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Proceedings of the Pacific regional peer review on biological benchmarks and building blocks for developing aggregate-level management targets for Skeena and Nass Sockeye Salmon, British Columbia

April 26-28, 2022
Virtual Meeting

Chairperson: Nicholas Komick
Editor: Jill Campbell

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Pacific Biological Station
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Foreword

The purpose of these Proceedings is to document the activities and key discussions of the meeting. The Proceedings may include research recommendations, uncertainties, and the rationale for decisions made during the meeting. Proceedings may also document when data, analyses or interpretations were reviewed and rejected on scientific grounds, including the reason(s) for rejection. As such, interpretations and opinions presented in this report individually may be factually incorrect or misleading, but are included to record as faithfully as possible what was considered at the meeting. No statements are to be taken as reflecting the conclusions of the meeting unless they are clearly identified as such. Moreover, further review may result in a change of conclusions where additional information was identified as relevant to the topics being considered, but not available in the timeframe of the meeting. In the rare case when there are formal dissenting views, these are also archived as Annexes to the Proceedings.

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SUMMARY

These Proceedings summarize the relevant discussions and key conclusions that resulted from a Fisheries and Oceans Canada (DFO) Canadian Science Advisory Secretariat (CSAS) Regional Peer Review meeting on April 26-28, 2022 via the online meeting platform Zoom. The working paper presented for peer review focused on the development and evaluation of stock and aggregate-level biological benchmarks for Skeena and Nass Sockeye Salmon stocks that consider stock-level diversity, spawning channel capacity, and time-varying productivity.

Due to the COVID-19 pandemic, in-person gatherings have been restricted and a virtual format for this meeting was adopted. Participation included DFO Science, Fisheries and Resource Management, and Salmonid Enhancement Program staff as well as representatives with relevant expertise from First Nations and First Nations organizations, Alaska Department of Fish and Game, environmental non-governmental organizations, and academia.

Meeting participants agreed the working paper satisfied all Terms of Reference objectives. The working paper was accepted with revisions. The conclusions and advice resulting from this review will be provided in the form of a Science Advisory Report providing advice to DFO Fisheries Management to inform the development of escapement goals for Skeena and Nass Sockeye Salmon, in addition to international obligations described in the Pacific Salmon Treaty (Chapter 2 para. 11).

The Science Advisory Report and supporting Research Document will be made publicly available on the [Canadian Science Advisory Secretariat](#) website.

INTRODUCTION

A Fisheries and Oceans Canada (DFO) Canadian Science Advisory Secretariat (CSAS) Regional Peer Review (RPR) was held on April 26-28, 2022 via the online meeting platform Zoom to review the working paper on the development and evaluation of stock and aggregate-level biological benchmarks for Skeena and Nass Sockeye Salmon stocks that consider stock-level diversity, spawning channel capacity, and time-varying productivity.

The Terms of Reference (TOR) for the science review (Appendix A) were developed in response to a request for advice from DFO Fisheries Management. Invitations to the science review and conditions for participation were sent to DFO Science, Fisheries and Resource Management, and Salmonid Enhancement Program staff as well as representatives with relevant expertise from First Nations and First Nations organizations, Alaska Department of Fish and Game, environmental non-governmental organizations, and academia.

The following working paper (WP) was prepared and made available to meeting participants prior to the meeting (working paper abstract provided in Appendix B):

Pestal, G. and Carr-Harris, C. Biological benchmarks and building blocks for developing aggregate-level management targets for Skeena and Nass Sockeye Salmon (*Oncorhynchus nerka*) CSAP Working Paper 2018SAL05.

The meeting Chair, Nicholas Komick, welcomed participants, reviewed the role of CSAS in the provision of peer-reviewed advice, and gave a general overview of the CSAS process. The Chair discussed the role of participants, the purpose of the various RPR publications (Science Advisory Report, Proceedings, and Research Document), and the definition and process around achieving consensus decisions and advice. Everyone was invited to participate fully in the discussion and to contribute knowledge to the process with the goal of delivering scientifically defensible conclusions and advice. It was confirmed with participants that all had received copies of the Terms of Reference, working paper, written reviews, and agenda.

The Chair reviewed the Agenda (Appendix C) and the Terms of Reference for the meeting, highlighting the objectives and identifying Jill Campbell as the Rapporteur for the review. The Chair then reviewed the ground rules and process for exchange, reminding participants that the meeting was a science review and not a consultation. Members were reminded that everyone at the meeting had equal standing as participants and that they were expected to contribute to the review process if they had information or questions relevant to the paper being discussed. In total, 40 people participated in the RPR (Appendix D).

