Proposed Final OMP-08

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Introduction

A preliminary version of OMP-08 was adopted by the Pelagic Working Group (PWG) in November 2007 and used to set the directed sardine and initial anchovy TACs and initial sardine TAC for 2008 (Cunningham and Butterworth 2007). Further analyses, particularly pertaining to the exceptional circumstances thresholds rules and to the evaluation of anchovy risk have been carried out. A Task Group of the PWG recently met to further analyse comparisons between alternative options (Cunningham and Butterworth 2008c) and a proposed OMP-08 is now presented.

Changes to OMP-08

The following changes to OMP-08 (from that adopted by the PWG in February 2008; see Cunningham and Butterworth 2008a) have been implemented:

i) the TAC to which the exceptional circumstances rules are applied is now the basic control rule, which includes the constraints of the minimum and maximum TACs
ii) the initial, revised and final anchovy TAC rules have been modified to ensure continuity by allowing for a downward-adjustment to the TAC up to an amount of $\Delta^A = 100\,000t$ above the exceptional circumstances threshold (no such smoothing is required for the directed sardine TAC as this function is already smooth due to the adjustment made below 800 000t)
iii) the minimum anchovy TAC has been decreased from 150 000t to 120 000t
iv) the maximum anchovy additional season TAC has been decreased from 150 000t to 120 000t
v) the sardine exceptional circumstances threshold has been increased from 250 000t to 300 000t
vi) in the event of sardine exceptional circumstances being declared, only 50% of the directed sardine TAC is given at the start of the year, and an upward adjustment may be made in mid-season depending on the results of the recruitment survey

Also note that (as in previous versions of OMP-08) the exceptional circumstances rules decrease the directed sardine TAC to zero by the time observed sardine biomass is 75 000t (25% of the proposed new exceptional circumstances threshold) and decrease the anchovy TAC to zero by the time the observed or projected anchovy biomass is 100 000t (25% of the exceptional circumstances threshold). However, in the case of a zero directed sardine TAC, allowance is still made for sardine bycatch associated with both the anchovy and red-eye fisheries.

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The proposed OMP-08 is fully described in Appendix A and the simulation testing framework used to test OMP-08 is described in Appendix B.

Trade-Off Curves and Control Parameters

The trade-off curves for the proposed final OMP-08 together with that of the "current" OMP-08 (Cunningham and Butterworth 2008a) are shown in Figure 1. These curves are constructed by limiting $risk_S < 0.18$ and $risk_A < 0.28$, where the definitions of risk have been maintained from OMP-04:

$risk_S$ - 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.

The 'corner point' of the curve where the directed average sardine catch is maximised while maintaining the maximum average anchovy catch is used. Figure 2 and Table 1 indicates that using a sardine risk threshold of 18% results in the sardine biomass distribution under the proposed final OMP-08 relative to that under a no-catch scenario after 20 years of simulation being close to that under OMP-04, though the lower 10% of the distribution is somewhat lower. Figure 3 and Table 2 indicate that using an anchovy risk threshold of 28% results in the anchovy biomass distribution under the proposed final OMP-08 relative to that under a no-catch scenario after 20 years of simulation being a little more pessimistic at higher percentiles to that under OMP-04, but the lower 10 percentile, which is of greater importance from a conservation point of view, is more optimistic. The control parameters corresponding to this corner point are listed in Table 1, with a comparison to earlier OMPs given in Table A.1.

Exceptional Circumstances Provisions

Table 3 compares some key summary statistics for the sardine resource under the proposed final OMP-08 to that under the "Current" OMP-08 and the two extremes of no catch or no exceptional circumstances provisions, while Table 4 gives similar statistics for anchovy. As expected, both the "Current" and proposed final OMP-08 summary statistics show a higher average directed catch together with an improved projected status of the resource after 20 years of simulation compared to the proposed final OMP-08 with no exceptional circumstances provisions. Under the proposed final OMP-08 sardine exceptional circumstances are projected to be declared 5% of the time while anchovy exceptional circumstances are projected to be declared 19% of the time. This high frequency for anchovy has been previously noted and could not be decreased through alternative options (eg Cunningham and Butterworth 2008b). Exceptional circumstances are seldom declared unnecessarily (3% for sardine and 1% for anchovy), while they are not declared when necessary for anchovy in 10% of cases.

Some examples of the ability of the exceptional circumstances provisions under the proposed final OMP-08 to enable the resource to recover rapidly can be seen in Figure 4 for sardine and Figure 5 for anchovy. In most cases the trajectories under the proposed final OMP-08 recover quicker than those under "Current" OMP-08. The best achievable recovery in the case of closure of the directed fishery once the threshold is breached is also shown for comparative purposes and indicate that these exceptional circumstances provisions do indeed help the resource to recover.

Proposed Final OMP-08 Catches

Table 5 gives a comparison of the risk and average projected catches and bycatches and TAC/Bs between the "Current" OMP-08 and the proposed final OMP-08. Note that the projected average catches and bycatches may be less than the projected average TAC/Bs. This is because the simulation testing framework takes into account a number of factors such as bycatch drop-off and the closing of the anchovy fishery should the sardine bycatch limit be reached before the anchovy TAC is fully taken. The average directed sardine catch under the proposed final OMP-08 is 188 000t, compared to 190 000t under "Current" OMP-08, while the average anchovy total catch under the proposed final OMP-08 is 269 000t, compared to 263 000t under "Current" OMP-08.

Table 6 lists the directed sardine TAC in 2009 under the proposed final OMP-08 dependent on observed November 2008 sardine biomass and, in the case of exceptional circumstances being declared, dependent on the observed May 2009 sardine recruitment. Table 7 lists the mean and median total anchovy catch under the proposed final OMP-08 from 2008 to 2012 and the average over the 20-year simulation period. The spread of the total anchovy catch is shown more clearly in Figure 6 for 2009 to 2012 and for the average over the 20-year simulation period. Note that the total anchovy catch can reach a maximum of 720 000t if the maximum normal season TAC of 600 000t and the maximum additional season TAC of 120 000t is allocated. With the modification made to the anchovy additional season TAC rule (Equation A.15, Figure A.1), the additional season anchovy TAC now reaches a maximum of 120 000t 60% of the time (Figure 7).

References

Cunningham, C.L., and Butterworth, D.S. 2007. Initial Sardine and Anchovy TACs and Sardine TAB for 2008, Using OMP-08. MCM Document MCM/2007/DEC/SWG-PEL/04. 4pp.

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

Cunningham, C.L., and Butterworth, D.S. 2008b. Further Analyses Regarding the Exceptional Circumstances Provisions for OMP-08. MCM Document MCM/2008/SWG-PEL/07. 19pp.

Cunningham, C.L., and Butterworth, D.S. 2008c. Further Considerations for OMP-08: Document for Pelagic Task Group Meeting, Thursday 10th April 2008. MCM Document MCM/2008/SWG-PEL/09B. 19pp.

Table 1. *The ratio of the percentiles of the distribution of sardine biomass in 2027 under OMP-08 for a sardine risk threshold of* $risk_S$ *<0.18 to a no-catch scenario at the corner point of the trade-off curve under the "Current OMP-08" presented in Cunningham and Butterworth (2008a) and under the proposed final OMP-08. The anchovy risk threshold is the same for both cases (* $risk_A$ *<0.28). A comparison is made to the ratio of the percentiles of the distribution of sardine biomass in 2023 under OMP-04 to a no-catch scenario using the previous assessment. Shaded cells represent cases for which the predicted ratio (depletion) is more pessimistic than that used for OMP-04.*

	OMP-04/No-catch	OMP-08/No-catch (Corner Point)	
		"Current OMP-08"	Final OMP-08
10%ile	0.59	0.50	0.51
20%ile	0.68	0.70	0.69
30%ile	0.69	0.74	0.74
40%ile	0.71	0.75	0.75
Median	0.72	0.74	0.74

Table 2. *The ratio of the percentiles of the distribution of anchovy biomass in 2027 under OMP-08 for an anchovy risk threshold of* $risk_A$ *<0.28 to a no-catch scenario under the "Current OMP-08" presented in Cunningham and Butterworth (2008a) and under the proposed final OMP-08. The sardine risk threshold is the same for all cases (* $risk_S$ *<0.18). A comparison is made to the ratio of the percentiles of the distribution of anchovy biomass in 2023 under OMP-04 to a no-catch scenario using the previous assessment. Shaded cells represent cases for which the predicted ratio (depletion) is more pessimistic than that used for OMP-04.*

	OMP-04/No-Catch	OMP-08/No-catch (Corner Point)	
		"Current OMP-08"	Final OMP-08
10%ile	0.25	0.26	0.28
20%ile	0.37	0.31	0.33
30%ile	0.45	0.39	0.42
40%ile	0.56	0.44	0.44
Median	0.58	0.48	0.47

Table 3. *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, 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[1]	Final OMP-08	Current OMP-08	Final OMP-08
β	N/A	0.096	0.094	0.094	0.096	0.094
α_{ns}	N/A	0.37	0.445	0.445	0.37	0.445
α_{ads}	N/A	0.74	0.6675	0.6675	0.74	0.6675
Exceptional Circumstances Threshold	N/A	250 000t	N/A	300 000t	250 000t	300 000t
$risk_S$	0.027	0.178	0.410	0.179	0.178	0.179
$\overline{C}^S$ (2008-2027)	0	190	169	188	79	78
AAV^S (2008-2027)	0	0.24	0.23	0.24	0.40	0.38
$\overline{B^S_{2027}/K^S_{non-peak}}$	0.93	0.70	0.47	0.70	0.18	0.18
$\overline{B^S_{2027}/Risk^S}$	17.34	10.77	7.38	10.79	1.88	1.85
$\overline{B^S_{2027}/B^S_{2007}}$	9.65	5.84	4.04	5.86	1.29	1.26
$\overline{B^S_{\min}/K^S_{non-peak}}$	0.33	0.26	0.19	0.26	0.06	0.06
$\overline{B^S_{\min}/Risk^S}$	2.24	1.78	1.28	1.78	0.39	0.40
Proportion of times Exceptional Circumstances are declared (2008-2027)	0.007[2]	0.035	N/A	0.047	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	0.158	N/A	N/A
Probability that Exceptional Circumstances are declared in the following year, given the declaration of Exceptional Circumstances in any year	0.123	0.172	N/A	0.170	N/A	N/A
Average number of years for which Exceptional Circumstances, if declared, are declared consecutively	2.438	3.924	N/A	4.000	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	0.013	N/A	N/A
Proportion of times Exceptional Circumstances are declared and true biomass is above the corresponding threshold[3]	0.006	0.024	N/A	0.034	N/A	N/A
Proportion of times Exceptional Circumstances are not declared when true biomass is below the corresponding threshold[4]	0.000	0.001	N/A	0.001	N/A	N/A

[1] This refers to the proposed final OMP-08 without any exceptional circumstances provisions.
[2] 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 300 000t.
[3] This reports the proportion of times exceptional circumstances are declared unnecessarily.
[4] This reports the proportion of times exceptional circumstances are not declared when they should have been.

Table 4. *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, 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[5]	Final OMP-08	Current OMP-08	Final OMP-08
β	N/A	0.096	0.094	0.094	0.096	0.094
α_{ns}	N/A	0.37	0.445	0.445	0.37	0.445
α_{ads}	N/A	0.74	0.6675	0.6675	0.74	0.6675
Exceptional Circumstances Threshold	N/A	400 000t	N/A	400 000t	400 000t	400 000t
$Risk_A$	0.037	0.278	0.463	0.279	0.278	0.279
$\overline{C}^A$ (2008-2027)	0	263	248	269	161	165
AAV^A (2008-2027)	0	0.40	0.36	0.37	0.52	0.49
$\overline{B^A_{2027}/K^A}$	0.96	0.61	0.44	0.62	0.31	0.31
$\overline{B^A_{2027}/Risk^A}$	2.57	1.71	1.27	1.70	1.00	0.97
$\overline{B^A_{2027}/B^A_{2007}}$	1.61	1.04	0.77	1.03	0.61	0.59
$\overline{B^A_{\min}/K^A}$	0.26	0.11	0.09	0.11	0.01	0.01
$\overline{B^A_{\min}/Risk^A}$	0.57	0.26	0.22	0.26	0.03	0.03
Proportion of times Exceptional Circumstances are declared (2008-2027)	0.038[6]	0.201	N/A	0.189	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	0.724	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	0.191	N/A	N/A
Average number of years for which Exceptional Circumstances, if declared, are declared consecutively	3.500	4.706	N/A	4.535	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	0.179	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	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	0.096	N/A	N/A

[5] This refers to the proposed final OMP-08 without any exceptional circumstances provisions.
[6] 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 exceptional circumstance threshold of 400 000t.

