Scientific Review Group Review of the “Management strategy evaluation of Pacific hake”

As presented to the Scientific Review Group
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1 OVERALL

A significant amount of work has been accomplished with the Pacific hake MSE since 2016 and we commend the analysts for their excellent progress, especially with the involvement of stakeholders in the MSE process. The analysts clearly understand that an MSE requires a workplan that spans many years, and that meetings with stakeholders are necessary to foster a transdisciplinary approach which fosters collaboration and eventually better acceptance. The progress is significant, but more work is needed to fully inform the questions being considered. Some details for improvement are provided in the sections below.

A major point we noticed was that there are not many specific management procedures (MPs) being evaluated, and the distinction between management procedures and scenarios is not clear. There are survey frequency MPs, and what are called implementation scenarios are actually management procedures. A goal (page 7) is to evaluate the current hake management procedures, which is confusing because theoretically, there is only one default management procedure. It would be useful to clearly state scenarios and management procedures, and clearly identify which management procedure(s) is used for which scenario. Also, some scenarios used the default management procedure, while others incorporated implementation variability. This difference makes it difficult to compare across scenarios.

In the future, because the objectives are on the path to being well defined, it may be useful to show some tables of the specific performance metrics along with the plots.

1.1 Document

The document is a useful reference that provides an understanding of the history of this MSE as well as an overview of the simulation model and objectives. The document could use some editing to improve readability and to help the reader understand the basics of the simulation model and other aspects of the MSE. Some specific suggestions are

- Separate equation numbers from equations to avoid confusion.
- Add section numbering to more clearly separate sections.
- Identify where assumptions differ from those used in Stock Synthesis (SS); for example, selectivity.

2 PACIFIC HAKE MSE PROCESS

This section is very useful and provides a nice overview to the process since 2017, however its value as a comprehensive reference could be increased by including a summary of the outcomes from the previous MSE analysis that was published in 2015 (Hicks et al 2016). For the Phase 1 MSE goals (p7), the motivation for undertaking simulation work should be described as well as the ecological hypotheses to be explored in simulation.

3 OBJECTIVES

We appreciate the detail provided for the objectives, and that a few objectives are prioritized (i.e., G and H are subject to satisfying other objectives). However, it was stated on page 9 that the focus is on maintaining a sustainable and equitable coastwide fishery, but it is not clear how achievement of this objective is measured. A few specifics are

- **Objective B (Low risk of the stock dropping below the specified management target)**: If 40% B_0 is a target, then does that imply that the objective is to be equally above and below the target? The Treaty does not seem to identify $B_{40\%}$ as a target, but as the trigger point for for reducing the harvest rate, as part of the control rule. The objective is stated as maintaining a biomass above 40% B_0 75% of the time (22.5 years out of 30). Perhaps the term 'threshold' or 'trigger' could be used. NOTE: assuming that the biomass is above or below the 'target' 50% of the time, the target (i.e., median) relative spawning biomass when fishing at an $F_{SPR=40\%}$ is 35.8% (according to Table f in the stock assessment; 656/1832) and a target of 40% is achieved with a $F_{SPR=43.4\%}$. Therefore, if the objective is to be above $B_{40\%}$ 75% of the time, then the target would be greater than $B_{40\%}$ and the fishing intensity (F_{SPR}) would be less than the fishing intensity associated with $F_{SPR=40\%}$ (e.g., SPR greater than 44%).
- **Objective C (low risk of stock dropping below the threshold that triggers a reduction in harvest rate)**: How is this different than objective B? Also, if the goal is to have a low risk of dropping below the trigger of 40%, then the indicator should be $S<0.4S_0$, not just `being on the ramp.' Finally, and possibly most importantly, this objective is not an `ends' objective, but is a means objective, meaning that it is not defining what is really desired. Is it `bad' (want low risk) to be below the trigger? It may be that being below the trigger results in more variable TAC's, but if that is the case then shouldn't the objective be to look at variability in the TAC (objective F), not in how often you are `on the ramp?'
- **Objective G (Maintain high catches in the short-term)** is a short-term objective, and other objectives use the time-period starting at year 1. MSE operating models are mostly devised to account for long-term variability. We suggest that you consider how well you can characterize these performance metrics in the short-term and in the medium-term, and what is long-term in the sense of when the simulated variability is stable. Is 30 years enough? Short-term harvest opportunities are highly-dependent upon initial conditions. Is this a situational objective that mainly relevant due to the recent high biomass levels (and might not be as relevant in a few years?).
- Summarizing results exclusively over a single time-period, from 1-30 years, may obscure important temporal tradeoffs that would be made more apparent through reporting over stanzas, or short-, medium-, and long-term periods. Presentation of results in a manner that allows inter-temporal tradeoffs to be considered would be beneficial.

