A simple age-based projection model to explore the impact of alternative sardine catches on the west coast of South Africa during 2016

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This document details two simple projection model approaches to considering the exploitation (or harvest) rate and equivalent approximate instantaneous fishing mortality rate on the sardine on the west coast of South Africa during 2016.

Projection of alternative catches

The first approach projects the November 2015 numbers-at-age as estimated by de Moor and Butterworth (2016) under alternative assumptions of the remaining sardine catch west of Cape Agulhas during 2016.

Assuming the November survey and June survey can be approximated by the biomass available on 1st November and 1st June, respectively, and assuming catch is taken in a pulse mid-way between these two times during the year, we have sardine numbers-at-age on the west coast of South Africa as follows:

$$N^{Jun}_{2016,a} = \left(N^{Nov}_{2015,a} e^{-3.5M/12} - C^{1}_{2016,a}\right) e^{-3.5M/12} \qquad 1 \le a \le 5^{+} \qquad \text{and } B^{Jun\,1+}_{2016} = \sum_{a=1}^{5+} \overline{w}^{Jun}_{a} N^{Jun}_{2016,a}$$

$$N^{Nov}_{2016,a} = \left(N^{Jun}_{2016,a-1} e^{-2.5M/12} - C^{2}_{2016,a-1}\right) e^{-2.5M/12} \qquad 2 \le a \le 5^{+} \qquad \text{and } B^{Nov\,2+}_{2016} = \sum_{a=2}^{5+} \overline{w}^{Nov}_{2016,a} N^{Nov}_{2016,a} ,$$

where

$$C^{1}_{2016,a} = F^{1} S^{1}_{a} N^{Nov}_{2015,a-1} e^{-3.5M/12} \qquad 1 \le a \le 5^{+} \qquad \text{and } C^{1}_{2016} = \sum_{a=1}^{5+} \overline{w}^{1}_{a} C^{1}_{2016,a}$$

$$C^{2}_{2016,a} = F^{2} S^{2}_{a} N^{May}_{2016,a} e^{-2.5M/12} \qquad 1 \le a \le 5^{+} \qquad \text{and } C^{2}_{2016} = \sum_{a=1}^{5+} \overline{w}^{2}_{a} C^{2}_{2016,a}$$

The initial age structure, $N^{Nov}_{2015,a}$ (in billions), $1 \le a \le 5^{+}$, the selectivity-at-age, adult natural mortality ($M = 0.8$ year^{-1}), and weight-at-age (in grams) are taken from de Moor and Butterworth (2016), and $B^{Nov\,1+}_{2015} = \sum_{a=1}^{5+} \overline{w}^{Nov}_{2015,a} N^{Nov}_{2015,a}$:

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$N^{Nov}_{2015,1}$	1.650	S^{1}_{1} #	0.36	S^{2}_{1} %	0.83	$\overline{w}_{2015,1}$ +*	44.52	$\overline{w}_{2016,1}$ ♦	36.79
$N^{Nov}_{2015,2}$	0.782	S^{1}_{2}	0.80	S^{2}_{2}	0.93	$\overline{w}_{2015,2}$	65.52	$\overline{w}_{2016,2}$	84.44
$N^{Nov}_{2015,3}$	0.103	S^{1}_{3}	0.86	S^{2}_{3}	0.94	$\overline{w}_{2015,3}$	70.39	$\overline{w}_{2016,3}$	97.41
$N^{Nov}_{2015,4}$	0.086	S^{1}_{4}	0.87	S^{2}_{4}	0.95	$\overline{w}_{2015,4}$	71.36	$\overline{w}_{2016,4}$	100.07
$N^{Nov}_{2015,5+}$	0.028	S^{1}_{5+}	0.87	S^{2}_{5+}	0.95	$\overline{w}_{2015,5+}$	71.55	$\overline{w}_{2016,5+}$	100.58

The fishing mortality rates, F^1 and F^2, are estimated by minimising a simple sum-of-squares likelihood:

$$-\ln L_1 = \left(C^{1}_{2016} - C^{1obs}_{2016}\right)^2 + \left(C^{2}_{2016} - C^{2obs}_{2016} - C^{2,\text{expected}}_{2016}\right)^2$$

The observed directed sardine catch and 'large' sardine bycatch tonnage from 1 November 2015 to 31 May 2016 is $C^{1,os}_{2016} = 47.596$ thousand tons (giving $F^1 = 0.63$) and from 1 June 2016 to 31 July 2016 is $C^{2,os}_{2016} = 2.796$ thousand tons.