Table 5. *Risk and average projected TAC/TAB and catch/bycatch for "Current OMP-08" (Cunningham and Butterworth 2008a) and the proposed final OMP-08. Results are given corresponding to the control parameters for the corner point of each alternative.*

	β	α_{ns}	α_{ads}	$risk_S$	$risk_A$	Average directed sardine TAC	Average total anchovy TAC	Average sardine TAB	Average directed sardine catch	Average anchovy catch	Average sardine bycatch
Current OMP-08	0.096	0.37	0.74	0.178	0.278	190 000t	288 000t	91 000t	190 000t	263 000t	69 000t
Final OMP-08	0.094	0.445	0.6675	0.179	0.279	188 000t	299 000t	93 000t	188 000t	269 000t	71 000t

Table 6*. Directed sardine TAC in 2009 (rounded to the nearest '000t) under the proposed final OMP-08 ($\beta = 0.094$). The ranges reflects the range of possibilities dependent on the result of the May 2009 recruitment survey.*

November Biomass	Initial TAC	Final TAC
0t	0	0
60 000t	0	0
80 000t	0.02	0.02-0.05
100 000t	0.6	0.6-1.2
120 000t	1.8	1.8-4.0
140 000t	3.8	3.8-8.3
160 000t	6.4	6.4-14.1
180 000t	9.8	9.8-21.6
200 000t	13.9	13.9-30.6
220 000t	18.7	18.7-41.1
240 000t	24.2	24.2-53.2
260 000t	30.4	30.4-66.9
280 000t	37.4	37.4-82.2
300 000t	90	90
350 000t	90	90
400 000t	90	90
450 000t	90	90
500 000t	90	90

Table 7. *The mean and median anchovy catch (rounded to the nearest '000t) under the proposed final OMP-08 during the next five years and over the 20 year projection period.*

	2008-2027	2008	2009	2010	2011	2012
Mean	269	378	335	312	295	278
Median	264	368	336	318	299	275

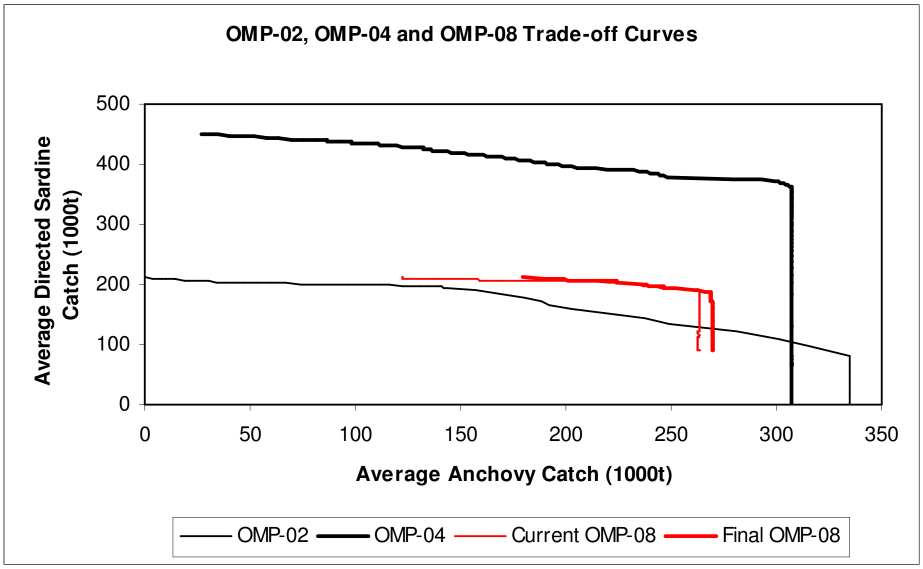


Figure 1*. Trade-off curves for OMP-02, OMP-04 and the "Current" and proposed final OMP-08. The trade-off curve for OMP-08 is determined by points satisfying* $risk_S < 0.18$ *and* $risk_A < 0.28$.

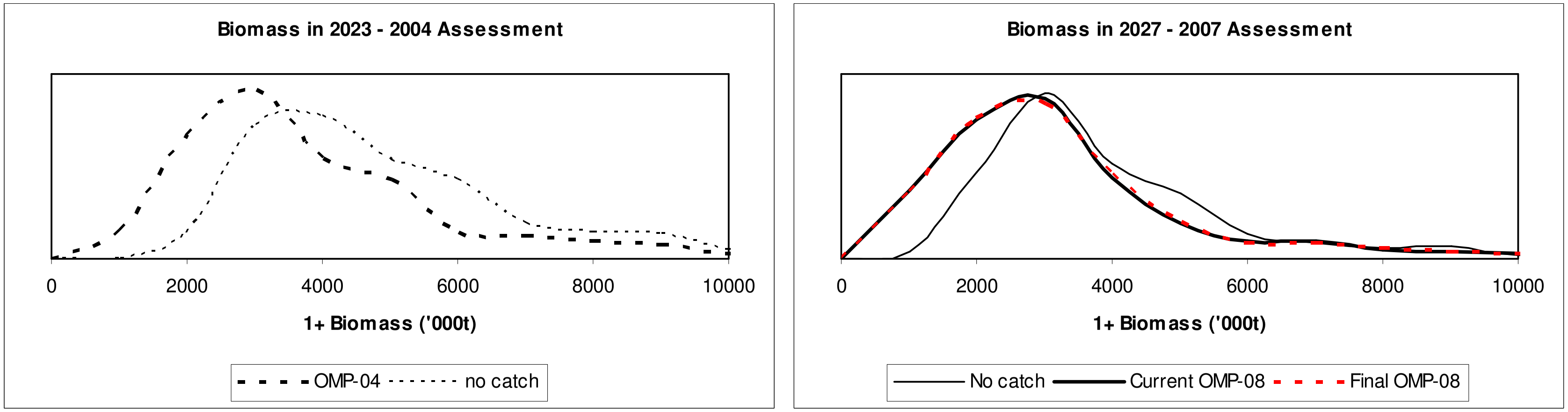
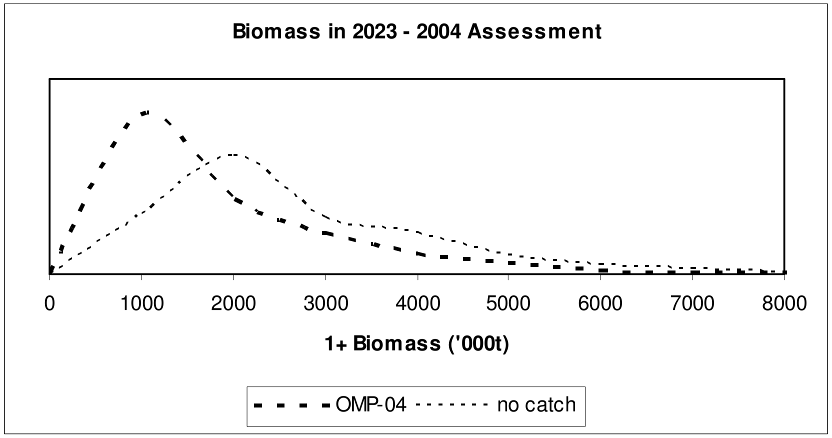


Figure 2. *Comparison of sardine biomass distributions in the final projection year under a no catch scenario and the pertinent OMP for the 2004 assessment (left panel) and the 2007 assessment (right panel). In the right panel the distribution under "Current OMP-08" from Cunningham and Butterworth (2008a) is shown together with the distribution under the proposed final OMP-08. The right panel is based on OMPs corresponding to the corner point (where $risk_S < 0.18$ and $risk_A < 0.28$).*



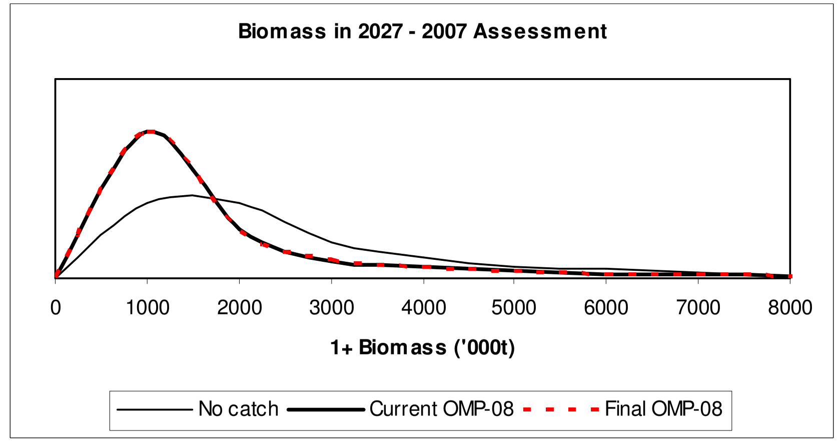
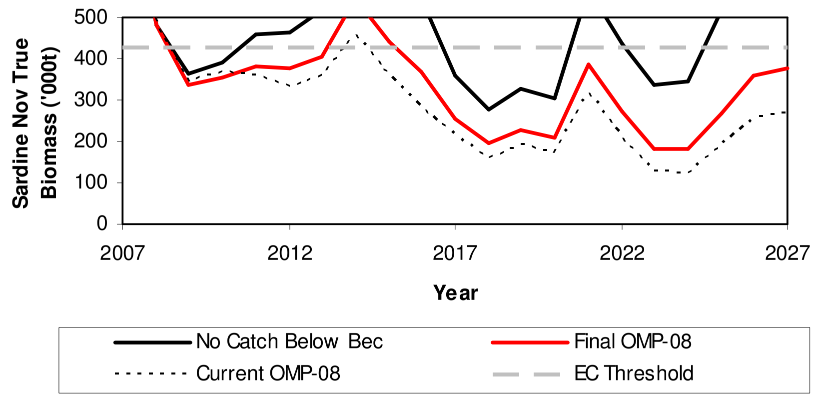


Figure 3. *Comparison of anchovy biomass distributions in the final projection year under a no catch scenario and the pertinent OMP for the 2004 assessment (left panel) and the 2007 assessment (right panels). In the right panel the distribution under "Current OMP-08" from Cunningham and Butterworth (2008a) is shown together with the distribution under the proposed final OMP-08. The right panel is based on OMPs corresponding to the corner point (where* $risk_S < 0.18$ *and* $risk_A < 0.28$*).*

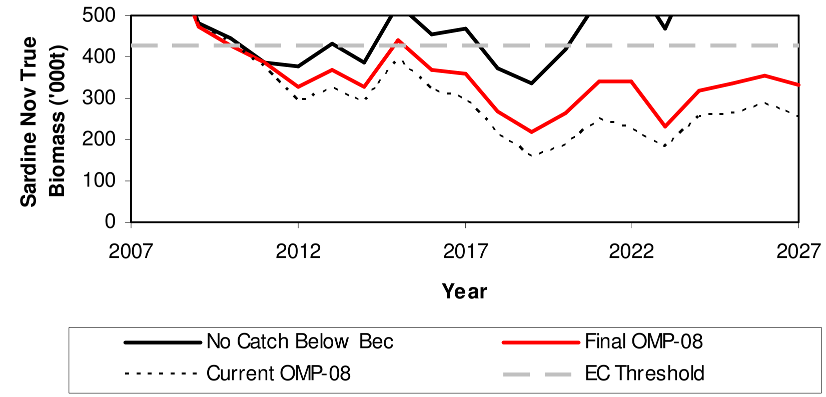
a)

Sardine Biomass Tajectories Near the Lower 2.5%ile of Biomass Levels Between 2008 and 2022



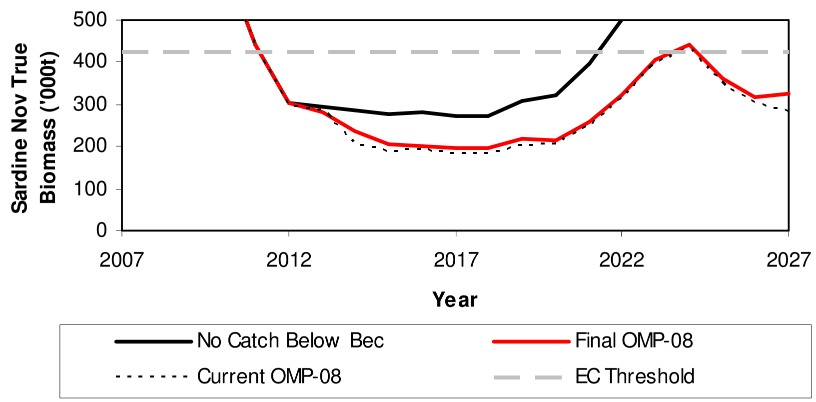
b)

Sardine Biomass Tajectories Near the Lower 2.5%ile of Biomass Levels Between 2008 and 2022



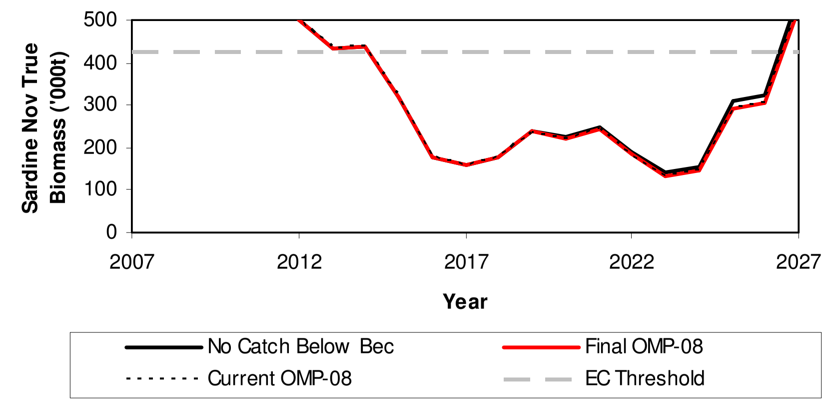
c)

Sardine Biomass Tajectories Near the Lower 2.5%ile of Biomass Levels Between 2008 and 2022



d)

Sardine Biomass Tajectories Near the Lower 2.5%ile of Biomass Levels Between 2008 and 2022



e)

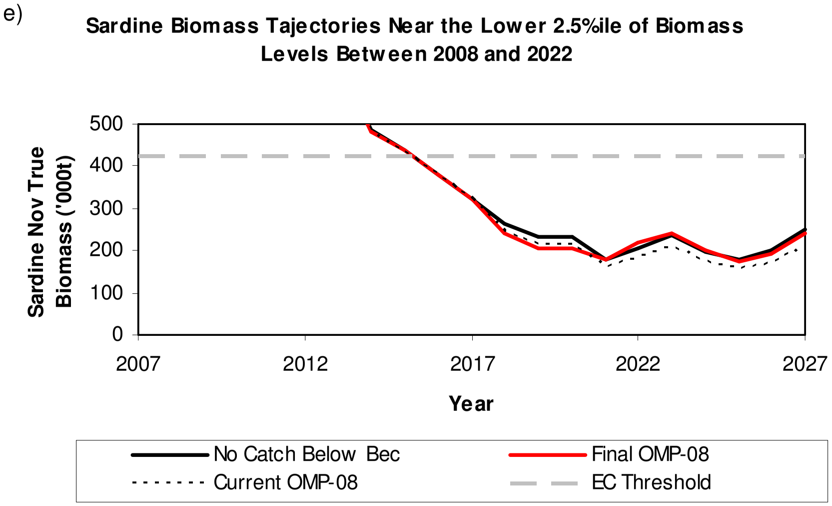
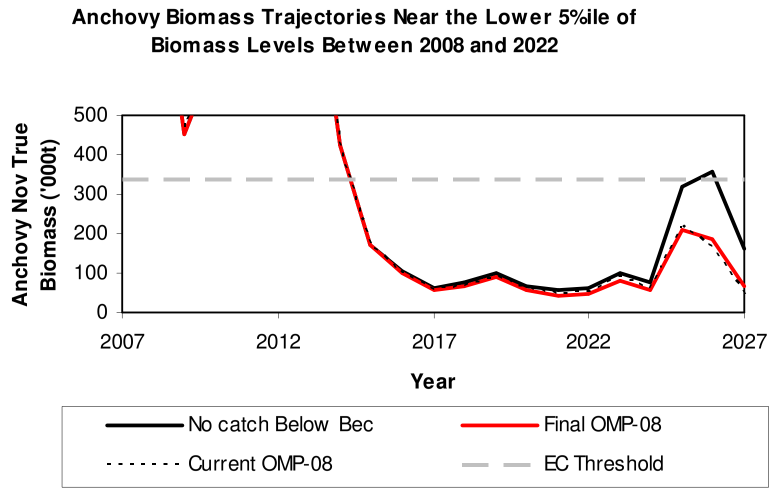
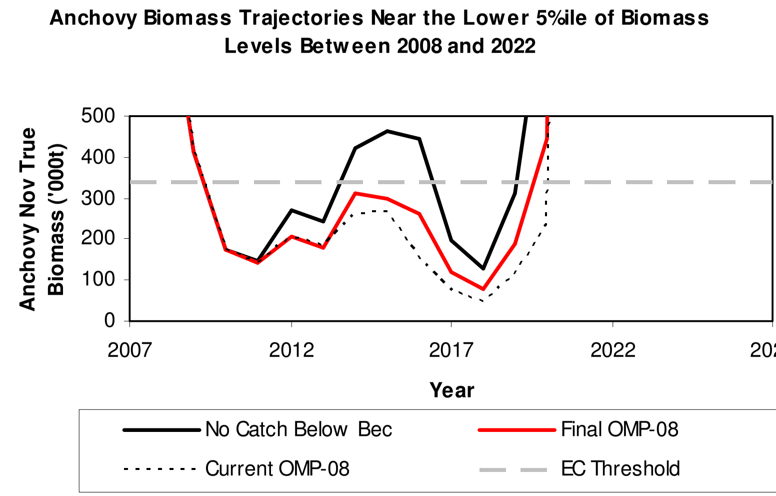