4 THE OPERATING MODEL

The operating model section contains the equations of the simulation model, but it is confusing to follow for a number of reasons. It would be helpful to separate the area-specific operating model equations and the coastwide estimation model equations, or make it more clear which equations relate to which model.

- It states that the operating model is a multi-area, seasonal model, but many equations are coastwide without a seasonal aspect. Are some of the equations specific to the estimation model?
- Many equations are missing subscripts and are inconsistent.
- It would be difficult to recreate the operating model with this description. We realize the model files are on Github, but a clearer explanation of the operating model would be helpful.

Specifics are given in the subsections below.

4.1 Equilibrium abundance

Interesting that you state this is a two-area model but the dynamics are not area specific. Are these equations for a coastwide model, or are the assumptions of your two-area model such that these equations hold on a coastwide level (e.g., same parameters for each area)? It would be interesting to see the implied equilibrium spatial abundance with the assumed movement.

Natural mortality (M_a) is notated as age-specific. Was it constant across ages and years?

4.2 Initial conditions

At this point, you have not described how you are forecasting. If you are simulating random recruitment deviations from a lognormal distribution, then you need to fully bias correct. You need to bias correct because you are trying to match the assessment which uses data to inform the recruitment deviations, which reduces their uncertainty (and thus the need for bias correction adjustment).

4.3 Growth

It seems that you are describing the historical model and not a projection/simulation model. What is done when simulating forward in time? Is weight-at-age the same for all areas within a year? How are seasons accounted for? Growth within a year is significant.

Is the weight-at-age taken from the assessment model and combined across all sources?

4.4 Reproduction

The bias adjustment on recruitment deviations for the simulations is confusing and this should not be the case. R_0 is the average unfished recruitment, and you need full bias correction to bring the average biomass to the biomass determined with σ_R=0 (i.e., no recruitment deviations). The 'bias correction' in SS is a result of informed recruitments having a smaller distribution than the uninformed recruitments (Methot & Taylor 2011).

It would be useful to investigate the cause of the bias in spawning biomass. It may be the use of area-specific stock-recruit relationships, or properties of the lognormal distribution and how it interacts with density-dependence. Setting steepness to 1 in a single-area model and testing various values of σ_R may help identify some of the causes.

On page 11, the inline equation for $Z_{t,a}$ specifies $M_{a,t}$ which is specified as 0.214 in Table 4. Should this M be adjusted for seasons such that across the four seasons it totals 0.214? M also has a time subscript here where it didn't in earlier equations.

4.5 Fishing

There are many reasons that selectivity should vary in the projections, one of which is that changes in weight-at-age are likely related to changes in growth, and if selectivity is a function of size then it will change. One reason that hake selectivity varies may be because selectivity is modeled as a function of age.

The baseline selectivity is a strong assumption; the assessment uses the average of the last five years. If short-term performance metrics are calculated, this may not be the best assumption.

4.6 Movement

The assumptions for movement in the last season fully specify movement in that season. It would be useful to state that more clearly, and possibly by specifying the parameters. Was there any justification for these choices and sensitivity analysis to them?

4.7 Catch

You use F from Pope's (which is an exploitation rate) in the Baranov catch equation. They are different concepts where Pope's approximation is an exploitation rate between 0 and 1 and F is between 0 and infinity. For small rates they may be similar. Note that typically, *u* is used for exploitation rate and *F* for instantaneous rates.

