Development and Testing of OMP-08

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Introduction

The current Operational Management Procedure (OMP-04) for the South African sardine and anchovy resources is due to be updated and replaced by OMP-08 by the end of 2007. A number of iterations of proposed "Straw" OMP-08 options have been presented thus far. This document details the latest proposed OMP-08 option, termed here "Straw3" OMP-08 and numerous results are given for this case, for alternative constraints within the OMP rules and for alternative underlying assessment (operating model) assumptions.

Methods

The management procedure, "Straw3 OMP-08", based on OMP-04, together with the simulation testing framework used to test a new MP are detailed fully in Appendix A, with relevant associated data given in Appendix B. "Straw3" OMP-08 differs from OMP-04 only in the changes to some of the constraint parameters (see Table 1). The maximum annual percentage decrease in directed sardine TAC has increased from 15% to 20%, requiring a change in the 2-tier threshold such that if the TAC in a year is above this threshold, it can be brought down to 204 000t in the following year, if necessary. As the mid-year revision to the TAC occurs towards the end of June, any increase to the normal season anchovy TAC must, theoretically, be caught during July and August before the switch to the additional season in September. The maximum increase in normal season anchovy TAC has thus been decreased from 200 000t to a more realistic level of 150 000t. Finally the proportion of the exceptional circumstances threshold below which the sardine TAC is zero has been increased from 0 to 0.25, since it seems desirable that (as currently with anchovy) there be a non-zero biomass level below which the directed sardine TAC is zero.

The operating models used to test the new MP utilise the joint posterior distributions from assessments of the sardine and anchovy resources, as determined by use of MCMC methodology. The base case assessment MCMC results for anchovy have already been reported to the Pelagic Working Group, together with a number of robustness tests (Cunningham and Butterworth 2007a). Appendix C records

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the results of a few remaining robustness tests. Convergence difficulties arose with respect to the σ_R parameter (the standard deviation of the residuals about the stock-recruitment relationship) for the sardine assessment. It is suspected that this is a consequence of the absence of input of age information to the current assessment, which impacts negatively on the precision with which σ_R can be estimated. In order that the sardine base case evaluation be comparable to that undertaken for OMP-04, it was decided that the posterior distribution used for σ_R in that evaluation (for OMP-04) be mimicked by carrying out MCMC runs for a number of fixed values of σ_R, and then taking a weighted average across the results, where the weighting is chosen to achieve correspondence with the earlier σ_R posterior (Cunningham and Butterworth 2007c). Due to time constraints, the posterior distributions for the sardine robustness tests were, however, sampled assuming σ_R =0.5. These are therefore compared to the base case with σ_R =0.5. The full sardine MCMC results for the base case and robustness tests will be presented elsewhereFurthermore, at this stage only the dominant "normal" stock-recruitment relationship is used for projections, with the low frequency component related to a peak in abundance of short duration (as over 2000 to 2004) to be added as a robustness test later.

Changes to Risk

The following 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.

Although the simulation framework is run from 2007 to 2027 (see Appendix A), because the TACs for 2007 have been set using OMP-04, the 20 year projection period above is taken to be 2008 to 2027. The trade-off curve obtained by limiting $risk_S < 0.18$ and $risk_A < 0.25$ (Cunningham and Butterworth 2007d).

Robustness Tests

"Straw3" OMP-08 was tested under a number of alternative underlying assumptions first about the sardine resource, with no change to the underlying anchovy dynamics, and then to alternative underlying assumptions about the anchovy resource, with no change to the underlying sardine dynamics. The alternatives tested are as follows, (the anchovy tests are further detailed in Cunningham and Butterworth 2007a and Appendix C):

S_0 – base case assessment ($M_j^S = 1.0$ and $M_{ad}^S = 0.8$)

S_{M1} – alternative natural mortality ($M_j^S = 1.0$ and $M_{ad}^S = 0.6$), with A_0

S_{M2} – alternative natural mortality ($M_j^S = 1.0$ and $M_{ad}^S = 0.4$), with A_0

S_{M3} – alternative natural mortality ($M_j^S = 0.8$ and $M_{ad}^S = 0.8$), with A_0

S_{M4} – alternative natural mortality ($M_j^S = 1.2$ and $M_{ad}^S = 1.0$), with A_0

S_{M4} – alternative natural mortality ($M_j^S = 1.2$ and $M_{ad}^S = 0.8$), with A_0

S_{bias1} – underestimation of acoustic biomass due to target strength error, such that the biomass estimate should be 1.3 times that actually computed

S_{bias2} – overestimation of acoustic biomass due to target strength error, such that the biomass estimate should be 0.7 times that actually computed

A_0 – base case assessment ($M_j^A = 1.2$ and $M_{ad}^A = 0.9$)

A_{M1} – alternative natural mortality: $M_j^A = 1.2$ and $M_{ad}^A = 1.2$, with S_0

A_{M2} – alternative natural mortality: $M_j^A = 1.5$ and $M_{ad}^A = 0.9$, with S_0

A_{M3} – alternative natural mortality: $M_j^A = 1.5$ and $M_{ad}^A = 1.2$, with S_0

A_{kegg1} – negatively biased egg surveys, i.e., $k_g^A = 0.75$, with S_0

A_{kegg2} – positively biased egg surveys, i.e., $k_g^A = 1.25$, with S_0

A_{BH} – Beverton Holt stock-recruitment curve, with S_0

A_R – Ricker stock-recruitment curve, with S_0

Note that, given this notation, “Straw3” OMP-08 was therefore tuned to S_0 and A_0.

One further set of scenarios for underlying sardine dynamics was also considered:

$S_{scor0708}$ – the serial correlation between recruitment in November 2006, 2007 and 2008 is increased (3 times that estimated by the assessment in 2007 and 2 times that estimated by the assessment in 2008)

$S_{rec0708}$ – recruitment in November 2007 and 2008 is set equal to that in November 2006.

These were chosen to mimic the effects of possible poor sardine recruitment in the near future.

Results

The trade-off curve calculated by tuning risk to the above levels is given in Figure 1, together with the comparative trade-off curves for OMP-02 and OMP-04. The point where the current sardine:anchovy rights trade-off crosses the “Straw3” OMP-08 trade-off curve is the trade-off point chosen for “Straw3” OMP-08. Some key summary statistics resulting from this choice of OMP are presented in Table 2. Considering the “corner point” of the trade-off curve, where the average anchovy catch is near maximum, it is noticeable that the chosen “Straw3” OMP-08 trade-off point differs from this “corner point” by a relatively large trade-off (47 000t) of anchovy for a small gain (3 000t) of directed sardine (Table 2).

The consequences of some alternative constraints to those chosen for “Straw3” OMP-08 have been evaluated, with the following key results (Figures 2 and 3):

- There is a 4% gain in the long-term average directed sardine catch when the maximum percentage by which the directed sardine TAC can be decreased is increased from 10% to 25% (Figure 2a).
- There is a 16% gain in the long-term average directed sardine catch when the minimum sardine TAC is decreased from 110 000t (maximum that can be allowed under the current simulation framework) to 80 000t (Figure 2b).
- There is little change in the average anchovy catch if a lower maximum increase (than 150 000t) in the normal season TAC is set (Figure 3a).
- There is a 3% gain in the long-term average anchovy catch when the maximum percentage by which anchovy normal season TAC can be decreased is increased from 20% to 30% (Figure 3b).
- There is little long-term (however, some short-term) gain in average anchovy catch achieved by decreasing the minimum anchovy TAC from 150 000t to 100 000t (Figure 3c).

An alternative assumption for adult sardine bycatch with red-eye was also tested, where the bycatch was assumed to increase linearly from 3 500t in 2007 to 7 000t in 2011 and remain at 7 000t for the remainder of the projection period. There was hardly any change in the summary statistics from those presented in Table 2, with the sardine risk increasing from 0.179 to 0.18.

Robustness tests

Summary statistics resulting from alternative underlying sardine dynamics are presented in Table 3. In order for direct comparisons to be made, "Straw3" OMP-08 is also run under the base case option with the standard deviation in the recruitment residuals being fixed to 0.5 for all simulations. The difference between this case ($S_{0\_0.5}$) and the base case is that the risk to both sardine and anchovy is lowered, given the overall lower natural variance in recruitment, and the sardine average catch is lower. The cases where sardine natural mortality is lower than the base case result in a lower risk to the sardine resource because the sardine live longer than expected when tuning "Straw3" OMP-08. Conversely, the cases where sardine natural mortality is higher than the base case result in a higher risk to the sardine resource. In all these cases the risk to the anchovy resource remains below 0.25, the value chosen to tune the OMP-08 trade-off curve. If the bias in the acoustic surveys is such that biomass is underestimated (S_{bias1}), then the risk to the sardine resource will be higher, with a lower average directed sardine catch while if the bias in the acoustic surveys is such that biomass is overestimated (S_{bias2}), then the risk to the sardine resource will be lower, with a higher average directed sardine catch. The sardine biomass at the end of the projection period remains a similar proportion (about 0.7) of carrying capacity[1] under all scenarios.

Summary statistics resulting from alternative underlying anchovy dynamics are presented in Table 4. A_{kegg2} and A_{BH} result in a substantially higher risk to the anchovy resource, also reflected in the higher percentage of times that anchovy exceptional circumstances are declared. The "worst case" scenario of

[1] This is carrying capacity during "non-peak" or "normal" years.

