OMP-08 Development, with Preliminary Results

C.L. Cunningham[*] and D.S. Butterworth[*]

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The current Operational Management Procedure (OMP-04) for the South African sardine and anchovy resources is due to be updated and replaced by OMP-08 by the end of 2007. This document details the framework used to test the new management procedure and provides some **VERY** preliminary results.

Methods

The management procedure, based on OMP-04, currently being used for these preliminary results, together with the simulation testing framework used to test the new MP are detailed fully in Appendix A, with relevant associated data given in Appendix B.

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. However for sardine convergence difficulties have arisen with respect to the σ_R parameter (the standard deviation of the residuals about the stock-recruitment relationship). 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 these circumstances, for an evaluation comparable to that undertaken for OMP-04, the intent is now to mimic the posterior distribution used for σ_R in that evaluation 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. This work is in progress; the results reported below are for an equally weighted combination of outputs from MCMC runs for $\sigma_R = 0.5$ and for $\sigma_R = 0.6$. Furthermore, 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 later (see below).

[*] MARAM (Marine Resource Assessment and Management Group), Department of Mathematics and Applied Mathematics, University of Cape Town, Rondebosch, 7701, South Africa. Email: c.l.cunningham@telkomsa.net, doug.butterworth@uct.ac.za.

Preliminary Results

Table 1 lists the control parameters for OMP-02 and OMP-04, and Fig. 1 shows the associated trade-off curves for expected directed sardine and anchovy catches. For a given value of the β control parameter, the α control parameter values are chosen to satisfy the specified *Risk* probability constraints for each species not to fall below a certain threshold abundance level over a 20-year projection period; thereafter a specific selection is made for β to achieve the desired trade-off between the catches of the two species.

Table 1 also includes a list of parameters chosen for testing a provisional OMP-08. Aside from the α and β parameters still to be selected, values of these parameters have preliminarily all been set equal to those for the re-revised OMP-04 except for an agreed minor alteration to the sardine bycatch allowance for the redeye fishery.

Fig. 2 compares distributions of sardine biomass in the final year of a 20-year projection period for both the updated assessment and the "2004 Assessment" upon which OMP-04 was based, both for catches under an OMP and in the absence of any catch. The upper panel of Fig. 2a shows that for the updated assessment, there is a greater probability of dropping to low levels of biomass. This arises because although attempts have been made to keep the σ_R distributions for the two cases reasonably comparable, the value of $M = 0.8$ for the updated assessment is much larger than the $M = 0.4$ used previously, so that there are effectively fewer year-classes in the population and consequently the probability that the pre-exploitation population can fluctuate naturally to below a certain level is greater.

These circumstances suggest an adjustment of the *Risk* criterion for sardine used in developing OMP-04, given that the resource is naturally capable of recovery from lower levels than previously indicated. Either the criterion's threshold abundance, or its probability of dropping below this, need to be adjusted in a way that leads to an arguably comparable basis for considering actual risk to the resource to that used when selecting OMP-04. Table 2a gives the probabilities of falling below a range of threshold abundances at least once during a 20-year projection period for OMP-04 and the 2004 assessment upon which it was based, together with equivalent statistics for the no catch scenario, while Table 2b gives corresponding statistics for the probability of being below such a threshold during the full projection period. In Tables 3a and b, corresponding probabilities are given for the no catch scenario for the updated assessment.

Tables 3a and b also attempt to specify sardine *Risk* levels for OMP-08 equivalent to those used for OMP-04 by seeking similar differences between probabilities in the presence and absence of fishing, achieving this either on an additive or multiplicative basis. Consideration of the equivalent threshold level to that used in 2004 and a multiplicative basis, or alternatively a threshold 25% higher and an additive basis, suggest a probability choice in the vicinity of 30% for sardine for OMP-08 would be appropriate.

Initial preliminary OMP-08 outputs have thus been computed using the equivalent threshold to that used previously (the average sardine biomass over 1991 to 1994), but now for a probability of 30% instead of 10% to define acceptable *Risk*. Fig. 1 includes the resultant anchovy *vs* directed sardine catch trade-off curve, and Figs 2a and 2b include distributions of biomass at the end of the 20-year projection period under a specific choice for this OMP which sets $\beta = 0.163$ for average annual catch levels of about 240 thousand tons of directed sardine take and 230 thousand tons of anchovy.

