INTERNATIONAL REVIEW PANEL REPORT FOR THE 2013 INTERNATIONAL FISHERIES STOCK ASSESSMENT WORKSHOP

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Introduction

The Panel recognised the very high quality of the research presented at the 2013 International Fisheries Stock Assessment Review Workshop. This included research on South African hake, sardine, and linefish, as well as research associated with the BCC ECOFISH project. The Panel thanked the workshop participants for their hard work preparing and presenting the workshop papers, for the extra analyses undertaken during the workshop, and for the informative input provided during discussions.

This report starts with observations from the Panel on some general issues for the species / programmes reviewed, and then focuses on the more detailed technical review and recommendations concerning each. The Panel deliberations for the South African hake and sardine were guided by a set of key issues (see Appendices 1 and 2) and the text in square parentheses at the end of some of the recommendations reflects the corresponding key issue(s). The Panel did not have time to address all of the key questions. The recommendations are annotated by their priorities (H, M, L and conclusions are indicated by asterisks).

Summary of general issues

Hake

The review focused on progress on steps in the process of revising the current hake OMP which commenced in March 2013 and is due for completion in September 2014. The current assessment model [MARAM IWS/DEC13/Hake/P2] was evaluated in some detail, with particular focus on fits to the longline fishery length-frequency data and the form of selectivity patterns [see recommendations A.4, A.5]. Alternative potential operating models were reviewed, including a model that allows for movement among spatial strata rather than treating spatial differences in length-frequency and abundance trends as being due to differences in selectivity among "fleets" (reflecting different areas and commercial CPUE or surveys) [MARAM IWS/DEC13/Hake/P9], and a model incorporating inter-specific predation and cannibalism [MARAM IWS/DEC13/Ecofish/P10]. The Panel also provided advice on selection of robustness tests [recommendation A.16] and OMP issues [recommendations A.17 and A.18].

Unavailability of the research vessel *Africana* continues to be an issue for hake surveys, hake assessments, and potentially hake OMPs. Issues associated with the use of industry vessels to conduct surveys were discussed [Section E], including the associated problem of calibration. Alternative scenarios for future surveys and their implications can be investigated during the OMP development process [recommendations E.3, E.4 and E.5].

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

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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 tradeoffs, 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.

Linefish

The Panel noted the very good progress made since the 2012 review in testing the method developed to standardize CPUE for linefish [MARAM IWS/DEC13/Linefish CPUE/P1]. This method could be of broad interest in multi-species fisheries and could have wide application. Some suggestions were made about final testing and application [Section D]. The method is sufficiently well developed for use in stock assessments for some linefish species and future reviews might desirably focus on broader aspects of linefish assessment.

BCC ECOFISH

The Panel reviewed several aspects of the BCC ECOFISH program, particularly those related to spatial structure in hake populations off South Africa and Namibia. The GeoPop approach [MARAM IWS/DEC13/Ecofish/P6 and MARAM IWS/DEC13/Ecofish/P7], combined with the genetic analyses [MARAM IWS/DEC13/Ecofish/P9], should be used to develop hypotheses about stock structure and movement for future assessments. The Panel encouraged much closer interactions between the biologists, geneticists and modellers involved in this work.

Other issues

The Panel was concerned about certain aspects of the arrangements for the review. In particular, these were the large number of issues and documents to be considered, compounded by the late delivery of several documents. The time pressure in the meeting also resulted in a number of papers not being presented or considered, of concern both to those who developed the papers and those who had to read them.

The Panel also had some concerns about convergence issues for a number of model runs presented. Section F and Appendix 3 of this report provide some guidelines for overcoming such difficulties. However, there is also value in the modellers checking each others' code and sharing techniques for overcoming problems such as a lack of convergence and how to avoid coding statements that are problematic for AD Model Builder.

The Panel was informed that environmental data were not collected during recent surveys because commercial vessels had to be substituted given the unavailability of the *Africana*. It strongly recommends that these data should be collected during surveys. They could be used to better understand environmental conditions and how these change over time, and in the case of the demersal surveys, following further analysis, to adjust the survey estimates of abundance for hake and hence hopefully reduce the variance of these estimates.

Hake

Assessment-related

A.1 (*) The assessment framework that incorporates movement explicitly is a major potential step forward in understanding the dynamics of South African hake. However, several issues need to be addressed before this framework could be included in the reference set of operating models for this (or any future) hake OMP revision (see recommendation A.9 below). While including this model in the robustness tests would be desirable, a number of assumptions regarding the spatial distribution of future effort would need to be made. Given the amount of time available it may not be possible to complete this model development in order to use it as an operating model to test candidate OMPs in the current review process due for completion by September 2014. [*Review progress on the development of approaches which model movement explicitly, and advise on their role in the current OMP review process*]

A.2 (*) Include the replacement line on all stock-recruitment relationships reported in Figures. [*Review progress on update of 2010 assessment approach leading to a new Reference Set*]

A.3 (H) Update the Reference Case specifications so that the penalty function on the change in survey catchability associated with the use of a new gear by *Africana* is set to the best estimate obtained in the most recent calibration analysis: for *M. capensis* this should be 0.653 (SE 0.073) rather than the *ad hoc* value specified in the past (0.8), and for *M. paradoxus* it should be updated based on "Model 1" (see Table 1). [*Advise on appropriate calibration factors for Africana old vs new gear*]

A.4 (H) Take the sex-specificity of the available length-frequency data for the longline fisheries into account in the assessment. This may require that some of the selectivity patterns be modified to allow them to be sex-specific. See also recommendations A.5 and A.6. [*Consider the implications of the sensitivity of the results to the addition of further longline CAL data*]

