for the 10% of simulations corresponding to the lowest projected biomass under "Current OMP-08", excluding cases where exceptional circumstances are declared between 2023 and 2027 (which may have biased results, given the lack of subsequent time for recovery in such cases).

	"Current" OMP-08	Lower EC Threshold	Lower EC Threshold	Higher EC Threshold	Cubic Rule	Continuous Rule
EC Threshold	400 000t	300 000t	350 000t	450 000t	400 000t	400 000t
Lower 5%ile	0.18	0.14	0.16	0.19	0.19	0.15
Median	3.76	2.85	3.47	4.07	4.48	3.61

Table 4b. As for Table 4a, except that results are presented for the 5% of simulations corresponding to the lowest projected biomass under "Current OMP-08", here including cases where exceptional circumstances are declared between 2023 and 2027.

	"Current" OMP-08	Lower EC Threshold	Lower EC Threshold	Higher EC Threshold	Cubic Rule	Continuous Rule
EC Threshold	400 000t	300 000t	350 000t	450 000t	400 000t	400 000t
Lower 5%ile	1.06	0.78	0.90	1.14	1.11	0.92
Median	5.18	3.70	4.34	5.49	5.57	4.69

[5] The maximum of these two quantities was taken to avoid the situations where the biomass tends to zero in poor cases under OMP-08 without exceptional circumstances provisions.

[6] The maximum of these two quantities was taken to avoid the situations where the biomass tends to zero in poor cases under OMP-08 without exceptional circumstances provisions.

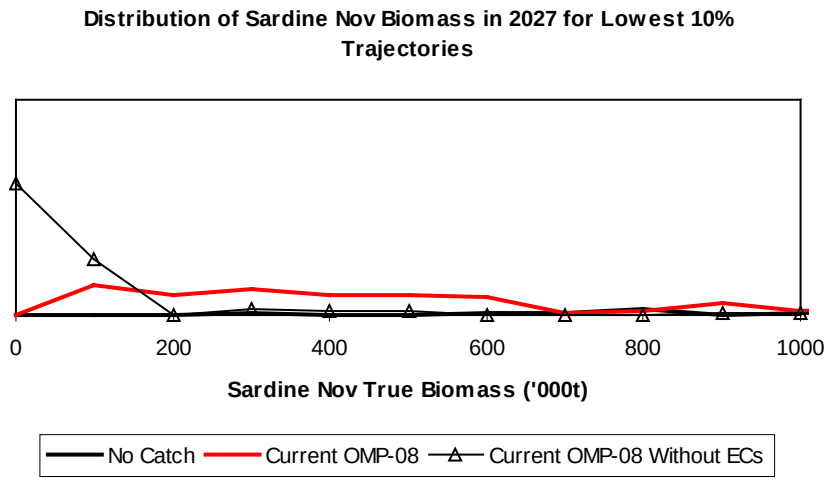
Table 5. Key summary statistics for the sardine resource: the probability that adult sardine biomass falls below the average adult sardine biomass over November 1991 to November 1994 (the "risk threshold", $Risk^S$) at least once during the projection period of 20 years, $risk_S$; average directed catch (in thousands of tons), $\overline{C}^S$; average proportional annual change in directed catch, AAV^S; average biomass at the end of the projection period as a proportion of carrying capacity, as a proportion of the risk threshold (lower 5%ile given in brackets), and as a proportion of biomass at the beginning of the projection period; and average minimum biomass over the projection period as a proportion of carrying capacity and as a proportion of the risk threshold. Statistics in the top half of the table are calculated from the 10% of simulations corresponding to the lowest projected biomass under "Current" OMP-08, while those in the lower half of the table are calculated from all simulations.

	Current OMP-08	Lower EC Threshold	Higher EC Threshold	Cubic Rule	Continuous Rule
Exceptional Circumstances Threshold	250 000t	200 000t	300 000t	250 000t	250 000t
$\overline{C}^S$ (2008-2027)	79	80	78	79	79
AAV^S (2008-2027)	0.40	0.35	0.41	0.40	0.34
$\overline{B^S_{2027} / K^S_{non-peak}}$	0.18	0.15	0.20	0.18	0.15
$\overline{B^S_{2027} / Risk^S}$	1.88 (0.05)	1.61 (0.02)	2.10 (0.07)	1.90 (0.05)	1.58 (0.00)
$\overline{B^S_{2027} / B^S_{2007}}$	1.29	1.11	1.43	1.30	1.09
$\overline{B^S_{\min} / K^S_{non-peak}}$	0.06	0.05	0.07	0.06	0.05
$\overline{B^S_{\min} / Risk^S}$	0.39	0.33	0.45	0.39	0.33
$risk_S$	0.178	0.185	0.175	0.179	0.185
Proportion of times Exceptional Circumstances are declared (2008-2027)	0.035	0.029	0.042	0.034	0.040
Mean number of times Exceptional Circumstances are declared for 2 or more consecutive years in a 20 year projection period	0.119	0.101	0.138	0.118	0.139
Probability that Exceptional Circumstances are declared in the following year, given the declaration of Exceptional Circumstances in any year	0.172	0.173	0.166	0.172	0.176
Average number of years for which Exceptional Circumstances, if declared, are declared consecutively	3.924	4.149	3.935	3.907	4.158
Proportion of times Exceptional Circumstances are declared and true biomass is below the corresponding threshold	0.010	0.011	0.010	0.010	0.015
Proportion of times Exceptional Circumstances are declared and true biomass is above the corresponding threshold	0.024	0.018	0.032	0.024	0.024
Proportion of times Exceptional Circumstances are not declared when true biomass is below the corresponding threshold	0.001	0.001	0.001	0.001	0.001

Table 6. Key summary statistics for the anchovy resource: 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 directed catch (in thousands of tons), $\overline{C}^A$, average proportional annual change in directed catch, AAV^A, average biomass at the end of the projection period as a proportion of carrying capacity, as a proportion of the risk threshold (lower 5%ile given in brackets), as a proportion of biomass at the beginning of the projection period, and average minimum biomass over the projection period as a proportion of carrying capacity and as a proportion of the risk threshold. Statistics in the top half of the table are calculated from the 10% of simulations corresponding to the lowest projected biomass under "Current" OMP-08, while those in the lower half of the table are calculated from all simulations.

