Progress on recommendations from the 2016 review panel report

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The international review panel report (Dunn et al. 2016) contains the following recommendations pertinent to sardine in response to key questions put to them at the annual stock assessment review meeting held at UCT from 28 November to 2 December 2016.

Comments on these recommendations are inserted in italics.

B.1 Stock structure

B.1.1 On the basis of the current preferred hypothesis (MARAM/IWS/DEC16/Sardine/P7), advise on how alternative hypotheses about the contribution of south coast spawning biomass to west coast recruitment are best constructed and weighted, taking account of: a) approaches involving fits to stock recruitment relationships; and b) ouput from the hydrodynamic individual–based model (IBM), and how the associated uncertainty is best quantified?

Several papers (e.g. MARAM/IWS/DEC16/Sardine/P6, P9, P10, and P11) provided ways to estimate the contribution of south coast spawning to west coast recruitment. The methods on which these papers were based differed, but all attempted to find the proportional contribution of south coast spawning to west coast recruitment (*p*) that leads to the best fits to the stock and recruitment data. These papers all concluded that the best estimate of *p* was likely to be large (close to 100% of south coast spawning contributing to recruitment on the west coast). However, the information in the data to support any particular value for *p* was very weak, highlighting the importance of the prior assigned to alternative values for *p*.

The Panel notes that the current hydrodynamic model that could be used to define a prior for *p* is based on several assumptions that need further exploration. The Panel supports the following proposed additional work on this hydrodynamic model:

- repeat the sardine IBM computations using the new 3-d hydrodynamic model (larger spatial coverage and nested models; 1/15° resolution and 100 vertical levels; 6-hourly wind, heat and salinity forcing);
- release particles during peak spawning periods (as inferred from GSI data) for fish off the west and south coasts; and
- include larval behavior (e.g. diurnal vertical movement (see Parada et al., 2008) or directed swimming, etc); larval feeding; and larval predation.

The Panel specifically highlights the importance of adding more biological realism to the IBM, for example in the form of accounting for diurnal vertical movement of larvae. The Panel notes further that quantifying some of the factors that might impact transportation rates such as feeding and predation rates has proved difficult in other regions, and hence difficult to include in IBMs.

The Panel was advised that the hydrodynamic model was unlikely to be updated before when its output would be needed to provide a prior to weighting values of *p*. Hence, in the short-term, the outputs by month from the current hydrodynamic model should be weighted by GSI values by month as this should (to a first approximation) weight estimates of transportation rates by the relative amount of spawning.

A new highly-resolved 3D hydrodynamic model has been developed that covers a larger spatial extent (eastward extension to Port Alfred to better represent the South Coast spawning and nursery areas) and over a longer time period. While final results are not yet publically available, repeating the IBM with this new hydrodynamic model indicates higher average proportions (p) of spawning products which originate from the south coast being successfully transported to west coast nursery areas (0.17) than the 0.09 estimated by Miller et al. (2006). However this p was again strongly influenced by transport from the Central Agulhas Bank and few sardine eggs are found on the inner Central Agulhas Bank. Weighting by biomass will reduce this value somewhat (McGrath and van der Lingen pers. comm).

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In the new model, eggs were released equally every month and not weighted by peak spawning as inferred by GSI data. However van der Lingen and McGrath (2017) showed that weighting by gonado-somatic index (GSI) made little difference.

The IBM is primarily Lagrangian and larval behaviour, feeding and predation were not modelled, although mortality due to lower lethal temperatures was.

van der Lingen and McGrath (2017) conducted the short-term analysis suggested above and weighted monthly outputs for p by monthly GSI values of sardine off the South Coast. The frequency distribution of modelled transport success differed only slightly from that estimated without the monthly GSI weightings.

Any weighting applied to the Operating Models with different values of p has thus far been based only on individual preferences of the Small Pelagics Scientific Working Group OMP Task Team (see MARAM/IWS/2017/Sardine/P6), considering the information from this hydrodynamic model and the fits of stock-recruitment relationships to spawner biomass and recruitment 'data' at the joint posterior mode (though see B.1.4 below).

