A risk analysis of the impact of harvesting sardine on the west coast of South Africa

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Background

OMP-14 was implemented together with a "Gentleman's agreement" that the South African pelagic industry self-regulate fishing pressure west of Cape Agulhas to ensure the spread of fishing west compared to east of Cape Agulhas is similar to that observed during recent November surveys:

> *In finalisation of OMP-14, however, the SPSWG agreed that due to an unclear understanding of the mixing dynamics of the two stocks, it is premature to move to an OMP developed on the baseline hypothesis of assuming two mixing stocks at this time. This was agreed on condition that some guidelines for spatial management of the directed sardine catches be developed and accepted as part of OMP-14. The agreed target percentage for the directed sardine TAC to be caught West of Cape Agulhas in any one year is the average of the percentages of sardine found west of Cape Agulhas in the November surveys in the preceding two years. A tolerance about this percentage of 10% has been set to allow some flexibility, especially because most of the sardine processing capacity remains on the West Coast and time is needed for industry to adapt to this new measure.* (from FISHERIES/2014/DEC/SWG-PEL/65)

The relatively low proportions of sardine biomass surveyed west of Cape Agulhas during Novembers 2014 and 2015 resulted in the 2016 sardine TAC[1] advice having the associated recommended restriction that no more than 45.6% (10% tolerance included) of the directed >14cm sardine TAC be taken west of Cape Agulhas (FISHERIES/2015/DEC/SWG-PEL/49). Industry has found this restriction very limiting in 2016, as a result in particular of logistical constraints on operations from Mossel Bay, and have requested the Small Pelagic Scientific Working Group to reconsider this recommended restriction for 2016 (FISHERIES/JUN/2016/SWG-PEL/19).

In this document we consider the risk to the sardine resource for the 2016 season, in terms of the west coast harvest rate. More specifically, we consider the expected harvest rate under alternative west coast catch scenarios in a risk analysis context, taking into consideration a range of alternative hypotheses concerning the proportion of south coast biomass at the time of the November hydro-acoustic survey that may contribute to west coast recruitment. The purpose of this risk analysis is to demonstrate to decision makers the level of extra risk involved as the catch allowed on the west coast is increased.

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[1] This recommendation applies to both initial and final directed >14cm sardine TACs during 2016.

Methods

Our risk analysis considers the impact on the sardine resource of a range of alternative possible catches west of Cape Agulhas during 2016 on a range of alternative hypotheses for the proportion of the biomass surveyed south of Cape Agulhas in November 2015 that may contribute to west coast recruitment.

The minimum catch west of Cape Agulhas in 2016 is taken to be 29 074t which was that already landed by 13th June 2016 (J. de Goede pers comm.). This extreme assumes that no further catch will be taken west of Cape Agulhas in 2016. The maximum catch west of Cape Agulhas in 2016 is taken to be 81 400t. This is almost the maximum possible final directed sardine TAC of 95 417t (which would result if the hydro-acoustic survey estimate of sardine recruitment in 2016 exceeds 16.48 billion recruits), less 14 017t of sardine already taken east of Cape Agulhas by 13th June 2016. This extreme assumes high sardine recruitment and no further catch to be taken east of Cape Agulhas in 2016. A "likely" range of sardine catch west of Cape Agulhas under the OMP-14 together with the "Gentleman's agreement" is informed by the following alternative assumptions.

i) A final directed >14cm sardine TAC of 70 000t (corresponding to a low survey estimate of recruitment of ~5 billion), would result in 24 900t[2] west of Cape Agulhas if the 'target' maximum proportion of 35.6% of the TAC taken west of Cape Agulhas is achieved (though note this is below the minimum above of 29 074t already taken), or 31 900t if the maximum proportion including tolerance of 45.6% is achieved.