	Current OMP-08	Lower EC Threshold	Lower EC Threshold	Higher EC Threshold	Cubic Rule	Continuous Rule
Exceptional Circumstances Threshold	400 000t	300 000t	350 000t	450 000t	400 000t	400 000t
$\overline{C}^A$(2008-2027)	161	158	160	163	162	163
AAV^A (2008-2027)	0.52	0.52	0.52	0.52	0.53	0.52
$\overline{B^A_{2027}/K^A}$	0.31	0.25	0.28	0.34	0.34	0.29
$\overline{B^A_{2027}/Risk^A}$	1.00 (0.01)	0.79 (0.01)	0.88 (0.01)	1.12 (0.01)	1.14 (0.01)	0.90 (0.01)
$\overline{B^A_{2027}/B^A_{2007}}$	0.61	0.48	0.53	0.68	0.69	0.54
$\overline{B^A_{\min}/K^A}$	0.01	0.01	0.01	0.02	0.02	0.01
$\overline{B^A_{\min}/Risk^A}$	0.03	0.03	0.03	0.04	0.04	0.03
$Risk_A$	0.278	0.416	0.361	0.235	0.259	0.313
Proportion of times Exceptional Circumstances are declared (2008-2027)	0.201	0.174	0.186	0.212	0.197	0.196
Mean number of times Exceptional Circumstances are declared for 2 or more consecutive years in a 20 year projection period	0.762	0.635	0.685	0.830	0.776	0.747
Probability that Exceptional Circumstances are declared in the following year, given the declaration of Exceptional Circumstances in any year	0.190	0.182	0.184	0.195	0.197	0.191
Average number of years for which Exceptional Circumstances, if declared, are declared consecutively	4.706	5.057	4.927	4.535	4.526	4.632
Proportion of times Exceptional Circumstances are declared and true biomass is below the corresponding threshold	0.191	0.169	0.179	0.203	0.187	0.186
Proportion of times Exceptional Circumstances are declared and true biomass is above the corresponding threshold	0.010	0.006	0.007	0.010	0.010	0.010
Proportion of times Exceptional Circumstances are not declared when true biomass is below the corresponding threshold	0.084	0.058	0.070	0.098	0.086	0.086

a)



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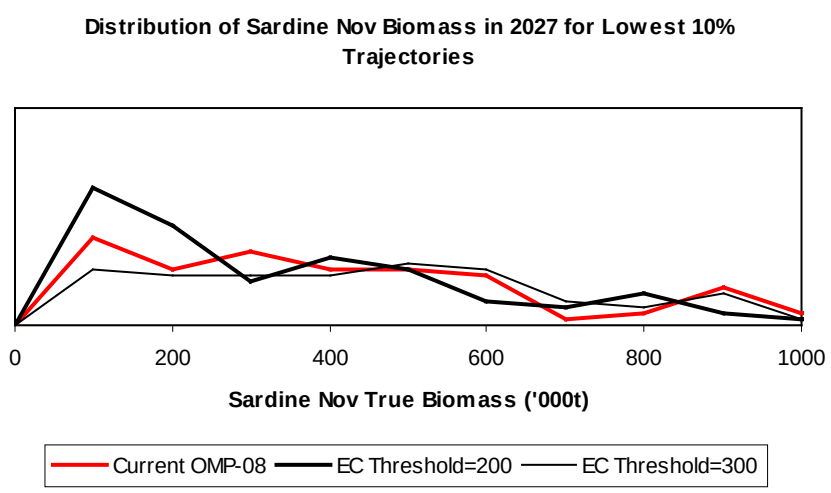

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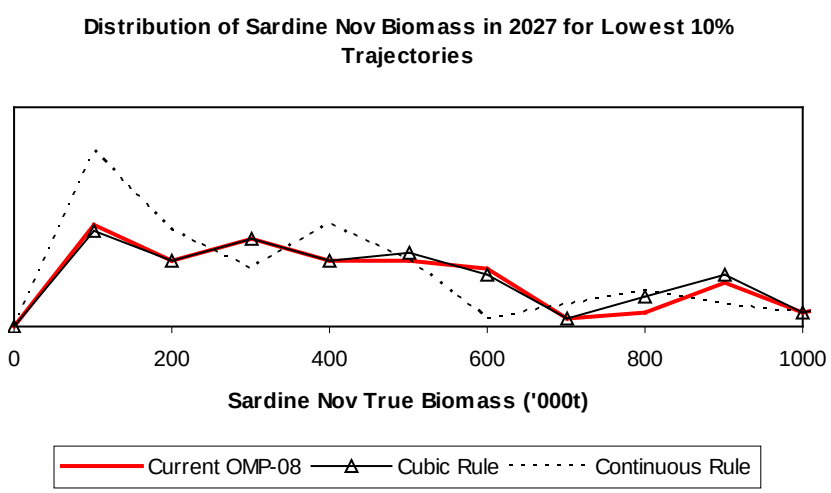
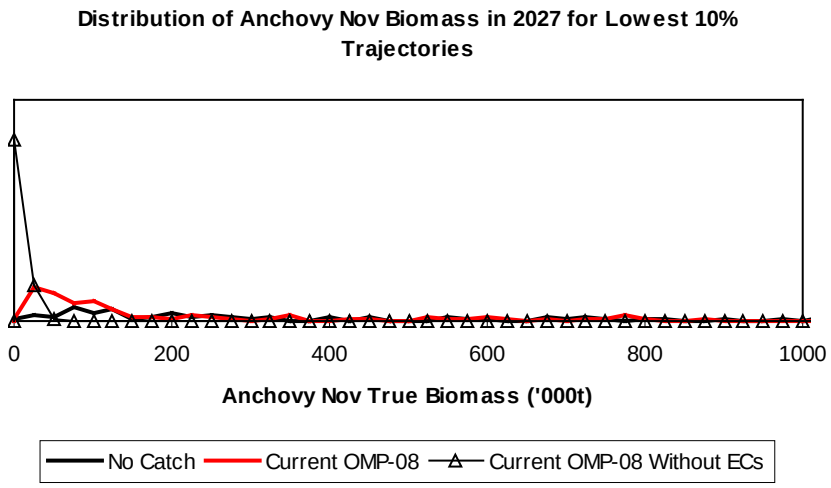