B.1.2 Advise whether other stock structure hypotheses need to be considered, taking account of the implications of the initial genetics results received very recently.

The stock structure hypothesis on which the assessment and OMP evaluation is proposed to be based involves a single stock (in the sense of a reproductively isolated unit) with two "components" (MARAM/IWS/DEC16/Sardine/P7). The genetic study currently underway, of which the Panel have only seen a presentation, suggests that there are three 'units' off South Africa inferred from analysis of genes under thermal selection, but that all three units are found off the west coast, off the south coast, and off the east coast, with no obvious link between unit and coast. This suggests there is no appreciable reproductive isolation among sardine across all three coasts, but that there appears to be a longshore cline for genes under thermal selective pressure. The Panel concluded that there is no need to change the current stock structure hypothesis.

No response required - the baseline operating models assume two sardine components according to this hypothesis.

B.1.3 Comment broadly on the implications of these various hypotheses concerning the need or otherwise for spatial management (i.e. for a directed sardine TAC split by area).

There is a need to consider OMP variants that include spatial management considerations given the stock structure hypothesis includes spatial components. The results of projections under OMP variants will likely depend on the contribution of south coast spawning to west coast recruitment (*p*), as well as other spatial aspects of the operating model such as the extent of west to south coast movement of age 1+ animals. The Panel does not recommend 'integrating' results across values for parameters that could have a substantial impact on the performance statistics (such as *p*). Such qualitative differences imply rather that the performance statistics for each such operating model should be considered separately.

The Panel recommends that OMP variants be developed that attempt to be 'adaptive' and hence able to respond to the further information that future data will provide towards resolving stock structure uncertainty. An example of such an OMP would involve modifying the ratio of the proportion of the catch taken on the west vs south coast based on spatial trends in recruitment estimates.

Candidate Management Procedures have thus far considered both single area and two area management of the directed sardine TAC (see MARAM/IWS/2017/Sardine/P7). An adaptive management proposal currently being considered is based on requiring explicit spatial management during "concerning periods" only (see MARAM/IWS/2017/Sardine/P7). Results have thus far been presented for individual choices of p and individual hypotheses of future movement of sardine from the west to south coasts, though there are some local suggestions for a weighting across these parameter values to simplify the process of comparing performance across a number of OMP variants (see MARAM/IWS/2017/Sardine/P6 and P7).

B.1.4 (H). Analyses that estimate the contribution of south coast spawning to west coast recruitment should plot the observed and model-predicted time-series of recruitment because the analyses in

MARAM/IWS/DEC16/Sardine/P11 suggest that even the best estimate for the parameter determining this contribution may not correspond to particularly good fits.

Not done. The utility of such plots is unclear to the authors of MARAM/IWS/DEC16/Sardine/P9 and P10. They consider that all fits to the pelagic stock-recruit relations are not "particularly good" given the high variability, and time-series plots would be similar and hardly distinguish preferences. Accordingly they consider that this seems better achieved by comparison of fit statistics such as log-likelihoods.

B.2 Proposed projection framework for OMP testing and related matters

B.2.1 Advise on which of the various future movement hypotheses that have been put forward (e.g. MoveR, MoveB) need be considered further, and on their relative plausibilities/weighting.

MARAM/IWS/DEC16/Sardine/P12 outlines the alternatives to model movement of age 1+ animals from the west to the south coast. The Panel agrees that the MoveR hypothesis (implemented as the proportion of 1 year olds that move being drawn randomly from the proportions estimated by the model for 2006-2015) be considered further. The hypothesis may not lead to "regime-like" trends on the south coast. Thus, the data on sediment core samples for Namibia should be explored to assess whether they provide information on inter-decadal variability of biomass. A scenario with regime-shifts in movement should be developed to match such variation if such variation is detected.