ii) A final directed >14cm sardine TAC of 75 000t (corresponding to a survey estimate of recruitment of ~7.6 billion – slightly higher than the average of 7.3 billion over the past five years), would result in 26 700t west of Cape Agulhas if the 'target' maximum proportion of 35.6% of the TAC taken west of Cape Agulhas is achieved (though again note this is below the minimum above), or 34 200t if the maximum proportion including tolerance of 45.6% is achieved.

iii) A final directed >14cm sardine TAC of 80 000t (corresponding to a survey estimate of recruitment of ~9.9 billion – slightly higher than the average of 9.7 billion over the past ten years), would result in 28 500t west of Cape Agulhas if the 'target' maximum proportion of 35.6% of the TAC taken west of Cape Agulhas is achieved (again note this is below the minimum above), or 36 500t if the maximum proportion including tolerance of 45.6% is achieved.

iv) A final directed >14cm sardine TAC of 85 000t (corresponding to a survey estimate of recruitment of 11.9 billion), would result in 30 200t west of Cape Agulhas if the 'target' maximum proportion of 35.6% of the TAC taken west of Cape Agulhas is achieved, or 38 700t if the maximum proportion including tolerance of 45.6% is achieved.

[2] All catches in this section are rounded to the nearest 100t.

While the above suggests a likely range of catches west of Cape Agulhas in 2016, which maintain the OMP-14 associated recommended maximum proportion of catch west of Cape Agulhas, would certainly not exceed 40 000t, Table 1 considers the impact of not only this likely range of catches but also higher west coast catches.

The options considered for the possible biomass in November 2015 that may contribute to west coast recruitment correspond to hypotheses of 0%, 20%, 40%, 60% and 100% of the south coast biomass at the time of the survey, contributing to the "effective" biomass on the west coast[3] (de Moor et al. 2014).

The "impact" is measured by the resultant harvest rate (catch divided by survey biomass) that would be associated with each potential west coast catch tonnage under each "effective" west coast biomass hypothesis.

To progress the risk analysis further, the alternative hypotheses for "effective" west coast biomass need to be plausibility weighted. To this end we consider how much the effective biomass[4] in the west is increased by contributing eggs transported from the south coast. We denote the survey biomass west and south of Cape Agulhas as B_w and B_s, respectively, and thus the proportion of biomass west of Cape Agulhas is $p_w = \frac{B_w}{B_w + B_s}$. Denoting the proportion of eggs produced west and south of Cape Agulhas that contribute to west coast recruitment as q_w and q_s respectively, the effective biomass contributing to west coast recruitment is:

$$q_w B_w + q_s B_s$$

The proportional increase in effective west coast biomass from the south coast is thus:

$$\frac{q_s B_s}{q_w B_w}$$

The proportion of effective biomass west of Cape Agulhas therefore increases from p_w to:

$$p_w\left(1+\frac{q_s B_s}{q_w B_w}\right) = p_w\left(1+\frac{q_s(1-p_w)}{q_w p_w}\right) = \frac{q_w p_w + q_s(1-p_w)}{q_w} \qquad (1).$$

Results and Discussion

The risk analysis (e.g. Hilborn et al. 1992, 1993) results are given in Table 1. This reports the west coast harvest rate[5] under alternative 2016 west coast catches and six hypotheses for the proportion of south coast survey biomass that contributes to west coast 'effective' biomass.

[3] This idea follows loosely from the hypothesis that part of the south stock spawner biomass on the south coast in November contributes through its egg production and transport to west stock recruitment (de Moor et al. 2014).
[4] Here 'effective biomass' would be the spawner biomass that contributes to west coast recruitment.
[5] The bias in the hydro-acoustic survey estimate of biomass is necessarily ignored in this analysis.