A.5 (H) Dome-shaped selectivity is currently modelled as a logistic function of length, with an exponential reduction in selectivity above a certain length. The length at which selectivity begins to drop is pre-specified rather than being estimated. Consider implementing a selectivity function which includes dome-shaped and asymptotic selectivity as special cases, and which allows the length when selectivity starts to decline to be estimated. The double-logistic function included in Stock Synthesis (Methot and Wetzel, 2013) is a 7-parameter function that has these properties and is differentiable. [*Review progress on update of 2010 assessment approach leading to a new Reference Set*]

A.6 (M) The current likelihood function for the length-frequency and conditional age-at-length data is not a true likelihood. Consider the alternative likelihood function for the length-frequency and conditional age-at-length data developed by Chris Francis (paper available on request from the author). [*Review progress on update of 2010 assessment approach leading to a new Reference Set*]

A.7 (M) The shape of the selectivity patterns for the south coast spring and autumn surveys for *M. paradoxus* in MARAM IWS/DEC13/Hake/P2 are surprising and hard to justify biologically. This might reflect imprecision of the estimates in question. Consider imposing a stronger penalty on how selectivity may change among length-classes. [*Review progress on update of 2010 assessment approach leading to a new Reference Set*]

A.8 (M) Use the approach of Francis (2011) to explore whether the extent to which the length frequency and conditional age-at-length data are downweighted is appropriate. [*Review progress on update of 2010 assessment approach leading to a new Reference Set*]

A.9 (M) The Panel has the following suggestions related to the stock assessment method which models movement explicitly. [*Review progress on the development of approaches which model movement explicitly, and advise on their role in the current OMP review process]*:

1. Estimate the spatial distribution of recruits as a vector of parameters, and start movement in the model at the first age at which hake are observed in surveys. This reduces the number of estimable parameters.
2. Estimate the initial distribution of abundance in 1978 using a vector of parameters by age or groups of ages. Estimation will be more stable if the deterministic numbers-at-age are first initialized deterministically, e.g., N(a) = R*exp(-M – init_F) and then adjusted via N(a) = N(a)*init_N_devs(a).
3. Explore why the model suggests that survey selectivity for *M. capensis* should be dome-shaped when essentially the entire range of the species is covered by the survey and model.
4. Longshore strata could be added to the model as needed and statistically justified by the data available for parameter estimation.
5. Report the proportion of each species in each spatial stratum by age, and develop methods for visualizing how this proportion changes over time.
6. Implement (weak normal) penalties on the parameters which determine movement to avoid parameters moving towards bounds.
7. Consider implementing smoothness penalties on the movement rates or functional forms for movement based on age and distance to avoid what appear to be unrealistic movement probabilities in some instances.
8. Work with biologists to evaluate whether the estimated movement probabilities and spatial distribution patterns match expectations. The output of the GeoPop model might be helpful in this regard.

A.10 (L) The GLM CPUE series are based on species-aggregated catch and effort data which are then disaggregated to species. There will be some correlation between the standardized CPUE series for the two hake species. Estimate the extent of between-species correlation in the residuals for the two species. If there is substantial correlation, develop a likelihood function which accounts for these correlations and generate future CPUE data by species with this correlation (as well as the temporal correlation referenced in A.15 below). [*Review progress on update of 2010 assessment approach leading to a new Reference Set*]

A.11 (L) There are only a few unsexed animals which are not immature. Drop these animals from the analysis to avoid fitting data for which the sample size is very small. [*Review progress on update of 2010 assessment approach leading to a new Reference Set*]

A.12 (L) Determine exactly how the early ("ICSEAF") CPUE series were coarsely standardised.

OMP-related

A.13 (*) The OMP evaluation could consider minimising changes over time in fishing mortality as a proxy for changes over time in effort amongst its objectives.

A.14 (*) Analyses provided to the Panel in MARAM IWS/DEC13/Hake/P2 suggest that there is a limited ability to forecast trends in commercial CPUE and survey indices of abundance.

A.15 (H) Modify the future projection specifications for OMP testing so that allowance is made for temporal autocorrelation in catchability when generating future CPUE indices of abundance. The extent of such correlation should be calculated for each CPUE series separately. [*Review progress on update of 2010 assessment approach leading to a new Reference Set*]

A.16 (H) In relation to robustness tests [*Advise on the selection of robustness tests;* see Appendix 4 for the updated list of robustness tests]:

1) Drop robustness test A.catches.1[5] because robustness test A.catches.2 provides a more complete examination of the implications of using the observer data to split the historical catches to species.
2) Add a robustness test based on the current robustness test A.catches.2 in which the species split is based on the "old algorithm" which allows for year effects in the algorithm relating these splits to hake size and depth.
3) Robustness test A.Catches.3 should refer to doubling the <u>catch</u> by the longline fisheries, not the fishing mortality rate. Also, the operating model should output the model-predicted discards (in total and by length-class) in absolute terms and relative to the landed catch, and the plausibility of this level of discards should be evaluated given the data collected by observers.
4) Add a robustness test in which there is hyper-stability in past and future CPUE-abundance relationships, for example, that CPUE is proportional to the square-root of abundance.
5) Add a robustness test in which there is hyper-stability in future CPUE-abundance relationships only.
6) Use CPUE standardization to explore the plausibility of the assumptions underlying robustness test A.CPUE.2 if it is selected for further consideration.
7) Robustness test A.CPUE.3 may involve a considerable amount of work to implement correctly, especially given the longline selectivity pattern is assumed to change over time. Completing this robustness test should be assigned a lower priority.
8) Implementation of robustness test A.survey.2 depends on having the relevant environment covariates for the entire time-series of survey estimates. It should only be implemented if such covariates are available and relationships have been established. [*Advise on possible approaches to take environmental co-variates into account in estimating abundance indices*].
9) Robustness test B.sel.3 should be divided into two robustness tests, one in which the scaling factor is increased and another in which it is decreased.
10) Robustness test B.SR.1 should be assigned low priority given that implementing the assessment as a random effects model is likely to be very challenging.
11) Robustness test B.SR.2 should be divided into two robustness tests, one in which the sex ratio is skewed towards females and another in which it is skewed towards males.