A_{BH} projects that anchovy biomass after 20 years will be 36% of that at carrying capacity, but that the minimum projected anchovy biomass over the projection period decreases to just 6% of that at carrying capacity. Under A_R, the risk to the anchovy resource is lower, but the risk to the sardine resource increases substantially. A higher average anchovy catch is taken under this scenario, with a higher annual variation in the catch. The higher risk to the sardine resource may result from a higher juvenile sardine bycatch taken with the anchovy fishery. Even under this scenario, though, the sardine resource is predicted to fall to a minimum of 22% of carrying capacity over the projection period, recovering to 60% by the end of the projection period.

The time series of median November recruitment (that surveyed in May of the following year) is plotted in Figure 4 under S_0 and the two alternative poorer sardine recruitment scenarios, and shows clearly the poorer recruitment expected under $S_{cor0708}$ and $S_{rec0708}$ compared to S_0. The 90% probability intervals around the base case hypothesis are given in Figure 5. Summary statistics resulting from these alternatives are presented in Table 5. As expected, the risk to the sardine resource increases, such that the probability of sardine biomass falling below the risk threshold once in the projected period increases to almost 50% in the 'worse case scenario'. However, in this case, the probability of sardine biomass falling below 250 000t and exceptional circumstances being declared remains low at 7.9%.

Catches in the near future

The rule to be applied under "Straw3" OMP-08 to calculate directed sardine TAC for 2008 dependent on the observed November 2007 sardine biomass is plotted in Figure 6. The projected average and 95% probability intervals for the directed sardine catch over each of the next 5 years is shown in Figure 7, indicating a slow increase in the average with time as the effect of the recent poor recruitment diminishes with time. Figure 8 shows the projected average and 95% probability intervals for total anchovy catch over each of the next 5 years, indicating a sharp decline from recent TACs in the near future (moderated by the 2-tier threshold and the maximum percentage decrease in normal season TAC) due to the chosen sardine:anchovy trade-off point and lower projected average sardine directed catch.

Discussion

This document details the further development of a new management procedure for the South African sardine and anchovy resources, OMP-08. "Straw3" OMP-08 is presented together with the consequences of changes to the constraints of the OMP and the consequences of alternative underlying resource dynamics to that assumed in the base case hypotheses. Further robustness tests will still be carried out as "tick tests" to ensure that there is no major deviation (increased risk to the resource) under alternative underlying dynamics. In addition, the rules governing the declaration of exceptional circumstances and the TACs to apply under exceptional circumstances will still be further reviewed.

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.

Cunningham, C.L., and Butterworth, D.S. 2007d. Proposed Change of Risk Criteria for Sardine and Anchovy. MCM Document MCM/2007/NOV/SWG-PEL/04. 5pp.

Table 1. Parameters and constraints in OMP-02, re-revised OMP-04, and "Straw3" 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**	**"Straw3" OMP-08**
β	directed sardine control parameter	0.14657	0.14387	0.11767
α_{ns}	directed anchovy control parameter for normal season	0.73752	0.72858	0.1375
α_{ads}	directed anchovy control parameter for additional season	1.47504	1.45716	0.275
Constraints		**OMP-02**	**Re-Revised OMP-04**	**"Straw3" OMP-08**
TAB_{rh}^{S}	fixed annual adult sardine bycatch	10 000t	10 000t	3 500t[2]
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	150 000t
c_{mxtac}^{S}	maximum directed sardine TAC	500 000t	500 000t	500 000t
c_{mxtac}^{A}	maximum directed 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	150 000t
TAB_{ads}^{S}	maximum sardine bycatch during the additional season	2 000t	2 000t	2 000t
B_{ec}^{S}	threshold at which exceptional circumstances are invoked for sardine	250 000t	250 000t	250 000t
B_{ec}^{A}	threshold at which exceptional circumstances are invoked for anchovy	400 000t	400 000t	400 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	0	0.25	0.25[3]

[2] An MP assuming TAB_{rh}^{S} increases from 3 500t in 2007 to 7 000t in 2011 has also be tested.

	threshold below which anchovy TAC is zero.			
Fixed Controls		**OMP-02**	**Re-Revised OMP-04**	**“Straw3” 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)

Table 2. Key summary statistics for the trade-off point for “Straw3” OMP-08 and the comparative values at the “corner point” of the trade-off curve. Average directed catch (in thousands of tons), $\overline{C}^S$ and $\overline{C}^A$, average proportional annual change in directed catch, AAV^S and 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.

	“Straw3” OMP-08	Corner point		“Straw3” OMP-08	Corner point
β	0.11767	0.114			
α_{ns}	0.1375	0.245			
α_{ads}	0.275	0.49			
Sardine			Anchovy		
Percentage of times Sardine Exceptional Circumstances are Declared (2008-2027)	3.4%	3.3%	Percentage of times Anchovy Exceptional Circumstances are Declared (2008-2027)	15.2%	16.5%
Percentage of times Sardine Exceptional Circumstances are Declared (2008-2010)	1.6%	1.6%			
$risk_S$	0.179	0.179	$risk_A$	0.243	0.245
$\overline{C}^S$ (2008-2027)	214	210	$\overline{C}^A$ (2008-2027)	179	226
AAV^S (2008-2027)	0.26	0.26	AAV^A (2008-2027)	0.45	0.43
$\overline{C}^S$ (2008-2010)	135	132	$\overline{C}^A$ (2008-2010)	223	279
AAV^S (2008-2010)	0.29	0.29	AAV^A (2008-2010)	0.44	0.42
$\overline{B^S_{2027}/K^S_{non-peak}}$	0.68	0.68	$\overline{B^A_{2027}/K^A}$	0.73	0.67
$\overline{B^S_{2027}/Risk^S}$	10.54	10.55	$\overline{B^A_{2027}/Risk^A}$	1.99	1.86
$\overline{B^S_{2027}/B^S_{2007}}$	5.71	5.71	$\overline{B^A_{2027}/B^A_{2007}}$	1.23	1.14
$\overline{B^S_{\min}/K^S_{non-peak}}$	0.26	0.26	$\overline{B^A_{\min}/K^A}$	0.15	0.13
$\overline{B^S_{\min}/Risk^S}$	1.76	1.77	$\overline{B^A_{\min}/Risk^A}$	0.33	0.31

Table 3. Key summary statistics for the trade-off point for "Straw3" OMP-08 and comparative values under alternative underlying sardine operating model assumptions.

	S_0	$S_{0\_0.5}$	S_{M1}	S_{M2}	S_{M3}	S_{M4}	S_{M5}	S_{bias1}	S_{bias2}
β	0.11767	0.11767	0.11767	0.11767	0.11767	0.11767	0.11767	0.11767	0.11767
α_{ns}	0.1375	0.1375	0.1375	0.1375	0.1375	0.1375	0.1375	0.1375	0.1375
α_{ads}	0.275	0.275	0.275	0.275	0.275	0.275	0.275	0.275	0.275
Percentage of times Sardine Exceptional Circumstances are Declared (2008-2027)	3.4%	3.1%	1.0%	0.1%	2.9%	4.1%	2.9%	3.0%	3.3%
Percentage of times Sardine Exceptional Circumstances are Declared (2008-2010)	1.6%	1.1%	0.3%	0.0%	1.2%	2.6%	1.4%	1.1%	1.0%
Percentage of times Anchovy Exceptional Circumstances are Declared (2008-2027)	15.2%	15.1%	15.1%	15.0%	15.3%	15.2%	15.2%	15.2%	15.1%
$risk_S$	0.179	0.166	0.069	0.012	0.164	0.241	0.173	0.187	0.162
$\overline{C}^S$ (2008-2027)	214	208	225	243	215	218	208	205	233
AAV^S (2008-2027)	0.26	0.26	0.25	0.26	0.25	0.25	0.27	0.25	0.26
$\overline{C}^S$ (2008-2010)	135	133	149	183	135	128	132	124	156
AAV^S (2008-2010)	0.29	0.29	0.29	0.28	0.29	0.30	0.29	0.26	0.32
$\overline{B^S_{2027}/K^S_{non-peak}}$	0.68	0.69	0.71	0.70	0.67	0.67	0.69	0.71	0.63
$\overline{B^S_{2027}/Risk^S}$	10.54	8.82	10.28	10.31	11.83	10.21	8.10	8.85	14.15
$\overline{B^S_{2027}/B^S_{2007}}$	5.71	4.89	4.29	3.02	6.25	6.39	4.39	5.03	6.52
$\overline{B^S_{\min}/K^S_{non-peak}}$	0.26	0.26	0.31	0.37	0.25	0.21	0.26	0.25	0.23
$\overline{B^S_{\min}/Risk^S}$	1.76	1.69	2.10	2.73	1.72	1.57	1.68	1.60	1.90
$risk_A$	0.243	0.236	0.242	0.241	0.242	0.243	0.248	0.243	0.238
$\overline{C}^A$ (2008-2027)	179	179	179	179	179	179	179	179	179
AAV^A (2008-2027)	0.45	0.44	0.45	0.45	0.44	0.45	0.45	0.44	0.45
$\overline{C}^A$ (2008-2010)	223	223	222	221	223	224	223	224	222
AAV^A (2008-2010)	0.44	0.44	0.45	0.46	0.44	0.44	0.44	0.44	0.45
$\overline{B^A_{2027}/K^A}$	0.73	0.73	0.73	0.73	0.74	0.74	0.73	0.74	0.74
$\overline{B^A_{2027}/Risk^A}$	1.99	1.99	1.99	1.99	2.00	2.00	1.99	2.00	1.99
$\overline{B^A_{2027}/B^A_{2007}}$	1.23	1.22	1.22	1.23	1.22	1.23	1.23	1.26	1.23
$\overline{B^A_{\min}/K^A}$	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.14	0.15
$\overline{B^A_{\min}/Risk^A}$	0.33	0.33	0.33	0.33	0.33	0.33	0.33	0.33	0.34

Table 4. Key summary statistics for the trade-off point for "Straw3" OMP-08 and comparative values under alternative underlying anchovy operating model assumptions.