As a basis for discussion of the weighting of alternative hypotheses for the proportion of November 2015 survey biomass south of Cape Agulhas that forms part of the effective west coast biomass, we consider the IBM of Miller et al. (2006) and subsequent work of Coetzee (2014) and de Moor et al. (2014) (Table 2). Allocating each of the “Alt-A” hypotheses an equal weight, Table 2 indicates that the hypothesis that 20% of the south coast November 2015 survey biomass forms part of the effective west coast biomass should receive 80% of the overall weight. An alternative that 10% of the survey biomass forms part of the effective west coast biomass should then receive 20% of the overall weight. As such an alternative does not exist amongst the hypotheses considered in Table 1, the 20% is split between the alternatives of 0% and 20% of south stock survey biomass forming part of the effective west coast biomass. This results in a low weight (10%) for hypothesis that the sardine on both coasts exhibit discrete spawner-recruit relationships, and a high weight (90%) that 20% of the south coast surveyed biomass contributes to west coast recruitment.

Conclusion

Ultimately the purpose of Table 1 is to inform decision makers of the likely consequences of alternative decisions regarding the catch of sardine to be allowed to be taken west of Agulhas this year. This should be accompanied by statements about the “safety” associated with expected harvest rate figures shown in the final column of that Table.

Table 1 shows that the catch already taken on the west coast ranges from 8% to 30% of the effective west coast surveyed biomass across the six hypotheses considered; when these hypotheses are plausibility weighted this expected harvest rate is 0.20. This expected rate increases to 0.24-0.28 if the west coast catch in 2016 increases to 35 – 40 000t. Note that one purpose of the catch-split agreement facilitating the adoption of OMP-14 was that the harvest rates on the west coast should be reduced compared to the recent past (see Figure 1). The higher the catch allowed on the west coast, the higher the harvest rate in 2016, and hence the worse the abundance of this population at the end of the year.

The harvest rates in Table 1 cannot be compared directly with those used internationally as they include the hydro-acoustic survey bias. Such rates would need to first be converted to “true” harvest rates (e.g. Figure 1b) and then to equivalent fishing mortality rates in order to compare with fishing mortality reference points used for small pelagic species elsewhere. Transformations to allow comparisons of this nature on the necessary equivalent footing indicated could be evaluated later if this was considered to be a helpful exercise.

References

Coetzee, J.C. 2014. Potential indicators of the effective spawning biomass derived from the proportion of eggs transported to or retained in either a west coast or south coast nursery area. Department of Agriculture, Forestry and Fisheries Document FISHERIES/2014/AUG/SWG-PEL/49. 9pp.

de Moor, C.L., Butterworth, D.S., van der Lingen, C.D., and Coetzee, J.C. 2014. Alternative hypotheses of two mixing stocks of South African sardine: Initial testing. International Fisheries Stock Assessment Workshop, Cape Town, December 2014. Document MARAM/IWS/DEC14/Sardine/P2. 20pp.

de Moor, C.L., Butterworth, D.S., and van der Lingen, C.D. The Quantitative Use of Parasite Data in Multi-Stock Modelling of South African Sardine (*Sardinops sagax*). Submitted to the Canadian Journal of Fisheries and Aquatic Sciences.

Hilborn, R. 1992. Current and Future Trends in Fisheries Stock Assessment and Management. S. Afr. J. mar. Sci. 12:975-988

Hilborn, R., Pikitch, E.K., and Francis, R.C. 1993. Current Trends in Including Risk and Uncertainty in Stock Assessment and Harvest Decisions. Can. J. Fish. Aquat. Sci. 50: 874-880.

Miller, D.C.M., Moloney, C.L., van der Lingen, C.D., Lett, C., Mullon, C., and Field, J.G. 2006. Modelling the effects of physical–biological interactions and spatial variability in spawning and nursery areas on transport and retention of sardine *Sardinops sagax* eggs and larvae in the southern Benguela ecosystem. Journal of Marine Systems 61: 212–229.

Table 1. A decision table showing the west coast harvest rate[6] (west coast catch divided by "effective" west coast biomass). For each alternative possible west coast catch, the expected value for the harvest rate is the sum of the probability of each effective biomass hypothesis multiplied by the associated harvest rate.