[5] These and following references in paragraph A.16 refer to the proposals in document MARAMIWS/DEC13/Hake/P6; some of these change in the revised list in Appendix 4.

12) Robustness test B.others.5 should be dropped as this aspect of robustness is covered by robustness test A.length.2
13) Robustness test C.future.3 involves undetected increases in catchability at 2% per annum. Arguments were made to the Panel that this may be an unrealistically high rate of increase to postulate.
14) Add a robustness test in which catchability is decreasing at 2% per annum to reflect the possible implications of changes in fishing practices.
15) Add a robustness test in which the operating model is not fit to the annual conditional age-at-length data, but rather to the age-compositions which are obtained by multiplying the age-length keys by the length-frequencies for the years which age-length keys are available. The length-frequencies used to construct age-compositions for those years should be ignored when fitting the operating model. [*Consider whether the current approach of fitting to CAL and ALK data, rather than externally derived CAA data as previously, should be considered*]
16) Add a robustness test which involves using the movement model as the operating model.

A.17 (H) Generate future species split proportions accounting for the extent of autocorrelation about the average relative fishing mortality between the two hake species as is currently used for projections [*Review current projection approaches and handling of species split*]

A.18 (H) Consider developing an OMP variant in which the proportional catches of each species are compared to a "target range" and perhaps adjust TACs or bring forward the review of the OMP should the catch by species move outside of its target range. [*Advise on appropriate forms of empirical catch control rules, including capabilities to avoid response delays*]

B. BCC ECOFISH Program

The Panel reviewed several of the products that are currently available. The bulk of these are currently "works in progress". Notwithstanding this, the Panel was able to evaluate the extent to which these projects should contribute to the objectives of BCC ECOFISH and to management of the hake resources off Namibia and South Africa.

1. MARAM IWS/DEC13/Ecofish/BG8 summarizes geographic distributions of abundance and length frequency for 2005-13 indicated by surveys, and concluded that *M. paradoxus* moves across the South Africa – Nambia border.
2. The GeoPop approach is a highly innovate modelling framework which integrates population dynamics processes and geostatistical modelling. GeoPop has been applied to the two hake species (*M. capensis* MARAM IWS/DEC13/ Ecofish/P6; *M. paradoxus* MARAM IWS/DEC13/Ecofish/P7). The results of this approach in its current form could not be used as a stock assessment method at present, but are relevant for developing hypotheses regarding movement patterns and also for validating population dynamics models which have less spatial structure, but are developed for stock assessment purposes (e.g. MARAM IWS/DEC13/Hake/P9). The Panel identified several areas in which the current implementation of GeoPop for southern African hake could be improved: (a) estimation of additional parameters, in particular survey selectivity, (b) use of shorter time-steps than a year to account for the timing of surveys and seasonal movement, (c) presentation of model fit diagnostics, (d) accounting for differences in the ability to assign species to cohorts, and (e) accounting for fishery size selectivity and spatial variation in fishing

mortality. The modelling should account for observed spatial variation in growth (see MARAM IWS/DEC13/Ecofish/P8). If GeoPop is to be developed to a stage that takes the factors raised above into account, it could be used as the basis for a transboundary operating model to test a future set of hake OMPs, including possible transboundary OMPs.

3. MARAM IWS/DEC13/Hake/P9 provides a first attempt at a stock assessment with age-dependent movement, implementing a number of the specifications recommended in the 2011 Review Panel report. The application is currently restricted to hake in South African waters, but the framework could be applied to the entire range of hake off southern Africa given detailed specifications of alternative hypotheses about stock structure. The Panel emphasizes the importance of selecting spatial strata so that availability (as distinct from gear selectivity) of fish to at least one and hopefully both the fishery and survey can reasonably be assumed to be constant within a stratum so that there is no need to allow for the possibility of dome-shaped selectivity patterns. More detailed technical comments on the method are given in recommendation A.9. [*Review progress on the development of approaches which model movement explicitly, and advise on their role in the current OMP review process*]
4. MARAM IWS/DEC13/Ecofish/P10 provides a preliminary version of a stock assessment which allows for the two hake species and inter-species predation as well as cannibalism. It combines features of previous multispecies assessment methods and the method used in recent years to assess South African hake. The current version of the model is difficult to fit because the population dynamics can be unstable given time-varying predation rates by age and species. The Panel recommends that (a) diet data used in the model be based on scaling hake prey-by-species data upwards to account for unidentified hake prey, (b) the model should examine the consequences of the timing of age-0 density-dependence relative to the timing of cannibalism and inter-species predation (i.e. whether most of the predation occurs before or after density-dependence), (c) the model should not be structured with pre-specified rations but instead the rations should be included as data in the likelihood function, (d) whether feeding relationships are different by gender and on the west and south coasts should be examined in due course, and (e) the feeding functional relationships should be parameterized so that it is possible to determine starting values for estimation of the associated parameters as reliably as possible.
5. MARAM IWS/DEC13/Ecofish/P3 provides a thorough, but primarily qualitative, evaluation of environmental hypotheses related to hake catchability. The key next step for this work is to develop a more quantitative evaluation of the effects identified; the aim should be to determine the extent to which incorporation of estimated quantitative relationships calculating abundance indices from surveys might reduce both bias and variance. The Panel emphasizes the value of collecting environmental covariates during surveys, noting that any corrections need to be made throughout the time-series, and that the variance of the resulting survey estimates needs to reflect the uncertainty associated with the identified correction factors. MARAM IWS/DEC13/Ecofish/P3 outlines a way to expand past survey results into deeper water. The Panel cautions that while it is attractive to extrapolate survey data into unsurveyed waters, the variance associated with the extrapolation needs to be quantified and taken into account when the resulting biomass indices are used in assessments. A method needs to be developed to predict the size-composition of animals in deeper water if a survey abundance estimate incorporating extrapolation is to be included in assessments. MARAM IWS/DEC13/Ecofish/P3 recommends that survey stations for which wind speed is higher than 25 knots should be omitted from

the calculation of biomass indices. This approach needs further consideration and possibly analysis before being adopted, in particular as to whether this adjustment will lead to strata without hauls and whether the requisite data are available. [*Advise on possible approaches to take environmental co-variates into account in estimating abundance indices*]

