Progress report on recommendations from the international review panel report for the 2013 and 2014 International Fisheries Stock Assessment Workshop: sardine two-stock hypothesis.

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The international review panel reports (MARAM/IWS/DEC13/General/4 and MARAM/IWS/DEC14/General/4) contained the following recommendations pertinent to the further development of a two-stock hypothesis for South African sardine. Comments on any progress in response to these recommendations are inserted in *italics.*

2013 Summary of general issues: Sardine

- The Panel was impressed by the biological and modelling work undertaken for the sardine two-stock hypothesis.
- The biological studies and stock assessment model favour a two-stock sardine population scenario with movement of age-0 fish from the west stock to the south stock.
- Although a two-stock model with no movement is possible, fits of the assessment model to the recruitment and abundance data are poor when there is no movement from the west stock to the south stock.
- While the two-stock model with movement should continue to be taken into account in finalising a revised OMP, the Panel recommends that further stock and recruitment scenarios be explored, including fitting to parasite data, and that additional precaution be exercised in setting TACs until this process reaches finality.
- The Panel recommends that further model development occur in the short-term even though there is strong desire by all participants to complete the OMP revision soon.
- The alternative models identified in Section C may lead to qualitatively different outcomes through the inclusion of additional data and should lead to a broader range of models that better encapsulate the uncertainty regarding the population dynamics of the South African sardine resource.
- The Panel suggests that the performance metrics identified to evaluate alternative OMPs might benefit from a wider discussion on objectives and trade-offs, which might possibly lead also to the use of a broader range of operating models, as well as to the definition of a set of additional conditions that may invoke the Exceptional Circumstances provisions under an OMP.

The Small Pelagic Scientific Working Group agreed early in 2014 to finalise OMP-14 based on a single sardine stock operating model only, but coupled with some spatial management, the spirit of which is to be a "warm up period" with the expectation that the next OMP will likely require spatial management components. The development of new operating models and a new OMP is to be brought forward, commencing in 2015 with the aim of being finalised before the end of 2016.

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2013 Recommendations: Sardine

C.1 (*) The Panel agrees that the evidence from biological studies favours a two-stock sardine population scenario with movement of age-0 fish from the west stock to the south stock. Although a two-stock model with no movement is possible, fits of the assessment model to the recruitment and abundance data are poor when there is no movement from the west stock to the south stock.

No response necessary, this is consistent with present thinking and the current sardine two-stock model.

C.2 (*) Abundance of age-0 sardine in the south coast November survey does not appear large enough to explain the observed scale and trends of age-1+ south coast abundance. Further, age-1+ biomass on the south coast is not correlated with the south coast recruit survey while it is correlated with the west coast recruit survey estimates. These observations support the hypothesis that immigrants from the west have made large contributions to the south stock abundance, at least over the period for which observations are available.

No response necessary, this is consistent with the current sardine two-stock model.

C.3 (*) Projections of the sardine population in the absence of exploitation under the assumption that the movement rate is related to environmental conditions on the south coast leads to median population sizes substantially lower than current population sizes, with smaller population sizes for longer environmental regimes. Risk measures will need to be redefined if OMP decisions are to be based on models with these characteristics. For example, a reference point of the average 1+ biomass over 1991-94 is not meaningful for the west coast stock if this stock is projected to collapse even under zero catch.

The choice of risk measures will be re-considered during the development of OMP-16 which will be simulation tested for both single and revised two stock hypothesis operating models.

C.4 (H) The two-stock sardine model with movement from the west to south stock is able to fit the available data on age-1+ abundance as well as the trends in the west coast recruit survey. The model attributes the large increase in south coast biomass to movement from the west coast. However, there are no direct estimates of the extent of movement. MARAM IWS/DEC13/Sardine/P6 presents information suggesting that prevalence of *Cardiocephaloides* parasites increases with body length for sardine on both coasts. This parasite is found in some age-0 sardine off the west coast but in no age-0 sardine on the south coast. The data on presence of parasites by length should be included in the assessment as a "biologically-tagged" population component; potentially this could provide a bound for the average movement rate of age-0 animals from the west to the south stocks.

van der Lingen and Winker (2014) and Ross-Gillespie and Butterworth (2014) confirmed that the parasite prevalence of infection does increases with length for sardine on the south coast which are assumed to be bigger than 1 year olds. The hypothesis of de Moor and Butterworth (2015a) (MARAM/IWS/DEC15/Sardine/BG4) - which assumed no movement of sardine older than recruits of the year (as they turn 1) from west to south coasts - needs revision. de Moor and Butterworth (2015b,c) (MARAM/IWS/DEC15/Sardine/P2 and MARAM/IWS/DEC15/Sardine/P4) consider the possibility of sardine older than recruits of the year moving from west to south coasts.