Figure 1. The lower portion of the distribution of sardine November biomass in 2027 for the 10% of simulations corresponding to the lowest projected biomass under "Current OMP-08". Comparisons are made against a) results with and without Exceptional Circumstances rules, b) alternative Exceptional Circumstances threshold levels and c) alternative Exceptional Circumstances rules.

a)



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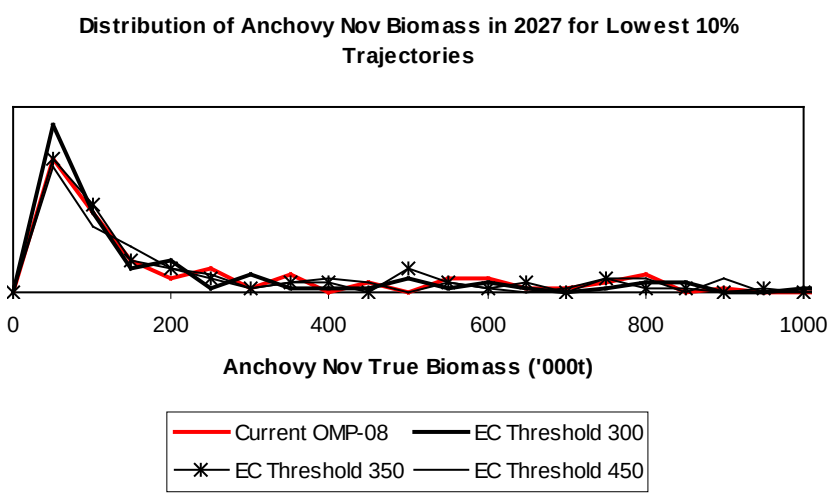

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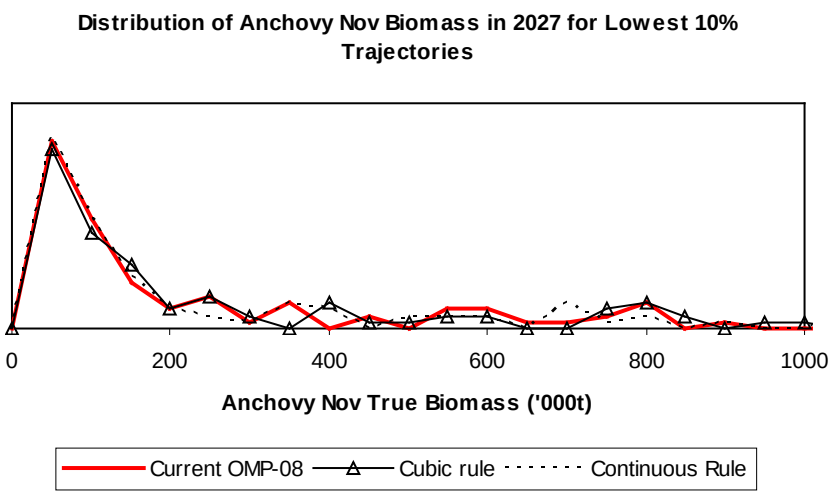
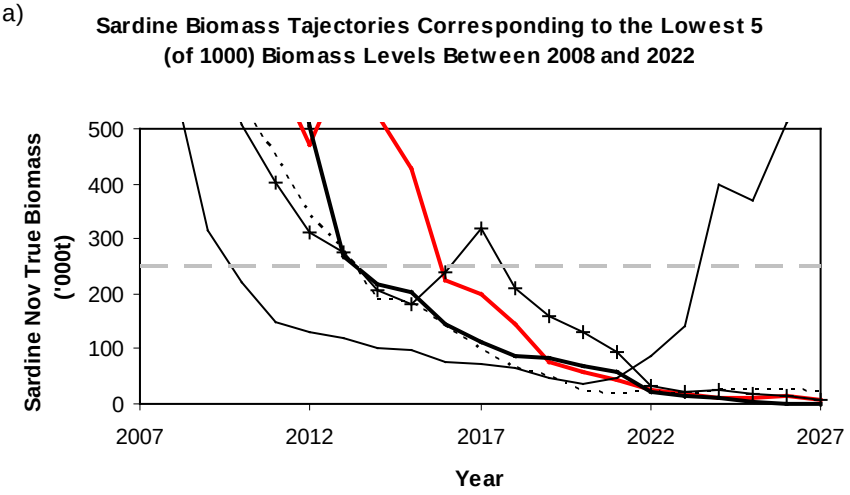


Figure 2. The lower portion of the distribution of anchovy November biomass in 2027 for the 10% of simulations corresponding to the lowest projected biomass under "Current OMP-08". Comparisons are made against a) results with and without Exceptional Circumstances rules, b) alternative Exceptional Circumstances threshold levels and c) alternative Exceptional Circumstances rules.

a)