Participants were informed that Toshihide (Hamachan) Hamazaki (Alaska Department of Fish and Game) and Mike Hawkshaw (DFO Science) had been asked before the meeting to provide detailed written reviews for the working paper to facilitate the peer-review process. Additionally, one participant (Randall Peterman), submitted a written review prior to the meeting which was distributed to participants.

The conclusions and advice resulting from this review will be provided in the form of a Science Advisory Report to DFO Fisheries Management to inform the development of escapement goals for Skeena and Nass Sockeye Salmon through stakeholder engagement in a management strategy evaluation process, in addition to international obligations described in the Pacific Salmon Treaty (Chapter 2 para. 11). The Science Advisory Report and supporting Research Document will be made publicly available on the [Canadian Science Advisory Secretariat](#) website.

GENERAL DISCUSSION

Following a presentation by the authors, the reviewers, Mike Hawkshaw (DFO Science) and Toshihide (Hamachan) Hamazaki (Alaska Department of Fish and Game), shared their comments and questions on the working paper. The discussion was then opened to all participants. This proceedings document summarizes the discussions that took place by topic, where points of clarification presented by the authors in their presentations and questions and comments raised by the reviewers and participants are captured under the appropriate Terms of Reference objective.

The overall objective of the paper was not clear to many participants as they expected to see recommended biological benchmark values and/or reference points. The authors explained that in the absence of clearly defined and agreed upon management objectives, they did not recommend specific aggregate or individual stock reference points in the paper. As well, no single approach or method to develop aggregate management targets was identified, as the choice of the method(s) depends on the context of the decision-making process. The group worked towards finding a balance between what was presented in the paper and what many in the group expected from this work.

TERMS OF REFERENCE OBJECTIVE ONE

Develop an approach for the evaluation and selection of spawner-recruit model fits using alternative datasets and alternative model forms, including time-varying model forms, and apply this approach at the stock and aggregate levels for Skeena and Nass Sockeye Salmon.

Kalman Filter terminology: A participant noted that the authors did not perform the fixed-interval smoothing step as would be expected in a Kalman Filter (KF) model. Through the discussion, it was determined that the authors had performed a recursive Bayes estimation of the time-varying productivity Ricker model instead (which is the same as modelling the Ricker alpha parameter as a random walk). Despite the methods giving similar results, a recursive Bayes method is not a KF model, therefore the authors will change the KF model terminology to 'time-varying alpha (TVA) model'. This terminology change was recommended at the end of the meeting, therefore, this proceedings will refer to the recursive Bayes method as KF, given this was the term used during the meeting. Discussing this distinction briefly in the Research Document will help alleviate some of the confusion in the literature on this topic (DFO 2020; Freshwater el al. 2020; Huang et al. 2021). The recursive Bayes estimation does not require a fixed-interval smoothing step. The authors will state that several stocks have smooth ln.alpha patterns even without the smoothing step. Follow-up work on comparing KF and Recursive Bayes estimates of time-varying productivity was identified as a high-priority for future work, and has been initiated by some of the meeting participants. This will be separate work from revisions to the Working Paper.

Infilling: There was some concern among participants as to the impact of the data infilling step on the Ricker lag-1 autocorrelation (AR1) and KF stock-recruit (SR) analysis results. The time series for many stocks are highly variable and taking the average of the data on either side of the missing observation may not accurately capture this variability. The authors indicated they conducted a sensitivity analysis to explore the effect of the data infilling and determined the effect was minimal and no more impactful than other data treatment steps. A participant indicated that since the infilled values were averaged the sensitivity test may not be able to properly detect the impact of the infilling data treatment step. The authors will generate alternative versions of the infilled data set, rerun the KF filter fit, and generate a comparison plot of the median ln.alpha patterns using an Monte Carlo bootstrapping approach.