6. MARAM IWS/DEC13/Ecofish/P8 provides strong evidence that *M. capensis* in Namibia lay down multiple growth rings annually and that growth ring formation likely differs between northern and southern Namibia. This is an important result which should lead to follow-up work in Namibia on *M. paradoxus* and in South Africa on both *M. capensis* and *M. paradoxus*. The follow-up work will require additional data collection, e.g. collection of monthly otolith and length-frequency samples off South Africa, to enable marginal increment analyses to be undertaken.
7. MARAM IWS/DEC13/Ecofish/P9 summarizes current progress related to genetic analyses for southern African hake. The work is preliminary and some of the results are surprising (e.g. Φ_{ST} between Namibia and the SA west coast is higher than between Namibia and the SA south coast). The Panel cautions against drawing conclusions regarding stock structure (the number of stocks of each species present, their distribution and their relative densities in areas of overlap) until the current study is complete. The current study includes samples from throughout Namibia and South Africa, as well as temporal replication, which should add robustness to any conclusions. The Panel supports use of tools (such as Geneland) to explore the spatial structure of any identified stocks.

Overall, the work conducted to date provides substantial information on the development of stock assessment methods / models which could form the basis for OMP evaluations as well as information to parameterize those models and identify the biological hypotheses which the models should represent. The Panel recommends that the biologists and modellers (South African, Namibian and Danish) collaborate to: (a) identify alternative hypotheses regarding stock structure, (b) test those hypotheses using existing data (i.e. the tests to be undertaken as part of the genetics study should be based on the identified hypotheses to the extent possible), and (c) population models should be implemented for the hypotheses that cannot be rejected given the tests conducted, to ensure that the models used for management reflect the range of plausible stock structure hypotheses.

C. 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. [*Briefly review evidence for multiple stocks*]

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. [*Might existing measures of stock differentiation place bounds on the extent of interchange between stocks, and how might these be estimated*]

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.

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. [*Might existing measures of stock differentiation place bounds on the extent of interchange between stocks, and how might these be estimated; How should relative plausibility best be assigned to different models, and how should such relative plausibilities best be taken into account in developing management advice*]

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 [*Does a wider range of movement scenarios than at present require exploration – which would be priorities*; *Are projections from some combinations of the current model and movement scenarios implausible, what further analyses might inform on that, and if so how should the model be adjusted to circumvent this situation*]:

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.
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 (see Appendix 5 for draft technical model specifications).
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).

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.

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. [*Review models for projecting future west/south movement*]

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.

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. [*Might existing measures of stock differentiation place bounds on the extent of interchange between stocks, and how might these be estimated*]

D. Linefish CPUE standardization

D.1 (*) The Panel recognizes that considerable effort and progress has been made in developing the Direct Principal Component (DPC) method. Promising simulation results suggest an improved ability to index the abundance of South African linefish species, as well as a broader class of multi-species fisheries in South Africa and other parts of the world. In addition, the simulation research could lead to a better understanding of how CPUE standardization methods perform in general. The Panel also notes that index standardization is only one component of developing a stock assessment. There may be value in a future Panel reviewing the entire process of conducting stock assessments for some South African linefish stocks.

D.2 (*) The Panel supports empirical tests of the Direct Principal Component (DPC) and other methods, including applying them to experimental survey CPUE data from shore-based angling for which fishing tactics are known. It also supports test applications of the DPC method to other South African fisheries, including those based on pelagic longlines, demersal trawl and shore-based angling. In relation to demersal trawl, the Panel recommends that the DPC method be applied to examine trends in both target species (e.g. hake) as well as bycatch species. It notes that care needs to be taken regarding when different species began to be recorded reliably in logbooks.

D.3 (H) The approach of MARAM IWS/DEC13/Linefish CPUE/P1 is an improvement on the earlier version of this approach because it accounts for zero catches and includes a way to select the number of Principal Components to include as covariates in the GAM. The revised method performs well in the simulations conducted to date. Additional standardization methods worth evaluating include (a) clustering trips and treating each cluster as a discrete covariate level, (b) the Stephens-MacCall subsetting method (Stephens and MacCall, 2004), and (c) treating the catch-rate of a bycatch species as a covariate. For method (c), the Panel suggests using a high volume bycatch species that is usually not caught with the principal target species being indexed by CPUE.

D.4 (H) Selecting the number of PCs used as covariates is a key part of the DPC method. Test a new DPC variant in which the number of PCs is selected objectively (e.g. using the Kaiser-Guttman rule or an objective version of Cattel's scree test [Cattell, 1996]). Ideally, explore a DPC variant that involves selecting between a model with no covariates and one in which PCs are covariates. This selection might be accomplished using cross-validation, given that methods such as AIC and BIC are likely to perform poorly based on results of the simulations conducted to date, and that many observations (left out in the data reduction/subseting step) will be available for prediction testing.

D.5 (H) Use the simulations to identify diagnostic tests aimed at indicating conditions in which the DPC method (and other methods) are likely to perform poorly.

D.6 (M) A follow-up project could be conducted to test the DPC standardization method under realistic operating models in which fishing effort is correlated to the abundances of target (positive correlation) or avoidance (negative correlation) species. Avoidance species are increasingly important in multi-species fisheries limited by species-specific individual vessel quotas, and probably also in fisheries constrained by individual bag limits. Dynamics of fishing effort can be linked to biomass as well as other covariates (e.g., distance from port, vessel class, tactics) in gravity or ideal free distribution models (aggregated effort), as well as discrete choice models (individual-based effort). Modelling the dynamic response of individual fish species/populations is another key component of this modelling framework, but there now appears to be improving trend and abundance information for building these models for some species. Effort dynamics would probably capture the main effects leading to hyperstable CPUE, but other features such as gear saturation and random variation in catchability could be added to the dynamics. Multiple species could be combined into higher order groups to reduce overall complexity.