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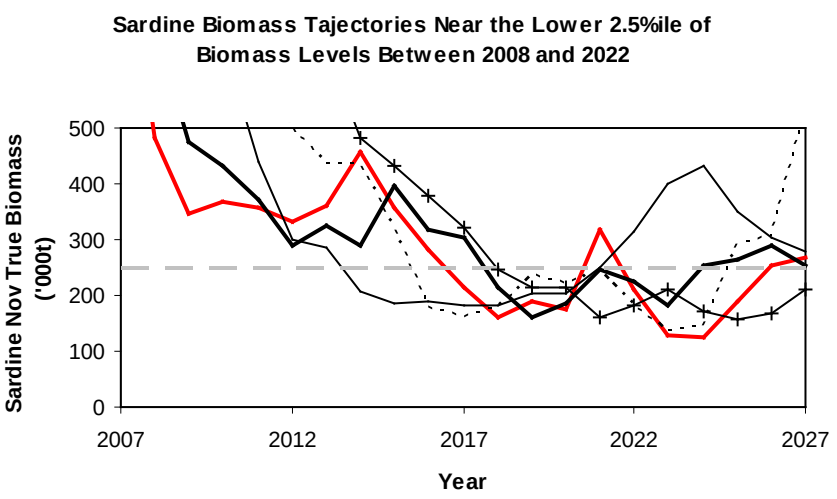
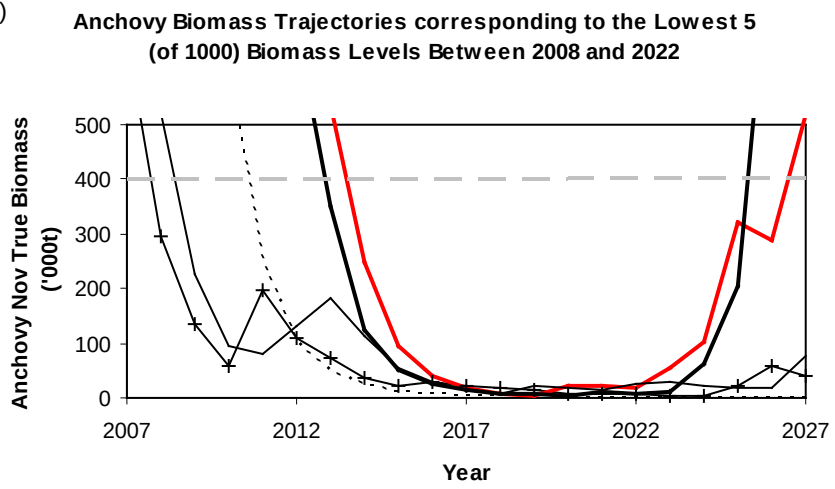


Figure 3. Sardine biomass trajectories under "Current OMP-08" corresponding to a) the five (of 1000) reaching the lowest biomass level between 2008 and 2022 and b) the 21-25th lowest (of 1000) biomass levels between 2008 and 2022. The grey dashed line indicates the reference case exceptional circumstances threshold of 250 000t.

a)



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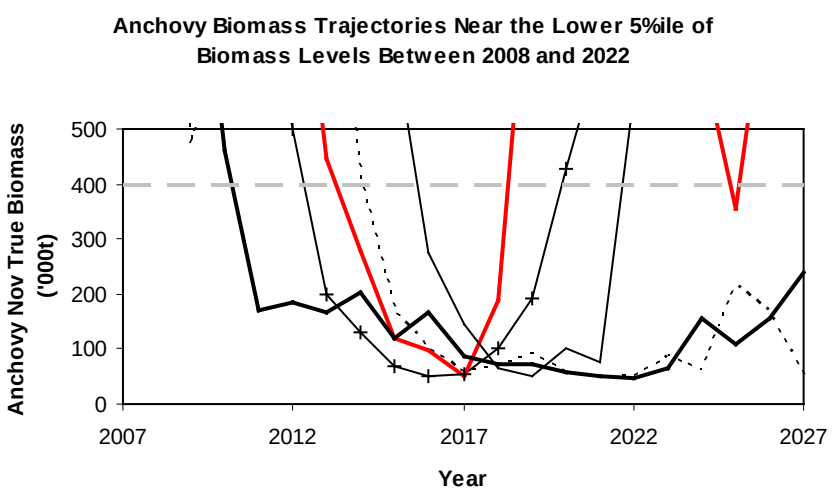

Figure 4. Anchovy biomass trajectories under "Current OMP-08" corresponding to a) the five (of 1000) reaching the lowest biomass level between 2008 and 2022 and b) the 51-55th lowest (of 1000) biomass levels between 2008 and 2022. The grey dashed line indicates the reference case exceptional circumstances threshold of 400 000t.

Appendix A: OMP-08

(from Cunningham and Butterworth 2007)

Sardine and anchovy total allowable catches (TACs) and sardine total allowable bycatches (TABs) are set at the start of the year and the latter two are revised during the year. Catches-at-age are given in this appendix in numbers of fish (in billions), whereas the TACs and TABs are given in thousands of tonnes.

Initial TACs / TAB (January)

The directed sardine TAC and initial directed anchovy TAC and TAB for sardine bycatch are based on the results of the November spawner biomass survey. These limits are announced prior to the start of the pelagic fishery at the beginning of each year.

The directed sardine TAC is set at a proportion of the previous year's November spawner biomass index of abundance, but subject to the constraints of a minimum and a maximum value. If the previous year's TAC is below the 'two-tier' threshold, then the TAC is subject to a maximum percentage drop from the previous year's TAC. If it is above this threshold, any reduction is limited only by a lower bound of the corresponding threshold less the maximum percentage drop.

The directed anchovy initial TAC is based on how the most recent November spawner biomass survey estimate of abundance relates to the historic (non-peak) average between 1984 and 1999. In the absence of further information, which will become available after the May recruitment survey, this initial TAC assumes the forthcoming recruitment (which will form the bulk of the catch) will be average. A 'scale-down' factor, δ, is therefore introduced to provide a buffer against possible poor recruitment. The anchovy TAC is subject to similar constraints as apply for sardine.

The initial sardine TAB consists of two components. The first component, consisting of mainly juvenile sardine, is proportional to the anchovy TAC. The second, consisting of mainly adult sardine, is a fixed tonnage to make allowance for bycatch with round herring.

Directed sardine TAC:
$$TAC_y^S = \beta\, B_{y-1,Nov}^{obs,S} \tag{A.1}$$

Subject to:
$$\begin{aligned} \max\left\{\left(1-c_{mxdn}^S\right)TAC_{y-1}^S\,;\,c_{mntac}^S\right\} \le\; TAC_y^S \;\le\; c_{mxtac}^S \quad & TAC_{y-1}^S \le c_{tier}^S \\ \left(1-c_{mxdn}^S\right)c_{tier}^S \;\le\; TAC_y^S \;\le\; c_{mxtac}^S \quad & TAC_{y-1}^S > c_{tier}^S \end{aligned} \tag{A.2}$$

Initial directed anchovy TAC:
$$TAC_y^{1,A} = \alpha_{ns}\;\delta\; q\left(\; p + (1-p)\frac{B_{y-1}^{obs,A}}{\overline{B}_{Nov}^A}\right) \tag{A.3}$$

Subject to:
$$\begin{aligned} \max\left\{\left(1-c_{mxdn}^A\right)TAC_{y-1}^{2,A}\,;\,c_{mntac}^A\right\} \le\; TAC_y^{1,A} \;\le\; c_{mxtac}^A \quad & TAC_{y-1}^{2,A} \le c_{tier}^A \\ \left(1-c_{mxdn}^A\right)c_{tier}^A \;\le\; TAC_y^{1,A} \;\le\; c_{mxtac}^A \quad & TAC_{y-1}^{2,A} > c_{tier}^A \end{aligned} \tag{A.4}$$

Initial sardine TAB: $$TAB_y^{1,S} = \gamma_y \, TAC_y^{1,A} + TAB_{rh}^S \qquad \text{(A.5)}$$

where: $$\gamma_y = 0.1 + \frac{0.1}{1 + \exp\left(-\frac{1}{0.1} 0.00025 \left(B_{y-1}^{obs,S} - 2000 \right) \right)}$$

In the above equations we have:

β - a control parameter reflecting the proportion of the previous year's November spawner biomass index of abundance that is used to set the directed sardine TAC.