Figure 4. *Sardine biomass trajectories under "Current OMP-08" from Cunningham and Butterworth (2008a), under the proposed final OMP-08 and under the proposed final OMP-08 with zero catch once exceptional circumstances are declared, corresponding to the a) 21st , b) 22nd , c) 23rd , d) 24th and e) 25th lowest (of 1000) biomass levels between 2008 and 2022. The grey dashed line indicates the median TRUE biomass reference case exceptional circumstances threshold of* $300\,000\text{t}/k$, *where* k *is the median estimate of the constant of proportionality (multiplicative bias) between the observed and model predicted sardine November biomass, output from the stock assessment models.*

a)


Anchovy Biomass Trajectories Near the Lower 5%ile of Biomass Levels Between 2008 and 2022
Anchovy Nov True Biomass ('000t)
500
400
300
200
100
0
2007
2012
2017
2022
2027
Year
No catch Below Bec
Final OMP-08
Current OMP-08
EC Threshold

b)


Anchovy Biomass Trajectories Near the Lower 5%ile of Biomass Levels Between 2008 and 2022
Anchovy Nov True Biomass ('000t)
500
400
300
200
100
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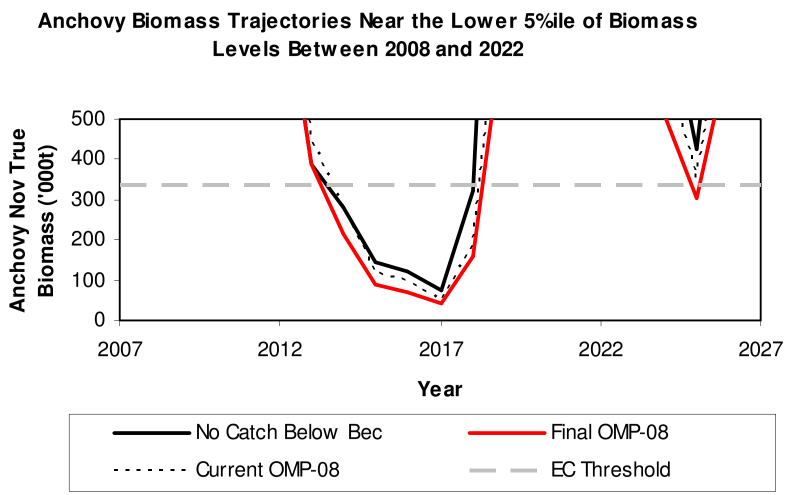
2007
2012
2017
2022
2027
Year
No Catch Below Bec
Final OMP-08
Current OMP-08
EC Threshold

c)


Anchovy Biomass Trajectories Near the Lower 5%ile of Biomass Levels Between 2008 and 2022
Anchovy Nov True Biomass ('000t)
500
400
300
200
100
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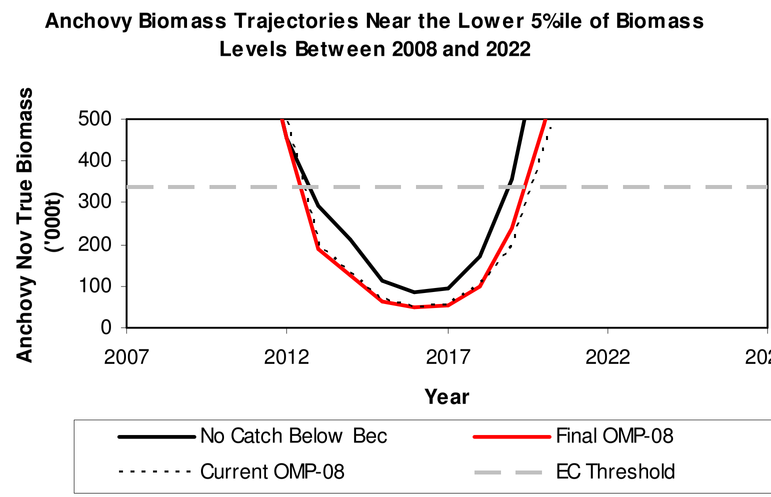
2007
2012
2017
2022
2027
Year
No Catch Below Bec
Final OMP-08
Current OMP-08
EC Threshold

d)


Anchovy Biomass Trajectories Near the Lower 5%ile of Biomass Levels Between 2008 and 2022
Anchovy Nov True Biomass ('000t)
500
400
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Final OMP-08
Current OMP-08
EC Threshold

e)

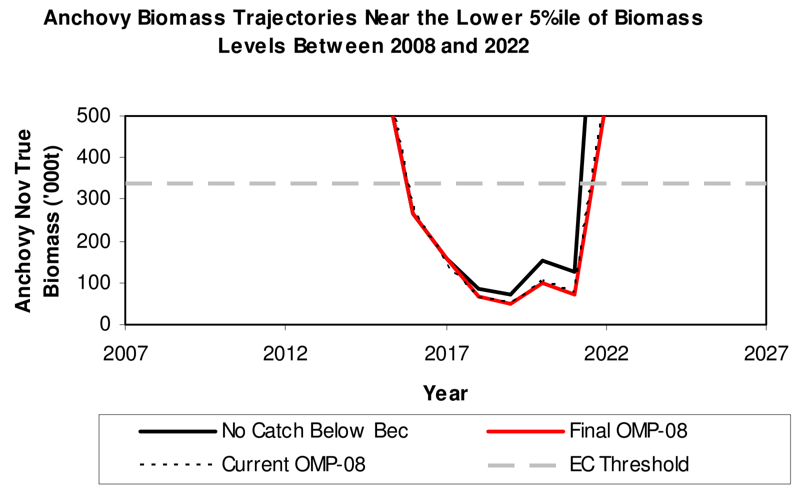
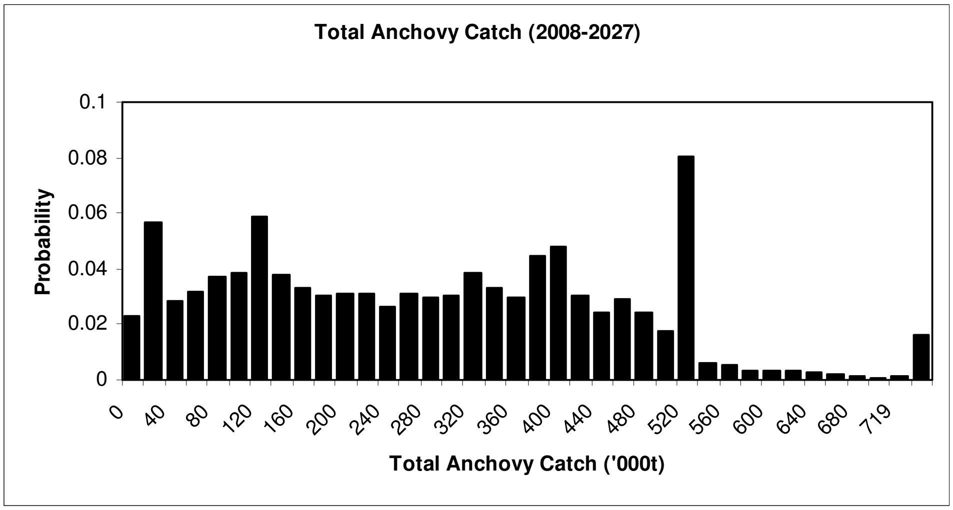
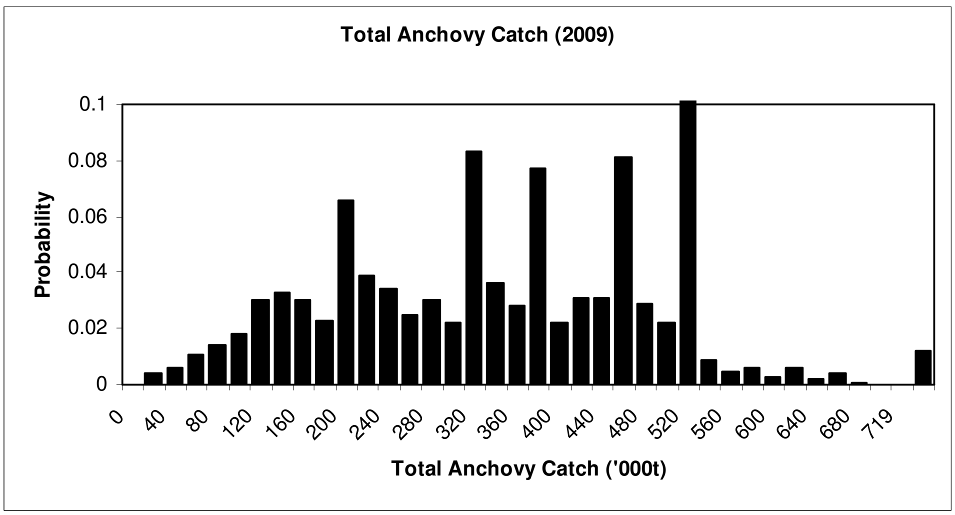


Figure 5. *Anchovy biomass trajectories under "Current OMP-08" from Cunningham and Butterworth (2008a) and under the proposed final OMP-08 and under the proposed final OMP-08 with zero catch once exceptional circumstances are declared, corresponding to the a) 51^{st}, b) 52^{nd}, c) 53^{rd}, d) 54^{th} and e) 55^{th} lowest (of 1000) biomass levels between 2008 and 2022. The grey dashed line indicates the median TRUE biomass reference case exceptional circumstances threshold of* $400\,000\text{t}/k$, *where* k *is the median estimate of the constant of proportionality (multiplicative bias) between the observed and model predicted anchovy November biomass, output from the stock assessment models.*





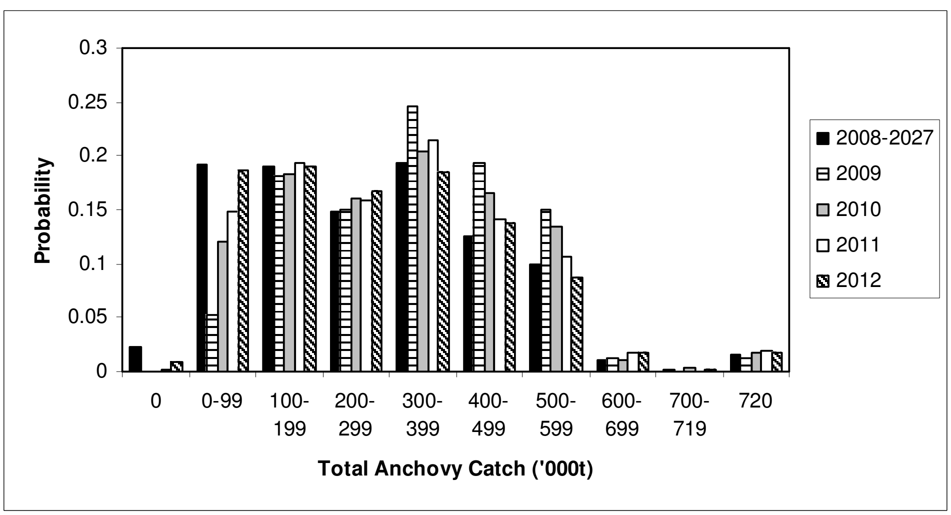


Figure 6. *Histograms of the total anchovy catch projected between 2008 and 2027 and in the individual years 2009 – 2012 for the proposed final OMP-08.*

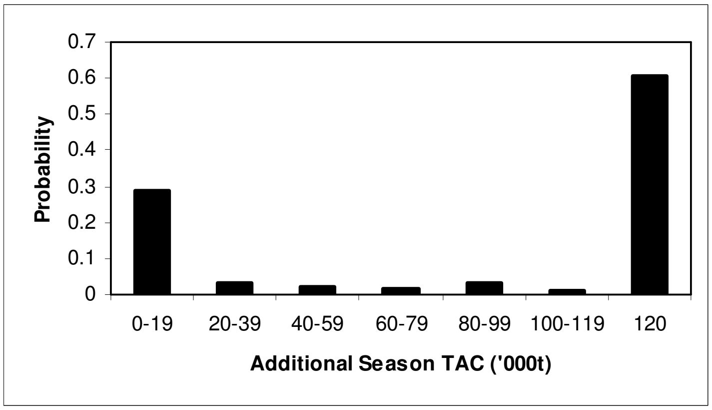


Figure 7. *Histogram of the average 2008 to 2027 additional season anchovy TAC for the proposed final OMP-08.*

Appendix A: Proposed Final OMP-08

In this Appendix, catches-at-age are given in numbers of fish (in billions), whereas the TACs and TABs are given in thousands of tons. 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 (or all three if Exceptional Circumstances apply for sardine).