	A_0	A_{M1}	A_{M2}	A_{M3}	A_{kegg1}	A_{kegg2}	A_R	A_{BH}
β	0.11767	0.11767	0.11767	0.11767	0.11767	0.11767	0.11767	0.11767
α_{ns}	0.1375	0.1375	0.1375	0.1375	0.1375	0.1375	0.1375	0.1375
α_{ads}	0.275	0.275	0.275	0.275	0.275	0.275	0.275	0.275
Percentage of times Sardine Exceptional Circumstances are Declared (2008-2027)	3.4%	3.2%	3.3%	3.1%	3.4%	3.2%	5.8%	3.3%
Percentage of times Sardine Exceptional Circumstances are Declared (2008-2010)	1.6%	1.4%	1.5%	1.4%	1.5%	1.4%	1.7%	1.5%
Percentage of times Anchovy Exceptional Circumstances are Declared (2008-2027)	15.2%	13.7%	14.5%	13%	11.1%	19.2%	9.7%	32.4%
$risk_S$	0.179	0.166	0.175	0.166	0.183	0.176	0.277	0.175
$\overline{C}^S$ (2008-2027)	214	216	215	217	214	214	198	216
AAV^S (2008-2027)	0.26	0.26	0.26	0.26	0.26	0.26	0.27	0.26
$\overline{C}^S$ (2008-2010)	135	135	135	135	135	135	133	135
AAV^S (2008-2010)	0.29	0.29	0.29	0.29	0.29	0.29	0.29	0.29
$\overline{B^S_{2027}/K^S_{non-peak}}$	0.68	0.69	0.68	0.69	0.68	0.68	0.60	0.70
$\overline{B^S_{2027}/Risk^S}$	10.54	10.70	10.46	10.75	10.47	10.56	8.77	10.86
$\overline{B^S_{2027}/B^S_{2007}}$	5.71	5.81	5.68	5.84	5.68	5.73	4.73	5.89
$\overline{B^S_{\min}/K^S_{non-peak}}$	0.26	0.27	0.26	0.27	0.26	0.26	0.22	0.26
$\overline{B^S_{\min}/Risk^S}$	1.76	1.80	1.77	1.80	1.77	1.76	1.53	1.78
$risk_A$	0.243	0.253	0.209	0.24	0.161	0.322	0.186	0.484
$\overline{C}^A$ (2008-2027)	179	179	182	179	203	168	199	176
AAV^A (2008-2027)	0.45	0.43	0.44	0.43	0.40	0.47	0.60	0.36
$\overline{C}^A$ (2008-2010)	223	226	221	221	235	217	239	233
AAV^A (2008-2010)	0.44	0.42	0.45	0.43	0.42	0.46	0.62	0.40
$\overline{B^A_{2027}/K^A}$	0.73	0.78	0.74	0.80	0.82	0.69	0.81	0.36
$\overline{B^A_{2027}/Risk^A}$	1.99	1.89	2.12	1.86	4.42	1.60	2.61	4.32
$\overline{B^A_{2027}/B^A_{2007}}$	1.23	1.04	1.64	1.18	2.75	1.13	1.78	2.69
$\overline{B^A_{\min}/K^A}$	0.15	0.15	0.15	0.15	0.16	0.13	0.16	0.06
$\overline{B^A_{\min}/Risk^A}$	0.33	0.32	0.34	0.32	0.46	0.27	0.50	0.42

Table 5. Key summary statistics for the trade-off point for "Straw3" OMP-08 and comparative values under alternative assumptions of poorer sardine recruitment in the near future.

	S_0	$S_{cor0708}$	$S_{rec0708}$
β	0.11767	0.11767	0.11767
α_{ns}	0.1375	0.1375	0.1375
α_{ads}	0.275	0.275	0.275
Percentage of times Sardine Exceptional Circumstances are Declared (2008-2027)	3.4%	5.4%	7.9%
Percentage of times Sardine Exceptional Circumstances are Declared (2008-2010)	1.6%	2.3%	6.2%
Percentage of times Anchovy Exceptional Circumstances are Declared (2008-2027)	15.2%	15.4%	15.6%
$risk_S$	0.179	0.265	0.489
$\overline{C}^S$ (2008-2027)	214	196	174
AAV^S (2008-2027)	0.26	0.27	0.28
$\overline{C}^S$ (2008-2010)	135	125	111
AAV^S (2008-2010)	0.29	0.28	0.32
$\overline{B^S_{2027}/K^S_{non-peak}}$	0.68	0.65	0.62
$\overline{B^S_{2027}/Risk^S}$	10.54	9.33	8.01
$\overline{B^S_{2027}/B^S_{2007}}$	5.71	5.03	4.29
$\overline{B^S_{\min}/K^S_{non-peak}}$	0.26	0.23	0.17
$\overline{B^S_{\min}/Risk^S}$	1.76	1.52	1.08
$risk_A$	0.243	0.241	0.250
$\overline{C}^A$ (2008-2027)	179	180	182
AAV^A (2008-2027)	0.45	0.44	0.43
$\overline{C}^A$ (2008-2010)	223	225	230
AAV^A (2008-2010)	0.44	0.43	0.42
$\overline{B^A_{2027}/K^A}$	0.73	0.73	0.73
$\overline{B^A_{2027}/Risk^A}$	1.99	1.99	1.99
$\overline{B^A_{2027}/B^A_{2007}}$	1.23	1.22	1.22
$\overline{B^A_{\min}/K^A}$	0.15	0.14	0.14
$\overline{B^A_{\min}/Risk^A}$	0.33	0.33	0.33

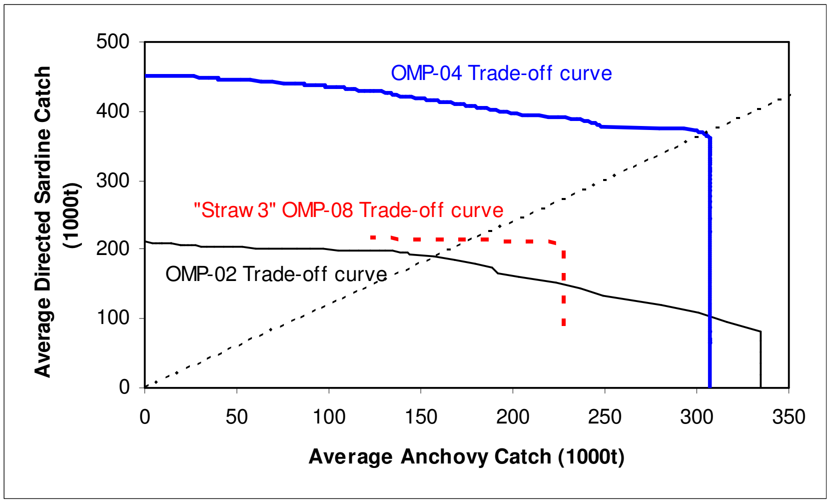

Figure 1: A comparison of trade-off curves for previous and new OMPs. Note that the trade-off curve for the new OMP has been computed for a changed sardine risk level: $risk_S$<0.18 instead of <0.1 as for OMP-04 and $risk_A$<0.25 instead of <0.3 for OMP-04.