We consider the impact of a range of alternative remaining catches west of Cape Agulhas from August to October 2016 on:

i) the adult (2+) biomass remaining in November 2016 from the 1+ biomass originally available in November 2015,

ii) the exploitation (or harvest) rate, ER, during 2016, i.e. the directed catches from November 2015 to October 2016 as a proportion of 1+ biomass in November 2015, and

iii) the equivalent instantaneous fishing mortality rate, $F = -0.8 - ln\left(\frac{\sum_{a=2}^{5+} N^{Nov}_{2016,a}}{\sum_{a=1}^{5+} N^{Nov}_{2015,a}}\right)$ (Appendix C of de Moor and Butterworth 2016).

While the ER column is comparable to the time series produced from South African sardine stock assessments, the ER for 2016 alone, assuming a zero catch in November and December 2016 is also given in the final two columns of the below table for interest:

Selectivity-at-age in the first period is taken from the selectivity-at-length estimated by de Moor and Butterworth (2016) in the second quarter of the year (when the majority of the first period catch was taken), for years 2002 – 2015. While selectivity-at-length has a maximum of 1 for at least one length class, the selectivity-at-age does not necessarily reach 1 for at least one age class.

% Selectivity-at-age in the second period is taken from the selectivity-at-length estimated by de Moor and Butterworth (2016) in the fourth quarter of the year, for years 2002 – 2015. While selectivity-at-length has a maximum of 1 for at least one length class, the selectivity-at-age does not necessarily reach 1 for at least one age class.

+ The catch weight-at-age in the two periods are taken to be the weighted average between the average November weight-at-age of the age before and after: $\overline{w}^{1}_{a} = 8.5\overline{w}_{y-1,a} + 3.5\overline{w}_{y,a+1}$ and $\overline{w}^{1}_{a} = 2.5\overline{w}_{y-1,a} + 9.5\overline{w}_{y,a+1}$

* The weight-at-age at the time of the Jun survey is taken to be the weighted average between the average November weight-at-age of the age before and after: $\overline{w}^{Jun}_{a} = 5\overline{w}_{y-1,a} + 7\overline{w}_{y,a+1}$

♦ The average November weight-at-age over 1984-2015 is used for November 2016.

$C^{2\,expected}$	$B_{2015}^{Nov\,1+}$	$B_{2016}^{Nov\,2+}$	$B_{2016}^{Nov\,2+}/B_{2015}^{Nov\,1+}$	F^2	ER	F	ER (2016)
3	140.134	64.379	0.46	0.08	0.38	0.49	0.27
5	140.134	62.523	0.45	0.11	0.40	0.52	0.28
8	140.134	59.739	0.43	0.15	0.42	0.56	0.30
10	140.134	57.882	0.41	0.18	0.43	0.59	0.32
12	140.134	56.026	0.40	0.21	0.45	0.63	0.33