$B_{y,N}^{obs,S}$ - the observed estimate of sardine abundance from the hydroacoustic spawner biomass survey in November of year y.

$B_{y,N}^{obs,A}$ - the observed estimate of anchovy abundance from the hydroacoustic spawner biomass survey in November of year y).

$\overline{B}_{Nov}^{A}$ - the historic average index of anchovy abundance from the spawner biomass surveys from November 1984 to November 1999, of 1380.28 thousand tonnes.

α_{ns} - a control parameter which scales the anchovy TAC to meet target risk levels for sardine and anchovy.

δ - a 'scale-down' factor used to lower the initial anchovy TAC to provide a buffer against possible poor recruitment.

p - the weight given to the recruit survey component compared to the spawner biomass survey component in setting the anchovy TAC.

q - a constant value reflecting the average annual TAC expected under OMP99 under average conditions if $\alpha_{ns} = 1$.

TAB_{rh}^S - the fixed tonnage of adult sardine bycatch set aside for the round herring fishery each year.

γ_y - a conservative estimate of the anticipated ratio of juvenile sardine to juvenile anchovy in subsequent catches.

c_{mxdn}^S - the maximum proportional amount by which the directed sardine TAC can be reduced from one year to the next.

c_{mxdn}^A - the maximum proportional amount by which the normal season directed anchovy TAC can be reduced from one year to the next, (note that the additional season anchovy TAC is not taken into consideration in this constraint, which consequently depends on $TAC_{y-1}^{2,A}$, not $TAC_{y-1}^{3,A}$ - see below for formulae for these quantities).

c_{mntac}^S - the minimum directed TAC to be set for sardine.

c_{mntac}^A - the minimum directed TAC to be set for anchovy.

c^{S}_{mxtac} - the maximum directed TAC to be set for sardine.

c^{A}_{mxtac} - the maximum directed TAC to be set for anchovy.

The fixed input value of $p = 0.7$ reflects the greater importance of the incoming recruits in the year's catch relative to the previous year's spawner biomass survey. Earlier OMPs used a fixed value of $\delta = 0.7$ to reflect the assumption that 70% of the final TAC to be expected in the case of average recruitment would be caught by the time the revised TAC is announced (Butterworth *et al*. 1993). For OMP-02 this control parameter was increased to 0.85 to reflect the industry's desire for greater 'up-front' TAC allocation for planning purposes, even if this meant some sacrifice in expected average TAC to meet the same risk criterion. $\delta = 0.85$ was retained for OMP-04 and OMP-08. Although $q = 300$ is based on an old OMP, the value is not adjusted here. This is to facilitate easy comparison between the outputs from OMP-08, OMP-04 and OMP-02 by stakeholders. During OMP-02 and OMP-04, the adult sardine bycatch, TAB^{S}_{rh}, was set at 10 000 t, 12.5% of 80 000 t, the predicted average red-eye catch (De Oliveria 2003). However, the sardine bycatch with red-eye has historically been around 3 000t. OMP-08 was simulation tested under two assumptions:

i) the sardine adult bycatch with red-eye will remain at 3 500t (rounded up to be conservative) over the projection period; or

ii) the average red-eye catch doubles over the next 5 years, such that bycatch increases from 3 500t in 2007 to 7 000t in 2011 and remains at 7 000t for the remainder of the projection period.

And assumption i) was chosen for recommending TABs under OMP-08.

Revised TACs / TAB (June)

The anchovy TAC and sardine TAB midyear revisions are based on the most recent November and now also recruit surveys. As the estimate of recruitment is now available, the 'scale-down' factor, δ, is no longer needed to set the directed anchovy TAC. The additional constraints include restricting the amount to which the revised anchovy TAC may exceed the initial anchovy TAC (because of limitations in industry processing capacity) and ensuring that the revised anchovy TAC is not less than the initial anchovy TAC.

The revised sardine TAB is calculated using an estimate of the ratio, r_y, of juvenile sardine to anchovy, provided this ratio is larger than γ_y, which was used to set the initial TAB.

Revised anchovy TAC:
$$TAC^{2,A}_{y} = \alpha_{ns}\, q \left(p \frac{N^{A}_{y-1,rec0}}{\overline{N}^{A}_{rec0}} + (1-p) \frac{B^{obs,A}_{y-1,N}}{\overline{B}^{A}_{Nov}} \right) \qquad \text{(A.6)}$$

Subject to:

$$\begin{array}{ll} \max\left\{\left(1-c^{A}_{mxdn}\right)TAC^{2,A}_{y-1}\,;\,TAC^{1,A}_{y}\,;\,c^{A}_{mntac}\right\} \le TAC^{2,A}_{y} \le \min\left\{c^{A}_{mxtac}\,;\,TAC^{1,A}_{y}+c^{ns,A}_{mxinc}\right\} & TAC^{2,A}_{y-1} \le c^{A}_{tier} \\ \max\left\{TAC^{1,A}_{y}\,;\left(1-c^{A}_{mxdn}\right)c^{A}_{tier}\right\} \le TAC^{2,A}_{y} \le \min\left\{c^{A}_{mxtac}\,;\,TAC^{1,A}_{y}+c^{ns,A}_{mxinc}\right\} & TAC^{2,A}_{y-1} > c^{A}_{tier} \end{array} \qquad \text{(A.7)}$$

Revised sardine TAB: $$TAB_y^{2,S} = \lambda\, TAC_y^{1,A} + r_y\,(TAC_y^{2,A} - TAC_y^{1,A}) + TAB_{rh}^{S} \qquad \text{(A.8)}$$

Where: $$\lambda = \max\{\gamma_y, r_y\}$$

Note that by construction $TAB_y^{2,S} \geq TAB_y^{1,S}$ as $\lambda \geq \gamma_y$ and $TAC_y^{2,A} \geq TAC_y^{1,A}$. In addition to the previous definitions, we have:

$N_{y-1,rec0}^{A}$ - the simulated estimate of anchovy recruitment from the recruitment survey in year y, back-calculated to 1 November $y-1$ by taking natural and fishing mortality into account; during the testing of OMP-08, these values are simulated using equation (A.11).