5 DATA GENERATION

In Equation (16) how is $N_{y,a,F}$ determined? Is this simply summed over the two areas? Is this comparable to the actual method used in the assessment of predicting numbers for various fleets (including Canada separate) and then combining them through weighting by catch?

6 SPATIAL ASSUMPTIONS IN THE TWO-BOX, FOUR SEASON MODEL

If country-specific catch is the input, why would it be conditioned to the TAC when the TAC's are not fully achieved historically?

How were the 0.25 and 0.75 for $R_{0,i}$ determined? Is there any benefit to modelling a coastwide stock-recruit relationship and then distributing the recruitment to the two areas with some variability? Could these individual stock-recruit relationships be contributing to the reason that the projections produce a different equilibrium? The last sentence of this paragraph is awkward because it discusses catch, not recruitment.

The 90% results in 75% may be awkward because there is a discontinuity from 75% to 90%. Was there a justification for this choice?

7 ESTIMATION MODEL

In the comparison to the assessment model, the difference between MLE and MCMC would likely make the biggest difference. Could this be corrected if there is a somewhat consistent bias? It is stated that it has similar dynamics to the operating model. Some explorations of differences between the assumptions in the OM and EM would be useful, as requested by the SRG in previous years.

It would be useful to have more comparisons between the assessment and the estimation model. The goal of the estimation model in an MSE is to capture the nuances of that specific model such as autocorrelation and biases. Is it possible to use the OM to simulate forward in time and compare the estimation model to the assessment model (MCMC possibly) for a few years with simulated data? It may be worthwhile to determine if the estimation model is actually performing similarly to the assessment model. Or perhaps a retrospective look?

Ageing error has quite a large effect in the assessment model, especially when a single large cohort is dominant. It is surprising that it shows little difference here. Examining the sensitivities to ageing error assumptions in the assessment model may be worthwhile, especially for the period before the 2010 cohort appeared. Ultimately, if this estimation model is not sensitive to ageing error but the stock assessment is sensitive, we would want to understand why that is.

8 DEFAULT MANAGEMENT MODEL

The formula in Equation (18) seems nonlinear in relation to the TAC. Does the treaty specify a linear reduction in the TAC from 0.4 to 0.1?

9 CONDITIONING THE OPERATING MODEL

Were the coastwide outputs of the operating model compared to the best estimates from the assessment model?

It would be useful to include confidence intervals in the comparison to data (such as survey biomass and age in Figures 8 and 10).

There are some large deviations from the area-specific survey biomass estimates. This variability may be important to capture and if not, then the results may not be completely informative.

Would comparing the coastwide spawning biomass, and possibly vulnerable (or summary) biomass, from the OM and the assessment be worthwhile? These are metrics that really characterize the general size and variability in the population. The OM needs to be able to capture this.

10 ALTERNATIVE IMPLEMENTATION SCENARIO

These seem to be management procedures that could actually be implemented. It may be useful to have discussions with managers and stakeholders to identify management procedures that would actually be considered for implementation, or at least of interest to evaluate.

It would be useful to show some individual trajectories, especially when discussing results of individual projections (i.e., page 21). Individual trajectories will also help stakeholders and managers understand that the stock is not stable like the median. Additionally, for particular purposes, it may be informative to provide other quantiles of result distributions, or attributes of subsets of trajectories. For other purposes, it might be useful to sum the number of runs that are below (or above) some threshold of interest for each possible number of years, i.e. 0-30.

Tables would be useful for Figures 12-16. Having numbers helps some people understand the result better than graphics. Tables and graphics are both useful.

11 CLIMATE SCENARIOS

It does not look as though κ_{return} is described anywhere. What is the return rate shown in Figure 6?

11.1 Selectivity scenarios

If the US is filling its quota with small fish, wouldn't this have a negative feedback on the number of old fish in future years? Do you think that this effect is not seen because the simulations are not long enough?