Parameter bias: A participant said that spawner recruit parameter estimates can be biased; therefore, it is important to test model priors every time they are built to ensure the models are performing accurately. Another participant noted research that indicated biases in spawner-recruitment parameters may also result from historical patterns of exploitation (Holt and Michielsens 2019). An author said that doing simulations to test prior biases without knowing which aggregation approach would be selected by managers would be too much work for this paper, especially given some stocks would be more or less impacted by bias in the capacity priors. Brendan Connors (DFO, personal communication) did simulations to determine how biased biological reference points were as a function of the total number of spawner-recruitment data points. These simulations suggested that bias in S_{MSY} is larger with fewer data points and also larger for the least productive stocks. Given there is limited data on many of these small stocks, it may be challenging to complete this work for this paper. The authors acknowledged that more could have been done to explore biases in the estimates if they were only responsible for modeling one stock, however the focus for this paper was to standardize the various approaches across all 20 modelled Skeena-Nass stocks. The authors acknowledged that this paper represents only one step in the broader plan and these simulation tests may be best suited for the next steps. It was decided that instead of doing simulations to explore bias in the parameter priors, the authors should mention the literature to support this future work.

Log-normal bias correction: The literature is divided on when to apply the log-normal bias correction and if the mean or median of the distribution should be used. A participant stated that when developing long-term reference points, the mean should be used as it represents the statistical expectation over the long term. Additionally, since the bias correction is applied while estimating S_{MSY}, which is an equilibrium based concept, the mean should be used rather than the median. Applying the log-normal bias correction using the mean value is consistent with Alaska Department of Fish and Game assessments and other marine fish stock assessments. An author noted that for some of the smaller, data-limited stocks, applying the bias correction resulted in large changes in model results. The authors will indicate in the Research Document which aggregate approaches should apply the log-normal bias corrected mean or the non-bias corrected median. A participant cautioned that a reliable estimate of the variance parameter is needed in order to apply the bias correction, otherwise additional noise would be added to the SR relationship.

Long-term average vs recent comparison: A reviewer stated that how the authors compared the long-term average productivity using the AR1 model and the last generation productivity with the KF model was not valid as it is difficult to tease apart the model differences from the productivity changes. A participant indicated that the AR1 and KF results did not differ much and did not see any major issues with how they were compared in this paper. The authors clarified that AR1 has been used in many other escapement goal analyses so they presented the long term productivity using the AR1 model to be consistent. The authors will provide text to clarify what they have presented.

Biological considerations:

- Model results will be impacted by the biological context of the priors, which are derived from the lake-based capacity data (which may be several decades old), and the characteristics of the SR data that the models are fit to. How this influences the data review and model testing steps should be considered in future work. This Research Document will recommend that future work investigate the effect of the priors using simulated data based on the priors only to check if the data generated with them are biologically plausible.

- Shared covariation in productivity among stocks is likely, given the shared lake and ocean environments. Participants agreed that correlation among stocks should be the base case scenario for forward simulations.
- Decreasing body size and fecundity have been observed in other species (Staton et al. 2021) as well as in Skeena Sockeye. Participants discussed one candidate approach for addressing this change, which is to define reference points and escapement goals in terms of egg targets rather than spawner targets. One participant noted that this egg-based approach has been implement for Somass Chinook.
- The biological considerations of the sea-type, river-type, and lake-type life histories should be considered during any future modeling or escapement goal analyses, especially if considering more recent timeframes. For example, the Nass early timed lake-type stocks have shown declines in recent years, but Lower Nass Sea and some River Type stocks have shown high productivity in recent years. Aggregate SR estimation approaches will not capture these important life-history type differences.

Future work:

- Explore the effect of the smoothing step in a KF model compared to the recursive Bayes method.
- Explore the effect of various data infilling methods on SR model results.
- Perform simulation tests of the SR model prior bias estimates using the aggregation approach(es) selected by management.
- Future sensitivity analyses of the Hierarchical Bayes Model (HBM) approach to estimating SR parameters should consider removing groups of stocks (e.g., Upper Skeena, Lower Skeena) rather than one stock at a time, to explore the effect on estimated shared year effects.

TERMS OF REFERENCE OBJECTIVE TWO

Develop an approach to identify plausible alternative productivity scenarios (e.g., long-term average vs. current productivity) and corresponding spawner-recruit parameter sets.

Alternative recent scenarios: Participants suggested a broader range of plausible future productivities should be explored, as capturing only the last four brood years may be insufficient. Participants agreed that management on the long-term average productivity assumption may not be appropriate, depending on how estimated biological benchmarks are used. In response, the authors will present a comparison of SR parameter estimates using the 2 and 3 most recent generations). The authors also noted that using either the long-term or current productivity scenarios depends on the management objectives. A recent analysis of Yukon Chinook used long term estimates of productivity as this was more cautious than using recent estimates of productivity in that specific management setting, which focuses on a fixed escapement goal.