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:

if $TAC_{y-1}^S \le c_{tier}^S$:

$$\max\left\{(1-c_{mxdn}^S)TAC_{y-1}^S \times \frac{B_{y-1,N}^{obs,S} - B_{ec}^S}{B^* - B_{ec}^S} + TAC_y^{S*}\frac{B_{smooth}^S - B_{y-1,N}^{obs,S}}{B_{smooth}^S - B_{ec}^S}\,;\, c_{mntac}^S\right\} \le TAC_y^S \le c_{mxtac}^S \quad if\ B_{y-1,N}^{obs,S} \le B_{smooth}^S$$

$$\max\left\{(1-c_{mxdn}^S)TAC_{y-1}^S\,;\, c_{mntac}^S\right\} \le TAC_y^S \le c_{mxtac}^S \quad if\ B_{y-1,N}^{obs,S} > B_{smooth}^S$$

where $TAC_y^{S*} = \max\left\{\beta\, B_{y-1,N}^{obs,S} ; c_{mntac}^{S}\right\}$

if $TAC_{y-1}^{S} > c_{tier}^{S}$: $\left(1 - c_{mxdn}^{S}\right)c_{tier}^{S} \le TAC_y^{S} \le c_{mxtac}^{S}$ (A.2)

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

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

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

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

To maintain continuity in the initial anchovy TAC as the exceptional circumstances threshold (see below), B_{ec}^{A}, is approached from above and below, if $B_{ec}^{A} \le B_{y-1,N}^{obs,A} \le B_{ec}^{A} + \Delta^{A}$ we have:

$$TAC_y^{1,A} = \left(1 - \frac{B_{y-1,N}^{obs,A} - B_{ec}^{A}}{\Delta^{A}}\right) \times TAC_y^{1,A\_before} + \left(\frac{B_{y-1,N}^{obs,A} - B_{ec}^{A}}{\Delta^{A}}\right) \times TAC_y^{1,A*} \quad \text{(A.6)}$$

where $TAC_y^{1,A*}$ is the value output from equations (A.3) and (A.4).

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 (see Table A.1)

$B_{y,N}^{obs,S}$ - the observed estimate of sardine abundance from the hydroacoustic spawner biomass survey in November of year y; during the testing of OMP-08, these values were simulated using equation (B.40).

$B_{y,N}^{obs,A}$ - the observed estimate of anchovy abundance from the hydroacoustic spawner biomass survey in November of year y; during the testing of OMP-08, these values were simulated using equation (B.40).

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

B_{smooth}^{S} - the threshold below which the directed sardine TAC is linearly decreased until the exceptional circumstances threshold, B_{ec}^{S}, is reached.

B_{ec}^{S} - the biomass threshold below which exceptional circumstances apply for sardine (see Table A.1).

B_{ec}^{A} - the biomass threshold below which exceptional circumstances apply for anchovy (see Table A.1).

Δ^{A} - the threshold below which the anchovy TAC is smoothed until the exceptional circumstances threshold, B_{ec}^{A}, is reached (see Table A.1).

α_{ns} - a control parameter which scales the anchovy TAC to meet target risk levels for sardine and anchovy (see Table A.1).

δ - a 'scale-down' factor used to lower the initial anchovy TAC to provide a buffer against possible poor recruitment (see Table A.1 – a value of $\delta = 0.85$, used since OMP-02, reflects the industry's desire for greater 'up-front' TAC allocation for planning purposes, even if this means some sacrifice in expected average TAC to meet the same risk criterion).

p - the weight given to the recruit survey component compared to the spawner biomass survey component in setting the anchovy TAC (see Table A.1 – the 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).

q - a constant value reflecting the average annual TAC expected under OMP99 under average conditions if $\alpha_{ns} = 1$ (see Table A.1 – unchanged since OMP-02 to facilitate easy comparison between the outputs from consecutive OMPs).

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 (see Table A.1).

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) (see Table A.1).

c_{mntac}^{S} - the minimum directed TAC to be set for sardine (see Table A.1).

c_{mntac}^{A} - the minimum directed TAC to be set for anchovy (see Table A.1).

c_{mxtac}^{S} - the maximum directed TAC to be set for sardine (see Table A.1).

c_{mxtac}^{A} - the maximum directed TAC to be set for anchovy during the normal season (see Table A.1).

During OMP-02 and OMP-04, the adult sardine bycatch, TAB_{rh}^{S}, 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.

The proposed final OMP-08 allows for an annual sardine adult bycatch with red-eye of 3 500t.

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:

$$TAC_y^{2,A} = \alpha_{ns}\, q\left(p\frac{N_{y-1,rec0}^{A}}{\bar{N}_{rec0}^{A}} + (1-p)\frac{B_{y-1,N}^{obs,A}}{\bar{B}_{Nov}^{A}}\right) \tag{A.7}$$

Subject to:

$$\begin{array}{ll} \max\left\{(1-c_{mxdn}^{A})TAC_{y-1}^{2,A};TAC_y^{1,A};c_{mntac}^{A}\right\} \le TAC_y^{2,A} \le \min\left\{c_{mxtac}^{A};TAC_y^{1,A}+c_{mxinc}^{ns,A}\right\} & TAC_{y-1}^{2,A} \le c_{tier}^{A} \\ \max\left\{TAC_y^{1,A};(1-c_{mxdn}^{A})c_{tier}^{A}\right\} \le TAC_y^{2,A} \le \min\left\{c_{mxtac}^{A};TAC_y^{1,A}+c_{mxinc}^{ns,A}\right\} & TAC_{y-1}^{2,A} > c_{tier}^{A} \end{array} \tag{A.8}$$

Revised sardine TAB:

$$TAB_y^{2,S} = \lambda\, TAC_y^{1,A} + r_y\,(TAC_y^{2,A} - TAC_y^{1,A}) + TAB_{rh}^{S} \tag{A.9}$$

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

To maintain continuity in the revised anchovy TAC as B_{ec}^{A} is approached from above and below, if $B_{ec}^{A} \le B_{y,proj}^{A} \le B_{ec}^{A} + \Delta^{A}$ we have:

$$TAC_y^{2,A} = \left(1 - \frac{B_{y,proj}^{A} - B_{ec}^{A}}{\Delta^{A}}\right)\times TAC_y^{2,A\_before} + \left(\frac{B_{y,proj}^{A} - B_{ec}^{A}}{\Delta^{A}}\right)\times TAC_y^{2,A*} \tag{A.10}$$

where $TAC_y^{2,A*}$ is the value output from equations (A.7) and (A.8) and $B_{y,proj}^{A}$ is determined by equation (A.22).

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, $N_{y,r}^{obs,A}$ [7], back-calculated to 1 November $y-1$ by taking natural and fishing mortality into account (equation (A.11)); during the testing of OMP-08, these values are simulated using equation (A.12).

$\overline{N}_{rec0}^{A}$ - the average 1985 to 1999 observed anchovy recruitment in May, back-calculated (using equation (A.11) 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 (see Table A.1).

$r_y = \frac{1}{2}(r_{y,sur} + r_{y,com})$

- the ratio of juvenile sardine to anchovy "in the sea" during May in year y, calculated from the recruit survey and the sardine bycatch to anchovy ratio in the commercial catches[8] during May; during the testing of OMP-08, these values are simulated using equations (B.10) and (B.11).

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:

$$N_{y-1,rec0}^{A} = (N_{y,r}^{obs,A} e^{0.5(6+t_y^A)1.2/12} + C_{y,0bs}^{A})\, e^{[0.5(6+t_y^A)]1.2/12} \qquad \text{(A.11)}$$

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*; during the testing of OMP-08, these values are simulated using equation (B.3).

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

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

[7] This estimate of recruitment is calculated using a cut-off length determined from modal progression analysis. In the event of this modal progression analysis being unable to detect a clear mode, a recruit cut-off (caudal) length of 10.5cm for anchovy and 15.5cm for sardine will be used. These are the cut-off lengths used historically and from which there has not been substantial deviation over a 10 year period (Coetzee pers. comm.).

[8] Only commercial catches comprising at least 50% anchovy with sardine bycatch are considered.

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

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. Two thresholds, $B_1 \geq B^{A}_{ec} + \Delta^{A}$ and $B_2 \geq B_1$ allow for a possible rapid increase to the maximum in the additional season anchovy TAC dependent on the projected November spawner biomass (based on the observed May recruitment). This rapid increase starts once the projected biomass exceeds B_1 and reaches the maximum when the projected biomass reaches B_2 (see Figure A.1). 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 $TAC^{3,A}_{y} - TAC^{2,A}_{y}$ and $TAB^{3,S}_{y} - TAB^{2,S}_{y}$ respectively.

Final anchovy TAC:
$$TAC^{3,A}_{y} = \alpha_{ads}\ q\left(p\frac{N^{A}_{y-1,rec0}}{\overline{N}^{A}_{rec0}} + (1-p)\frac{B^{obs,A}_{y-1,N}}{\overline{B}^{A}_{Nov}}\right) \qquad \text{(A.13)}$$

Subject to: $\max\{TAC^{2,A}_{y}\ ;\ c^{A}_{mntac}\} \leq TAC^{3,A}_{y} \leq \min\{c^{A}_{mxtac}\ ;\ TAC^{2,A}_{y} + c^{ads,A}_{mxinc}\}$ (A.14)

In addition:

$$\begin{aligned}
&TAC^{3,A}_{y} = TAC^{3,A*}_{y} && \text{if } B^{A}_{y,proj} < B_1\\
&TAC^{3,A}_{y} = TAC^{2,A}_{y} + \frac{c^{ads,A}_{mxinc} - \left(TAC^{3,A*}_{y} - TAC^{2,A}_{y}\right)}{B_2 - B_1}\left(B^{A}_{y,proj} - B_1\right) + \left(TAC^{3,A*}_{y} - TAC^{2,A}_{y}\right) && \text{if } B_1 \leq B^{A}_{y,proj} < B_2\\
&TAC^{3,A}_{y} = TAC^{2,A}_{y} + c^{ads,A}_{mxinc} && \text{if } B^{A}_{y,proj} \geq B_2
\end{aligned}$$

(A.15)

where $TAC^{3,A*}_{y}$ is the value output from equations (A.13) and (A.14) and $B^{A}_{y,proj}$ is calculated using the equivalent of equation (A.22) for the final TAC.

Sardine 3rd TAB:
$$TAB^{3,S}_{y} = TAB^{2,S}_{y} + \min\left\{TAB^{S}_{ads}\ ;\ \gamma_y\ (TAC^{3,A}_{y} - TAC^{2,A}_{y})\right\} \qquad \text{(A.16)}$$

To maintain continuity in the revised anchovy TAC as B^{A}_{ec} is approached from above and below, if $B^{A}_{ec} \leq B^{A}_{y,proj} \leq B^{A}_{ec} + \Delta^{A}$ we have:

$$TAC^{3,A}_{y} = \left(1 - \frac{B^{A}_{y,proj} - B^{A}_{ec}}{\Delta^{A}}\right) \times TAC^{3,A\_before}_{y} + \left(\frac{B^{A}_{y,proj} - B^{A}_{ec}}{\Delta^{A}}\right) \times TAC^{3,A**}_{y} \qquad \text{(A.17)}$$

where $TAC_y^{3,A**}$ is the value output from equations (A.13), (A.14) and (A.15). We also specify the following:

α_{ads} - a control parameter which scales the anchovy TAC to meet target risk levels for sardine and anchovy (see Table A.1).

$c_{mxinc}^{ads,A}$ - the maximum amount by which the anchovy TAC is allowed to be increased within the additional sub-season (see Table A.1).

B_1 - a biomass-related control parameter determining the point at which the anchovy additional sub-season TAC can increase more rapidly (see Figure A.1 and Table A.1).

B_2 - a biomass-related control parameter determining the point at which the anchovy additional sub-season TAC reaches a maximum (see Figure A.1 and Table A.1).

TAB_{ads}^S - the maximum fixed tonnage of juvenile sardine bycatch set aside for the anchovy additional sub-season each year (see Table A.1).

<u>Exceptional Circumstances</u>

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. Only a portion (half) of the directed sardine TAC is awarded with the initial TACs, with a revised TAC in June dependent on the observed May sardine recruitment (see Figure A.2):

$$\text{Initial TAC:} \quad TAC_{y,init}^S = 0.5 \times \begin{cases} 0 & \text{if } \dfrac{B_{y-1,N}^{obs,S}}{B_{ec}^S} < x^S \\ TAC_y^{S\_before}\left(\dfrac{\dfrac{B_{y-1,N}^{obs,S}}{B_{ec}^S} - x^S}{1-x^S}\right)^2 & \text{if } x^S < \dfrac{B_{y-1,N}^{obs,S}}{B_{ec}^S} < 1 \end{cases} \tag{A.18}$$

$$\text{Revised TAC:} \quad TAC_y^S = \begin{cases} TAC_{y,init}^S + 1.2 \times \dfrac{N_{y,r}^{obs,S}}{R_{crit}} TAC_{y,init}^S & \text{if } \mathrm{N_{y,r}^{obs,S}} \le R_{crit} \\ TAC_{y,init}^S + 1.2 \times TAC_{y,init}^S & \text{if } \mathrm{N_{y,r}^{obs,S}} > R_{crit} \end{cases} \tag{A.19}$$

where $TAC_y^{S\_before} = \beta\, B_{y-1,N}^{obs,S}$, subject to $c_{mntac}^S \le TAC_y^{S\_before} \le c_{mxtac}^S$. The rule allows for the TAC to be set to zero if the survey estimated sardine biomass falls below x^S of the threshold (see Table A.1). Further we have:

R_{crit} - the level of sardine recruitment required in order to achieve the maximum possible mid-year increase in sardine TAC under exceptional circumstances (see Figure A.2 and Table A.1).