What are the assumptions for selectivity in the EM? Are they unchanged across selectivity scenarios?

11.2 Survey frequency MPs

These are management procedures, not scenarios.

Other harvest rules may perform differently with annual, biennial, and triennial surveys. Broad conclusions may not be possible with the limited set of MPs evaluated here.

12 ADDITIONAL CONSIDERATIONS AND NEXT STEPS

Work on objectives that reflect management and fishery goals is very important and should be prioritized, possibly above additional work on the OM and EM.

13 FIGURES

In Figure 3, is this movement out of the area or into the area?

In Figure 6, the reference to Figure 2 is incorrect.

REFERENCES

Hicks AC, Cox S, Taylor N, Taylor IG, Grandin CJ, Ianelli J. 2016. Conservation and yield performance of harvest control rules for the transboundary Pacific hake (*Merluccius productus*) fishery in U.S. and Canadian waters. *In* Edwards CTT, Dankel DJ (eds.) *Management Science in Fisheries: An Introduction to Simulation-based Methods*. Routledge. 452 p.

Methot RD, Taylor IG. 2011. Adjusting for bias due to variability of estimated recruitments in fishery assessment models. Canadian Journal of Fisheries and Aquatic Sciences 68:1744-1760.

APPENDIX A: TECHNICAL COMMENTS ON THE OPERATING MODEL IN THE PACIFIC HAKE MANAGEMENT STRATEGY EVALUATION

The comments below focus primarily on some technical details associated with the mathematical equations presented in the draft "Management Strategy Evaluation of Pacific Hake", which was provided to the Scientific Review Group (SRG) prior to the SRG's meeting in February 2020. These comments are intended to clarify details of the equations and resolve uncertainty regarding the inner workings of the Management Strategy Evaluation's (MSE) operating model. These comments are provided as a supplement to the "Review of the Pacific Hake MSE" provided by the SRG.

Page references below refer to the draft "Management Strategy Evaluation of Pacific Hake" document.

1. Page 9, Operating model. Change "To be persistent with …" to "To be consistent with …".
2. "The time scale of the model is four seasons per year." Clarify whether the seasons are equal in duration (i.e., 3 months each).
3. Pages 10 and following. As mentioned earlier, the lines with equation numbers should be formatted so the equation numbers are clearly separated from the equations.
4. Page 10, Initial conditions. "The first year of the simulation is … initialized with the following age distribution."
   - 4.1. Given that there are two areas in the operating model, the equation (3) for N_a should have an index for area.
   - 4.2. Please be more specific regarding the purpose of the bias adjustment factor b_y in equation (3). The term $-0.5*\sigma^2_R$ is the adjustment for the lognormal bias. No additional bias adjustment is needed in the operating model, except when estimating recruitment deviates as is done in SS. To replicate the SS assessment model, the bias correction may be necessary, but when generating recruitment from a lognormal distribution the full bias correction is required. It seems that this could be used to correct a difference between SS and the OM.
   - 4.3. It seems to me that the conditioning should impact the results, otherwise conditioning would not be needed. Is the statement near the middle of page 10 ("In general, the initial conditions have an impact on the conditioning of the OM, but little impact on the forecast years used in the calculations of results of this analysis") vague?
5. Page 10, Growth.
   - 5.1. "Growth follows the empirical weight at age approach used in the Pacific hake stock assessment …". Given that the operating model has four seasons, the documentation should at least comment on the suitability of the simplifying assumption that there is no within-year change in weight-at-age (i.e., no growth except as a step-change at the end of a calendar year). For example, an age-3 fish in December could have a dramatically different average weight in January? Additionally, growth likely differs greatly between the first and last seasons.
   - 5.2. What is done with growth when simulating forward in time? Is it held constant over years? Is the inter-annual variability simulated?
6. Page 10, Reproduction. "Recruitment is assumed to occur at the beginning of the year … and follows a Beverton-Holt stock recruitment curve with annual deviations."
   - 6.1. Are you assuming a fecundity relationship? E_a does not appear in Table 4.