Issues still to be addressed

The simulation testing framework is still to incorporate the following new aspects:

i) Allowing sardine recruitment to switch regimes to one resembling the recent peak, with a probability of about 1 in 40. In such a case, recruitment to the sardine population would be governed by parameters estimated during the recent peak period from the assessments.

ii) Taking effort and biomass into consideration when generating survey observations. A relationship of survey CV to total transect length and biomass estimated from historical data will be incorporated, with the assumption made that the survey effort on future surveys will be the average of that achieved over the last five years.

Given the change to the posterior distribution for the standard deviation of the recruitment residuals (σ_R) for the updated anchovy assessment compared to that used for testing OMP-04, the definition of the risk criterion for anchovy will need to be adjusted in a similar way to that suggested above for sardine.

As indicated above, the sardine base case stock assessment posterior distributions used in the MP testing results reported have been based upon equal draws from the base case with the standard deviation in recruit residuals (σ_R) during non-peak years being fixed at 0.5 and 0.6. This will be expanded to incorporate cases where σ_R is fixed at 0.4 and 0.7 as well, so as to mimic the posterior distribution used for σ_R when testing OMP-04.

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. The Proposed Issues to be Addressed in the Revision of the Pelagic OMP. MCM Document MCM/2007/MAY/SWG-PEL/09. 17pp

Table 1. Parameters and constraints in OMP-02 and re-revised OMP-04, together with those used for the preliminary testing of OMP-08 reported in this document. (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	Provisional OMP-08 Testing
β	directed sardine control parameter	0.14657	0.14387	to be selected
α_{ns}	directed anchovy control parameter for normal season	0.73752	0.72858	to be selected
α_{ads}	directed anchovy control parameter for additional season	1.47504	1.45716	to be selected
Constraints		**OMP-02**	**Re-Revised OMP-04**	**Provisional OMP-08 Testing**
TAB_{rh}^{S}	fixed annual adult sardine bycatch	10 000t	10 000t	3 500t[1]
c_{mxdn}^{S}	maximum proportion by which directed sardine TAC can be annually reduced	0.15	0.15	0.15
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	240 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	200 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^*	threshold below which sardine TAC can decrease faster than c_{mxdn}^{S}			800 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

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

x^S	the proportion of the exceptional circumstances threshold below which sardine TAC is zero.	0	0	0[2]
x^A	the proportion of the exceptional circumstances threshold below which anchovy TAC is zero.	0	0.25	0.25[3]
Fixed Controls		**OMP-02**	**Re-Revised OMP-04**	**Provisional OMP-08 Testing**
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)

[2] It is recommended that consideration be given to increasing this from 0, as currently for anchovy, so that there is a non-zero biomass level for sardine below which the TAC is set to zero.

Table 2a. The probability that sardine biomass drops below B^*_{04} at least once during the projection period of 20 years, using the OMP-04 simulation framework with the associated 2004 assessment (this defines "*Risk*" for OMP-04). B^*_{04} is the average 1991 to 1994 sardine November biomass calculated using the 2004 sardine assessment.

	B^*_{04}	$1.25\times B^*_{04}$	$1.5\times B^*_{04}$
C=0	0.01	0.03	0.054
C=OMP-04	0.098	0.188	0.272

Table 2b. The proportion of times that sardine biomass drops below B^*_{04} during the projection period of 20 years, using the OMP-04 simulation framework.

	B^*_{04}	$1.25\times B^*_{04}$	$1.5\times B^*_{04}$
C=0	0.0013	0.004	0.0096
C=OMP-04	0.0285	0.0462	0.0686

Table 3a. The probability that sardine biomass drops below B^*_{07} at least once during the projection period of 20 years, using the OMP-08 simulation framework with the associated updated assessment. B^*_{07} is the average 1991 to 1994 sardine November biomass calculated using the 2007 sardine assessment.

	B^*_{07}	$1.25\times B^*_{07}$	$1.5\times B^*_{07}$
C=0	0.032	0.127	0.343
$(C=OMP\text{-}04)^{04}/(C=0)^{04}x(C=0)^{08}$	0.3136	0.7959	1.7277
$(C=OMP\text{-}04)^{04}-(C=0)^{04}+(C=0)^{08}$	0.12	0.285	0.561

Table 3b. The proportion of times that sardine biomass drops below B^*_{07} during the projection period of 20 years, using the OMP-08 simulation framework.