Initial Anchovy 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:

$$TAC_y^{1,A} = \begin{cases} 0 & \text{if} \quad \dfrac{B_{y-1,N}^{obs,A}}{B_{ec}^{A}} < x^A \\ TAC_y^{1,A\_before}\left(\dfrac{\dfrac{B_{y-1,N}^{obs,A}}{B_{ec}^{A}} - x^A}{1-x^A}\right)^2 & \text{if} \quad x^A < \dfrac{B_{y-1,N}^{obs,A}}{B_{ec}^{A}} < 1 \end{cases} \tag{A.20}$$

where $TAC_y^{1,A\_before} = \alpha_{ns}\delta\, q\left(p + (1-p)\dfrac{B_{y-1,N}^{obs,A}}{\overline{B}_{Nov}^{A}}\right)$, subject to $c_{mntac}^{A} \le TAC_y^{1,A\_before} \le c_{mxtac}^{A}$. The rule allows for the TAC to be set to zero if the survey estimated anchovy biomass falls below x^A of the threshold (see Table A.1).

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. Define $TAC_y^{2,A\_before} = \alpha_{ns} q\left(p\dfrac{N_{y-1,rec0}^{A}}{\overline{N}_{rec0}^{A}} + (1-p)\dfrac{B_{y-1,N}^{obs,A}}{\overline{B}_{Nov}^{A}}\right)$, subject to $\max\{TAC_y^{1,A}; c_{mntac}^{A}\} \le TAC_y^{2,A\_before} \le c_{mxtac}^{A}$, a projected anchovy biomass, $B_{y,proj0}^{A}$, is calculated as follows:

$$B_{y,proj0}^{A} = \max \text{ of}\left\{0; \left(N_{y,rec}^{A} - \left[\frac{TAC_y^{2,A\_before}}{\overline{w}_{0c}^{A}} - C_{y,1}^{A} - C_{y,0bs}^{A}\right]\right)e^{-5.5*1.2/12}\,\overline{w}_1^{A}\right\}. \tag{A.21}$$

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

$$B_{y,proj}^{A} = \left(\frac{B_{y-1,N}^{obs,A}}{\overline{w}_1^{A}} e^{-5*0.9/12} - C_{y,1}^{A}\right)e^{-7\times 0.9/12}\,\overline{w}_2^{A} + B_{y,proj0}^{A} \tag{A.22}$$

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:

$$\theta = \frac{[B_{ec}^{A} - (B_{y,proj}^{A} - B_{y,proj0}^{A})]}{\overline{w}_1^{A}} e^{5.5*1.2/12} + \frac{TAC_y^{2,A\_before}}{\overline{w}_{0c}^{A}} - C_{y,1}^{A} - C_{y,0bs}^{A} \qquad (A.23)$$

This is back-calculated to November of the previous year in the same way as equation (A.11) during OMP implementation:

$$N_{y-1,rec0}^{A*} = (\theta\, e^{0.5(6+t_y^A)1.2/12} + C_{y,0bs}^{A})\, e^{[0.5(6+t_y^A)]1.2/12} \qquad (A.24)$$

or equation (A.12) during simulation testing:

$$N_{y-1,rec0}^{A*} = (\theta\, e^{3.25\times1.2/12} + C_{y,0bs}^{A})\, e^{3.25\times1.2/12} \qquad (A.25)$$

The revised anchovy TAC is calculated by reducing TAC_y^{2,A_before} 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:

$$TAC_y^{2,A} = \max \text{ of} \begin{cases} TAC_y^{1,A};\, TAC_y^{2,A\_before} \dfrac{\left(\dfrac{p\dfrac{N_{y-1,rec0}^{A}}{\overline{N}_{rec0}^{A}} + (1-p)\dfrac{B_{y-1,N}^{obs,A}}{\overline{B}_{Nov}^{A}}}{p\dfrac{N_{y-1,rec0}^{A*}}{\overline{N}_{rec0}^{A}} + (1-p)\dfrac{B_{y-1,N}^{obs,A}}{\overline{B}_{Nov}^{A}}} - x^A \right)^2}{(1-x^A)^2} & \text{if } x^A < \dfrac{p\dfrac{N_{y-1,rec0}^{A}}{\overline{N}_{rec0}^{A}} + (1-p)\dfrac{B_{y-1,N}^{obs,A}}{\overline{B}_{Nov}^{A}}}{p\dfrac{N_{y-1,rec0}^{A*}}{\overline{N}_{rec0}^{A}} + (1-p)\dfrac{B_{y-1,N}^{obs,A}}{\overline{B}_{Nov}^{A}}} < 1 \\ TAC_y^{1,A};0 & \text{if } \dfrac{p\dfrac{N_{y-1,rec0}^{A}}{\overline{N}_{rec0}^{A}} + (1-p)\dfrac{B_{y-1,N}^{obs,A}}{\overline{B}_{Nov}^{A}}}{p\dfrac{N_{y-1,rec0}^{A*}}{\overline{N}_{rec0}^{A}} + (1-p)\dfrac{B_{y-1,N}^{obs,A}}{\overline{B}_{Nov}^{A}}} < x^A \end{cases} \qquad (A.26)$$

Final Anchovy TAC

The same procedure as for the revised anchovy TAC is followed, except that $TAC_y^{3,A\_before} = \alpha_{ads} q \left(p\dfrac{N_{y-1,rec0}^{A}}{\overline{N}_{rec0}^{A}} + (1-p)\dfrac{B_{y-1,N}^{obs,A}}{\overline{B}_{Nov}^{A}} \right)$, subject to $\max\{TAC_y^{2,A}; c_{mntac}^{A}\} \le TAC_y^{3,A\_before} \le c_{mxtac}^{A}$ replaces TAC_y^{2,A_before} in equations (A.21), (A.23) and (A.26) above. Furthermore, $TAC_y^{2,A}$ replaces $TAC_y^{1,A}$ in equation (A.26) above.

References

De Oliveira, J.A.A. 2003. The Development and Implementation of a Joint Management Procedure for the South African Pilchard and Anchovy Resources. PhD Thesis, University of Cape Town, South Africa.

Table A.1. Parameters and constraints in OMP-02, re-revised OMP-04, and the proposed final OMP-08. (Note that although all biomass values are given in tons in the table, the equations in the appendix use biomass in thousands of tons.)

Control Parameter		OMP-02	Re-Revised OMP-04	Final OMP-08
β	directed sardine control parameter	0.14657	0.14387	0.094
α_{ns}	directed anchovy control parameter for normal season	0.73752	0.72858	0.445
α_{ads}	directed anchovy control parameter for additional season	1.47504	1.45716	0.6675
Constraints		**OMP-02**	**Re-Revised OMP-04**	**Final OMP-08**
TAB_{rh}^{S}	fixed annual adult sardine bycatch	10 000t	10 000t	3 500t
c_{mxdn}^{S}	maximum proportion by which directed sardine TAC can be annually reduced	0.15	0.15	0.20
c_{mxdn}^{A}	maximum proportion by which normal season anchovy TAC can be annually reduced	0.25	0.25	0.25
c_{mntac}^{S}	minimum directed sardine TAC	90 000t	90 000t	90 000t
c_{mntac}^{A}	minimum directed anchovy TAC	150 000t	150 000t	120 000t
c_{mxtac}^{S}	maximum directed sardine TAC	500 000t	500 000t	500 000t
c_{mxtac}^{A}	maximum directed normal season anchovy TAC	600 000t	600 000t	600 000t
c_{tier}^{S}	2-tier break for directed sardine TAC	240 000t	240 000t	255 000t
c_{tier}^{A}	2-tier break for directed anchovy TAC	330 000t	330 000t	330 000t
$c_{mxinc}^{ns,A}$	maximum increase in normal season anchovy TAC	200 000t	200 000t	150 000t
$c_{mxinc}^{ads,A}$	maximum additional season anchovy TAC	150 000t	150 000t	120 000t
TAB_{ads}^{S}	maximum sardine bycatch during the additional season	2 000t	2 000t	2 000t
B_{smooth}^{S}	threshold at which directed sardine TAC is linearly decreased	N/A	800 000t	800 000t
B_{ec}^{S}	threshold at which exceptional circumstances are invoked for sardine	250 000t	250 000t	300 000t
B_{ec}^{A}	threshold at which exceptional circumstances are invoked for anchovy	400 000t	400 000t	400 000t
B_1	threshold above which the anchovy additional sub-season TAC can increase more rapidly	N/A	N/A	1 000 000t
B_2	threshold above which the anchovy additional sub-season TAC reaches a maximum	N/A	N/A	1 500 000t
x^S	the proportion of the exceptional circumstances threshold below which sardine TAC is zero.	0	0	0.25
x^A	the proportion of the exceptional circumstances threshold below which anchovy TAC is zero.	0	0.25	0.25
R_{crit}	sardine recruitment threshold above which the maximum possible mid-year increase in sardine TAC under exceptional circumstances is achieved	N/A	N/A	17.38
Δ^A	threshold above B_{ec}^{A} at which linear smoothing is introduced before anchovy exceptional circumstances are declared (to ensure continuity)	N/A	N/A	100 000t

Table A.1 (continued).

Fixed Controls		OMP-02	Re-Revised OMP-04	Final OMP-08
δ	'scale-down' factor on initial anchovy TAC	0.85	0.85	0.85
p	weighting given to recruit survey in anchovy TAC	0.7	0.7	0.7
q	relates to average TAC under OMP99	300	300	300
γ_y	conservative initial estimate of juvenile sardine : anchovy ratio	0.1-0.2 (eqn. A.5)	0.1-0.2 (eqn. A.5)	0.1-0.2 (eqn A.5)

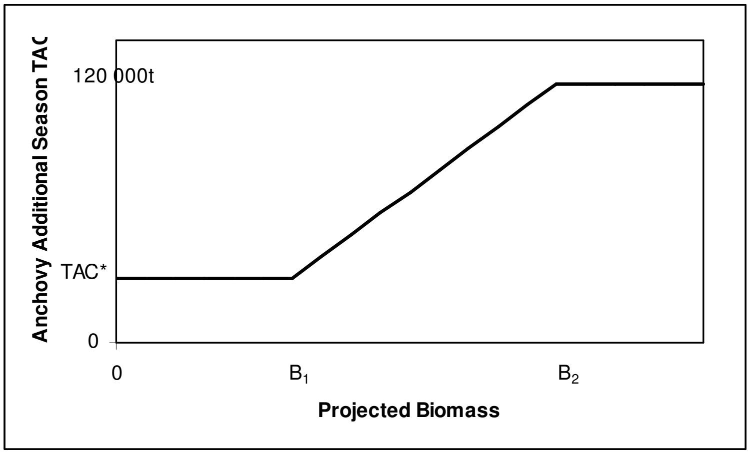


Figure A.1. *The rule used for anchovy additional season TAC in the proposed final OMP-08, which increases linearly from* $TAC^* = TAC_y^{3,A*} - TAC_y^{2,A}$*, where* $TAC_y^{3,A*}$ *is that output from equations (A.13) and (A.14), at* $B_{proj} = B_1$ *to the maximum of 120 000t for* $B_{proj} \geq B_2$*. For the proposed final choice of OMP-08,* $B_1 = 1$ *million tons and* $B_2 = 1.5$ *million tons.*

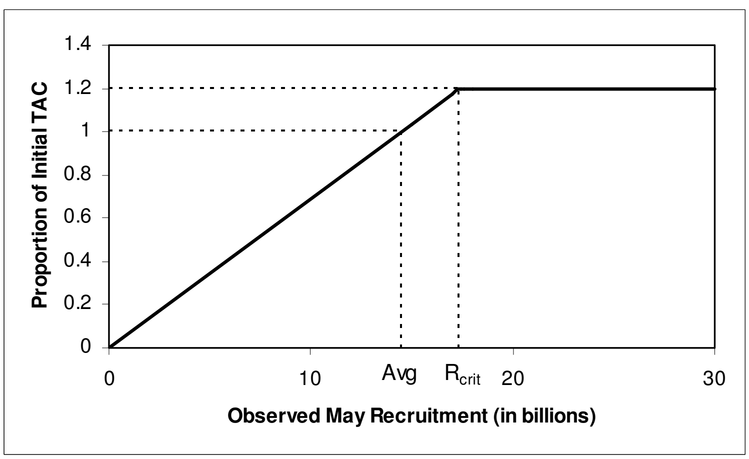


Figure A.2. *The proportion of the initial directed sardine TAC that is awarded in the mid-year revision to the directed sardine TAC if exceptional circumstances are declared. The historic (May 1984 – 2006, i.e. including the peak years) average observed May sardine recruitment is 14.48 billion recruits. For the proposed final OMP-08,* $R_{crit} = 17.38$*, such that the mid-year revision is the same as the initial TAC when observed recruitment is average.*

Appendix B: Simulation Testing Framework

This Appendix details the implementation model, population dynamics model and observation model of the fishery management system used to simulation test OMP-08. In this appendix, catches-at-age are given in numbers of fish (in billions), whereas the TACs and TABs are given in thousands of tons.

Implementation model

Given the TAC / TABs output from OMP-08, the implementation model simulates the implementation of these catch limits by the industry to yield future catches-at-age. The historic average weights-at-age in the catches, $\overline{w}^{i}_{ac}$, for $i = A, S$ are given in Table B.1.

Assumptions made during the implementation include:

i) The initial normal season anchovy TAC, $TAC^{1,A}_{y}$, is caught by the end of June.

ii) All the anchovy adults are caught by mid-May, the simulated time of the recruit survey.

Annual sardine adult catch by number

$$C^{S}_{y,a} = N^{S}_{y-1,a} S^{S}_{a} F_{y} e^{-M^{S}_{ad}/2}, \qquad a = 1,\ldots,5+ \qquad \text{(B.1)}$$

where $$F_{y} = \frac{TAC^{S}_{y} + TAB^{S}_{rh}}{\left(\sum_{a=1}^{5+} N^{S}_{y-1,a} S^{S}_{a} \overline{w}^{S}_{ac}\right) e^{-M^{S}_{ad}/2}}.$$

The fishing selectivities-at-age, $S^{S}_{1} = 0.43$, $S^{S}_{2} = S^{S}_{3} = S^{S}_{4} = S^{S}_{5} = 1$ are output from the sardine stock assessment model (Cunningham and Butterworth 2007b).