The Panel was concerned that the relationship identified for the MoveB hypothesis (proportion of 1 year olds that move in November of year *y* is assumed to be related to the ratio of south to west biomass in November year *y*-1) is unlikely to reflect a causal relationship, but instead may result from higher south coast biomass arising through higher movement rates. However, the outputs for the projections based on the MoveR hypothesis should be plotted to check that the resulting patterns match those in Fig. 6 of MARAM/IWS/DEC16/Sardine/P12, because the pattern in Fig. 6 should be an emergent property of the model. If neither the MoveR hypothesis nor a hypothesis based on regime shifts in movement of 1+ animals from the west to the south coast, is able to produce a pattern similar to that of Figure 6 of MARAM/IWS/DEC16/Sardine/P12, it may be necessary to develop a variant of the MoveB hypothesis in which the proportion of 1 year olds that move in November of year *y* has a dome-shaped relationship with the ratio of south to west biomass in November year *y*-1.

In summary, the MoveR hypothesis should form the basis for OMP evaluations unless the analyses of the sediment core samples for Namibia suggest the need for a regime-shift model for movement or the outputs from projections using the MoveR hypothesis do not match the pattern evident in Fig. 6 of MARAM/IWS/DEC16/Sardine/P12.

MoveR has continued to be used as a baseline hypothesis in our Operating Models (see MARAM/IWS/2017/Sardine/P6 for robustness tests). Sediment core samples from Namibia could not be used to inform on inter-decadal variability of South African sardine. MoveB has been dropped as a hypothesis (see Appendix of MARAM/IWS/2017/Sardine/P6).

B.2.2 Comment on how future recruitment is best generated for projections, taking into consideration: (a) which stock recruitment relationship(s) to use; (b) whether to fit them internally or externally to the assessment, and in the latter case how best to proceed in a Bayesian (MCMC) context; and (c) how best to generate residuals about that relationship.

(a) The reference case analysis should consider (roughly) three variants of the operating model of MARAM/IWS/DEC16/Sardine/P2 (i.e. different values for *p*) in which recruitment is related to spawning stock biomass according to a Hockey-Stick stock-recruitment relationship. The extent of variability in recruitment, σ_R, for each draw from the posterior should be set to 0.5, while the extent of auto-correlation in recruitment for each draw should be calculated by fitting an AR-1 model to the residuals by draw.

(b) The robustness tests that involve changing the form of the stock-recruitment relationship (Beverton-Holt, Generalized Ricker, and Shepherd should be considered) should be based on fitting an operating model with no stock-recruitment relationship (with log-recruitments being estimated rather than deviations about the stock-recruitment relationship). The parameters of the stock-recruitment relationship for each draw from the posterior should be based on either (i) fitting the stock-recruitment relationship to the estimates of stock and recruitment and taking the best estimates, (ii) fitting the stock-recruitment relationship to the estimates of stock and recruitment and generating values for the stock-recruitment relationship parameters from a multivariate normal distribution defined by inverting the Hessian matrix, or (iii) applying MCMC to the stock and recruitment data for each draw. Approach (iii) is much more computationally intensive than approaches (i) and (ii). Which approach is to be used should be determined for one of the reference case models (and some values for *p* / OMP variants) by comparing risk statistics among the approaches to determine whether one of the simpler approaches performs adequately. This would involve conducting projections based on the MCMC values for the stock-recruitment relationship parameters (to mimic approach (iii) and hence the ideal approach), and then using approaches (i) and (ii) to see if the risk statistics do not change appreciably, thus supporting the use of a simpler approach.

Operating Models with alternative p values were run with the Hockey stick stock-recruitment relationship estimated during conditioning (i.e. (a) above). The MCMC chain for p=0 converged and this OM is available for use (de Moor 2017). The MCMC chains for p=0.08 and p=0.4 did not satisfy quantitative convergence tests, but have been used for some 'robustness testing' (de Moor 2017). The MCMC chains for p=0.2 and p=0.3 have not yet been used. The MCMC chain for p=0.6 did not converge.
Operating Models with alternative p values for results presented for this workshop are based on stock-recruitment relationships fitted after conditioning (i.e. (b) method (i)) above. Only this simple method has been used (thus far) without MCMC estimation of the stock-recruitment parameters for each simulation.
Approach (b (i)) was selected due to time constraints.