	B^*_{07}	$1.25\times B^*_{07}$	$1.5\times B^*_{07}$
C=0	0.00375	0.01645	0.0406
$(C=OMP\text{-}04)^{04}/(C=0)^{04}x(C=0)^{08}$	0.0822	0.19	0.2901
$(C=OMP\text{-}04)^{04}-(C=0)^{04}+(C=0)^{08}$	0.0053	0.05865	0.0996

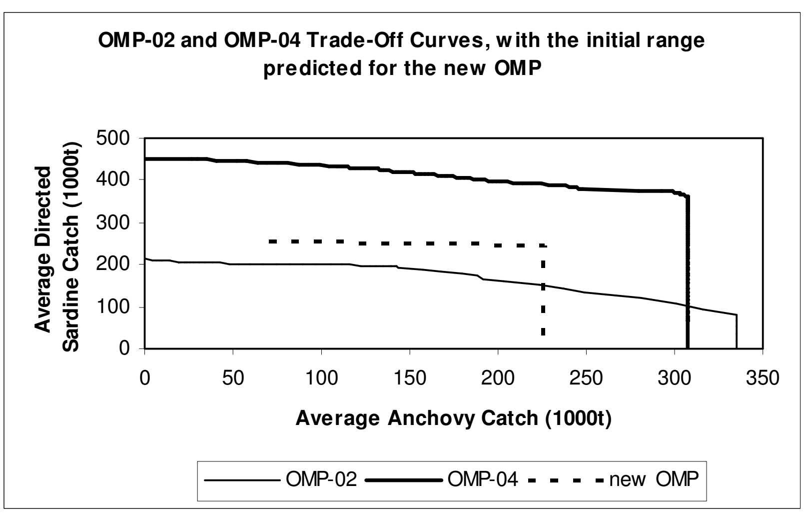


Fig. 1: A comparison of trade-off curves for previous and (provisional) new OMPs. Note that the trade-off curve for the new OMP has been computed for a changed sardine risk level: *risk*$_S$<0.3 instead of <0.1 as for OMP-04.

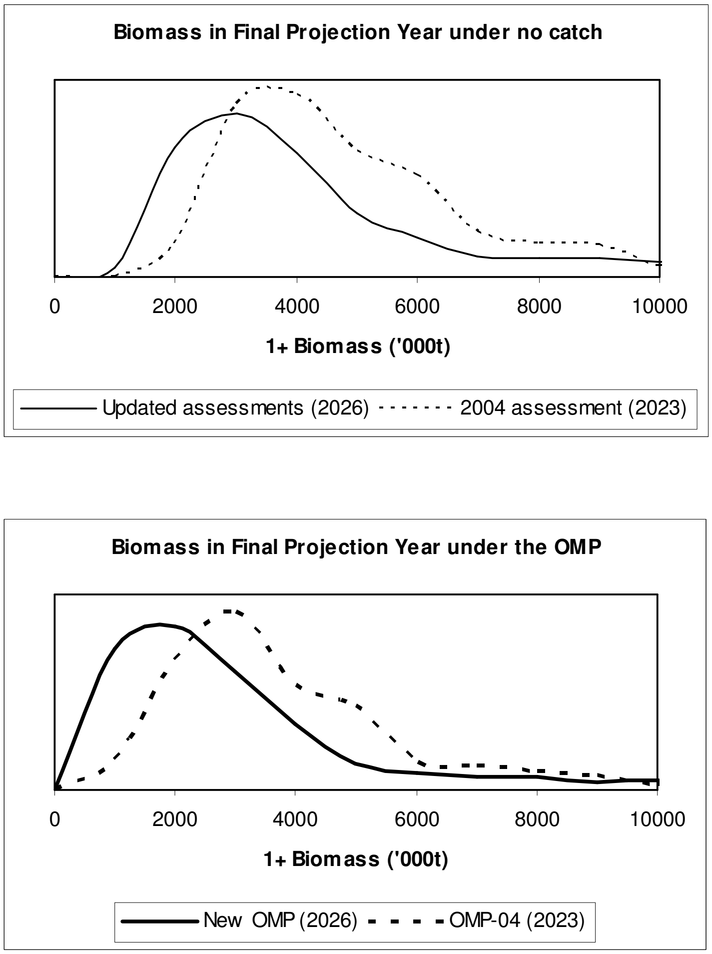
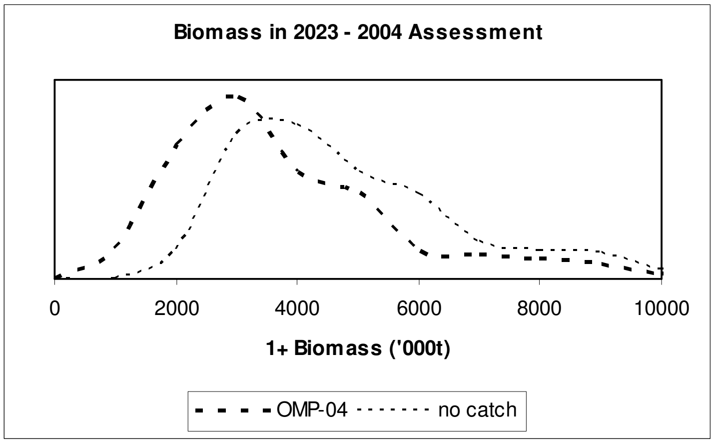