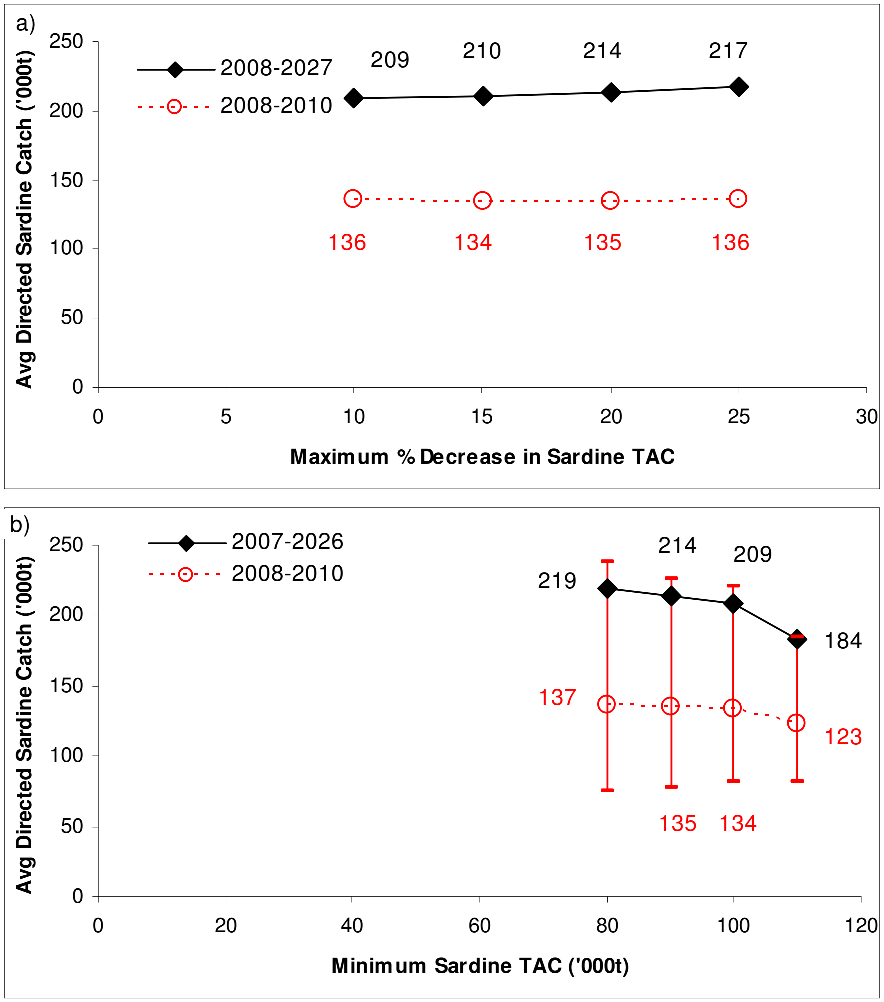

Figure 2. The 2008 – 2027 and 2008-2010 average directed sardine catch under "Straw3" OMP-08 and alternative constraints a) c^S_{mxdn} and b) c^S_{mntac}. The 95% probability intervals around the average 2008 – 2010 catch are also given in b).

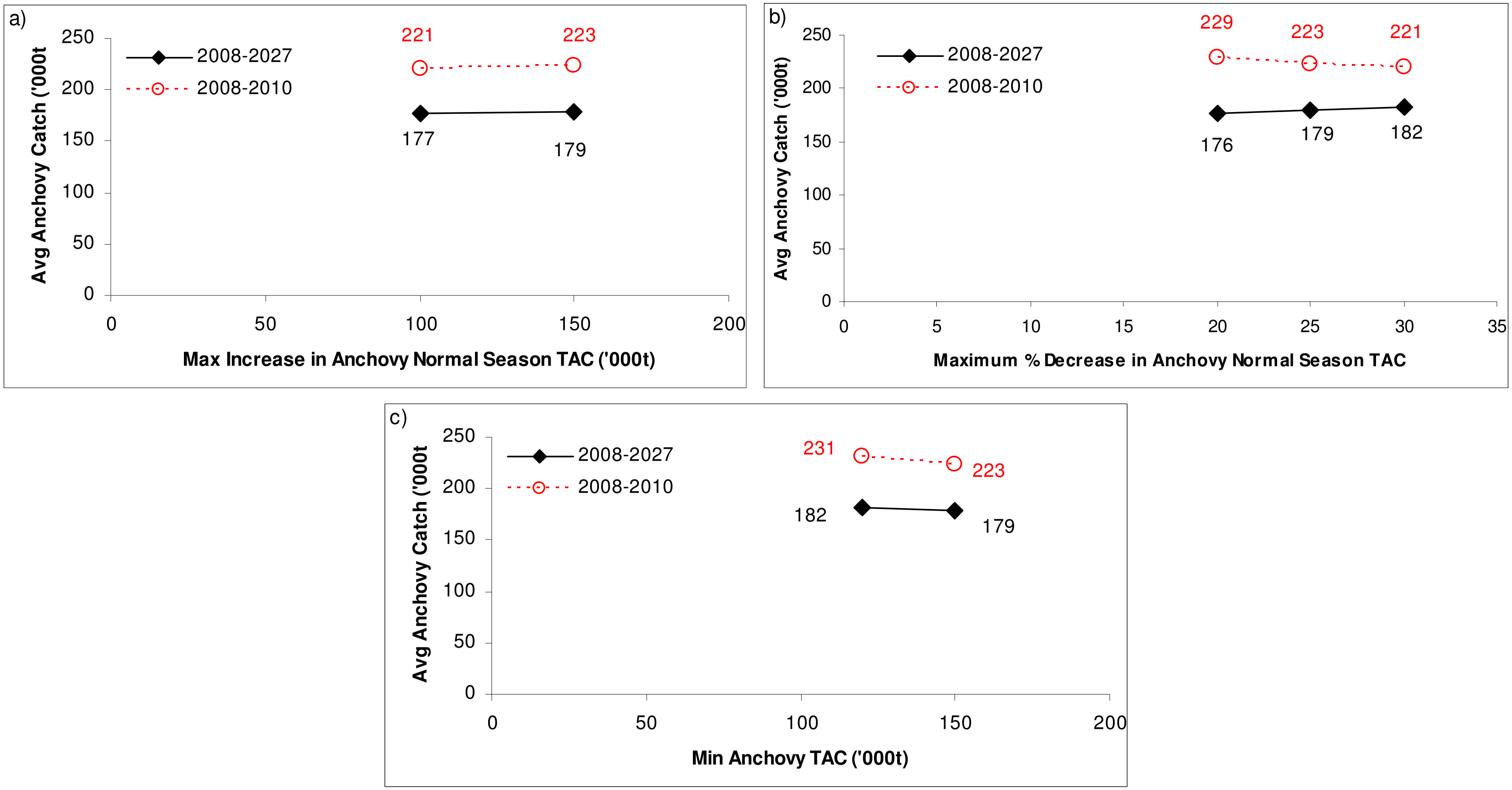

Figure 3. The 2008 – 2027 and 2008 – 2010 average total anchovy catch under "Straw3" OMP-08 and alternative constraints a) $c^{ns,A}_{mxinc}$*, b)* c^{A}_{mxdn} *and c)* c^{A}_{mntac}.

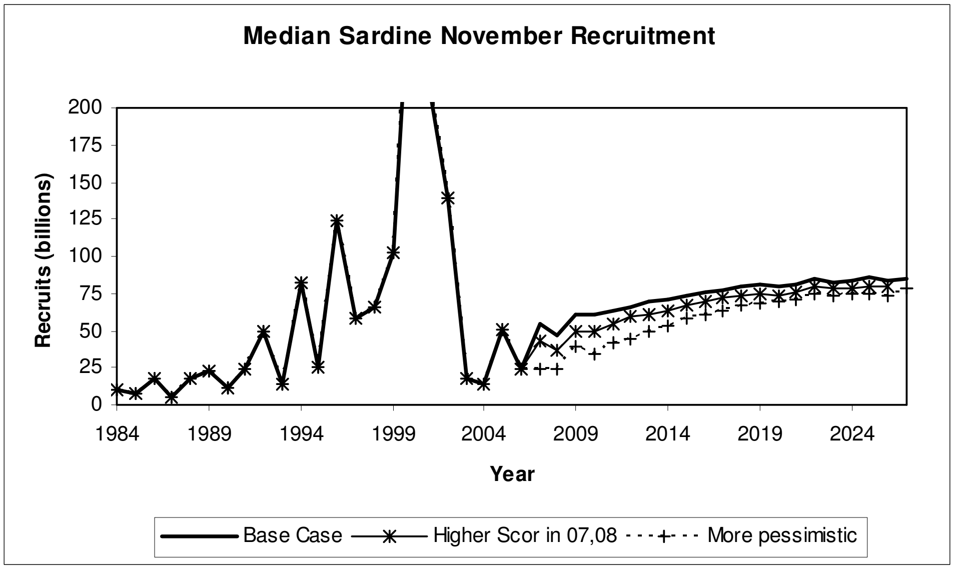

Figure 4. Median sardine November recruitment under the base case hypothesis (S_0), and the two poorer sardine recruitment scenarios ($S_{cor0708}$ and $S_{rec0708}$).

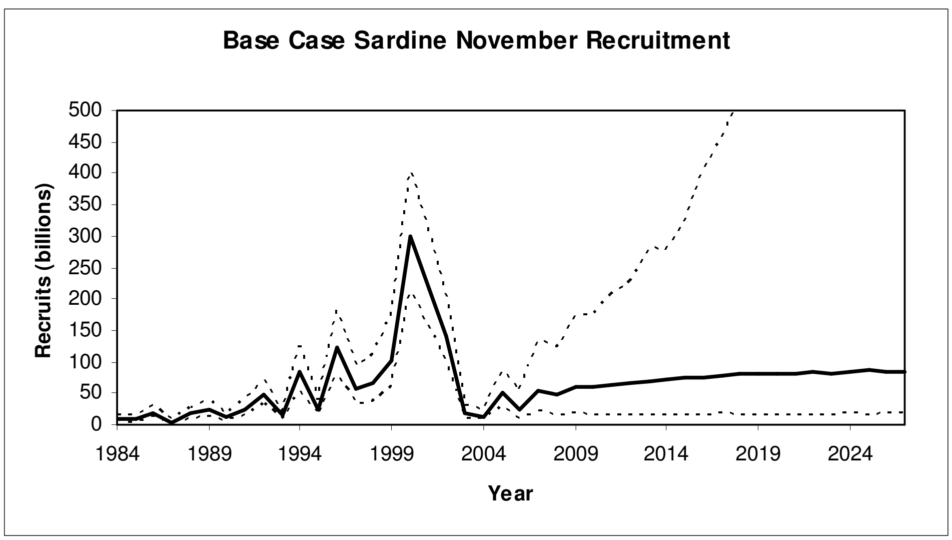

Figure 5. Median and 90% probability intervals around the sardine November recruitment under the base case hypothesis (S_0).