6.2. If I have correctly interpreted the statement on page 14 -- "We make the assumption that the unfished recruitment … is divided between the two countries … as R[0,CAN] = 0.25 R[0] and R[0,USA] = 0.75 R[0], … creating two similar productivity relationships." -- then each area has its own R[0] and there is a separate Beverton & Holt stock-recruitment relationship for each area. Canadian recruits are produced by the spawning biomass in the Canadian area and US recruits are produced by the spawning biomass that is in the USA area. The variables N[a] and R[0] should both have subscripts for the area.

6.3. It would be worth clarifying in the text that these initial conditions do NOT represent equilibrium conditions because they do not account for movement between the areas. (In a later comment I provide more comments regarding the equilibrium conditions.)

6.4. The MSE report should discuss the logic for assuming separate stock-recruit curves for fish in Canadian versus US waters. What mechanism(s) result in separate density-dependent effects?

6.5. The subscripts on Z in Equation (7) are reversed for N[t+1,a] and in the inline Z[t,a] above. Also, should the right side of the equation have N[t,a]?

7. Page 11. "We use bias correction, b, as an input to the model … ."

7.1. The term $\sigma_R^2/2$ is the adjustment for lognormal bias when simulating from a lognormal distribution. A multiplier on this bias adjustment is needed in the operating model only when entering specific recruitment deviations to match the assessment.

7.2. That said, a bias adjustment is needed, however, in the estimation model because "estimated recruitment variability will always be less than the true variability among recruitments" (Methot and Taylor 2011).

7.3. The bias adjustments shown in equation (5) should only be applied in the operating model to specifically match the assessment model when using the specific estimated recruitment deviations from the assessment model. They should be applied appropriately in the estimation model.

8. Page 11, equation (6). This equation, which is supposed to indicate the survival of age-a fish in year y during the last season of year y, is poorly (and incorrectly) formulated. The variable on the left-hand side (N[y+1,a+1]) denotes the numbers-at-age at the start of the year with the year index as the first subscript, whereas the variables on the right-hand side do not have a year subscript, but instead have the season index as the first subscript. Also, total mortality (Z) is specific to the year, season, age, and area and therefore should have four indices.

9. Page 11, equation (7). Total mortality (Z) is year-, season-, age-, and area-specific and therefore should have four indices. This is also the case for the numbers-at-age. The way the equation is written is muddled. The N on the left-hand side has two indices (for season and age); N on the right-hand side has only one index (for season).

10. Pages 11-12, fishing.

10.1. "We assume that fishery selectivity does not change within a year." The text should clarify if the operating model also assumes that fishery selectivity is the same in both areas. Equations (8), (9), and (10) lack any area index on the selectivity variable (s), which implies that selectivity does not vary by area.

11. Page 12, equation 11.

11.1. For completeness the text should clarify that the numbers-at age variable in this equation represents the populations at the start of the first (the 0^{th}) year (i.e., the implied season index is 0 or 1, depending on the indexing scheme).

11.2. I note that the numbers-at-age variables in equation (12) use a different notation from equation (11). In equation (12) the first subscript represents the season and the subscript for year is implied.

11.3. Should Ω have an '*i*' subscript in Equation (11)? If not, then the N's should be vectors.

12. Page 12, equation 12.

12.1. "We assume that movement and mortality occur at the same time." This statement is incorrect. The equations for survival (e.g., eq.(1), (3), (6), and (7)) assume that mortality occurs continuously. That is why there are the exponential terms with –Z in them. In contrast, movement occurs either at the end or the beginning of each seasonal time-step. From equation (12) one cannot tell when movement is applied (at the start or at the end).

12.2. There should be an equals sign between the N[t,a,i] and the opening curly brace.

12.3. In each of the three lines on the right-hand side of equation (12) the terms with N should be multiplied by survival fractions. The fish in a given area at the start of a time-step is composed of two parts: (a) survivors that were in the area in the previous time-step that did not move from the area plus (b) survivors that were in other areas in the previous time-step that moved into the area.