Fig. 2a: Comparison of biomass distributions in the final projection year for the updated and the 2004 assessments under a no catch scenario (upper panel) and under respective OMP applications (lower panel).



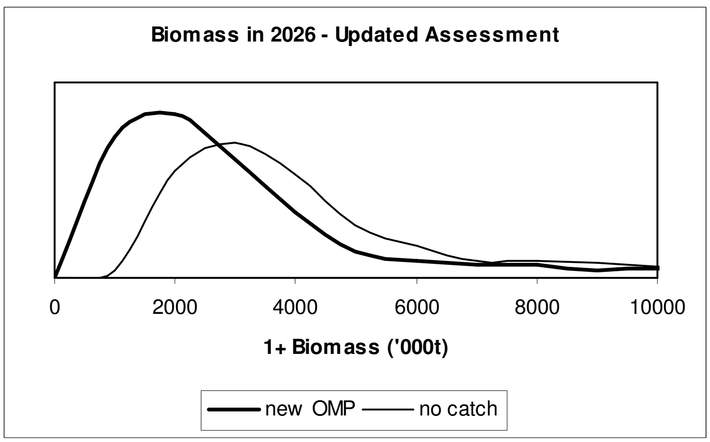


Fig. 2b: Comparison of biomass distributions in the final projection year under a no catch scenario and the pertinent OMP for the 2004 assessment (upper panel) and the updated assessment (lower panel).

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.

<u>OMP-04 (Harvest Control Model)</u>

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 observed sardine spawner biomass is above the threshold B^*. If the observed sardine spawner biomass is below B^* then the TAC would decrease linearly from this constraint down to a minimum (being the maximum of either $c^S_{mntac} = 90\,000\,\mathrm{t}$ or $\beta \times B^{obs,S}_{y-1,N}$. If the previous year's TAC is above the 'two-tier' 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: $$TAC^S_y = \beta\, B^{obs,S}_{y-1,Nov} \tag{A.1}$$

Subject to:

if $TAC^S_{y-1} \le c^S_{tier}$:

$$\max\left\{\left(1-c^S_{mxdn}\right)TAC^S_{y-1}\times\frac{B^{obs,S}_{y-1,N}-250}{B^*-250}+TAC^{S*}_y\,\frac{B^*-B^{obs,S}_{y-1,N}}{B^*-250};c^S_{mntac}\right\}\le TAC^S_y\le c^S_{mxtac}\quad if\ B^{obs,S}_{y-1,N}\le B^*$$

$$\max\left\{\left(1-c^S_{mxdn}\right)TAC^S_{y-1};c^S_{mntac}\right\}\le TAC^S_y\le c^S_{mxtac}\quad if\ B^{obs,S}_{y-1,N}>B^*$$

where $TAC^{S*}_y=\max\left\{\beta\, B^{obs,S}_{y-1,N};c^S_{mntac}\right\}$

if $TAC^S_{y-1}>c^S_{tier}$:

$$\left(1-c^S_{mxdn}\right)c^S_{tier}\le TAC^S_y\le c^S_{mxtac}\qquad\text{(A.2)}$$

Initial directed anchovy TAC:

$$TAC^{1,A}_y=\alpha_{ns}\;\delta\, q\left(p+(1-p)\frac{B^{obs,A}_{y-1}}{\overline{B}^A_{Nov}}\right)\qquad\text{(A.3)}$$

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

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

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

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

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

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

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

c_{mxtac}^{A} - 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 currently for 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_{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 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: $$TAC_y^{2,A} = \alpha_{ns}\ q\left(p\frac{N_{y-1,rec0}^{A}}{\bar{N}_{rec0}^{A}} + (1-p)\frac{B_{y-1,N}^{obs,A}}{\bar{B}_{Nov}^{A}}\right) \tag{A.6}$$

Subject to:

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

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

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).