D.7 (M) Consider possible Year*FT and Year*PC interactions in the models to explore whether the estimated abundance trend differs among fishing tactics.

E. Surveys

E.1 (*) The Panel supports the suggestion that future South African demersal surveys be conducted exclusively using the new gear.

E.2 (H) Use the updated estimates from the new calibration analysis [MARAM IWS/DEC13/Hake/P1; Table 1], which now takes account of data from 2006 as well for both species in the reference set and OMP, replacing the *ad hoc* 0.8 factor used for *M. capensis* and the 2004 analysis' estimate for *M. paradoxus*. [*Advise of aspects of hake abundance survey strategy, particularly as regards inter-vessel calibration*]

E.3 (H) Conduct OMP projections to assess the consequences of conducting future surveys using industry vessels. Projections should be conducted for two cases: 1) assuming a single future survey vessel and 2) assuming that the survey vessel changes each year. The projections should also consider the benefits of conducting calibration experiments in the future. These OMP projections should be tuned to achieve the same level of risk to the resource as would occur if surveys continue to be conducted using *Africana*. The cost associated with each option should be determined as the loss in catch relative to the use of *Africana*. Projections should be undertaken for the reference case trials as well as trials in which there are trends in catchability or a non-linear relationship between CPUE and abundance. [*Advise on a strategy for developing calibration factors between industry vessels and the Africana*]

E.4 (H) The default CV for the extent of variation in catchability among vessels should be taken to be 0.2 based on an estimate for Pacific hake from an analysis of a multi-vessel survey of the US west coast (Thorson and Ward, in review). The Panel did not review Thorson and Ward (in review) in detail, but recommends that the Working Group conduct a detailed review of this paper before making final decisions. [*Advise on a strategy for developing calibration factors between industry vessels and the Africana*]

E.5 (H) The OMP projections should allow for variation in the mean difference in catchability between *Africana* and *Andromeda* which could be informed by (i) data from Leslie on the performance of the net when towed by the two vessels and (ii) the results of the summer 2013 surveys by *Nansen* and *Andromeda*, which occurred a month apart. Account should be taken of the difference in the timing (and associated related uncertainty) between these surveys. The results of the GLM standardization of the CPUE data (specifically the month effects and their precision) could be used to quantify the latter source of uncertainty.

E.6 (M) Consider analyses of the calibration data to explore why the CVs for the estimates of the calibration factor (the ratio of the *Africana* catchability for the new gear relative to the old gear) increase given additional data, and examine whether length-specific calibration factors can be estimated if the calibration factor is related to length using a smooth functional form.

F. Other matters

F.1 (*) The probability of obtaining a positive definite Hessian matrix when AD Model Builder is used for parameter estimation is maximized when the objective function is a quadratic function of the parameters. The Panel’s experience suggests that the following approaches help to avoid the problem of non-positive definite Hessian matrices (see also Appendix 3):

1) Model fishing using the Baranov catch equation rather than Pope’s equation. Either estimate each fishing mortality rate as a parameter or solve the Baranov equation using an iterative method for which the number of iterations is pre-set to maintain differentiability. An extra penalty related to the ability of the model to match the observed catches needs to be added to the objective function if Pope’s method is not used. Implementing this approach will reduce the need for “if statements” and “posfun”.
2) If penalty functions are used, they should be differentiable across when the penalty does and does not apply.

References

Cattell, R.B. 1966. The scree test for the number of factors. *Journal of Multivariate Behavioral Research* 1: 245–276.

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Methot, R.D. and C.R. Wetzel. 2013. Stock Synthesis: a biological and statistical framework for fish stock assessment and fishery management. *Fisheries Research* 142: 86–99.

Stephans, A., and A. MacCall. 2004. A multispecies approach to subsetting logbook data for purposes of estimating CPUE. *Fisheries Research* 70: 299–310.

Thorson, J.T. and E.J. Ward. In review. Accounting of vessel effects when standardizing catch rates from cooperative surveys. *Fisheries Research* 00: 00–00.

Table 1: Estimates of catchability ratios for *Africana* new compared to old gear, with their associated standard errors in parenthesis, for the length-independent model including the 2006 data.

	M. paradoxus	*M. capensis*
Brandao *et al.* (2004)	0.948 (0.117)	0.610 (0.141)
Model 1 (excluding 2006 data)	0.938 (0.085)	0.597 (0.050)
Model 1	0.883 (0.082)	0.652 (0.073)

Appendix 1

SA HAKE – KEY ISSUES

Basic Objectives

1) Review progress on current hake OMP revision process, and make recommendations regarding completion of Operating Models for the resource by March and the testing of Candidate OMPs to be finalised by September 2014
2) Advise of aspects of hake abundance survey strategy, particularly as regards inter-vessel calibration

Assessments/Operating Models

1) Review progress on update of 2010 assessment approach leading to a new Reference Set
2) Consider the implications of the sensitivity of the results to the addition of further longline CAL data
3) Consider whether the current approach of fitting to CAL and ALK data, rather than externally derived CAA data as previously, should be considered
4) Review progress on the development of approaches which model movement explicitly, and advise on their role in the current OMP review process
5) Advise on the selection of robustness tests

Surveys

1) Review past survey practice on the *Africana*, and advise on the implications for use of these data in assessments, and on the future use of old and new gear
2) Advise on appropriate calibration factors for *Africana* old *vs* new gear
3) Advise on a strategy for developing calibration factors between industry vessels and the *Africana*, with particular attention accorded to:
   a) the development of an informative prior, and
   b) taking account, through the OMP evaluation process, of the implications of simply setting this calibration factor to 1
4) Advise on possible approaches to take environmental co-variates into account in estimating abundance indices