12.4. The description of movement parameterization is confusing, because it is unclear what ω actually is. Ω above is a vector of proportions to distribute the numbers-at-age to each area. ω here is the proportion moving? From where to where? If ω_i is an element of a matrix (we assume that ω is a matrix) then some may interpret Ω as the matrix of ωs.

12.5. Regardless, the equations in (12) suggest that the ωs are also simply proportions in an area since there is no '*i*' subscript on N. However, it still doesn't make sense because if *i*=1 then $N_{t,a,i}=N_{t-1,a}(\omega_2-\omega_1)$. With ω_1 being subtracted that suggests that ω is movement out of the area of interest. But, if that is the case, then shouldn't all movement out of all areas into 1 be in the equation? It may be best to present this as a two-area model, or more specifically define movement.

13. Page 13, near the top. "There are two other assumptions … : 1) 80% of all spawning biomass in the Northern part move south to spawn in the last season of the year, …"

13.1. Clarify when spawning occurs. I think the operating model and estimation model both assume that spawning occurs at the start of each year (i.e., on January 1st).

13.2. Clarify that the 80% of mature biomass in the north moves to the southern region at the end of the last season of the year, meaning that these fish spawn in the south at the start of the following year.

13.3. Does the previous point (if correct) mean that 20% of the mature biomass in the north spawns in the northern region?

13.4. It seems to me it seems that the fraction of mature biomass in the north at the start of each year will depend on the movement parameters. If that is the case, I do not understand why there is an assumption that "80% of all spawning biomass in the Northern part move south to spawn in the last season of the year". No assumption is required. The value for this percentage is a direct consequence of the movement parameters, survival rates, and growth.

13.5. Is there any empirical evidence (e.g., Pacific hake eggs or recently hatched larvae) to support the idea that Pacific hake spawning occurs in Canadian waters?

14. Page 13, Catch, equation (14). The subscripts in this equation appear incomplete and the equation is not easily interpreted.

14.1. The catch should have four subscripts, for year, age, season, and area. The catch (C) on the left-hand side of eq. (14) has three subscripts (t,a,i), either representing year, age, and area or representing season, age, and area. I suppose the year subscript has been left off (for economy of notation).

14.2. On the right-hand side the selectivity coefficient (s) has subscripts for year and age but none for season or area.

14.3. On the right-hand side the fishing mortality coefficient (F) has a single subscript (t), but it is unclear if this represents year, season or area.

14.4. On the right-hand side the N variable has three subscripts (t,a,i), the same as the catch.

14.5. In Equation 14, Z in the exponential should have subscripts.

15. Page 14, Data generation, equation (17).

15.1. This equation needs a Sigma to sum over the ages.

15.2. Should $N_{y,a}$ have a t=3 subscript instead of y since it is assumed to take part in the third quarter?

16. Page 14, Spatial assumptions … . "We make the assumption that the unfished recruitment used in the stock recruitment relationship (R[0]) is divided between the two countries as R[0,CAN] = 0.25 R[0] and R[0,CAN] = 0.75 R[0], …"

16.1. The exact meaning of the above statement should be spelled out in equations. Is there one Beverton & Holt relationship for the spawning biomass in the waters off Canada and a second Beverton & Holt relationship for the spawning biomass in the waters off the US. If that is the case then there are two R[0] parameters in the operating model, one for the Canadian portion of the stock and another for the US portion.

16.2. Regardless of whether there is a single stock-recruitment function for the entire stock or one each for Canada and the US, the value for R[0] is obtained from the intersection of the stock-recruitment curve and the line through the origin having slope equal to the inverse of the unfished spawning biomass per recruit.

16.3. There is no need to assume that 25% of the recruits occur in Canada and 75% in the US. In fact, these assumed values are very likely to be inconsistent with the stock-recruitment curve and the unfished spawning biomass per recruit.

16.4. The unfished spawning biomass per recruit that occurs off Canada versus the unfished spawning biomass per recruit that occurs off the US will vary with the set of assumed movement parameters.