C.5 (H) The magnitude of age-0 sardine movement from the west stock to the east stock remains a critical uncertainty for the two-stock model. It is therefore important to consider a range of alternative models for sardine. The Panel identified several alternative models / modelling assumptions

5.1. (H) Exclude the south coast recruit survey from the assessment because it involves questionable assumptions about the relative scales and correlations between recruits resulting from winter (not observed) and summer spawning.

This alternative has not yet been attempted with the revised model. Initial attempts at modelling two sardine stocks showed an improvement in model fit to survey estimates of 1+ biomass when the time series of survey estimates of recruitment to the south stock were included (de Moor and Butterworth 2009a,b). Admittedly, the model has been adapted quite substantially since that work, and it is anticipated that this alternative will be attempted with the revised model.

5.2. (H) Collate data on age-0 abundance from the November surveys and include these data in the assessment by allowing in addition for winter recruitment cohorts in the model. This would involve assuming that the current south coast survey indexes some time-varying proportion of the total annual recruitment while the November survey indexes the rest of the annual recruitment. In such a model, the relative bias parameter for the recruitment survey on the south coast relative to the west coast may need to be removed to avoid confounding with the added recruitment series.

Assuming a constant cut-off length of 8cm between recruits and 1+ sardine in the November survey east of Cape Agulhas, de Moor et al. (2014a) showed that, on average, winter-spawned recruits contributed 26% to the total recruitment of the year, and in two years the contribution by winter-spawned recruits was greater than that of summer-spawned recruits. However, they also showed that even if the May survey fails to cover the majority of south stock recruits, it is still likely that the increase in south stock biomass in the early 2000s was primarily a result of movement of sardine from the west to the south stock.

Rather than try to separate the November survey estimate of abundance into that of 0-year-olds and that of 1+, the revised model assumes the survey biomass represents 0+ rather than 1+ biomass. Using weight-at-length (rather than age) combined with the (relatively wide) distribution of length-at-age 0 allows for indirect modelling of an extended period of spawning/recruitment.

A further modification to the model, if deemed necessary due to poor fits to the data, will be to model the south stock recruitment as occurring in two pulses (November and May), thereby requiring two cohorts of south stock sardine to be modelled. The May recruitment will not be assumed to form part of the May survey estimate of recruit abundance, but will be assumed to contribute to the November survey estimate of total biomass. A "total annual recruitment" will be modelled relating to the spawner biomass with a stock-recruitment relationship, and, in the absence of further data precluding the estimation of time-varying proportions, the proportion of this annual recruitment occurring in November and May will likely be assumed to remain constant over all years.

5.3. (L) Assume that density-dependence is a function of the total spawning biomass rather than the spawning biomass by stock. This model can be implemented by estimating (i) annual deviates about the common stock-recruitment relationship and (ii) the annual proportions of total recruitment "settling" to the west and south coast areas. This hypothesis is worth modelling even though the presence of two spawning grounds, along with winter spawning only on the south coast, is less plausible than the current two-spawning stock approach given oceanographic model results (see recommendation C.8).

Given the low priority, this has not yet been considered. While the authors are hesitant as to whether the model will be able to distinguish between the annual proportions of total recruitment "settling" to the west and the south coasts in addition to the annual proportions of recruits (and older sardine) moving from the west to the south stocks, we plan to consider this as a sensitivity test.

5.4. (H) The probability of population persistence is related to (a) the rate of movement from the west to the south coast (lower for higher rates of movement), (b) the form of the stock-recruitment relationship (lower for a hockey-stick stock-recruitment relationship than for a relationship which is more compensatory at lower stock size), and (c) the relative recruits/spawner ratios on the west and south coasts. Constraints (ideally based on analogy for similar resources elsewhere in the world) on each of these factors should be imposed so that there is an acceptable probability that the population persists in the absence of exploitation.