$\overline{N}_{rec0}^{A}$ - the average 1985 to 1999 observed anchovy recruitment in May, back-calculated (using equation (A.10) to November of the previous year of 197.96 billion recruits.

$c_{mxinc}^{ns,A}$ - the maximum amount by which the anchovy TAC is allowed to be increased within the normal season.

r_y - the simulated average of the juvenile sardine to anchovy ratio in the commercial catches in May and in the recruit survey, in year y.

In calculating r_y, only the commercial catches comprising at least 50% anchovy with sardine bycatch were considered. The ratio of juvenile sardine to anchovy "in the sea" during May, r_y, is calculated from the recruit survey and the sardine bycatch to anchovy ratio in the commercial catches during May as follows:

$$r_y = \tfrac{1}{2}(r_{y,sur} + r_{y,com}). \qquad \text{(A.9)}$$

The anchovy TAC equations require that $N_{y,r}^{obs,A}$, the recruitment numbers estimated in the survey, be back-calculated to November of the previous year, assuming a fixed value of 1.2 *year*$^{-1}$ for M_j^A. When simulating, the value of 1.2 *year*$^{-1}$ is used regardless of the operating model used. This is because the harvest-control rule needs to be independent of the potential population dynamics models, and is therefore based on the base case assessment model. The back-calculated recruitment numbers are calculated as follows:

$$N_{y-1,rec0}^{A} = (N_{y,r}^{obs,A} e^{0.5(6+t_y^A)1.2/12} + C_{y,0bs}^{A})\, e^{[0.5(6+t_y^A)]1.2/12} \qquad \text{(A.10)}$$

During the simulation testing of the OMP, the assumption is made that the survey begins mid-May:

$$N_{y-1,rec0}^{A} = \left[N_{y,r}^{obs,A} e^{3.25*1.2/12} + C_{y,0bs}^{A}\right] \mathrm{e}^{3.25*1.2/12} \qquad \text{(A.11)}$$

In actual implementation of the OMP, the observed survey results are used:

In the above equation we have

$C_{y,0bs}^{A}$ - the observed anchovy landed by number (in billions) from the 1st of November year *y-1* to the day before the recruit survey commences in year *y*.

t_y^A - the timing of the anchovy recruit survey in year *y* (number of months) relative to the 1st of May that year.

Final TACs / TABs (the anchovy additional sub-season from September)

The final anchovy TAC is adjusted from the revised June TAC to achieve better utilisation of the anchovy resource later in the year when the anchovy and juvenile sardine no longer shoal together in large quantities. The sardine TAB is increased by a small tonnage. This increase is the minimum of a fixed tonnage or γ_y of the difference between the anchovy revised and final TACs.

Because the anchovy additional sub-season is treated as completely separate from the anchovy normal season, the anchovy TAC and sardine TAB actually applied during the sub-season are $TAC_y^{3,A} - TAC_y^{2,A}$ and $TAB_y^{3,S} - TAB_y^{2,S}$ respectively.

Final anchovy TAC: $$TAC_y^{3,A} = \alpha_{ads}\ q\left(p\frac{N^{A}_{y-1,rec0}}{\overline{N}^{A}_{rec0}} + (1-p)\frac{B^{obs,A}_{y-1,N}}{\overline{B}^{A}_{Nov}} \right) \quad \text{(A.12)}$$

Subject to: $$\max\{TAC_y^{2,A}\,;\, c^{A}_{mntac}\} \le TAC_y^{3,A} \le \min\{c^{A}_{mxtac}\,;\, TAC_y^{2,A} + c^{ads,A}_{mxinc}\} \quad \text{(A.13)}$$

Sardine 3rd TAB: $$TAB_y^{3,S} = TAB_y^{2,S} + \min\left\{TAB^{S}_{ads}\,;\, \gamma_y\,(TAC_y^{3,A} - TAC_y^{2,A})\right\} \quad \text{(A.14)}$$

We also define the following:

α_{ads} - a control parameter which scales the anchovy TAC to meet target risk levels for sardine and anchovy.

$c^{ads,A}_{mxinc}$ - the maximum amount by which the anchovy TAC is allowed to be increased within the additional sub-season.

TAB^{S}_{ads} - the maximum fixed tonnage of juvenile sardine bycatch set aside for the anchovy additional sub-season each year.

Appendix B: Exceptional Circumstances Provisions

The reference case rules and thresholds for exceptional circumstances are as follows:

Sardine directed TAC

Exceptional Circumstances for the sardine directed TAC apply if:

$$B_{y-1,N}^{obs,S} < B_{ec}^{S}$$

in which case the TAC under Exceptional Circumstances is calculated as follows:

$$TAC_y^S = \begin{cases} 0 & \text{if } \dfrac{B_{y-1,N}^{obs,S}}{B_{ec}^{S}} < x^S \\ TAC_y^{S*}\left(\dfrac{\dfrac{B_{y-1,N}^{obs,S}}{B_{ec}^{S}} - x^S}{1-x^S}\right)^2 & \text{if } x^S < \dfrac{B_{y-1,N}^{obs,S}}{B_{ec}^{S}} < 1 \end{cases} \qquad \text{(B.1)}$$

where TAC_y^{S*} is calculated using equation (A.1). For the reference case, $B_{ec}^{S} = 250$ thousand tons, while $x^S = 0.25$ implying that the sardine TAC will become zero at a quarter of the exceptional circumstances threshold (or below this).