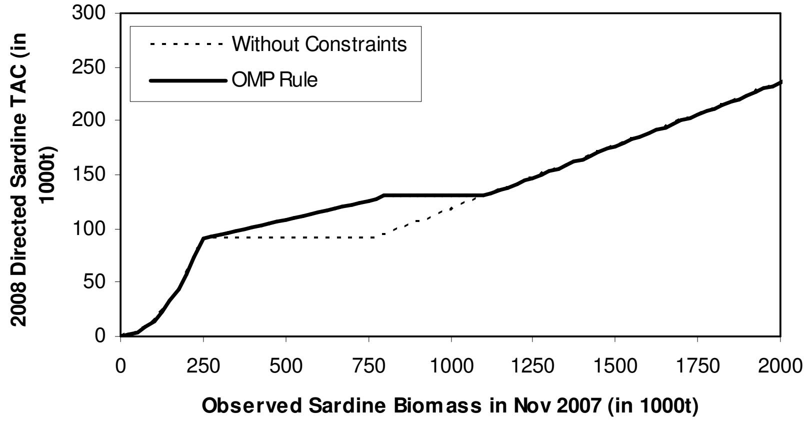

Figure 6. The rule to be applied under "Straw3" OMP-08 to calculate directed sardine TAC in 2008, dependent on the observed sardine biomass in November 2007.

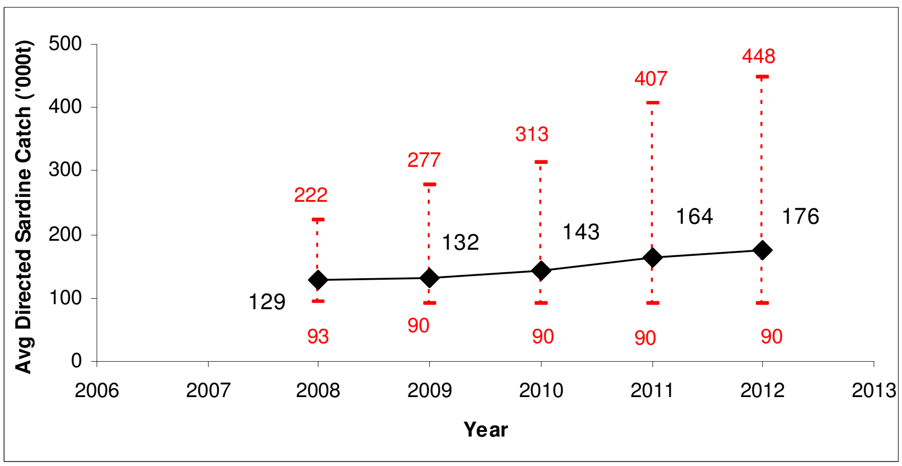

Figure 7. The projected average and 95% probability intervals of directed sardine catch over the next 5 years, under "Straw3" OMP-08.

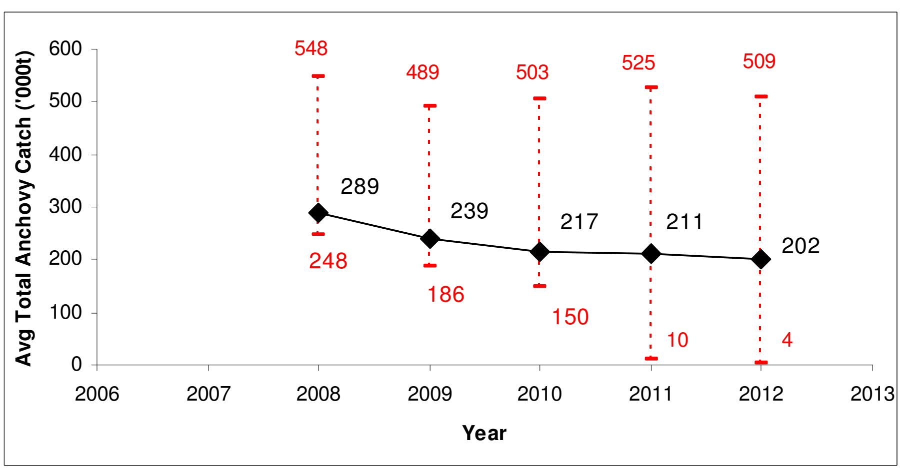

Figure 8. The projected average and 95% probability intervals of total anchovy catch over the next 5 years, under "Straw3" OMP-08.

Appendix A: The Fishery Management System for OMP-08

In addition 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.

OMP-04 (Harvest Control Model)

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.

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: $$TAC_y^S = \beta\, B_{y-1,Nov}^{obs,S} \qquad \text{(A.1)}$$

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

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

Subject to:
$$\begin{array}{ll} \max\left\{\left(1-c^A_{mxdn}\right)TAC^{2,A}_{y-1}\ ;c^A_{mntac}\right\} \le\ TAC^{1,A}_y\ \le\ c^A_{mxtac} & TAC^{2,A}_{y-1} \le c^A_{tier} \\ \left(1-c^A_{mxdn}\right)c^A_{tier}\ \le\ TAC^{1,A}_y\ \le\ c^A_{mxtac} & TAC^{2,A}_{y-1} > c^A_{tier} \end{array} \qquad \text{(A.4)}$$

Initial sardine TAB:
$$TAB^{1,S}_y = \gamma_y\ TAC^{1,A}_y\ + TAB^S_{rh} \qquad \text{(A.5)}$$

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

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.

$B^{obs,S}_{y,N}$ - 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 are simulated using equation (A.62).

$B^{obs,A}_{y,N}$ - 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 are simulated using equation (A.62).

$\overline{B}^A_{Nov}$ - 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^S_{rh} - 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^S_{mxdn} - the maximum proportional amount by which the directed sardine TAC can be reduced from one year to the next.

c^A_{mxdn} - 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 $TAC^{2,A}_{y-1}$, not $TAC^{3,A}_{y-1}$ - see below for formulae for these quantities).

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

c^{A}_{mntac} - 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 is 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.

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

Subject to:

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

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

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

Note that by construction $TAB_y^{2,S} \ge TAB_y^{1,S}$ as $\lambda \ge \gamma_y$ and $TAC_y^{2,A} \ge TAC_y^{1,A}$. 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; during the testing of OMP-08, these values are simulated using equations (A.32) and (A.33).

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:

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

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:

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

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

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

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

In the above equation we have

$C^{A}_{y,0bs}$ - 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 (A.25).

t^{A}_{y} - 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 $TAC^{3,A}_{y} - TAC^{2,A}_{y}$ and $TAB^{3,S}_{y} - TAB^{2,S}_{y}$ respectively.

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

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

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

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.

Exceptional Circumstances

Exceptional circumstances rules are applied on 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.

Sardine directed TAC

Exceptional Circumstances for the sardine directed TAC apply if:

$B^{obs,S}_{y-1,N} < B^S_{ec}$

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

$$TAC^S_y = \begin{cases} 0 & \text{if } \dfrac{B^{obs,S}_{y-1,N}}{B^S_{ec}} < x^S \\ TAC^{S*}_y \left(\dfrac{\dfrac{B^{obs,S}_{y-1,N}}{B^S_{ec}} - x^S}{1-x^S} \right)^2 & \text{if } x^S < \dfrac{B^{obs,S}_{y-1,N}}{B^S_{ec}} < 1 \end{cases} \tag{A.15}$$

where TAC^{S*}_y is calculated using equation (A.1).

Initial Anchovy TAC

Exceptional Circumstances for the initial anchovy TAC apply if

$B^{obs,A}_{y-1,N} < B^A_{ec}$

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

$$TAC^{1,A}_y = \begin{cases} 0 & \text{if } \dfrac{B^{obs,A}_{y-1,N}}{B^A_{ec}} < x^A \\ TAC^{1,A*}_y \left(\dfrac{\dfrac{B^{obs,A}_{y-1,N}}{B^A_{ec}} - x^A}{1-x^A} \right)^2 & \text{if } x^A < \dfrac{B^{obs,A}_{y-1,N}}{B^A_{ec}} < 1 \end{cases} \tag{A.16}$$

where $TAC^{1,A*}_y$ is calculated using equation (A.3).