OMP

1) Review current objectives, in particular:
   a) what further objectives might be added (eg related to effort stability/TAC caps)?
   b) how might these appropriately quantified?
   c) if recovery targets need reconsideration, what factors should be taken into account?
2) Review current projection approaches and handling of species split
3) Advise on appropriate forms of empirical catch control rules, including capabilities to avoid response delays
4) Advise on approaches to deal with missed surveys

Appendix 2

SARDINE TWO-STOCK MODEL – KEY ISSUES

Basic Objectives

Review the current two-stock sardine assessment model and associated projection models, and advise how these might best be further developed if necessary and taken forward to provide a basis for management advice for the directed sardine fishery

Present models

1) Briefly review evidence for multiple stocks
2) Review current two-stock assessment model
3) Review models for projecting future west/south movement
4) Review implications of resource projections under these models

Items for possible further consideration

1) Might existing measures of stock differentiation place bounds on the extent of interchange between stocks, and how might these be estimated?
2) Does a wider range of movement scenarios than at present require exploration – which would be priorities?
3) Are projections from some combinations of the current model and movement scenarios implausible, what further analyses might inform on that, and if so how should the model be adjusted to circumvent this situation. Possible issues/approaches to be considered include:
    a. the form and estimation of stock-recruitment relationships
    b. assumptions about pre-1994 movement in the assessment
    c. incomplete coverage in recruitment surveys
    d. the use of retrospective analyses
4) How should relative plausibility best be assigned to different models, and how should such relative plausibilities best be taken into account in developing management advice

Appendix 3

FURTHER PANEL COMMENTS ON THE USE OF AD MODEL BUILDER

General comment. In general, stock assessment models need to be simulation-tested before being applied to actual fisheries data. Many of the ADMB and MCMC problems discussed below can be resolved by determining parameter estimability using simulation. It is relatively straightforward to replicate the assessment model in R, generate/write ADMB data sets, fit the model to each set and determine what is statistically estimable and what is not, given the expected type and quality of real data.

One solution is to assign priors to all parameters that at least respect proper bounds or biologically realistic ranges. Sometimes vague normal priors can improve behaviour by giving slight location information during the early ADMB phases. An old ADMB trick is to constrain the long-term average fishing mortality to a sensible value in early phases and then remove the constraint in later phases. It sometimes helps to use a $1/K$ prior on scaling parameters such as carrying capacity or unfished biomass. [*A "quick fix" is to add penalty functions. Are there other better solutions?*][6]

Scale parameters (e.g., B_0, K, average recruitment, etc.) should be active in the first phase. Also, they should always be initialized at values greater than would be expected for the final answer. Recruitment devs should be estimated alone, before any other devs. These will affect the temporal variation in population scale and a few recdevs are often needed to explain large catches. [*Any tips for choosing phases for parameters?*]

The maxgrad criterion is usually a reliable indicator of convergence. Although a relatively high value does not necessarily imply a poor fit, it is not good practice to ignore it. Remove or inactivate parameters that are not estimable such as devs near the end points of time-series. Individual elements of vector parameters (e.g., revdevs) can be deactivated by declaring the whole vector as a number_vector and then assigning a vector of phase numbers (using -1 for deactivated elements). Note though that some methods (like norm2) do not work on init_bounded_number_vector parameters. Individual gradients will indicate which parameters are the problematic ones. It helps to setup the PARAMETER_SECTION so that parameters in the gradient output can be easily identified (they come out in the same order as initially declared). [*What to look for in the gradient vector/ what to do if gradients of certain parameter are not getting small enough – how reliable is this statistic as a determinant of (non-)convergence?*]

Use of posfun in ADMB should be avoided as much as possible. It is usually only used in catch equations of the form, N(t+1) = s(N(t) – C(t)), to make sure the LHS remains positive. Use the Baranov equation instead in one of two ways: (1) treat F(t) values as parameters and fit to the catch (and discard) series or (2) solve for F(t) in a Newton-Raphson algorithm with a fixed number of iterations for which the user provides the derivative code. Add an input variable in DATA_SECTION that controls how many iterations are to be done (usually < 5 or so). [*The use of **posfun** – is this always OK, or are there problems and if so for what should one look in output to identify that a problem has occurred?*]

Always use a .pin file of initial parameter values. This can be created by simply changing the last *.par file to *.pin. Usually a reasonable phase sequence should make this less of an issue.

[6] The *italicised* sentences in square parenthesis quote specific questions posed to the Panel.

It is always best to separate vector parameters such as recruitment, initial numbers-at-age, or movement rates into average (or where applicable "equilibrium") and deviation components. This also simplifies starting parameter choices. [*Any tips for choosing starting positions for parameters?*]

High sensitivity can occur with least squares because the influence function is linear everywhere – larger residual deviations have larger influence on the outcomes. Robust likelihoods are locally linear around the expected value, but then flatten out as residual error increases to the point where residuals of ~4 have no more influence than one of ~3. Cauchy, Geman-Mclure and Welsch are three robust estimators that are continuous and differentiable. [*Any tips on what to do if the final estimates are highly sensitive to small changes in relative terms to initial parameter value choices?*]

Contradictory trends can only be fixed by adding parameters to the model, and then one is usually left with contradictory parameters. Obviously, the data should be checked all the way to raw sources if necessary. If at least one contradictory data source is a fishery CPUE index, then (i) downweight or drop this or (ii) add deviation parameters (e.g., time-varying catchability) to deal with this. Log-likelihood penalties on deviations will then reduce their influence on the overall result. Two alternative interpretations (models) should be carried forward to the policy analysis as alternative hypotheses if there is no rationale to favour one data series over the other. [*How best to deal with contradicting trends in data?*]