Anchovy initial TAC

Exceptional Circumstances for the initial anchovy TAC apply if

$$B_{y-1,N}^{obs,A} < B_{ec}^{A}$$

in which case the TAC under Exceptional Circumstances is calculated as follows:

$$TAC_y^{1,A} = \begin{cases} 0 & \text{if } \dfrac{B_{y-1,N}^{obs,A}}{B_{ec}^{A}} < x^A \\ TAC_y^{1,A*}\left(\dfrac{\dfrac{B_{y-1,N}^{obs,A}}{B_{ec}^{A}} - x^A}{1-x^A}\right)^2 & \text{if } x^A < \dfrac{B_{y-1,N}^{obs,A}}{B_{ec}^{A}} < 1 \end{cases} \qquad \text{(B.2)}$$

where $TAC_y^{1,A*}$ is calculated using equation (A.3). For the reference case, $B_{ec}^{A} = 400$ thousand tons, while $x^S = 0.25$ implying that the anchovy initial TAC will become zero at a quarter of the exceptional circumstances threshold (or below this).

Revised anchovy TAC

The results of the most recent November and recruit surveys are projected forward, taking natural and anticipated fishing mortality into account, in order to provide a proxy ($B_{y,proj}^{A}$) for the forthcoming November

survey, and hence have a basis for invoking Exceptional Circumstances, if necessary. Given $TAC_y^{2,A*}$ from equation (A.6), a projected anchovy biomass, $B_{y,proj0}^A$, is calculated as follows:

$$B_{y,proj0}^A = \max \text{of} \left\{ 0; \left(N_{y,rec}^A - \left[\frac{TAC_y^{2,A*}}{\overline{w}_{0c}^A} - C_{y,1}^A - C_{y,0bs}^A \right] \right) e^{-5.5*1.2/12} \overline{w}_1^A \right\}. \quad \text{(B.3)}$$

Calculate $B_{y,proj}^A$ as follows:

$$B_{y,proj}^A = \left(\frac{B_{y-1,N}^{obs,A}}{\overline{w}_1^A} e^{-5*0.9/12} - C_{y,1}^A \right) e^{-7\times 0.9/12} \overline{w}_2^A \quad + \quad B_{y,proj0}^A \quad \text{(B.4)}$$

If $B_{y,proj}^A < B_{ec}^A$, then Exceptional Circumstances apply. The recruit survey result in year y (in numbers) that would be sufficient to yield a $B_{y,proj}^A$ value of exactly B_{ec}^A is calculated as follows:

$$\theta = \frac{[B_{ec}^A - (B_{y,proj}^A - B_{y,proj0}^A)]}{\overline{w}_1^A} e^{5.5*1.2/12} \quad + \quad \frac{TAC_y^{2,A*}}{\overline{w}_{0c}^A} - C_{y,1}^A - C_{y,0bs}^A \quad \text{(B.5)}$$

This is back-calculated to November of the previous year in the same way as equations (A.10) during OMP implementation:

$$N_{y-1,rec0}^{A*} = (\theta\, e^{0.5(6+t_y^A)1.2/12} + C_{y,0bs}^A)\, e^{[0.5(6+t_y^A)]1.2/12} \quad \text{(B.6)}$$

or equation (A.11) during simulation testing:

$$N_{y-1,rec0}^{A*} = (\theta\, e^{3.25\times 1.2/12} + C_{y,0bs}^A)\, e^{3.25\times 1.2/12} \quad \text{(B.7)}$$

The revised anchovy TAC is calculated by reducing $TAC_y^{2,A*}$ by the ratio (squared) of $TAC_y^{2,A}$ calculated with the annual recruitment for year y to $TAC_y^{2,A}$ calculated with θ, thus providing a means to reduce the TAC fairly rapidly when the Exceptional Circumstances threshold is surpassed. The rule allows for the TAC to be set to zero (or to the initial anchovy TAC, if greater than zero) if the survey estimated anchovy recruitment and biomass falls below a quarter of the threshold:

$$TAC_y^{2,A} = \max \text{of} \begin{cases} TAC_y^{1,A}; TAC_y^{2,A*} \left(\dfrac{p \dfrac{N_{y-1,rec0}^A}{\overline{N}_{rec0}^A} + (1-p) \dfrac{B_{y-1,N}^{obs,A}}{\overline{B}_{Nov}^A}}{p \dfrac{N_{y-1,rec0}^{A*}}{\overline{N}_{rec0}^A} + (1-p) \dfrac{B_{y-1,N}^{obs,A}}{\overline{B}_{Nov}^A}} - 0.25 \right)^2 & \text{if } 0.25 < \dfrac{p \dfrac{N_{y-1,rec0}^A}{\overline{N}_{rec0}^A} + (1-p) \dfrac{B_{y-1,N}^{obs,A}}{\overline{B}_{Nov}^A}}{p \dfrac{N_{y-1,rec0}^{A*}}{\overline{N}_{rec0}^A} + (1-p) \dfrac{B_{y-1,N}^{obs,A}}{\overline{B}_{Nov}^A}} < 1 \\ TAC_y^{1,A}; 0 & \text{if } \dfrac{p \dfrac{N_{y-1,rec0}^A}{\overline{N}_{rec0}^A} + (1-p) \dfrac{B_{y-1,N}^{obs,A}}{\overline{B}_{Nov}^A}}{p \dfrac{N_{y-1,rec0}^{A*}}{\overline{N}_{rec0}^A} + (1-p) \dfrac{B_{y-1,N}^{obs,A}}{\overline{B}_{Nov}^A}} < 0.25 \end{cases} \quad \text{(B.8)}$$

For the reference case, $\overline{w}_{0c}^A = 4.88$, $\overline{w}_1^A = 9.72$, $\overline{w}_2^A = 13.94$, $p = 0.7$, $\overline{N}_{rec0}^A = 197.96$ billion recruits and $\overline{B}_{Nov}^A = 1380.28$ thousand tonnes.

Final anchovy TAC

The same procedure as for the revised anchovy TAC is followed, except that equation (A.12) is used to calculate $TAC_y^{3,A*}$, which then replaces $TAC_y^{2,A*}$ in equations (B.3), (B.5) and (B.8) above. Furthermore, $TAC_y^{2,A}$ replaces $TAC_y^{1,A}$ in equation (B.8) above.