$\bar{N}_{rec0}^{A}$ - 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:

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

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

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

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

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

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

In the above equation we have

$C_{y,0bs}^{A}$ - the observed anchovy landed by number (in billions) from the 1st of November year *y-1* to the day before the recruit survey commences in year *y*; during the testing of OMP-08, these values are simulated using equation (A.25).

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

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

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

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

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

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

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

We also define the following:

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

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

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

<u>Exceptional Circumstances</u>

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:

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

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

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

where TAC_y^{S*} is calculated using equation (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:

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

where $TAC_y^{1,A*}$ 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:

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

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

$$B^A_{y,proj} = \left(\frac{B^{obs,A}_{y-1,N}}{\overline{w}^A_1} e^{-5*0.9/12} - C^A_{y,1} \right) e^{-7\times0.9/12} \overline{w}^A_2 \quad + \quad B^A_{y,proj0} \tag{A. 18}$$

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:

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

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

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

or equation (A.11) during simulation testing:

$$N^{A*}_{y-1,rec0} = (\theta\, e^{3.25\times1.2/12} + C^A_{y,0bs})\, e^{3.25\times1.2/12} \tag{A. 21}$$

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:

$$TAC^{2,A}_y = \max \text{ of} \begin{cases} TAC^{1,A}_y; TAC^{2,A*}_y \left(\dfrac{p\dfrac{N^A_{y-1,rec0}}{\overline{N}^A_{rec0}} + (1-p)\dfrac{B^{obs,A}_{y-1,N}}{\overline{B}^A_{Nov}}}{p\dfrac{N^{A*}_{y-1,rec0}}{\overline{N}^A_{rec0}} + (1-p)\dfrac{B^{obs,A}_{y-1,N}}{\overline{B}^A_{Nov}}} - 0.25 \right)^2 & \text{if } 0.25 < \dfrac{p\dfrac{N^A_{y-1,rec0}}{\overline{N}^A_{rec0}} + (1-p)\dfrac{B^{obs,A}_{y-1,N}}{\overline{B}^A_{Nov}}}{p\dfrac{N^{A*}_{y-1,rec0}}{\overline{N}^A_{rec0}} + (1-p)\dfrac{B^{obs,A}_{y-1,N}}{\overline{B}^A_{Nov}}} < 1 \\ TAC^{1,A}_y; 0 & \text{if } \dfrac{p\dfrac{N^A_{y-1,rec0}}{\overline{N}^A_{rec0}} + (1-p)\dfrac{B^{obs,A}_{y-1,N}}{\overline{B}^A_{Nov}}}{p\dfrac{N^{A*}_{y-1,rec0}}{\overline{N}^A_{rec0}} + (1-p)\dfrac{B^{obs,A}_{y-1,N}}{\overline{B}^A_{Nov}}} < 0.25 \end{cases} \tag{A. 22}$$

Final Anchovy TAC

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

<u>Implementation model</u>

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

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

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:

$$C_{y,0bs}^{S} = k_{jan:may}\frac{N_{y-1,0}^{S}}{N_{y-1,0}^{A}}e^{\sigma_{jan:may}\eta_{y,jan:may}}\frac{(C_{y,0bs}^{A}\overline{w}_{0c}^{A} + C_{y,1}^{A}\overline{w}_{1c}^{A})}{\overline{w}_{0c}^{S}}, \qquad \text{where } \eta_{y,jan:may} \sim N(0;1) \tag{A.27}$$

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

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 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:

$$k_{jan:may} = \exp\left\{\sum_{y=1987}^{2006}\left[\ln(C_{y,jan:may}^{S,byc} / C_{y,jan:may}^{A}) - \ln(N_{y-1,0}^{S} / N_{y-1,0}^{A})\right]\Big/\sum_{y=1987}^{2006}1\right\} \tag{A.28}$$

and

$$\varepsilon'_{y,jan:may} = \ln(C_{y,jan:may}^{S,byc} / C_{y,jan:may}^{A}) - \ln(k_{jan:may}N_{y-1,0}^{S} / N_{y-1,0}^{A}) \qquad y = 1987,...,2006 \tag{A.29}$$

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:

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

Annual sardine 0-year-old catch by number

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

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)).