ADMB MCMC

Some parameters can have important scaling effects that differ substantially between MLEs and posterior means/medians. Fixing parameters creates steeper pdfs and hence greater sensitivity. Using vaguely informative priors can reduce posterior sensitivity, which explains why informative priors are increasingly common for natural mortality rate parameters. One can still generate robustness scenarios by sampling from extremes of the posteriors for parameters that would otherwise have been fixed. [*Fix certain parameters at their penalised MLE values before starting the MCMC: e.g., if the extent of stock depletion is the measure of key concern, fixing some selectivity-at-age parameters in this way may hardly impact results.*]

Problems for MCMC mainly arise from multi-modal distributions for some parameters. If the data support alternative hypotheses, then the challenge is to properly sample from multi-modal or complex-shaped posteriors. For instance, one could try ADMB's hybrid MCMC option. The chances of having difficult posteriors decreases as prior distributions on parameters are formalised, rather than assuming ADMB's bounding algorithm which reflects a uniform prior. [*Select successive portions of chains and calculate statistics of the posterior distribution of the parameter of interest for each. If these show little variability, despite formal convergence tests failing, are results for those parameters at least sufficiently reliable?*]

Vaguely informative priors help to give general location information. It is important that priors be as symmetric as possible, so as not to create additional information that may not be present. Providing priors on parameters allows for efficient MLE convergence and MCMC sampling that can then be checked using standard Bayesian model-checking methods. [*Place bounds on certain parameters (i.e. reduce the range of prior distributions, particularly of intended "uninformative" ones) as problems often seem associated with outlying values: e.g. putting an upper bound on K can stabilise situations where difficulties are associated with rather uninformative stock-recruitment data.*]

Appendix 4

ROBUSTNESS TESTS FOR THE REVISED HAKE OMP

A. Data input options

Catches

(H) A.catches.1: Offshore trawl (post-1978): Alternative species-split of the offshore trawl catches from a species splitting algorithm from an analysis of observer data, used in conjunction with alternative GLM-standardised CPUE based on observer data.

(H) A.catches.2: As A.catches.1 above but species-split based on the "old algorithm" (OLRAC, 2009) which allows for year effects in the algorithm relating these splits to hake size and depth when predicting species splits.

(M) A.catches.3: Including discards. Discarding by offshore and inshore trawlers is modelled as an increase in the commercial selectivity of 0.2 for ages 1 and 2 for *M. capensis* and *M. paradoxus*; the loss of fish from longlines is also included by doubling the catch from this fleet. (The operating model should output the model-predicted discards (in total and by length-class) in absolute terms and relative to the landed catch, and this level of discards should be evaluated given the data collected by observers.)

(L) A.catches.4: Alternative inshore trawl catch species split (assume 20% *M. paradoxus*).

CPUE

(L) A.CPUE.1: Changes in efficiency the CPUE series because of the introduction of navigational aides; split series in 1994/1995, with different *q*'s estimated for the two periods.

(L) A.CPUE.2: From 1997 to 2002 *q* for CPUE dropped by 20% as a result of shorter tows. (Use CPUE standardization to explore the plausibility of the assumptions underlying this robustness test if it is selected for further consideration.)

(L) A.CPUE.3: Condition the operating model also on the longline CPUE series.

(M) A.CPUE.4: Added weighting on the last five years' CPUE and survey data to fit recent abundance indices more closely.

(H) A.CPUE.5: Include hyper-stability in past and future CPUE-abundance relationships (for example, CPUE proportional to the square-root of abundance).

(H) A.CPUE:6: Include hyper-stability in future CPUE-abundance relationships only.

Surveys

(M) A.survey.1: Alternative calibration factors between old and new *Africana* gear.

(L) A.survey.2: Adjust survey abundance estimates to take account of environmental co-variates.

(L) A.survey.3: Include 2013 *Nansen* calibrated abundance estimates with some allowance for correlation with *Africana* survey results.

Age and length data

(L) A.length.1: Ageing out by 1 year for *M. capensis* and *M. paradoxus*.

(H) A.length.2: Ages of *M. capensis* adjusted to reflect a growth curve more closely related to that estimated for this species off Namibia in MARAM IWS/DEC13/Ecofish/P8.

B. Model assumptions

Selectivities

(H) B.sel.1: Alternative slope assumptions (all commercial and survey selectivity slopes (in cm^{-1}): +0.04, b)+0.02, c)-0.04 and d) -0.02).

(L) B.sel.2: Alternative assumption re *M. capensis* offshore selectivity (RC: as inshore, shifted 10cm with slope of 1/3 of inshore slope).

(L) B.sel.3: Alternative assumptions re south coast female *M. paradoxus* selectivity scaling factor: a) increase the scaling factor, and b) decrease the scaling factor.

(L) B.sel.4: Allow random walk variation over time in selectivities-at-length.

(L) B.sel.5: SAM-based assessment.

Natural Mortality

(L) B.M.1: Gender-specific natural mortality (+0.05 for males, -0.05 for females).

(M) B.M.2: Increasing M at large ages (linear from 0.375 at age 8 to 1 at age 15).

Stock-recruitment relationship

(L) B.SR.1: Alternative σ_R value (0.6).

(L) B.SR.2: Alternative male/female ratio at birth (instead of 50/50): a) skewed towards females, and b) skewed towards males.

(H) B.SR.3: Other combinations of BH/Ricker and level of natural mortality (select the most pessimistic combination of the major uncertainty factor choices; previously this was Rob5 based on RS1 and RS11 of OMP-2011: True Ricker, trawl catches shift center in 1950 and M_{2-}=0.9 and M_{5+}=0.5 for both species).

(L) B.SR.4: No shrinkage of recent recruitments towards the stock-recruitment relationship prediction.

(L) B.SR.5. Model σ_R as random effect to estimate directly.

Other model assumptions

(H) B.others.1: Assessments commencing in 1978, estimating q and ζ.