Projection of alternative catches using May 2016 survey data

The second approach estimates the November 2015 total numbers, N_{2015}^{Nov}, but retains the proportions of numbers-at-age as estimated by de Moor and Butterworth (2016) and adjusts the November 2015 total numbers given the information available from the adult[1] biomass estimated by the November 2015 survey ($B_{2015}^{Novobs} = 98.467$, $CV_{2015}^{Nov} = 0.31$) and by the June 2016 survey ($B_{2016}^{Junobs} = 110.687$, $CV_{2016}^{Jun} = 0.52$):

$$-\ln L_2 = \frac{\left(\ln\left(k_{ac}^S B_{2015}^{Nov\,1+}\right) - \ln\left(B_{2015}^{Novobs}\right)\right)^2}{2{CV_{2015}^{Nov}}^2} + \frac{\left(\ln\left(k_{ac}^S B_{2016}^{Jun\,1+}\right) - \ln\left(B_{2016}^{Junobs}\right)\right)^2}{2{CV_{2016}^{Jun}}^2}.$$

The biases are again taken from de Moor and Butterworth (2016) ($k_{ac}^S = 0.749$ [2]).

By minimising $-\ln L_1 - \ln L_2$, we again consider the impact of a range of alternative remaining catches west of Cape Agulhas from August to October 2016:

$C^{2\,expected}$	N_{2015}^{Nov}	$B_{2015}^{Nov\,1+}$	$B_{2016}^{Nov\,2+}$	$B_{2016}^{Nov\,2+}/B_{2015}^{Nov\,1+}$	F^1	F^2	ER	F	ER (2016)
3	3.064	162.059	81.075	0.50	0.55	0.07	0.33	0.41	0.23
5	3.064	162.059	79.220	0.49	0.55	0.09	0.34	0.43	0.24
8	3.064	162.059	76.438	0.47	0.55	0.12	0.36	0.47	0.26
10	3.064	162.060	74.583	0.46	0.55	0.14	0.37	0.49	0.27
12	3.064	162.059	72.728	0.45	0.55	0.17	0.38	0.51	0.29

In Summary

The catch data available for these analyses indicate that 34 454t of directed sardine and 'large' sardine bycatch have been caught west of Cape Agulhas between January and July 2016, of which 29 828t is directed sardine. Projecting the simple model forward assuming 33 500t of directed sardine are caught west of Cape Agulhas will result in an exploitation rate of just over 0.38, which is substantially higher than that of the recent past (Figure 1) and substantially

[1] This is typically taken to be the total biomass in November, but given the small weight of recruits, will be similar to the 1+ biomass. The adult biomass from the May survey may be an underestimate give that the May transects do not extend as far offshore as the November survey.

[2] This acoustic bias was estimated for the total biomass surveyed in November. While it is likely that the estimate of 1+ biomass from the May survey is a further underestimate of true biomass (compared to the November survey) as the transects don't extend as far offshore, the same bias is nevertheless used for this simplified model.

higher than that corresponding to years of past increase in the west stock sardine (Butterworth and Coetzee 2016). Taking consideration of the adult biomass estimated by the May 2016 survey (and discounting the surveys prior to November 2015 which inform the model estimated numbers-at-age in 2015), a directed sardine catch of 33 500t west of Cape Agulhas will result in an exploitation rate of 0.33.

References

Butterworth, D.S. and Coetzee J.C. 2016. Comparative harvest rates for sardine and anchovy stocks elsewhere. DAFF: Branch Fisheries Document FISHERIES/2016/AUG/SWG-PEL/35.

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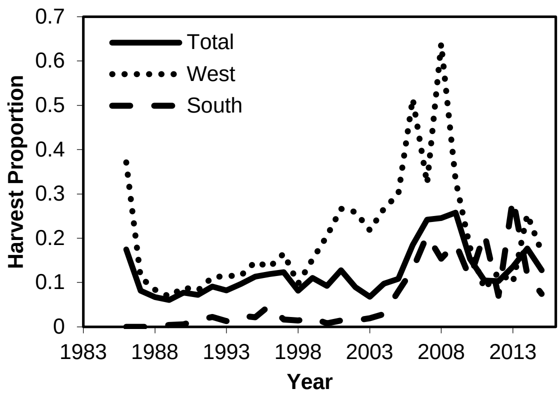

Figure 1. The historical harvest proportions of South African sardine (de Moor and Butterworth 2016b). Over the last six years the average on the west coast has been 0.15.