Annual anchovy 1-year-old catch by number

Between 1984 and 2006, the total 1-year-old catch in tons formed, on average, 36% of the anchovy catch biomass between January and June (the period during which $TAC^{1,A}_{y}$ applies). Assuming all the 1 year old anchovy are caught by mid-May each year, the anchovy 1 year old catch is taken to be 36% of the initial normal season anchovy TAC:

$$C^{A}_{y,1} = \frac{1}{\overline{w}^{A}_{1c}} \left(0.36 \times TAC^{1,A}_{y}\right). \qquad \text{(B.2)}$$

Anchovy 0-year-old catch by number

Between 1984 and 2006 the anchovy juvenile catch in tons from 1st January to 30th April, together with half the May juvenile catch in tons was 26% of the total anchovy catch biomass from 1st January to 30th June. This proportion increases to 28% if data from 1999 to 2006 only is used. As fishing practices may have changed over the years, the latter proportion is considered more reliable for use in testing the MP. Using the above assumption that $TAC_y^{1,A}$ is caught by the end of June, the anchovy 0-year-old catch taken prior to the recruit survey is:

$$C_{y,0bs}^{A} = 0.28 \frac{TAC_y^{1,A}}{\overline{w}_{0c}^{A}} \tag{B.3}$$

and for the normal season as a whole:

$$C_{y,0}^{A*} = \frac{1}{\overline{w}_{0c}^{A}} \left(TAC_y^{2,A} - C_{y,1}^{A} \times \overline{w}_{1c}^{A} \right) \tag{B.4}$$

Sardine 0-year-old catch by number prior to the recruit survey

The 0-year-old sardine catch prior to the recruit survey is based on the January to May bycatch occurring with directed anchovy juvenile and adult catches. As the majority of adult catch has historically been landed by the end of May, the full anchovy adult catch together with the juvenile anchovy catch prior to the survey is used to calculate the 0-year-old sardine catch prior to the survey:

$$C_{y,0bs}^{S} = k_{jan:may} \frac{N_{y-1,0}^{S}}{N_{y-1,0}^{A}} e^{\sigma_{jan:may} \eta_{y,jan:may}} \frac{(C_{y,0bs}^{A} \overline{w}_{0c}^{A} + C_{y,1}^{A} \overline{w}_{1c}^{A})}{\overline{w}_{0c}^{S}}, \qquad \text{where } \eta_{y,jan:may} \sim N(0;1) \tag{B.5}$$

and $k_{jan::may}$ and $\sigma_{jan:may}$ are given in equations (B.6) and (B.8) respectively; see (B.3) above for $C_{y,0bs}^{A}$.

Ratio of sardine bycatch to anchovy between January and May

The ratio of sardine bycatch to anchovy in the commercial catches from January to May is needed to simulate the 0-year-old sardine caught prior to the recruit survey (see equation B.5). The relationship between the historical sardine bycatch to anchovy ratio in the catches from January to May, together with the stock assessment model prediction for the ratio of sardine to anchovy November recruitment, is used to provide this ratio (the predicted recruitment ratio is used because the catch of 0-year-old anchovy dominates that of older anchovy, so applying the ratio also to the early season adult anchovy catch will not introduce substantial error). The constant of proportionality estimated and the associated time series of residuals are as follows:

$$k_{jan:may} = \exp\left\{ \sum_{y=1987}^{2006} \left[\ln(C_{y,jan:may}^{S,byc} / C_{y,jan:may}^{A}) - \ln(N_{y-1,0}^{S} / N_{y-1,0}^{A}) \right] \Big/ \sum_{y=1987}^{2006} 1 \right\} \tag{B.6}$$

and

$$\varepsilon'_{y,jan:may} = \ln(C_{y,jan:may}^{S,byc} / C_{y,jan:may}^{A}) - \ln(k_{jan:may} N_{y-1,0}^{S} / N_{y-1,0}^{A}) \qquad y = 1987,...,2006 \tag{B.7}$$

where $C_{y,jan:may}^{S,byc}$ and $C_{y,jan:may}^{A}$ are given in Table B.2 and $N_{y,0}^{i}$ is the model predicted recruitment of species i, $i = S, A$ in November of year y (from which catches of 0-year-old sardine and anchovy are made in year $y+1$). The subset of years used is that for which the catch data and assessed recruitment estimates for both species are available. The standard deviation of the residuals is given by:

$$\sigma_{jan:may} = \sqrt{\sum_{y=1987}^{2006} \left(\varepsilon'_{y,jan:may}\right)^2 \Big/ \sum_{y=1987}^{2006} 1} \,. \qquad \text{(B. 8)}$$

Annual sardine 0-year-old catch by number

$$C_{y,0}^{S*} = \frac{1}{\overline{w}_{0c}^{S}} \left(\lambda\, TAC_y^{1,A} + r_y \left(TAC_y^{2,A} - TAC_y^{1,A}\right)\right), \quad \text{where } \lambda = \max\{\gamma_y, r_y\} \qquad \text{(B.9)}$$

where γ_y is the initial conservative bycatch ratio given in equation (A.5). When implementing OMP-08, both $r_{y,sur}$ and $r_{y,com}$ will be observations that will be available to input into the OMP formula. During simulation these ratios are derived from recruit survey estimates:

$$r_{y,sur} = k_{sur} \frac{N_{y,r}^{obs,S}}{N_{y,r}^{obs,A}}\,, \qquad \text{(B.10)}$$

and the simulated sardine bycatch to anchovy ratio in commercial catches in May, given by:

$$r_{y,com} = k_{may} \frac{N_{y,r}^{S}}{N_{y,r}^{A}} e^{\sigma_{may}\, \varepsilon_{y,may}}\,. \qquad \text{(B.11)}$$

where $\varepsilon_{y,may} = \rho_{may} \eta_{y,jan:may} + \sqrt{1-(\rho_{may})^2}\; \eta_{y,may}$, where $\eta_{y,may} \sim N(0;1)$ (B.12)

Here we have

$N_{y,r}^{obs,S/A}$ - the simulated survey observations, from equation (B.41).

$N_{y,r}^{S/A}$ - the model-predicted recruitment, projected forward to the time of the survey, from equation (B.42).

k_{may} - the constant of proportionality from equation (B.13).

σ_{may} - the residual standard deviation from equation (B.15).

ρ_{may} - the correlation coefficient from equation (B.16).

$\eta_{y,jan:may}$ - from equation (B.5).

Simulating ratios of sardine bycatch to anchovy catch in May, using information from the recruit survey and catches from the commercial fishery

For equation (B.10), the relationship between the sardine to anchovy ratio in the recruit survey ($N_{y,r}^{obs,S} / N_{y,r}^{obs,A}$), given in Table B.3, and the sardine bycatch to anchovy ratio in the commercial catches in May ($C_{y,may}^{S,byc} / C_{y,may}^{A}$), given in Table B.2, is estimated for historical observations. Figure B.1 plots these historical observations and fits a linear regression, forced through the origin (i.e., minimising $\sum_{y=1987}^{2006}\left[\left(C_{y,may}^{S,byc} / C_{y,may}^{A}\right) - k_{sur}\left(N_{y,r}^{obs,S} / N_{y,r}^{obs,A}\right)\right]^2$ w.r.t. k_{sur}). This indicates a slope of $k_{sur} = 0.684$ which is then applied to simulated recruit survey data to obtain an estimate of the ratio of juvenile sardine to anchovy in catches in May (equation (B.10)).

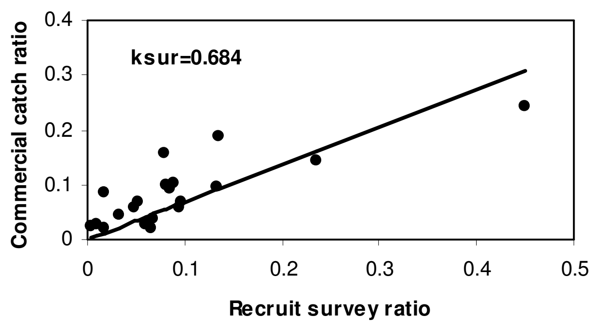


Figure B.1. Relationship between the sardine to anchovy ratio in the recruit survey ($N_{y,r}^{obs,S} / N_{y,r}^{obs,A}$), and the sardine bycatch to anchovy ratio in commercial catches in May ($C_{y,may}^{S,byc} / C_{y,may}^{A}$) for 1987-2006. The slope of the linear regression forced through the origin is $k_{sur} = 0.684$.

For equation (B.11), the constant of proportionality estimated and the associated time series of residuals are as follows:

$$k_m = \exp\left\{ \sum_{y=1987}^{2006} \left[\ln(C_{y,m}^{S,byc} / C_{y,m}^{A}) - \ln(N_{y,r}^{S} / N_{y,r}^{A}) \right] \Big/ \sum_{y=1987}^{2006} 1 \right\}, \qquad m = may \quad \text{(B.13)}$$

and

$$\varepsilon'_{y,m} = \ln(C_{y,m}^{S,byc} / C_{y,m}^{A}) - \ln(k_m N_{y,r}^{S} / N_{y,r}^{A}) \qquad y = 1987,...,2006 \text{ and } m = may \quad \text{(B.14)}$$

where $C_{y,m}^{S,byc}$ and $C_{y,m}^{A}$ are from Table B.2, and $N_{y,r}^{i}$ is the assessment model-predicted November recruitment of species i, $i = S, A$ in year $y-1$, projected forward to the time of the recruit survey in year y (see equation (B.42)). The associated residual standard deviation is:

$$\sigma_m = \sqrt{ \sum_{y=1987}^{2006} \left(\varepsilon'_{y,m}\right)^2 \Big/ \sum_{y=1987}^{2006} 1 }, \qquad m = may \quad \text{(B.15)}$$

A correlation coefficient between the January to May and May residuals, for use in equation (B.12) above, is then calculated by:

$$\rho_{may} = \frac{\sum_{y=1987}^{2006} \varepsilon'_{y,jan:may} \varepsilon'_{y,may}}{\left(\sum_{y=1987}^{2006} 1 \right) \sigma_{jan:may} \sigma_{may}} \qquad \text{(B.16)}$$

Sardine 0-year-old catch adjusted for bycatch drop-off after May-June

$C^{S*}_{y,0}$ in equation (B.9) assumes that the ratio of juvenile sardine to anchovy "in the sea" during May, r_y, will remain a constant for the remainder of the season. However, Figure B.2 (a repeat of Figure B.1, but with August commercial catch data added) shows that there is a drop-off in this ratio of about 50% by August. This effect is simulated by adjusting $C^{S*}_{y,0}$ to reflect the actual level of 0-year-old sardine to be expected in the catches, given the historical pattern of sardine bycatch to anchovy ratio changes (usually a drop-off) from May to August. The anchovy catch, $C^{A}_{y,0}$, is also adjusted if the adjusted $C^{S}_{y,0}$ exceeds $TAB^{2,S}_{y} - TAB^{S}_{rh}$ (equation (B.27)), in order to reflect the closure of the anchovy fishery once the sardine bycatch allowance linked to anchovy is reached.

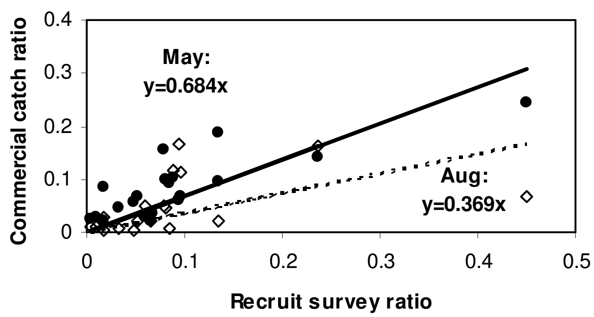


Figure B.2. A repeat of Figure B.1, but with commercial catch data for August ($C^{S,byc}_{y,aug} \big/ C^{A}_{y,aug}$ *) added*

Simulating ratios of sardine bycatch to anchovy in catches after May

When simulating sardine bycatch to anchovy ratios in the catches in June, July and August, it is assumed the correlations between the residuals in successive months follow the following pattern:

	June	July	August
May	ρ_{byc}	$(\rho_{byc})^2$	$(\rho_{byc})^3$
June		ρ_{byc}	$(\rho_{byc})^2$
July			ρ_{byc}

However, in order to estimate the value of ρ_{byc} to be used in the implementation model, the actual correlations between the residuals in successive months were calculated using the catches for the corresponding months (Table B.2) and the stock assessment predicted recruitments at the beginning of the recruitment survey, i.e., $N^{i}_{y,r}$ from equation (B.42).

The constants of proportionality, k_{jun}, k_{jul} and k_{aug} are calculated using equation (B.13), $\varepsilon'_{y,jun}$, $\varepsilon'_{y,jul}$ and $\varepsilon'_{y,aug}$ are calculated using equation (B.14) and σ_{jun}, σ_{jul} and σ_{aug} are calculated using equation (B.15), with the sum over years excluding 1989 and 1996 for August due to zero catches. The actual correlations,

$\rho_{m,j}$ (i.e., the correlation between the residual time series in month m, and the j^{th} month prior to month m), can then be calculated using equation (B.16). For example, for m=jul and j=2, and Y clarified in parentheses below:

$$\rho_{jul,2} = \frac{\sum_{y\in Y} \varepsilon_{y,may}\varepsilon_{y,jul}}{\left(\sum_{y\in Y} 1\right)\sigma_{may}\sigma_{jul}} \tag{B.17}$$

so that the following correlations are calculated:

	June	July	August
May	$\rho_{jun,1}$	$\rho_{jul,2}$	$\rho_{aug,3}$
June		$\rho_{jul,1}$	$\rho_{aug,2}$
July			$\rho_{aug,1}$

(Note that because of the difference in the length of the August time series compared to the other months, k_{may}, k_{jun}, k_{jul}, $\varepsilon'_{y,may}$, $\varepsilon'_{y,jun}$, $\varepsilon'_{y,jul}$, σ_{may}, σ_{jun} and σ_{jul} need to be recalculated excluding 1989 and 1996, in order to calculate $\rho_{aug,1}$, $\rho_{aug,2}$ and $\rho_{aug,3}$.)

Finally, ρ_{byc} is estimated by differentiating the following objective function, g (derived by summing the squared differences between the two correlation tables), with respect to ρ_{byc}:

$$g = \sum_{m=jun,jul,aug} [\rho_{byc} - \rho_{m,1}]^2 + \sum_{m=jul,aug} [(\rho_{byc})^2 - \rho_{m,2}]^2 + [(\rho_{byc})^3 - \rho_{aug,3}]^2 \tag{B.18}$$

and setting the result to zero, so that solutions for ρ_{byc} may be obtained by finding the roots of the following equation:

$$3(\rho_{byc})^5 + 4(\rho_{byc})^3 - 3\rho_{ag,3}(\rho_{byc})^2 + [3 - 2\sum_{m=jul,aug} \rho_{m,2}]\rho_{byc} - \sum_{m=jun,jul,aug} \rho_{m,1} = 0 \tag{B.19}$$

It can be shown that the above equation has only one real root.