(H) B.others.2: Changes in past K values over time (30% linear decrease over 1980 to 2000 for both species).

(M) B.others.3: Alternative weighting for length data (W_{CAL}=0.01 and W_{CAL}=1.0).

(M) B.others.4: Alternative weighting for age-length-key data (W_{ALK}=0.001 and W_{ALK}=0.1).

(H) B.others.5: Alternative maturity-at-length with fixed lower h values.

(H) B.others.6: Not fitting to the annual conditional age-at-length data, but rather to the age-compositions which are obtained by multiplying the age-length keys by the length-frequencies for the years which age-length keys are available. The length-frequencies used to construct age-compositions for those years should be ignored when fitting the operating model.

(M) B.others.7: Base projections on the movement model.

C. Changes in the future

(H) C.future.1: Missing/reduced surveys and surveys on another only imprecisely calibrated vessel.

(M) C.future.2: Decrease all future survey CVs by a multiplicative factor of 1/SQRT(2).

(L) C.future.3: MPA possible effects on future CPUE: a) no CPUE, b) new CPUE series with prior on *q*, c) new CPUE series with lower *q*, d) new CPUE series with higher *q*, and e) new CPUE series with no prior on *q*.

(M) C.future.4: Trend in Fratio over time. (assumed constant for the RS (Rademeyer and Butterworth, 2010; see Recommendation A.17 above for the revision for this current process): a) +2% p.a. and b) -2% p.a., for 10 years, then constant.

(H) C.future.5: Undetected 2% p.a. increase in catchability related to CPUE.

(H) C.future.6: Undetected 2% p.a. decrease in catchability related to CPUE.

(M) C.future.7: Change in discard pattern.

(H) C.future.8: Decrease in *K*.

(M) C.future.9: Allow for serial correlation in recruitment residuals.

(L) C.future.10: Maximum proportion of cohort catchable in one year decreases from 90% to 70%.

Rademeyer RA and Butterworth DS. 2010a. Candidate Management Procedures for the South African Hake Resource: Draft Objectives and Testing Methodology. Unpublished report. MCM/2010/MAY/SWG-DEM/22(Rev).

Appendix 5

DRAFT MODIFICATIONS TO SARDINE MODEL TO TAKE ACCOUNT OF WINTER RECRUITS OBSERVED IN THE NOVEMBER SURVEY OF THE SOUTH COAST

The present model gives the number of recruits available for observation in the May recruitment survey in Equation A.18 of document MARAM/IWS/DEC13/Sardine/P1, with the manner in which this is taken into account in the negative log-likelihood detailed in the $-\ell n L^{rec}$ term of Equation A.26.

For the two-stock model, and for model recruitment on the south coast, Equation A.18 becomes:

$$N^S_{2,y,r} = k^S_{2,r}\left(\left(\left(N^S_{2,y-1,0}e^{-M^S_0/8} - C^S_{2,y,1,0}\right)e^{-M^S_0/4} - C^S_{2,y,2,0}\right)e^{-M^S_0/8-0.5t^S_yM^S_0/12} - \tilde{C}^S_{2,y,Obs}\right)e^{-0.5t^S_yM^S_0/12} \quad \text{(A5.1)}^7$$

where

$$k^S_{2,r} = k^S_{ac}\,\mathrm{x}\,k^S_{\mathrm{cov}}\,\mathrm{x}\,k^S_{\mathrm{covE}} \quad \text{(A5.2)}$$

where k^S_{ac} denotes the acoustic survey bias, k^S_{cov} the proportion of the recruits available to the west coast part of the recruit survey (expected <1) and $k^S_{\mathrm{cov}E}$ the proportion available on the south coast relative to the west coast (again expected <1).

With winter as well as summer spawning on the south coast, Equation A5.1 is modified to:

$$N^S_{2,y,r} = k^S_{2,r}\left(\left(\left(p_y N^S_{2,y-1,0}e^{-M^S_0/8} - C^S_{2,y,1,0}\right)e^{-M^S_0/4} - C^S_{2,y,2,0}\right)e^{-M^S_0/8-0.5t^S_yM^S_0/12} - \tilde{C}^S_{2,y,Obs}\right)e^{-0.5t^S_yM^S_0/12} \quad \text{(A5.3)}$$

where p_y is an estimable parameter for each year, drawn from a beta-distribution with mean μ_p and variance σ^2_p, both of which are estimable parameters of the log-likelihood minimisation, with an appropriate term being added to $-\ell n L$ for this.

Recruits observed in the November survey on the south coast are taken to be late contributors to the cohort that contributed to the south coast recruits observed in the May survey that year (*y*), specifically:

$$N^S_{2,y,r} = \theta k^S_{ac}(1-p_y)N^S_{2,y-1,0} \quad \text{(A5.4)}$$

where θ is an estimable parameter that subsumes coverage effects and differential natural mortality effects related to the different timing of the November survey (clearly Equation A5.4 is an approximation, but sufficient for the purposes at hand).

7 Note that a missing term to account for natural mortality over mid-March to the end of April has been added to the original equation.

An additional term is then added to the $-\ell n\, L^{rec}$ part of Equation A.26 of similar form, but now in relation to the winter recruits and the difference between observation and model prediction:

$$\ell \mathrm{n} \hat{N}_{2,y,r}^{S,\mathrm{Nov}} - \ell \mathrm{n} N_{2,y,r}^{S,\mathrm{Nov}} \tag{A5.5}$$

Note:

a) k_{ac}^{S} is included in Equation A5.4 to take out a common factor. A reality check would involve comparing $\hat{\theta}$ with $k_{2,r}^{S} = k_{\mathrm{cov}}^{S} \mathrm{x}\, k_{\mathrm{covE}}^{S}$, etc.

b) Because of possible confounding, it may be necessary to fix $k_{\mathrm{cov}E}^{S}$ on input, or assign an informative prior to this parameter.