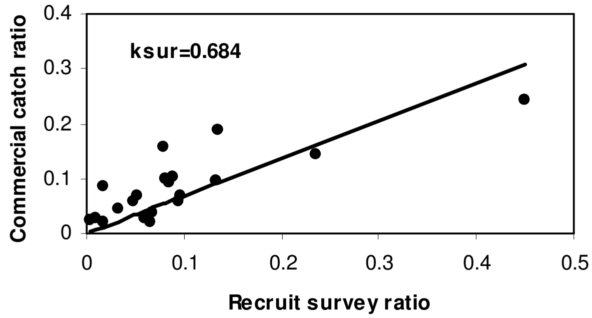


Figure A.1. Relationship between the sardine to anchovy ratio in the recruit survey ($N^{obs,S}_{y,r} / N^{obs,A}_{y,r}$), and the sardine bycatch to anchovy ratio in commercial catches in May ($C^{S,byc}_{y,may} / C^{A}_{y,may}$) for 1987-2006. The slope of the linear regression forced through the origin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

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

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

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:

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

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

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

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 $C_{y,0}^{S*}$ 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, $C_{y,0}^{A}$, is also adjusted if the adjusted $C_{y,0}^{S}$ exceeds $TAB_{y}^{2,S} - TAB_{rh}^{S}$ (equation (A.49)), in order to reflect the closure of the anchovy fishery once the sardine bycatch allowance linked to anchovy is reached.

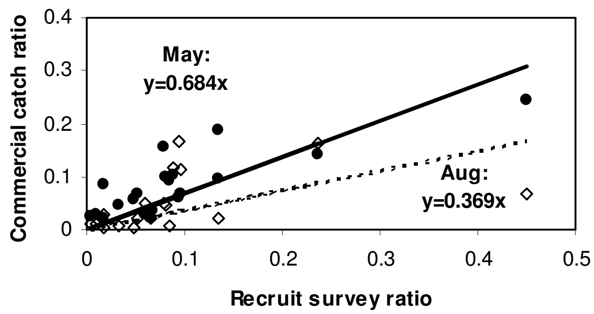


Figure A.2. A repeat of Figure A.1, but with commercial catch data for August ($C_{y,aug}^{S,byc} \big/ C_{y,aug}^{A}$) added

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., $N_{y,r}^{i}$ 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:

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

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

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

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

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

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):

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

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

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

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:

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

and

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

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:

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

and

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

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.

Population Dynamics Model

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:

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

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

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

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

Anchovy:

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

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

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

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

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

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

$$\varepsilon^i_y = s^i_{cor}\varepsilon^i_{y-1} + \sqrt{1-(s^i_{cor})^2}\;\omega^i_y, \qquad \text{where } \omega^i_y \sim N(0;1) \text{ and } y = 2007,...,2026$$

$N^i_{2006,0}$, $i = S, A$ 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.

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

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

The standard deviations of the residuals are given by:

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

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

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

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

$$\varepsilon_{y,r}^{i} = \ln N_{y,r}^{obs,i} - \ln(k_r^i N_{y,r}^{i}) \qquad y = 1985,...,2006 \tag{A.59}$$

where

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

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

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

The standard deviations of the residuals are given by:

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

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

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

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

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

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

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

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

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

$TAC_{2007}^S = 162.436$, $TAC_{2007}^{1,A} = 186.942$, $TAB_{2007}^{1,S} = 29.413$,

$TAC_{2007}^{2,A} = 386.942$, $TAB_{2007}^{2,S} = 36.503$,

$TAC_{2007}^{3,A} = TAC_{2007}^{2,A} + 150.000$, $TAB_{2007}^{3,S} = TAB_{2007}^{2,S} + 2$

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 $N_{2007,r}^{obs,S} = 5.05$ billion and $N_{2007,r}^{obs,A} = 420.87$ 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:

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

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

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

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

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.

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 $C^{S,by}_{y,aug} / C^{A}_{y,aug}$ 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		