Adjusting $C_{y,0}^{S*}$

Between 1999 and 2006, the sardine bycatch from January to 31st May has been 1.404 times that from January to mid-May[9]. Adjusting the sardine bycatch prior to the survey to take account of this additional bycatch by the end of May, equation (B.9) is modified as follows:

$$C_{y,0}^{S**} = 1.404 \times C_{y,0bs}^{S} + \frac{1}{\overline{w}_{0c}^{S}}\left(r_{y,jun}C_{y,jun}^{A} + r_{y,jul}C_{y,jul}^{A} + r_{y,aug}C_{y,aug}^{A}\right) \tag{B.20}$$

[9] Bycatch from 1st to 15th May approximated by half the bycatch from the full month of May.

The sardine bycatch to anchovy ratios, $r_{y,m}$, are simulated in a similar way to $r_{y,com}$ in equation (B.11) as follows:

$$r_{y,m} = k_m \frac{N^S_{y,r}}{N^A_{y,r}} e^{\sigma_m \varepsilon_{y,m}}, \qquad m = jun,\ jul,\ aug \quad \text{(B.21)}$$

where k_m and σ_m are from equations (B.13) and (B.15), summing over years for which anchovy directed catch is non-zero, and:

$$\varepsilon_{y,jun} = \rho_{byc}\varepsilon_{y,may} + \sqrt{1-(\rho_{byc})^2}\ \eta_{y,jun}$$

$$\varepsilon_{y,jul} = (\rho_{byc})^2\varepsilon_{y,may} + \rho_{byc}\sqrt{1-(\rho_{byc})^2}\ \eta_{y,jun} + \sqrt{1-(\rho_{byc})^2}\ \eta_{y,jul}$$

$$\varepsilon_{y,aug} = (\rho_{byc})^3\varepsilon_{y,may} + (\rho_{byc})^2\sqrt{1-(\rho_{byc})^2}\ \eta_{y,jun} + \rho_{byc}\sqrt{1-(\rho_{byc})^2}\ \eta_{y,jul} + \sqrt{1-(\rho_{byc})^2}\ \eta_{y,aug} \quad \text{(B.22)}$$

The above equations reflects the correlative relationships between successive months, where ρ_{byc} is from equation (B.19), $\varepsilon_{y,may}$ from equation (B.12), and

$$\eta_{y,m} \sim N(0;1). \qquad m = jun,\ jul,\ aug \quad \text{(B.23)}$$

Between 1984 and 2006 the average total anchovy catch from January to May was 69% of that from January to June. This percentage deceases to 61% if the period is shortened to 1999 to 2006. As above, these latter years are considered most reliable for projecting into the future. Assuming 61% of $TAC^{1,A}_y$ is caught by the end of May, and given the assumption that $TAC^{1,A}_y$ is caught by the end of June, the anchovy catches in equation (B.20), $C^A_{y,m}$ ($m = jun, jul$ and aug), are derived as follows (in tons):

$$C^A_{y,jun} = 0.39 \times TAC^{1,A}_y \quad \text{(B.24)}$$

$$C^A_{y,jul} = p_{jul}(TAC^{2,A}_y - TAC^{1,A}_y) \quad \text{(B.25)}$$

$$C^A_{y,aug} = (1 - p_{jul})(TAC^{2,A}_y - TAC^{1,A}_y) \quad \text{(B.26)}$$

where $p_{jul} = 0.55$ is taken to be the average 1999 to 2006 proportion of total anchovy catch during July and August that is taken in July.

Adjusting $C^{A*}_{y,0}$, when the normal season bycatch limit is reached

The consequent adjustment to $C^{A*}_{y,0}$ (given by equation (B.4)) when $C^{S**}_{y,0}\overline{w}^S_{0c} > TAB^{2,S}_y - TAB^S_{rh}$, where $C^{S**}_{y,0}$ is given by equation (B.20), assumes that the anchovy TAC is taken at the same rate as the sardine bycatch allowance, and therefore we have:

$$C^{A**}_{y,0} = \begin{cases} C^{A*}_{y,0} & \text{if} \quad C^{S**}_{y,0}\overline{w}^S_{0c} \le TAB^{2,S}_y - TAB^S_{rh} \\ \dfrac{1}{\overline{w}^A_{0c}}\left(TAC^{2,A}_y\left[\dfrac{TAB^{2,S}_y - TAB^S_{rh}}{C^{S**}_{y,0}\overline{w}^S_{0c}}\right] - C^{A*}_{y,1}\overline{w}^A_{1c}\right) & \text{if} \quad C^{S**}_{y,0}\overline{w}^S_{0c} > TAB^{2,S}_y - TAB^S_{rh} \end{cases} \quad \text{(B.27)}$$

and

$$C^{S**}_{y,0} = \min\left\{1.404 \times C^{S}_{y,0bs} + \frac{1}{\overline{w}^{S}_{0c}}\left(r_{y,jun}C^{A}_{y,jun} + r_{r,jul}C^{A}_{y,jul} + r_{y,aug}C^{A}_{y,aug}\right), \frac{TAB^{2,S}_{y} - TAB^{S}_{rh}}{\overline{w}^{S}_{0c}}\right\} \quad \text{(B.28)}$$

Additional sub-season

A final adjustment is made to $C^{S**}_{y,0}$ and $C^{A**}_{y,0}$, given by equations (B.28) and (B.27) respectively, to reflect the catches taken in the additional sub-season, as follows:

$$C^{S}_{y,0} = C^{S**}_{y,0} + \frac{1}{\overline{w}^{S}_{0c}} \min\left\{TAB^{S}_{ads}; r_y\left(TAC^{3,A}_{y} - TAC^{2,A}_{y}\right)\right\} \quad \text{(B.29)}$$

and

$$C^{A}_{y,0} = C^{A**}_{y,0} + \frac{1}{\overline{w}^{A}_{0c}}\left(TAC^{3,A}_{y} - TAC^{2,A}_{y}\right) \quad \text{(B.30)}$$

where λ in the above equation ensures consistency with the proportion used for the mid-season update and that the bycatch in the additional sub season is at most λ of that portion of the anchovy final TAC taken in the sub-season.

General

For all catches simulated in the operating model, an upper limit is placed on the industry's efficiency by assuming that no more than 95% of the "exploitable" stock may be caught. Furthermore, appropriate adjustments are made to ensure non-negative values for catches.

<u>Population Dynamics Model</u>

Given the numbers-at-age at the beginning of the projection period (i.e., November 2006, output from the stock assessment models (Cunningham and Butterworth, 2007a,b)), values for future catches output from the implementation model, $C^{i}_{y,a}$, $i = S, A$, the stock assessment model projects numbers-at-age and spawning biomass at the beginning of November in $y = 2007,...,2026$ as follows:

Sardine:

$$N^{S}_{y,1} = \left(N^{S}_{y-1,0}\mathrm{e}^{-M^{S}_{j}/2} - C^{S}_{y,0}\right)\mathrm{e}^{-M^{S}_{j}/2}$$

$$N^{S}_{y,a} = \left(N^{S}_{y-1,a-1}\mathrm{e}^{-M^{S}_{ad}/2} - C^{S}_{y,a-1}\right)\mathrm{e}^{-M^{S}_{ad}/2} \qquad a = 2,3,4$$

$$N^{S}_{y,5+} = \left(N^{S}_{y-1,4}\mathrm{e}^{-M^{S}_{ad}/2} - C^{S}_{y,4}\right)\mathrm{e}^{-M^{S}_{ad}/2} + \left(N^{S}_{y-1,5+}\mathrm{e}^{-M^{S}_{ad}/2} - C^{S}_{y,5+}\right)\mathrm{e}^{-M^{S}_{ad}/2}$$

$$B^{S}_{y,N} = \sum_{a=1}^{5+} N^{S}_{y,a}\overline{w}^{S}_{a}$$

$$SSB^{S}_{y,N} = \sum_{a=2}^{5+} N^{S}_{y,a}\overline{w}^{S}_{a} \quad \text{(B.31)}$$

Anchovy: $N_{y,1}^{A}=\left(N_{y-1,0}^{A}\mathrm{e}^{-8.5M_{j}^{A}/12}-C_{y,0}^{A}\right)\mathrm{e}^{-3.5M_{j}^{A}/12}$

$$N_{y,2}^{A}=\left(N_{y-1,1}^{A}\mathrm{e}^{-5M_{ad}^{A}/12}-C_{y,1}^{A}\right)\mathrm{e}^{-7M_{ad}^{A}/12}$$

$$N_{y,3}^{A}=N_{y-1,2}^{A}\ \mathrm{e}^{-M_{ad}^{A}}$$

$$N_{y,4+}^{A}=N_{y-1,3}^{A}\ \mathrm{e}^{-M_{ad}^{A}}+N_{y-1,4+}^{A}e^{-M_{ad}^{A}}$$

$$B_{y,N}^{A}=SSB_{y,N}^{A}=\sum_{a=1}^{4+}N_{y,a}^{A}\overline{w}_{a}^{A} \qquad \text{(B.32)}$$

The average weights-at-age from the historic November spawner biomass surveys, $\overline{w}_{a}^{i}$, are given in Table B.1. The juvenile, M_{j}^{i}, and adult, M_{ad}^{i}, natural mortalities and the numbers-at-age at 1 November 2006 (the beginning of the projection period) are outputs from the stock assessment models (Cunningham and Butterworth, 2007a,b). The sardine adult catch is assumed to be taken half way between 1st November and 31st October each year. (The sardine stock assessment was fit to quarterly commercial proportion at length data and thus catch was modelled to be taken quarterly (Cunningham and Butterworth 2007b). The catch tonnage between 1984 and 2006, however, is almost equally split from 1 November to 30 April and 1 May to 31 October.) The anchovy juvenile catch is assumed to be taken as a pulse at 15th July and the adult catch is assumed to be taken as a pulse at 1st April (Cunningham and Butterworth 2007c). Letting $f(SSB_{y,N}^{i})$ denote the stock-recruitment curve of the chosen model, with parameters a^{i} and b^{i}, then future recruitment $N_{y,0}^{i}$, $i=S,A$, is assumed to be log-normally distributed about a stock-recruit relationship as follows:

$$N_{y,0}^{i}=f(SSB_{y,N}^{i})\,\mathrm{e}^{\varepsilon_{y}^{i}\sigma_{r}^{i}} \qquad \text{(B.33)}$$

where

$$\varepsilon_{y}^{i}=s_{cor}^{i}\varepsilon_{y-1}^{i}+\sqrt{1-(s_{cor}^{i})^{2}}\ \omega_{y}^{i}, \qquad \text{where } \omega_{y}^{i}\sim N(0;1) \text{ and } y=2007,...,2027$$

$N_{2006,0}^{i}$, $i=S,A$ are not estimated by the stock assessment models and are therefore calculated from the above equation, using the model predicted spawner biomass from the November 2006, output from the stock assessment models (Cunningham and Butterworth 2007a,b). The recruitment residual standard deviation, σ_{r}^{i}, correlation parameter s_{cor}^{i} and standardised recruitment residual for November 2006, ε_{2006}^{i}, are output from the stock assessment models (note a different notation for ε_{2006}^{i} is used in Cunningham and Butterworth 2007a,b, viz η_{2006}^{i}).

Observation Model

Correlation in survey residuals

Correlations in the November spawner biomass and May recruit surveys resulting from the stock assessments are required in simulating future survey observations.

The sardine and anchovy November survey residuals are given by ($i = S, A$):

$$\varepsilon^i_{y,N} = \ln B^{obs,i}_{y,N} - \ln(k^i_N B^i_{y,N}) \qquad y = 1984,...,2006 \quad \text{(B.34)}$$

where

$B^{obs,i}_{y,N}$ - the observed November 1+ biomass in year y.

$B^i_{y,N}$ - the corresponding stock assessment estimate of 1+.

k^i_N - the constant of proportionality (multiplicative bias) between $B^{obs,i}_{y,N}$ and $B^i_{y,N}$, output from the stock assessment models (Cunningham and Butterworth, 2007a,b).

The standard deviations of the residuals are given by:

$$\sigma^i_{Nov} = \sqrt{\sum_{y=1984}^{2006} \left(\varepsilon^i_{y,N}\right)^2 \Big/ \sum_{y=1984}^{2006} 1} . \qquad \text{(B.35)}$$

The correlation in the residuals between the sardine and anchovy November survey estimates is therefore calculated as follows:

$$\rho_{Nov} = \frac{\sum_{y=1984}^{2006} \varepsilon^S_{y,N} \varepsilon^A_{y,N}}{\left(\sum_{y=1984}^{2006} 1\right) \sigma^S_{Nov} \sigma^A_{Nov}} . \qquad \text{(B.36)}$$

Similarly, the sardine and anchovy recruitment survey residuals are given by ($i = S, A$):

$$\varepsilon^i_{y,r} = \ln N^{obs,i}_{y,r} - \ln(k^i_r N^i_{y,r}) \qquad y = 1985,...,2006 \quad \text{(B.37)}$$

where

$N^{obs,i}_{y,r}$ - the observed May recruitment for year y.

$N^i_{y,r}$ - the corresponding stock assessment estimate of recruitment.

k^i_r - the constant of proportionality (multiplicative bias) between $N^{obs,i}_{y,r}$ and $N^i_{y,r}$, output from the stock assessment models (Cunningham and Butterworth, 2007a,b).