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 ($B^A_{y,proj}$) for the forthcoming November survey, and hence have a basis for invoking Exceptional Circumstances, if necessary. Given $TAC^{2,A*}_y$ from equation (A.6), a projected anchovy biomass, $B^A_{y,proj0}$, is calculated as follows:

$$B^A_{y,proj0} = \text{max of}\left\{0; \left(N^A_{y,rec} - \left[\frac{TAC^{2,A*}_y}{\overline{w}^A_{0c}} - C^A_{y,1} - C^A_{y,0bs}\right]\right) e^{-5.5*1.2/12}\overline{w}^A_1\right\}. \quad \text{(A. 17)}$$

Calculate $B^A_{y,proj}$ as follows:

$$B^A_{y,proj} = \left(\frac{B^{obs,A}_{y-1,N}}{\overline{w}^A_1} e^{-5*0.9/12} - C^A_{y,1}\right) e^{-7\times 0.9/12}\overline{w}^A_2 \quad + \quad B^A_{y,proj0} \quad \text{(A. 18)}$$

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

$$\theta = \frac{[B^A_{ec} - (B^A_{y,proj} - B^A_{y,proj0})]}{\overline{w}^A_1} e^{5.5*1.2/12} \quad + \quad \frac{TAC^{2,A*}_y}{\overline{w}^A_{0c}} - C^A_{y,1} - C^A_{y,0bs} \quad \text{(A. 19)}$$

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

$$N^{A*}_{y-1,rec0} = (\theta\, e^{0.5(6+t^A_y)1.2/12} + C^A_{y,0bs})\, e^{[0.5(6+t^A_y)]1.2/12} \quad \text{(A.20)}$$

or equation (A.11) during simulation testing:

$$N^{A*}_{y-1,rec0} = (\theta\, e^{3.25\times 1.2/12} + C^A_{y,0bs})\, e^{3.25\times 1.2/12} \quad \text{(A. 21)}$$

The revised anchovy TAC is calculated by reducing $TAC^{2,A*}_y$ by the ratio (squared) of $TAC^{2,A}_y$ calculated with the annual recruitment for year y to $TAC^{2,A}_y$ 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:

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

(A. 22)

Final Anchovy TAC

The same procedure as for the revised anchovy TAC is followed, except that equation (A.12) is used to calculate $TAC^{3,A*}_y$, which then replaces $TAC^{2,A*}_y$ in equations (A.17), (A.19) and (A.22) above. Furthermore, $TAC^{2,A}_y$ replaces $TAC^{1,A}_y$ in equation (A.22) above.

Implementation model

Given the TAC / TABs output from OMP-07, 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, $\overline{w}_{ac}^{i}$, for $i = A, S$ are given in Table B.3.

Assumptions made during the implementation include:

i) The initial normal season anchovy TAC, $TAC_y^{1,A}$, 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

$$C_{y,a}^{S} = N_{y-1,a}^{S} S_a^S F_y e^{-M_{ad}^{S}/2}, \qquad a = 1,...,5+ \tag{A.23}$$

where $$F_y = \frac{TAC_y^S + TAB_{rh}^S}{\left(\sum_{a=1}^{5+} N_{y-1,a}^{S} S_a^S \overline{w}_{ac}^{S}\right) e^{-M_{ad}^{S}/2}}.$$

The fishing selectivities-at-age, $S_1^S = 0.43$, $S_2^S = S_3^S = S_4^S = S_5^S = 1$ 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 $TAC_y^{1,A}$ 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:

$$C_{y,1}^{A} = \frac{1}{\overline{w}_{1c}^{A}} \left(0.36 \times TAC_y^{1,A}\right). \tag{A.24}$$

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:

$$C_{y,0bs}^{A} = 0.28 \frac{TAC_y^{1,A}}{\overline{w}_{0c}^{A}} \tag{A.25}$$

and for the normal season as a whole:

$$C_{y,0}^{A*} = \frac{1}{\overline{w}_{0c}^{A}} \left(TAC_y^{2,A} - C_{y,1}^{A} \times \overline{w}_{1c}^{A}\right) \tag{A.26}$$

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:

$$C^S_{y,0bs} = k_{jan:may} \frac{N^S_{y-1,0}}{N^A_{y-1,0}} e^{\sigma_{jan:may}\eta_{y,jan:may}} \frac{(C^A_{y,0bs}\overline{w}^A_{0c} + C^A_{y,1}\overline{w}^A_{1c})}{\overline{w}^S_{0c}}, \qquad \text{where } \eta_{y,jan:may} \sim N(0;1) \quad \text{(A.27)}$$

and $k_{jan::may}$ and $\sigma_{jan:may}$ are given in equations (A.28) and (A.30) respectively; see (A.25) above for $C^A_{y,0bs}$.

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 A.27). 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:

$$k_{jan:may} = \exp\left\{ \sum_{y=1987}^{2006} \left[\ln(C^{S,byc}_{y,jan:may} / C^A_{y,jan:may}) - \ln(N^S_{y-1,0} / N^A_{y-1,0}) \right] \Big/ \sum_{y=1987}^{2006} 1 \right\} \quad \text{(A.28)}$$

and

$$\varepsilon'_{y,jan:may} = \ln(C^{S,byc}_{y,jan:may} / C^A_{y,jan:may}) - \ln(k_{jan:may} N^S_{y-1,0} / N^A_{y-1,0}) \qquad y = 1987,...,2006 \quad \text{(A.29)}$$

where $C^{S,byc}_{y,jan:may}$ and $C^A_{y,jan:may}$ are given in Table B.2 and $N^i_{y,0}$ 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:

$$\sigma_{jan:may} = \sqrt{\sum_{y=1987}^{2006} \left(\varepsilon'_{y,jan:may}\right)^2 \Big/ \sum_{y=1987}^{2006} 1}\,. \quad \text{(A. 30)}$$

Annual sardine 0-year-old catch by number

$$C^{S*}_{y,0} = \frac{1}{\overline{w}^S_{0c}} \left(\lambda\, TAC^{1,A}_y + r_y \left(TAC^{2,A}_y - TAC^{1,A}_y \right) \right), \qquad \text{where } \lambda = \max\{\gamma_y, r_y\} \quad \text{(A.31)}$$

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:

$$r_{y,sur} = k_{sur} \frac{N_{y,r}^{obs,S}}{N_{y,r}^{obs,A}}, \qquad \text{(A.32)}$$

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

$$r_{y,com} = k_{may} \frac{N_{y,r}^{S}}{N_{y,r}^{A}} e^{\sigma_{may}\,\varepsilon_{y,may}}. \qquad \text{(A.33)}$$

where $\varepsilon_{y,may} = \rho_{may}\eta_{y,jan:may} + \sqrt{1-(\rho_{may})^2}\,\eta_{y,may}$, where $\eta_{y,may} \sim N(0;1)$ (A.34)

Here we have

$N_{y,r}^{obs,S/A}$ - the simulated survey observations, from equation (A.63).

$N_{y,r}^{S/A}$ - the model-predicted recruitment, projected forward to the time of the survey, from equation (A.64).

k_{may} - the constant of proportionality from equation (A.35).

σ_{may} - the residual standard deviation from equation (A.37).

ρ_{may} - the correlation coefficient from equation (A.38).

$\eta_{y,jan:may}$ - from equation (A.27).

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

For equation (A.32), 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.1, 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 A.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 (A.32)).

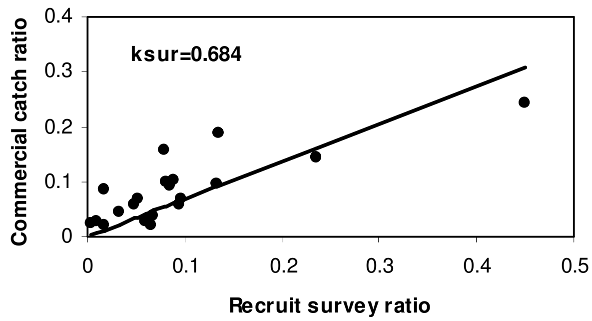

Figure A.1. Relationship between the sardine to anchovy ratio in the recruit survey ($N^{obs,S}_{y,r} / N^{obs,A}_{y,r}$ *), and the sardine bycatch to anchovy ratio in commercial catches in May (* $C^{S,byc}_{y,may} / C^{A}_{y,may}$ *) for 1987-2006. The slope of the linear regression forced through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

For equation (A.33), the constant of proportionality estimated and the associated time series of residuals are as follows:

$$k_m = \exp\left\{ \sum_{y=1987}^{2006} \left[\ln(C^{S,byc}_{y,m} / C^{A}_{y,m}) - \ln(N^{S}_{y,r} / N^{A}_{y,r}) \right] \Bigg/ \sum_{y=1987}^{2006} 1 \right\}, \qquad m = may \quad \text{(A.35)}$$

and

$$\varepsilon'_{y,m} = \ln(C^{S,byc}_{y,m} / C^{A}_{y,m}) - \ln(k_m N^{S}_{y,r} / N^{A}_{y,r}) \qquad y = 1987,...,2006 \text{ and } m = may \quad \text{(A.36)}$$

where $C^{S,byc}_{y,m}$ and $C^{A}_{y,m}$ are from Table B.2, and $N^{i}_{y,r}$ 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 (A.64)). The associated residual standard deviation is:

$$\sigma_m = \sqrt{\sum_{y=1987}^{2006} (\varepsilon'_{y,m})^2 \Bigg/ \sum_{y=1987}^{2006} 1}, \qquad m = may \quad \text{(A.37)}$$

A correlation coefficient between the January to May and May residuals, for use in equation (A.34) above, is then calculated by:

$$\rho_{may} = \frac{\sum_{y=1987}^{2006} \varepsilon'_{y,jan:may} \varepsilon'_{y,may}}{\left(\sum_{y=1987}^{2006} 1 \right) \sigma_{jan:may} \sigma_{may}} \qquad \text{(A.38)}$$

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

$C^{S*}_{y,0}$ in equation (A.31) 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 A.2 (a repeat of Figure A.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 (A.49)), in order to reflect the closure of the anchovy fishery once the sardine bycatch allowance linked to anchovy is reached.