Note that, in the above reference case rules, exceptional circumstances rules are applied to the TAC calculated BEFORE any constraints are applied, i.e. the implementation of exceptional circumstances overrides any of the possible constraints that would under normal circumstances be applied to the TAC.

Alternative Exceptional Circumstances Thresholds and Rules

The update to the survey biomass series taking account of receiver saturation, new target strength calculations and, for sardine, attenuation, may require a corresponding update to the exceptional circumstances thresholds against which these survey observations are compared. However, these thresholds are at low biomass levels and the effect of the update to the survey biomass series was much greater at higher, rather than lower, densities.

The following alternative thresholds or rules were tested for sardine:

i) a decrease in the exceptional circumstances threshold to $B_{ec}^S = 200$ thousand tons.

ii) an increase in the exceptional circumstances threshold to $B_{ec}^S = 300$ thousand tons.

iii) a cubic instead of quadratic rule, such that the TAC would be decreased at a faster rate once exceptional circumstances are declared, i.e. equation (B.1) is replaced by:

$$TAC_y^S = \begin{cases} 0 & \text{if } \dfrac{B_{y-1,N}^{obs,S}}{B_{ec}^S} < x^S \\ TAC_y^{S*}\left(\dfrac{\dfrac{B_{y-1,N}^{obs,S}}{B_{ec}^S} - x^S}{1 - x^S}\right)^3 & \text{if } x^S < \dfrac{B_{y-1,N}^{obs,S}}{B_{ec}^S} < 1 \end{cases} \qquad \text{(B.9)}$$

iv) a continuous rule, such that the TAC recommended by OMP-08 would be continuous over the threshold. This requires that exceptional circumstances rules are applied to the TAC calculated AFTER any constraints from equation (A.2) are applied.

The following alternative thresholds or rules were tested for anchovy:

i) a decrease in the exceptional circumstances threshold to $B_{ec}^A = 300$ thousand tons.

ii) a decrease in the exceptional circumstances threshold to $B_{ec}^A = 350$ thousand tons.

iii) an increase in the exceptional circumstances threshold to $B_{ec}^S = 450$ thousand tons.

iv) a cubic instead of quadratic rule, such that the TAC would be decreased at a faster rate once exceptional circumstances are declared, i.e. equations (B.2) and (B.8) are replaced by:

$$TAC_y^{1,A} = \begin{cases} 0 & \text{if} \quad \dfrac{B_{y-1,N}^{obs,A}}{B_{ec}^{A}} < x^A \\ TAC_y^{1,A^*} \left(\dfrac{\dfrac{B_{y-1,N}^{obs,A}}{B_{ec}^{A}} - x^A}{1 - x^A} \right)^3 & \text{if} \quad x^A < \dfrac{B_{y-1,N}^{obs,A}}{B_{ec}^{A}} < 1 \end{cases} \tag{B.10}$$

$$TAC_y^{2,A} = \max \text{ of} \begin{cases} TAC_y^{1,A}; TAC_y^{2,A^*} \left(\dfrac{p \dfrac{N_{y-1,rec0}^{A}}{\overline{N}_{rec0}^{A}} + (1-p) \dfrac{B_{y-1,N}^{obs,A}}{\overline{B}_{Nov}^{A}}}{p \dfrac{N_{y-1,rec0}^{A^*}}{\overline{N}_{rec0}^{A}} + (1-p) \dfrac{B_{y-1,N}^{obs,A}}{\overline{B}_{Nov}^{A}}} - 0.25 \right)^3 & \text{if } 0.25 < \dfrac{p \dfrac{N_{y-1,rec0}^{A}}{\overline{N}_{rec0}^{A}} + (1-p) \dfrac{B_{y-1,N}^{obs,A}}{\overline{B}_{Nov}^{A}}}{p \dfrac{N_{y-1,rec0}^{A^*}}{\overline{N}_{rec0}^{A}} + (1-p) \dfrac{B_{y-1,N}^{obs,A}}{\overline{B}_{Nov}^{A}}} < 1 \\ TAC_y^{1,A}; 0 & \text{if } \dfrac{p \dfrac{N_{y-1,rec0}^{A}}{\overline{N}_{rec0}^{A}} + (1-p) \dfrac{B_{y-1,N}^{obs,A}}{\overline{B}_{Nov}^{A}}}{p \dfrac{N_{y-1,rec0}^{A^*}}{\overline{N}_{rec0}^{A}} + (1-p) \dfrac{B_{y-1,N}^{obs,A}}{\overline{B}_{Nov}^{A}}} < 0.25 \end{cases} \tag{B.11}$$

v) a continuous rule, such that the TAC recommended by OMP-08 would be continuous over the threshold. This requires that exceptional circumstances rules are applied to the TAC calculated AFTER any constraints from equation (A.4), (A.7) or (A.13) are applied.

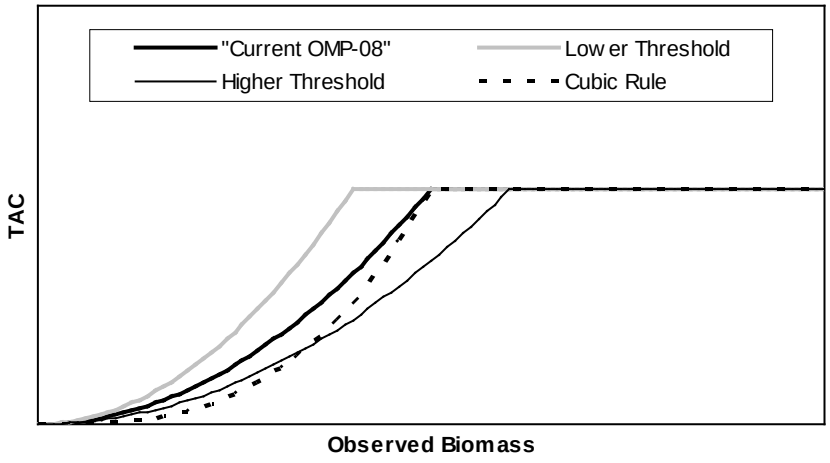

Figure B1. The TAC applicable under exceptional circumstances for alternative thresholds and rules.