This work is yet to be initiated; ideally it will first consider the RAM legacy database and contact will also be made with scientists undertaking quantitative assessments of major sardine resources worldwide.

C.6 (H) The Panel finds that the evidence in favour of movement proportion being a function of the ratio of the south coast to west coast biomass is weak (Model Move B) and recommends that more weight be assigned to the model in which movement rates are related to environmental change (Model Move E). A simpler way to model the probability of moving from the west to south coast would be as an autocorrelated time-series.

An operating model with autocorrelated future sardine movement ("MoveAutoC") was developed (de Moor and Butterworth 2014). The Small Pelagic Scientific Working Group agreed to concentrate on "Move E" and a new alternative "MoveAutoC" for the short-term. The alternative movement hypotheses will be revisited, following the revised estimation of 1994 to 2014 movement, during the development of operating models for OMP-16.

C.7 (L) Conduct a retrospective analysis in which the two-stock model is projected forward from (say) 2003 with the observed recruitments and catches by coast but with movement governed by the postulated movement models.

de Moor (2014) projected the operating model forward for 8 years with the following changes from the simulation testing framework used to develop OMP-14:
a) the sardine and anchovy starting numbers-at-age, 1+ biomass and SSB match those in November 2003 instead of November 2011.
b) the November 2003 recruitment is informed by the May 2004 survey observation and the stock-recruitment curve.
c) the proportion of west stock recruits moving to the south stock in the "most recent year" is changed from that estimated in November 2011 to 2003, for use in future movement scenarios that use the former year's proportion in calculating the current year's proportion moving. In the "MoveE" hypothesis, the "switch" years are fixed at 2003 and 2009.
d) the anchovy and directed sardine TACs are fixed at the 2004 to 2011 values, while the anchovy catch-at-age 0 and 1 are fixed at the (lower than TAC) 2004 to 2011 observations.
Note, however, that the observed recruitments in May each year were not used to over-ride the model generated recruitment from the stock-recruitment relationship.

The above changes resulted in projections of sardine 1+ biomass relatively near to the actual observations from November 2004 to 2011 under "MoveE" and "MoveAutoC", while under "NoMove" the survey observations are outside the model projected sardine 1+ biomass 90% probability interval for some years.

C.8 (L) The egg/larval individual based model is a useful way to develop hypotheses regarding movement patterns of age-0 fish and to establish the likelihood that fish spawned by one stock move to the area in which the other stock is predominantly found. However, the value of this tool would be enhanced, and the ability to draw conclusions strengthened, if it proves possible to extend the model to account for variation in oceanographic conditions as well as in the distribution of predators and prey.

Coetzee (2014) further investigated the potential contribution of sardine spawning on the west and south coasts to recruitment on both coasts, by considering the IBM analyses of Miller et al. (2006). This shows that a larger proportion of eggs spawned on the west coast are "lost". Assuming the movement/retention of eggs correlates directly with sardine recruitment, Coetzee (2014) reports there to be a greater probability that south coast spawning makes a contribution to recruitment on the west coast than west coast spawning does to the south coast recruitment.

de Moor et al. (2014b) (MARAM IWS/DEC15/Sardine/BG5) considered alternative hypotheses (the "A" hypotheses) of two mixing sardine stocks based on this work, assuming the "effective" spawning biomass of each stock was a proportion of both stocks. Following the recommendations of the 2014 review panel (see below), this hypothesis has not been further developed given the higher prioritisation of alternative hypotheses.

2014 Summary of general issues: Sardine

The process implemented following the 2013 review involved biologists and modellers collaborating to synthesize multiple sources of information for sardine off South Africa to identify plausible stock structure hypotheses. The process also identified the data that might be used to fit models based on those hypotheses. This process has been very successful. The hypotheses identified through this process, while not yet final, represent an effective synthesis of a diverse set of information. The work of the Panel focused on ranking the various model formulations and identifying the technical changes to these formulations so that maximum use can be made of available data, in particular the data that has recently become available from parasites.

No response necessary.