The standard deviations of the residuals are given by:

$$\sigma^A_{rec} = \sqrt{\sum_{y=1985}^{2006} \left(\varepsilon^i_{y,r}\right)^2 \Big/ \sum_{y=1985}^{2006} 1} \qquad \text{(B.38)}$$

The correlation in the residuals between the sardine and anchovy recruitment survey estimates is therefore calculated as follows:

$$\rho_{rec} = \frac{\sum_{y=1985}^{2006} \varepsilon^S_{y,r} \varepsilon^A_{y,r}}{\left(\sum_{y=1985}^{2006} 1\right) \sigma^S_{rec} \sigma^A_{rec}} . \tag{B.39}$$

Simulating survey data

The survey estimates for spawner biomass and recruitment are generated by the observation model as follows ($i = A, S$):

$$B^{obs,i}_{y,N} = k^i_N B^i_{y,N} e^{\varepsilon^i_{y,Nov}} , \tag{B.40}$$

where $\varepsilon^S_{y,Nov} = \eta^S_{y,Nov} \tilde{\sigma}^S_{Nov}$, where $\eta^S_{y,Nov} \sim N(0;1)$

and $\varepsilon^A_{y,Nov} = \left(\rho_{Nov} \eta^S_{y,Nov} + \sqrt{1-(\rho_{Nov})^2}\ \eta^A_{y,Nov} \right) \tilde{\sigma}^A_{Nov}$, where $\eta^A_{y,Nov} \sim N(0;1)$

Here $\tilde{\sigma}^S_{Nov} = \max\left(0.999, \sqrt{0.0684 + \frac{98.9101}{B^S_{y,N}}} \right)$ and $\tilde{\sigma}^A_{Nov} = \max\left(0.2794, \sqrt{0.0102 + \frac{36.0661}{B^A_{y,N}}} \right)$ obtained from a regression of the observed CV against the base case assessment model predicted biomass between 1984 and 2006.

$$N^{obs,i}_{y,r} = k^i_r N^i_{y,r} e^{\varepsilon^i_{y,rec}} , \tag{B.41}$$

where $\varepsilon^S_{y,rec} = \eta^S_{y,rec} \tilde{\sigma}^S_{rec}$, where $\eta^S_{y,rec} \sim N(0;1)$

and $\varepsilon^A_{y,rec} = \left(\rho_{rec} \eta^S_{y,rec} + \sqrt{1-(\rho_{rec})^2}\ \eta^A_{y,rec} \right) \tilde{\sigma}^A_{rec}$, where $\eta^A_{y,rec} \sim N(0;1)$.

Here $\tilde{\sigma}^S_{rec} = \max\left(0.5610, \sqrt{0.1592 + \frac{0.3434}{N^S_{y,r}}} \right)$ and $\tilde{\sigma}^A_{rec} = \max\left(0.2177, \sqrt{0.0319 + \frac{0.3678}{N^A_{y,r}}} \right)$ obtained from a regression of the observed CV against the base case assessment model predicted recruitment between 1985 and 2006.

Assuming that the recruit survey begins mid-May each year, and that both juvenile sardine and anchovy are caught half-way between 1 November and the start of the survey (in line with the assumptions made in the assessments) we simulate

$$N^S_{y,r} = (N^S_{y-1,0} e^{-3.25 M^S_j/12} - C^S_{y,0bs}) e^{-3.25 M^S_j/12}$$

$$N^A_{y,r} = (N^A_{y-1,0} e^{-3.25 M^A_j/12} - C^A_{y,0bs}) e^{-3.25 M^A_j/12} \tag{B.42}$$

where $C^{i}_{y,0bs}$ are the catches (in billions) of 0-year-old fish of species *i* taken before the recruit survey.

Assumptions made for 2007

As the stock assessments (Cunningham and Butterworth 2007a,b) covered the period to November 2006, the OMP testing framework begins from November 2006 and projects to November 2026. A number of parameters that would be simulated in the testing framework for 2007, have however already been observed. Thus the following changes are made to the simulation framework above for 2007:

i) The TAC/TABs (in thousands of tons) for 2007 have already been set using OMP-04, thus

$TAC^{S}_{2007} = 162.436$, $TAC^{1,A}_{2007} = 186.942$, $TAB^{1,S}_{2007} = 29.413$,

$TAC^{2,A}_{2007} = 386.942$, $TAB^{2,S}_{2007} = 36.503$,

$TAC^{3,A}_{2007} = TAC^{2,A}_{2007} + 150$, $TAB^{3,S}_{2007} = TAB^{2,S}_{2007} + 2$

ii) The ratio of juvenile sardine to anchovy in the May survey and commercial catches have been observed and thus equations (B.10) and (B.11) are replaced with $r_{2007,sur} = 0.031$ and $r_{2007,com} = 0.0399$

iii) As the May 2007 survey observations are available, no error is required, thus equation (B.41) is replaced by $N^{obs,S}_{2007,r} = 5.05$ billion and $N^{obs,A}_{2007,r} = 420.87$ billion.

iv) The model predicted recruitment in November 2006 is not calculated using the stock recruit function (equation (B.33)), but rather back-calculated from the observed May 2007 recruitment as follows:

$N'^{S}_{2007,r} = \frac{1}{k^{S}_{r}} N^{obs,S}_{2007,r} e^{-\varepsilon^{S}_{2007,rec}}$ (from equation (B.41))

$N'^{A}_{2007,r} = \frac{1}{k^{A}_{r}} N^{obs,A}_{2007,r} e^{-\varepsilon^{A}_{2007,rec}}$ (from equation (B.41))

$$N^{S}_{2006,0} = (N'^{S}_{2007,r} e^{0.5(6+0.548)M^{S}_{j}/12} + C'^{S}_{2007,0bs}) e^{0.5(6+0.548)M^{S}_{j}/12}$$

$$N^{A}_{2006,0} = (N'^{A}_{2007,r} e^{0.5(6+0.548)M^{A}_{j}/12} + C'^{A}_{2007,0bs}) e^{0.5(6+0.548)M^{A}_{j}/12}$$

where $C'^{A}_{2007,0bs} = 6.159$ billion, being the anchovy catch from 1 April to the day before the recruit survey and used in setting the 2007 revised anchovy TAC and sardine TAB, and $C'^{S}_{2007,0bs} = 0.276$ billion.

v) The model predicted recruitment at the time of the survey takes into account the observed start date of the May 2007 recruit survey, thus equation (B.42) is replaced by:

$$N^{S}_{2007,r} = (N^{S}_{2006,0} e^{-0.5(6+0.548)M^{S}_{j}/12} - C^{S}_{2007,0bs}) e^{-0.5(6+0.548)M^{S}_{j}/12}$$

$$N^{A}_{2007,r} = (N^{A}_{2006,0} e^{-0.5(6+0.548)M^{A}_{j}/12} - C^{A}_{2007,0bs}) e^{-0.5(6+0.548)M^{A}_{j}/12}$$

where $C^{A}_{2007,0bs}$ and $C^{S}_{2007,0bs}$ are simulated using equations (B.3) and (B.55) respectively.

vi) Although no recruitment residual is required to simulate the recruitment in November 2006 (see iv) above), a distribution of the recruitment residuals in November 2006 is still required in order that the effect of the serial correlation between years is retained (so that November 2007 recruitment depends on November 2006). Within the assessment, the recruitment residuals are influenced by both the survey observation and the stock recruit curve. Thus an inverse-variance weighting of these two effects is used in the following manner:

a) $\tilde{\varepsilon}^{i}_{2006,1} = \ln\left(\frac{N^{i}_{2006,0}}{N'^{i}_{2006,0}}\right) \Big/ \sigma^{i}_{rec}$, where $N^{i}_{2006,0}$ is taken from vi) above and $N'^{i}_{2006,0} = f(SSB^{i}_{2006,N})$, giving a distribution $\tilde{\varepsilon}^{i}_{2006,1} \sim N\left(\tilde{\mu}^{i}, \left(\tilde{\sigma}^{i}\right)^{2}\right)$,

b) recruitment was assumed to be lognormally distributed around the stock recruit curve; thus $\tilde{\varepsilon}^{i}_{2006,2} \sim N(0,1)$,

c) using inverse-variance weighting, a combined normal distribution for the recruitment residuals for November 2006 is $\varepsilon^{i}_{2006} \sim N\left(\frac{\frac{\tilde{\mu}^{i}}{\left(\tilde{\sigma}^{i}\right)^{2}} + \frac{0}{1}}{\frac{1}{\left(\tilde{\sigma}^{i}\right)^{2}} + \frac{1}{1}}, \frac{1}{\frac{1}{\left(\tilde{\sigma}^{i}\right)^{2}} + \frac{1}{1}}\right)$

References

Cunningham, C.L., and Butterworth, D.S. 2007a. Assessment of the South African Anchovy Resource. MCM Document MCM/2007/SEPT/SWG-PEL/05. 29pp.

Cunningham, C.L. and Butterworth, D.S. 2007b. Base Case Assessment of the South African Sardine Resource. MCM Document MCM/2007/SEPT/SWG-PEL/06. 30pp.

Cunningham, C.L., and Butterworth, D.S. 2007c. OMP-08 Development, with Preliminary Results. MCM Document MCM/2007/OCT/SWG-PEL/04. 30pp.

Table B1. Average weights-at-age (in grams) from the historic catches ($\overline{w}^{i}_{ac}$, $i = S, A$) and from the historic November spawner biomass surveys ($\overline{w}^{i}_{a}$, $i = S, A$). As sardine catch weight-at-age is not directly available, an average from the model predicted quarterly catch weight is obtained, weighted by the quarterly catch numbers.

Weights-at-age in the catch				Weights-at-age in the survey			
Non-peak (sardine)		Peak years (sardine)		Non-peak (sardine)		Peak years (sardine)	
$\overline{w}^{S}_{0c}$	18.57	$\overline{w}^{S}_{0c}$	15.80	$\overline{w}^{S}_{1}$	32.38	$\overline{w}^{S}_{1}$	25.46
$\overline{w}^{S}_{1c}$	44.42	$\overline{w}^{S}_{1c}$	34.83	$\overline{w}^{S}_{2}$	58.56	$\overline{w}^{S}_{2}$	43.47
$\overline{w}^{S}_{2c}$	70.16	$\overline{w}^{S}_{2c}$	57.90	$\overline{w}^{S}_{3}$	83.61	$\overline{w}^{S}_{3}$	75.17
$\overline{w}^{S}_{3c}$	87.95	$\overline{w}^{S}_{3c}$	79.58	$\overline{w}^{S}_{4}$	92.70	$\overline{w}^{S}_{4}$	84.81
$\overline{w}^{S}_{4c}$	99.99	$\overline{w}^{S}_{4c}$	90.54	$\overline{w}^{S}_{5+}$	108.82	$\overline{w}^{S}_{5+}$	96.49
$\overline{w}^{S}_{5+c}$	108.66	$\overline{w}^{S}_{5+c}$	97.43	$\overline{w}^{A}_{1}$	9.72		
$\overline{w}^{A}_{0c}$	4.88			$\overline{w}^{A}_{2}$	13.94		
$\overline{w}^{A}_{1c}$	11.09			$\overline{w}^{A}_{3}$	16.01		
				$\overline{w}^{A}_{4+}$	16.73		

Table B.2. Anchovy catch (in thousands of tons) from landings that have targeted[*] anchovy ($C^{A}_{y,m}$), for the period January to May ("janmay") and four single month ("may", "jun", "jul", "aug") periods, with the associated recorded landings of sardine bycatch ($C^{S,by}_{y,m}$).

Year	$C^{A}_{y,janmay}$	$C^{A}_{y,may}$	$C^{A}_{y,jun}$	$C^{A}_{y,jul}$	$C^{A}_{y,aug}$	$C^{S,by}_{y,janmay}$	$C^{S,by}_{y,may}$	$C^{S,by}_{y,jun}$	$C^{S,by}_{y,jul}$	$C^{S,by}_{y,aug}$
1987	377.3	14.9	50.5	78.5	67.9	2.2	0.3	1.4	1.5	1.4
1988	252.5	50.1	74.2	60.7	70.4	1.7	1.2	2.4	0.5	0.7
1989	232.4	83.0	39.2	13.7	**	7.3	3.0	1.5	0.4	**
1990	88.3	36.3	59.5	0.5	0.2	3.5	2.1	3.8	0.0	0.0
1991	90.4	22.7	51.4	6.1	1.0	2.8	0.5	2.2	0.0	0.0
1992	178.1	58.7	34.5	44.3	56.3	5.0	1.7	2.6	2.3	2.8
1993	110.6	12.9	0.8	10.8	66.9	3.3	1.2	0.2	0.6	1.5
1994	92.8	38.0	17.1	0.2	29.2	8.9	3.9	1.9	0.0	3.5
1995	55.7	13.0	35.1	31.7	37.2	3.6	1.9	4.3	5.1	6.1
1996	19.3	9.0	12.9	0.1	**	3.8	1.7	1.8	0.0	**
1997	0.3	0.3	0.7	20.0	10.0	0.1	0.1	0.3	1.4	0.7
1998	38.3	21.9	42.0	11.9	3.7	5.0	3.4	4.5	0.9	0.2
1999	29.9	18.7	28.2	20.0	33.1	1.8	1.3	2.3	0.5	0.7
2000	102.8	41.2	15.6	50.8	55.0	5.0	1.9	1.1	0.6	0.3
2001	84.0	32.7	44.9	10.1	30.0	3.7	2.3	2.6	1.1	3.4
2002	34.8	6.6	48.6	48.1	33.7	0.8	0.4	1.8	1.3	5.6
2003	41.0	23.2	77.4	47.8	16.7	4.1	2.1	4.3	1.1	0.1
2004	58.5	38.5	20.2	65.4	22.3	4.3	3.3	0.5	0.7	0.6
2005	133.1	55.7	21.2	42.0	26.9	3.8	1.5	0.4	0.4	0.3
2006	18.7	7.0	31.1	35.5	20.6	1.0	0.7	2.3	2.8	1.0

* A landing is assumed to have targeted anchovy when the ratio anchovy : (anchovy + directed sardine + horse mackerel + round herring) exceeds 0.5 (in terms of mass).

** These have been omitted because $C^{A}_{y,aug} = 0$, and that would have meant that the ratio $C^{S,by}_{y,aug} / C^{A}_{y,aug}$ could not be used in these cases.

Table B.3. Historic observed sardine and anchovy recruitment (in billions).

y	$N^{obs,S}_{y,r}$	$N^{obs,A}_{y,r}$	y	$N^{obs,S}_{y,r}$	$N^{obs,A}_{y,r}$
1987	8.06	124.44	1997	40.72	90.40
1988	0.44	129.01	1998	10.72	136.52
1989	2.26	33.14	1999	10.38	199.23
1990	2.50	51.15	2000	20.00	624.68
1991	1.90	113.58	2001	60.07	627.20
1992	5.59	93.71	2002	49.15	520.41
1993	15.43	115.07	2003	36.45	430.31
1994	2.70	30.56	2004	4.09	238.57
1995	26.04	110.40	2005	1.69	176.92
1996	3.49	25.76	2006	9.56	117.46