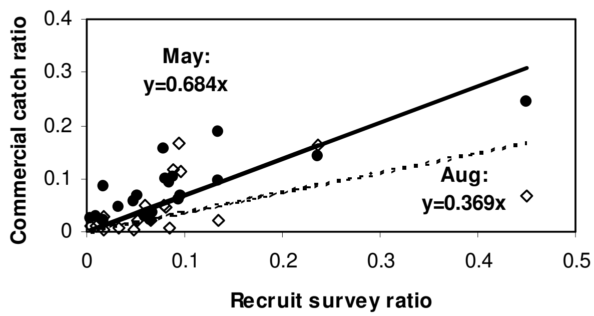

Figure A.2. A repeat of Figure A.1, but with commercial catch data for August ($C^{S,byc}_{y,aug} / C^A_{y,aug}$ *) added*

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 (A.64).

The constants of proportionality, k_{jun}, k_{jul} and k_{aug} are calculated using equation (A.35), $\varepsilon'_{y,jun}$, $\varepsilon'_{y,jul}$ and $\varepsilon'_{y,aug}$ are calculated using equation (A.36) and σ_{jun}, σ_{jul} and σ_{aug} are calculated using equation (A.37), 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 (A.38). For example, for *m*=*jul* and *j*=2, and Y clarified in parentheses below:

$$\rho_{jul,2} = \frac{\sum_{y \in Y} \varepsilon_{y,may} \varepsilon_{y,jul}}{\left(\sum_{y \in Y} 1\right) \sigma_{may} \sigma_{jul}} \tag{A.39}$$

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}:

$$g = \sum_{m=jun,jul,aug} [\rho_{byc} - \rho_{m,1}]^2 + \sum_{m=jul,aug} [(\rho_{byc})^2 - \rho_{m,2}]^2 + [(\rho_{byc})^3 - \rho_{aug,3}]^2 \tag{A.40}$$

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

$$3(\rho_{byc})^5 + 4(\rho_{byc})^3 - 3\rho_{ag,3}(\rho_{byc})^2 + [3 - 2\sum_{m=jul,aug} \rho_{m,2}]\rho_{byc} - \sum_{m=jun,jul,aug} \rho_{m,1} = 0 \tag{A.41}$$

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

Adjusting $C^{S*}_{y,0}$

Between 1999 and 2006, the sardine bycatch from January to 31st May has been 1.404 times that from January to mid-May[4]. Adjusting the sardine bycatch prior to the survey to take account of this additional bycatch by the end of May, equation (A.31) is modified as follows:

$$C^{S**}_{y,0} = 1.404 \times C^{S}_{y,0bs} + \frac{1}{\overline{w}^{S}_{0c}} \left(r_{y,jun} C^{A}_{y,jun} + r_{y,jul} C^{A}_{y,jul} + r_{y,aug} C^{A}_{y,aug} \right) \tag{A.42}$$

The sardine bycatch to anchovy ratios, $r_{y,m}$, are simulated in a similar way to $r_{y,com}$ in equation (A.33) as follows:

$$r_{y,m} = k_m \frac{N^{S}_{y,r}}{N^{A}_{y,r}} e^{\sigma_m \varepsilon_{y,m}}, \qquad m = jun, jul, aug \tag{A.43}$$

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

where k_m and σ_m are from equations (A.35) and (A.37), summing over years for which anchovy directed catch is non-zero, and:

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

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

$$\varepsilon_{y,aug} = (\rho_{byc})^3\varepsilon_{y,may} + (\rho_{byc})^2\sqrt{1-(\rho_{byc})^2}\,\eta_{y,jun} + \rho_{byc}\sqrt{1-(\rho_{byc})^2}\,\eta_{y,jul} + \sqrt{1-(\rho_{byc})^2}\,\eta_{y,aug} \quad \text{(A.44)}$$

The above equations reflects the correlative relationships between successive months, where ρ_{byc} is from equation (A.41), $\varepsilon_{y,may}$ from equation (A.36), and

$$\eta_{y,m} \sim N(0;1). \qquad m = jun,\ jul,\ aug \quad \text{(A.45)}$$

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 $TAC_y^{1,A}$ is caught by the end of May, and given the assumption that $TAC_y^{1,A}$ is caught by the end of June, the anchovy catches in equation (A.42), $C_{y,m}^A$ ($m = jun, jul$ and aug), are derived as follows (in tonnes):

$$C_{y,jun}^A = 0.39 \times TAC_y^{1,A} \quad \text{(A.46)}$$

$$C_{y,jul}^A = p_{jul}(TAC_y^{2,A} - TAC_y^{1,A}) \quad \text{(A.47)}$$

$$C_{y,aug}^A = (1-p_{jul})(TAC_y^{2,A} - TAC_y^{1,A}) \quad \text{(A.48)}$$

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

The consequent adjustment to $C_{y,0}^{A*}$ (given by equation (A.26)) when $C_{y,0}^{S**}\overline{w}_{0c}^S > TAB_y^{2,S} - TAB_{rh}^S$, where $C_{y,0}^{S**}$ is given by equation (A.42), assumes that the anchovy TAC is taken at the same rate as the sardine bycatch allowance, and therefore we have:

$$C_{y,0}^{A**} = \begin{cases} C_{y,0}^{A*} & \text{if} \quad C_{y,0}^{S**}\overline{w}_{0c}^S \le TAB_y^{2,S} - TAB_{rh}^S \\ \dfrac{1}{\overline{w}_{0c}^A}\left(TAC_y^{2,A}\left[\dfrac{TAB_y^{2,S} - TAB_{rh}^S}{C_{y,0}^{S**}\overline{w}_{0c}^S}\right] - C_{y,1}^{A*}\overline{w}_{1c}^A\right) & \text{if} \quad C_{y,0}^{S**}\overline{w}_{0c}^S > TAB_y^{2,S} - TAB_{rh}^S \end{cases} \quad \text{(A.49)}$$

and

$$C_{y,0}^{S**} = \min\left\{1.404 \times C_{y,0bs}^S + \frac{1}{\overline{w}_{0c}^S}\left(r_{y,jun}C_{y,jun}^A + r_{r,jul}C_{y,jul}^A + r_{y,aug}C_{y,aug}^A\right), \frac{TAB_y^{2,S} - TAB_{rh}^S}{\overline{w}_{0c}^S}\right\} \quad \text{(A.50)}$$

Additional sub-season

A final adjustment is made to $C_{y,0}^{S**}$ and $C_{y,0}^{A**}$, given by equations (A.50) and (A.49) respectively, to reflect the catches taken in the additional sub-season, as follows:

$$C_{y,0}^{S} = C_{y,0}^{S**} + \frac{1}{\overline{w}_{0c}^{S}} \min\left\{TAB_{ads}^{S}; \lambda\left(TAC_{y}^{3,A} - TAC_{y}^{2,A}\right)\right\} \quad \text{(A.51)}$$

and

$$C_{y,0}^{A} = C_{y,0}^{A**} + \frac{1}{\overline{w}_{0c}^{A}} \left(TAC_{y}^{3,A} - TAC_{y}^{2,A}\right) \quad \text{(A.52)}$$

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, $C_{y,a}^{i}$, $i = S, A$, the stock assessment model projects numbers-at-age and spawning biomass at the beginning of November in $y = 2007,...,2026$ as follows:

Sardine:

$$N_{y,a}^{S} = \left(N_{y-1,a-1}^{S} \mathrm{e}^{-M_{ad}^{S}/2} - C_{y,a-1}^{S}\right)\mathrm{e}^{-M_{ad}^{S}/2} \qquad a = 1,...,4$$

$$N_{y,5+}^{S} = \left(N_{y-1,4}^{S} \mathrm{e}^{-M_{ad}^{S}/2} - C_{y,4}^{S}\right)\mathrm{e}^{-M_{ad}^{S}/2} + \left(N_{y-1,5+}^{S} \mathrm{e}^{-M_{ad}^{S}/2} - C_{y,5+}^{S}\right)\mathrm{e}^{-M_{ad}^{S}/2}$$

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

$$SSB_{y,N}^{S} = \sum_{a=2}^{5+} N_{y,a}^{S} \overline{w}_{a}^{S} \quad \text{(A.53)}$$

Anchovy:

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

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

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

$$N^A_{y,4+} = N^A_{y-1,3}\, \mathrm{e}^{-M^A_{ad}} + N^A_{y-1,4+} e^{-M^A_{ad}}$$

$$B^A_{y,N} = SSB^A_{y,N} = \sum_{a=1}^{4+} N^A_{y,a} \overline{w}^A_a \qquad \text{(A.54)}$$

The average weights-at-age from the historic November spawner biomass surveys, $\overline{w}^i_a$, are given in Table B.3. The juvenile, M^i_j, and adult, M^i_{ad}, 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 $f(SSB^i_{y,N})$ denote the stock-recruitment curve of the chosen model, with parameters a^i and b^i, then future recruitment $N^i_{y,0}$, $i = S, A$, is assumed to be log-normally distributed about a stock-recruit relationship as follows:

$$N^i_{y,0} = f(SSB^i_{y,N})\, \mathrm{e}^{\varepsilon^i_y \sigma^i_r} \qquad \text{(A.55)}$$

where

$$\varepsilon^i_y = s^i_{cor}\varepsilon^i_{y-1} + \sqrt{1-(s^i_{cor})^2}\, \omega^i_y, \qquad \text{where } \omega^i_y \sim N(0;1) \text{ and } y = 2007,...,2027$$

$N^i_{2006,0}$, $i = S, A$ 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^i_r, correlation parameter s^i_{cor} and standardised recruitment residual for November 2006, ε^i_{2006}, are output from the stock assessment models (note a different notation for ε^i_{2006} is used in Cunningham and Butterworth 2007a,b, viz η^i_{2006}).