2014 Recommendations: Sardine

C.1 (*) The alternative models (see MARAM/IWS/DEC14/Sardine/P2) should be implemented in the following priority order:

- Alternative D (Varied Adult Movement). Fits to the parasite data should be used to evaluate the plausibility of the sub-variants of this model variant. MARAM/IWS/DEC14/General/4 13
- Alternative C (Varied Adult Distribution). Fits to the parasite data should be used to evaluate the plausibility of the sub-variants of this model variant.
- Alternative A (Effective Spawning Biomasses). An additional sub-variant in which the proportion of south SSB off the west coast exceeds 20% should be considered. Whether this sub-model is taken forward depends on whether auxiliary information suggests that it is plausible. See also recommendation C.4.
- Alternative B (Varied Recruit Distributions). Alternative B is assigned lowest priority because the extent to which south stock recruits are assumed to be distributed west of Cape Infanta at the time of recruit survey is essentially arbitrary. Alternative A is given next lowest priority because it depends on

the results of the linked biological-hydrodynamic model (MARAM/IWS/DEC14/Sardine/BG8), but those results are likely subject to considerable uncertainty owing to an inability to model the response of early life stages to environmental conditions.

The revised two-stock hypothesis presented at this workshop is based on Alternative D, which allows sardine of all ages to move from the west to the south coast rather, than just age 1 fish (de Moor and Butterworth 2015b,c – MARAM IWS/DEC15/Sardine/P2 and MARAM IWS/DEC15/Sardine/P4).

C.2 (H) The parasite data have the potential to evaluate the relative plausibility of the alternatives listed in MARAM/IWS/DEC14/Sardine/P2. These data should be included routinely in the likelihood maximized when fitting the model. The approach outlined in MARAM/IWS/DEC14/Sardine/P3 will need to be extended to allow predictions of prevalence and abundance of the parasite to be made. In particular, the prevalence of the parasite by age and over time needs to be tracked for the "South from west stock" animals. More complex models will be needed to implement alternative 'C' variants. For example, it will be necessary to keep track of 'South visited West" animals.

Please see combined response below to C.2 and C.3.

C.3 (H) Initial focus for model development should relate to including prevalence of the parasite, but the abundance (intensity) of the parasite may provide additional information and should be considered as a qualitative reality check if possible.

As a first step, the revised sardine two-stock model tracks sardine by stock and by infection (i.e. infected or not infected). This enables the model to estimate the prevalence-at-length of sardine infected with the parasite in each stock. This first step also only includes prevalence data from November survey samples between 2010 and 2014 in the likelihood.

Planned extensions to this model during 2016 will include the sampled prevalence data from the November 2015 survey and the prevalence data from the 2010 to 2015 recruit surveys. Fitting the model to sampled prevalence-at-length (by stock) from commercial data from 2011 to 2015 is also planned, but may require revision of the model regarding the timing of movement (e.g. closer to May than November each year, or a little at the beginning of August and November?).

Including sampled infection intensity-at-length (by stock) in the likelihood may help further inform on the duration for which individuals were present on the west coast (i.e. the age at which they move from west to south coasts). This has been prioritised as a second step (if time permits prior to OMP-16 implementation) and will require further modification to the model to track south-stock sardine originating from the west stock. It is expected that this portion of the population will need to be additionally modelled by age/year of movement to account for the higher infection intensity expected from individuals that spend more time on the west coast prior to moving to the south coast.

Note that is important to appreciate that "intensity" and "abundance" refer to different metrics of parasite infection and should not be confused. "Mean infection intensity" is the average number of parasites per infected fish in a sample and hence pertains to infected fish only, whereas "mean parasite abundance" is the average number of parasites per fish in a sample and hence pertains to all fish, both infected and uninfected. Because of this, abundance and prevalence metrics for a sample of fish are not independent. At this stage we plan to use infection intensity in addition to parasite prevalence in further model development so that the

data remain (pretty much) independent. However, the alternative use of abundance data in addition to parasite prevalence will also be considered at the time of implementation.

C.4 (H) Alternative B should be implemented accounting for the implications of south stock recruits being found throughout the west coast, and hence being subject to the fisheries there, and possibly being infected by the parasite.

As this is a low priority (see C.1 above), the hypothesis will likely not be further developed prior to OMP-16.

C.5 (H) The alternative models should be evaluated in terms of their ability to fit the available data and to mimic more generic expectations for the dynamics of sardine populations. In particular, individual future projected trajectories of population size should exhibit the boom-and-bust dynamics typical of small pelagic fishes.

Projections from revised operating models have not yet been undertaken.