Catch west of Cape Agulhas during 2016	Alternative hypotheses of the proportion of biomass surveyed east of Cape Agulhas in November 2015 that forms part of the "effective" west coast biomass for 2016						Expected harvest rate
	0.0	0.2	0.4	0.6	0.8	1.0	
	Probability						
	0.1	**0.9**	**0.0**	**0.0**	**0.0**	**0.0**	
29 074 t	0.30	0.19	0.14	0.11	0.09	0.08	**0.20**
30 000t	0.30	0.20	0.15	0.12	0.10	0.08	**0.21**
32 500t	0.33	0.21	0.16	0.13	0.10	0.09	**0.23**
33 500t	0.34	0.22	0.16	0.13	0.11	0.09	**0.23**
35 000t	0.36	0.23	0.17	0.14	0.11	0.10	**0.24**
36 000t	0.37	0.24	0.18	0.14	0.12	0.10	**0.25**
37 500t	0.38	0.25	0.18	0.15	0.12	0.10	**0.26**
40 000t	0.41	0.26	0.20	0.16	0.13	0.11	**0.28**
50 000t	0.51	0.33	0.24	0.19	0.16	0.14	**0.35**
60 000t	0.61	0.40	0.29	0.23	0.19	0.17	**0.42**
70 000t	0.71	0.46	0.34	0.27	0.23	0.19	**0.49**
81 400t	0.83	0.54	0.40	0.32	0.26	0.22	**0.57**

[6] The bias in the hydro-acoustic survey estimate of biomass is necessarily ignored in this analysis.

Table 2. Alternative hypotheses for the proportion of south stock spawner biomass that contributes to west stock recruitment, based on the "Alternative A" hypotheses considered by de Moor et al. (2014). The final row gives the proportion of south stock biomass from the November 2015 survey that is considered to contribute to the west stock effective biomass, where the proportion of the survey biomass west of Cape Agulhas in November 2015 was $p_w = 0.27$. Bold hypotheses are those currently considered most likely by the authors.

	Current	Alt A-1	Alt A-2	**Alt A-3**	Alt A-4	**Alt A-5**
Prop[7] west SSB contributing to west ESSB[8]	1.0	1.0	1.0	**0.98**	0.29	**0.29**
Prop west SSB contributing to south ESSB	0.0	0.0	0.0	**0.02**	0.005	**0.005**
Prop south SSB contributing to west ESSB	0.0	0.1	0.18	**0.18**	0.1	**0.13**
Prop south SSB contributing to south ESSB	1.0	0.9	0.82	**0.82**	0.46	**0.59**
Reason for hypothesis	Current two mixing stock model	Intermediate hypothesis	% of eggs from Coetzee (2014), ignoring props[6] of eggs 'lost to the system', considering south coast eggs only	% of eggs from Coetzee (2014), ignoring props of eggs 'lost to the system'	% of eggs from Coetzee (2014), assuming the props of eggs 'lost to the system' equates to unproductive spawning biomass	% of eggs from Coetzee (2014), assuming the props of eggs 'lost to the system' equates to unproductive spawning biomass, and that this prop is overestimated by a factor of two for the south stock
Renormalised prop west SSB contributing to west ESSB	1.000	1.000	1.000	0.980	0.983	0.983
Renormalised prop south SSB contributing to west ESSB	0.000	0.100	0.180	0.180	0.179	0.181
Eff prop of November 2015 survey biomass west of Cape Agulhas (eqn 1)	0.271	0.344	0.402	0.405	0.403	0.405
November 2015 survey biomass south of Cape Agulhas that contributes to EB west of Cape Agulhas	0	26 476t	47 657t	48 630t	48 094t	48 629t
Prop of November 2015 survey biomass that contributes to EB west of Cape Agulhas	0.000	0.100	0.180	**0.184**	0.182	**0.184**