<u>Observation Model</u>

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 ($i = S, A$):

$$\varepsilon^i_{y,N} = \ln B^{obs,i}_{y,N} - \ln(k^i_N B^i_{y,N}) \qquad y = 1984,...,2006 \quad \text{(A.56)}$$

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:

$$\sigma^{i}_{Nov} = \sqrt{\sum_{y=1984}^{2006} \left(\varepsilon^{i}_{y,N}\right)^2 \Big/ \sum_{y=1984}^{2006} 1} . \tag{A.57}$$

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

$$\rho_{Nov} = \frac{\sum_{y=1984}^{2006} \varepsilon^{S}_{y,N} \varepsilon^{A}_{y,N}}{\left(\sum_{y=1984}^{2006} 1\right) \sigma^{S}_{Nov} \sigma^{A}_{Nov}} . \tag{A.58}$$

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

$$\varepsilon^{i}_{y,r} = \ln N^{obs,i}_{y,r} - \ln(k^{i}_{r} N^{i}_{y,r}) \qquad y = 1985,...,2006 \tag{A.59}$$

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:

$$\sigma^{A}_{rec} = \sqrt{\sum_{y=1985}^{2006} \left(\varepsilon^{i}_{y,r}\right)^2 \Big/ \sum_{y=1985}^{2006} 1} \tag{A.60}$$

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

$$\rho_{rec} = \frac{\sum_{y=1985}^{2006} \varepsilon^{S}_{y,r} \varepsilon^{A}_{y,r}}{\left(\sum_{y=1985}^{2006} 1\right) \sigma^{S}_{rec} \sigma^{A}_{rec}} . \tag{A.61}$$

Simulating survey data

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

$$B_{y,N}^{obs,i} = k_N^i B_{y,N}^i e^{\varepsilon_{y,Nov}^i}, \tag{A.62}$$

where $\varepsilon_{y,Nov}^S = \eta_{y,Nov}^S \tilde{\sigma}_{Nov}^S$, where $\eta_{y,Nov}^S \sim N(0;1)$

and $\varepsilon_{y,Nov}^A = \left(\rho_{Nov}\eta_{y,Nov}^S + \sqrt{1-(\rho_{Nov})^2}\,\eta_{y,Nov}^A\right)\tilde{\sigma}_{Nov}^A$, where $\eta_{y,Nov}^A \sim N(0;1)$

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

$$N_{y,r}^{obs,i} = k_r^i N_{y,r}^i e^{\varepsilon_{y,rec}^i}, \tag{A.63}$$

where $\varepsilon_{y,rec}^S = \eta_{y,rec}^S \tilde{\sigma}_{rec}^S$, where $\eta_{y,rec}^S \sim N(0;1)$

and $\varepsilon_{y,rec}^A = \left(\rho_{rec}\eta_{y,rec}^S + \sqrt{1-(\rho_{rec})^2}\,\eta_{y,rec}^A\right)\tilde{\sigma}_{rec}^A$, where $\eta_{y,rec}^A \sim N(0;1)$.

Here $\tilde{\sigma}_{rec}^S = \max\left(0.5610, \sqrt{0.1592 + \frac{0.3434}{N_{y,r}^S}}\right)$ and $\tilde{\sigma}_{rec}^A = \max\left(0.2177, \sqrt{0.0319 + \frac{0.3678}{N_{y,r}^A}}\right)$ 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

$$N_{y,r}^S = (N_{y-1,0}^S e^{-3.25 M_j^S/12} - C_{y,0bs}^S) e^{-3.25 M_j^S/12}$$

$$N_{y,r}^A = (N_{y-1,0}^A e^{-3.25 M_j^A/12} - C_{y,0bs}^A) e^{-3.25 M_j^A/12} \tag{A.64}$$

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

<u>Assumptions made for 2007</u>

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

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

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

$TAC^{3,A}_{2007} = TAC^{2,A}_{2007} + 150.000$, $TAB^{3,S}_{2007} = TAB^{2,S}_{2007} + 2$

ii) The ratio of juvenile sardine to anchovy in the May survey and commercial catches have been observed and thus equations (A.32) and (A.33) 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 (A.63) 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 (A.55)), but rather back-calculated from the observed May 2007 recruitment as follows:

$$N'^{S}_{2007,r} = \frac{1}{k^{S}_{r}} N^{obs,S}_{2007,r} e^{-\varepsilon^{S}_{2007,rec}} \quad \text{(from equation (A.63))}$$

$$N'^{A}_{2007,r} = \frac{1}{k^{A}_{r}} N^{obs,A}_{2007,r} e^{-\varepsilon^{A}_{2007,rec}} \quad \text{(from equation (A.63))}$$

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

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

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 $C'^{S}_{2007,0bs} = 0.28$ 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 (A.64) 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 (A.25) and (A.27) 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 $\varepsilon^{i}_{2006} \sim N\left(\frac{\frac{\tilde{\mu}^{i}}{\left(\tilde{\sigma}^{i}\right)^{2}} + \frac{0}{1}}{\frac{1}{\left(\tilde{\sigma}^{i}\right)^{2}} + \frac{1}{1}}, \frac{1}{\left(\tilde{\sigma}^{i}\right)^{2}} + \frac{1}{1}\right)$

Appendix B: Tables of Input Data to the SA Pelagic Fishery Management System

Table B.1. Historic observed sardine and anchovy recruitment (in billions).

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

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 $C^{S,by}_{y,aug} \big/ C^{A}_{y,aug}$ could not be used in these cases.

Table B.3. 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		

Appendix C: Further Robustness Tests for the Anchovy Assessment

Cunningham and Butterworth (2007a) did not report results for the posterior distributions from the robustness tests A_R (Ricker stock-recruitment curve) or A_{BH} (Beverton Holt stock-recruitment curve) and there was a typo in the results for A_{M3} (alternative natural mortality: $M_j^A = 1.5$ and $M_{ad}^A = 1.2$). These are given in Table C.1 below.

Table C.1. The MCMC chain length, thinning and burn-in used to get a sample from the posterior distribution for the robustness tests. The posterior means and CVs of key model parameters and outputs are also shown.

	A_0		A_{M3}		A_{BH}		A_R	
Total chain length	20 000 000		20 000 000		50 000 000		50 000 000	
Thinning	1 000		1 000		2 000		2 000	
Chain excluded (eg for burn-in)	1 000 000		11000 000		Only used samples from 22-24 000 000		20 000 000 (and excluded after 38 000 000)	
Length of chain used for posterior	19 000		9 000		1 000		9 000	
Parameter	Mean	CV	Mean	CV	Mean	CV	Mean	CV
k_N^A	1.20	0.14	1.21	0.14	1.18	0.15	1.22	0.14
k_R^A	1.31	0.19	0.87	0.19	1.29	0.19	1.34	0.19
k_p^A	0.93	0.06	0.86	0.05	0.94	0.06	0.93	0.07
$(\lambda_r^A)^2$	0.376	0.49	0.244	0.50	0.307	0.43	0.411	0.50
$N_{2006,1}^A$	54.1	0.38	73.1	0.31	58.4	0.36	53.7	0.40
$N_{2006,2}^A$	46.8	0.27	44.0	0.24	45.6	0.28	47.4	0.26
$N_{2006,3}^A$	10.4	0.34	7.7	0.29	10.9	0.33	10.0	0.35
$N_{2006,4+}^A$	16.7	0.20	7.5	0.20	17.3	0.20	16.2	0.19
$\overline{B}_{Nov}^A$	1152	0.14	1763	0.19	1889	0.19	1831	0.18
a^A / α^A / ϑ^A	228.4	0.45	403.1	0.36	2688	0.73	1.13	0.10
b^A / β^A / η^A	556.7	0.74	539.0	0.53	15737	0.72	0.0009	0.25
η_{2005}^A	-0.21	1.95	-0.19	1.83	-0.60	0.76	-0.46	0.74
σ_r^A	1.11	0.19	1.06	0.19	1.00	0.20	1.51	0.20
s_{cor}^A	0.45	0.21	0.47	0.18	0.23	0.48	0.68	0.08
K^A	2783	0.74	2695	0.53	12641	1.47	3651	0.34