B.2.3 Provide comments on other aspects of the specifications proposed for OMP testing.
The Panel was informed that industry was interested that OMP variants be examined that consider moving the boundary between the south and west management areas. The Panel recommends:
1) the operating models should be based on an assumed "true" stock boundary at Cape Agulhas to reduce computational demands associated with conditioning operating models;
2) the analysts should work with the industry to identify how the spatial pattern of catches would likely change given a change to the boundary; and
3) it will be necessary to modify how abundance estimates are generated if the boundary is moved by a substantial extent from the line at Cape Agulhas.

The OMP testing should consider alternative values for the proportional contribution of south coast spawning to west coast recruitment (*p*). The Panel recommends considering values for *p* of 0 (no contribution of south coast spawning to west coast recruitment), a value based on the hydrodynamic model, and a larger value given that there are several sources of uncertainty that are not included in the hydrodynamic model. The Panel could not identify an objective basis for assigning weights to alternative values for *p*. Consequently, the Panel recommends that results be shown for each individual choice for *p*.

Development of a candidate Management Procedure with flexibility in a west-east boundary has not yet begun given initial work has focussed on two area management with a fixed boundary.
Operating Models assuming two sardine components have been constructed for p=0, p=0.08 (average biomass weighted proportion of eggs spawned on the South Coast that were estimated by the hydrodynamic model to be successfully transported to the West Coast nursery area (Coetzee 2016)), p=0.2 and p=0.6. Results have thus far been presented for individual choices of p, though there are some local suggestions for a weighting across these p values to simplify the process of comparing performance across a number of OMP variants (see MARAM/IWS/2017/Sardine/P6 and P7).

B.2.4 Advise on an appropriate risk specification, noting the comparison available of the productivity of South African sardine relative to other sardine stocks worldwide, and advising both how this might best be taken into account and how that analysis might be improved.
MARAM/IWS/DEC16/Sardine/P13 provided information on the proportion of sustainable yield to spawning biomass for sardine stocks for which data were available. However, the underlying data appear to be of questionable accuracy in some cases. Moreover, most sardine stocks (including that off South Africa) are not

managed on the basis of a constant exploitation rate strategy. A potentially more informative question to answer would be how one might make the risks comparable among the different harvest strategies used in each example case. One possibility would be to compare their relative performance in terms of the particular fisheries' response to application of the harvest strategy in use. Possible measures of that performance could be how often the stock declines to low levels (pre-defined limits). It might also be useful to determine whether or not, in each example case, fishing in fact can have a meaningful influence on each stock.

The evaluation of OMP variants relies on the risk criterion that is used when tuning OMP variants. The probability of dropping below the current threshold used to compute risk (the average biomass from 1991 to 1994) is substantially higher under the current assessment than that on which OMP-14 was based, in particular in the absence of catches. It is necessary to fully understand why the change in the estimate of the average biomass under zero fishing ("K") and in risk has occurred. Reasons to explore include how maturity in the model is defined, but whether this is the key reason is unclear. Options to consider if the risk criterion is to be changed include defining the threshold as some proportion of the biomass at which expected recruitment declines and some proportion of K (as estimated for one form of stock-recruitment model).

Risk criteria have not been specified for the two component operating model. The Panel recommends that risk criteria be selected for each of the south and west coasts, but that the probability of being below the threshold need not be the same for the two coasts.

It is expected that the next Operational Management Procedure will be tuned to avoid a limit (or limit-like) reference point with a high probability for anchovy and each sardine component. Documents MARAM/IWS/2017/Sardine/P2 and MARAM/IWS/2017/Sardine/P3 provide further information on this topic. Note that K is not preferred as the basis for a threshold for small pelagics due to the high variability in the estimate of K for alternative stock-recruitment relationships fitted to the same set of data.

B.2.5.1 (M) Create plots of the proportion of each sampled fish according to its genetic unit after arranging the samples by longshore location, using the genetics data by season to assess whether there is more evidence for population structure, for example temporally.

Not yet done.

References

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