[7] Prop – Proportion   Props - Proportions
[8] ESSB - Effective spawner biomass   EB – Effective biomass

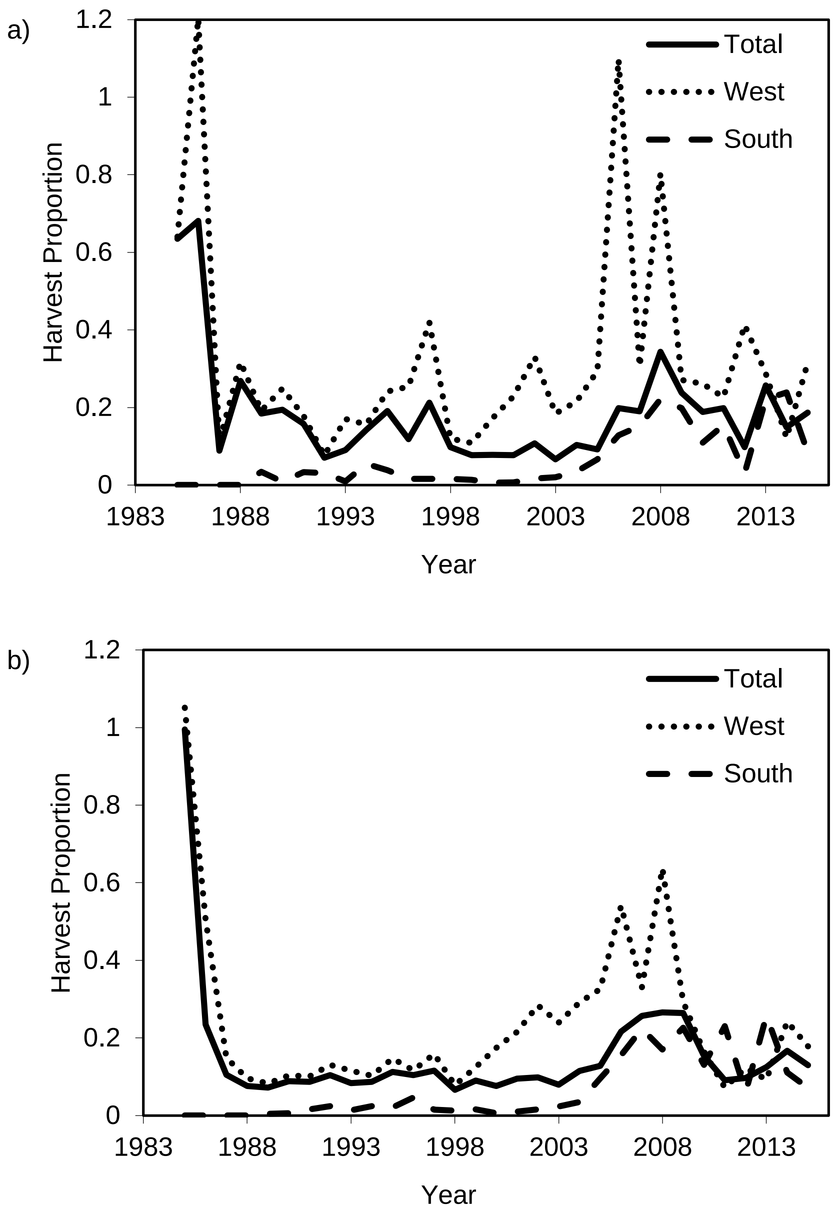

Figure 1. The historical harvest rates of South African sardine where catch is divided by a) hydro-acoustic survey biomass and b) the 'true' biomass based on the current two mixing stock hypothesis (de Moor et al. In Review). The former compares more directly with harvest rates in Table 1 while the latter are 'true' harvest rates without survey bias. Over the last six years the average on the west coast has been a) 0.27 and b) 0.15.