C.6 (H) An attempt should be made to estimate the recruitment from winter spawning on the south coast. The two approaches in MARAM/IWS/DEC14/Sardine/P3 should be explored.

It is unclear which "two approaches" are being referred to.

Approach a) of MARAM/IWS/DEC14/Sardine/P3 – assuming the November survey represents total rather than 1+ biomass - has already been implemented in the revised sardine model (de Moor and Butterworth 2015b – MARAM/IWS/DEC15/Sardine/P2).

Approach b) of MARAM/IWS/DEC14/Sardine/P3 – modelling recruitment to the south stock to occur in two pulses (November and May) - will be modelled as a second step if poor fits to the data still result from the revised sardine two stock model. The May recruitment will not be assumed to form part of the May survey estimate of recruit abundance, but will be assumed to contribute to the November survey estimate of total biomass. A "total annual recruitment" will be modelled relating to the spawner biomass with a stock-recruitment relationship, and, in the absence of further data precluding the estimation of time-varying proportions, the proportion of this annual recruitment occurring in November and May will likely be assumed to remain constant over all years.

Approach c) of MARAM/IWS/DEC14/Sardine/P3 has not yet been attempted due to the requirement of re-calibration of pre-1998 survey data which is not possible with capacity limitations in the short term.

C.7 (H) The selectivity of the trawls used during the November survey is estimated to be domed-shaped. This was unexpected given the nature of an acoustic survey which should survey the entire biomass (uniform over all ages), and suggests that the trawls provide a biased view of the length-structure of the population. However, this will be inconsequential for assessment purposes if the trend in abundance is not sensitive to selectivity. The following ways should be explored to determine the extent to which this selectivity could impact the results of sardine assessments: (a) compute length-frequencies based on biomass weighted length-frequencies stratified by survey stratum and broad size group, and (b) compute biomass estimates using length-frequencies where the abundance of the length classes assumed not to be fully selected are scaled up by the estimates of selectivity by length-class in Figure 6 of MARAM/IWS/DEC14/Sardine/BG6.

a) *Not yet attempted, and current capacity limits this undertaking in the near future.*
b) *Not yet attempted – waiting first for revised model estimates of acoustic selectivity-at-length.*

C.8 (M) Show "worm plots" of movement probabilities to evaluate whether the behaviour of, in particular, the MoveAutoC option results in realistic behaviour.

de Moor and Butterworth (2015a) (MARAM IWS/DEC15/Sardine/BG4) shows the estimated proportion of sardine moving each year at the joint posterior mode. "Worm plots" of estimated future movement, in addition to median and 95% confidence intervals will be produced in due course.

C.9 (M) Age-0 animals should be included in the model predictions of the biomass available to the November survey.

The revised sardine assessment model assumes the November survey provides an estimate of 0+ biomass.

C.10 (M) If computationally feasible, full account should be taken of the uncertainty associated with the parameters of the stock-recruitment relationship if this relationship is fitted outside of the process of fitting the population dynamics model.

The revised sardine assessment model continues to estimate a stock-recruitment relationship within the model. If time permits, an alternative model which does not impose a stock-recruitment relationship internally will be explored, with the output stock and recruitment estimates, together with their associated variance-covariance matrix used to take full account of uncertainty, applied in estimating this relationship externally.

C.11 (M) Consider an alternative model in which the effective spawning biomass is the spawning biomass off the south coast, under the assumption that all of the west coast recruitment originates from the south coast, as a sensitivity test.

Not yet considered.

C.12 (M) Further examine whether an environmental variable exists that links environmental variables and recruitment / movement in the operating model (not necessarily the candidate OMPs). Although evaluations of the potential for environmental variables to explain movement and recruitment have been conducted in the past, substantially more data appear to be now available.

A separate project is considering simpler models of sardine and anchovy with the aim of linking movement or recruitment residuals to environmental variables (Global Learning for Local solutions: Reducing vulnerability of marine-dependent coastal communities http://www.marinehotspots.org/index.php/featured-projects/gulls). The results from this project may assist in guiding future work regarding the incorporation of environmental variables within the sardine (and anchovy) operating models.

C.13 (L) The Panel continues to support its earlier recommendation that an alternative model be developed that assumes that recruitment is dependent on total west+south biomass and in which the proportion recruiting to the south and west is estimated.

Not yet considered (see C5.3 above in the 2013 section).

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