Future work:

- A future Management Strategy Evaluation (MSE) could also consider various productivity scenarios for the enhanced stocks, perhaps by using a modification of the Ricker model.
- There are often cyclical decadal patterns that influence populations, and the long-term average productivity patterns should not be discounted. These historic environmental patterns may be useful in bounding definitions of ‘recent’ productivity timeframes (e.g.

temperature-productivity relationships, future projections of temperature changes). Stock-by-stock analyses will be most valuable to explore since individual stocks are anticipated to respond differently. This should be considered in any future work.

- Plausible/possible future productivity scenarios could also be generated based on known productivity-environment relationships (e.g., sea-surface temperature during first few months of ocean entry) and downscaled projections of sea surface temperature under alternative future climate scenarios.

TERMS OF REFERENCE OBJECTIVE THREE

Develop stock-level biological benchmarks using current datasets and appropriate methods for wild and enhanced Skeena and Nass Sockeye Salmon stocks including:

a. Estimate and evaluate candidate biological benchmarks (e.g. Smsy, Smax, Sgen, Umsy) from model fits based on the plausible alternative productivity scenarios for wild Skeena and Nass Sockeye Salmon stocks.

Aggregate equilibrium trade-off considerations: A participant suggested that aggregate equilibrium trade-off considerations be added to the suite of alternative aggregation approaches presented in the paper. Biological reference points and aggregate tradeoffs should not be derived from HBM based estimates of productivity because of inherent “shrinkage” towards global mean results in upward (downward) bias in productivity for the least (most) productive populations (Walters et al. 2008). The aggregate equilibrium trade-off approach may present ‘mixed stock exploitation rate’ on the x-axis and ‘number of overfished or extinct Conservation Units (CUs)’ on the y-axis. Caution is recommended on how to best label the y-axis. ‘Overfished’ should be in reference to MSY level, not framed that the stock may collapse. ‘Extinction’ could be framed as falling below a lower biological benchmark (e.g., S_{GEN}). However, closed-loop simulations are important to perform as this approach assumes all stocks are equally vulnerable to exploitation. Authors agreed to implement the aggregate equilibrium tradeoffs approach and include examples of the results in the paper.

b. Review channel capacity and observed patterns in productivity for channel-enhanced Skeena Sockeye Salmon stocks originating from the Babine Lake Development Project.

Enhanced-wild interactions: Many participants expressed concern over the impact the channel-enhanced stocks are perceived to have on the wild Babine stocks and a reviewer indicated that wild Babine Lake stock escapement is not sufficient to describe wild Babine Lake stock recruitment. Based on the graphs in Figure 15 of the research document, there are clear density dependent effects on the growth and survival of fry and smolts and since fry from the enhanced channels and stream sections rear together with wild fry in Babine Lake there is concern this could amplify density dependent effects on the wild smolts. Additional context around the wild-enhanced population dynamics were presented by a participant and an author. Babine sockeye currently account for 90% of the Skeena aggregate return, and prior to the Babine Lake Development Project (BLDP) and as early as the 1960s, concerns were raised about declining returns of non-Babine Sockeye populations. The contribution of the Pinkut and Fulton stocks, which are now enhanced has increased from approximately 30% to approximately 80% of the Babine Sockeye return. The largest rate of decrease in smolt size occurred after the Babine slide in 1950 but before the start of the BLDP, and there has been a less pronounced decline in smolt size since the BLDP. The three wild stocks that rear in Babine Lake (Late Babine wild, mid-Babine wild, and early Babine wild) and the two enhanced stocks (Pinkut and Fulton) are geographically segregated. They also noted that these stocks have distinct run timing (and therefore fishing pressure differs), different rearing habitats, distinct genetics and different patterns of recruitment. The Lake Babine wild stock rears in Nilkitkwa

Lake and the North Arm of Babine Lake. The remaining wild and enhanced stocks rear in the main basin of Babine Lake. There is little evidence that the enhanced stocks are influencing the wild stocks but more research is needed. The authors will ensure this background context is provided in the Research Document.

SR models for the channel-enhanced stock: Many participants asked to see more analysis included on the channel-enhanced populations. Considering the enhanced population comprises the vast majority of the aggregate Skeena run size, it is important to have a better understanding of these two stocks. An author mentioned that under the Wild Salmon Policy, assessments should only include enhanced CUs when the CU is dominated by natural spawners. In this case, the enhanced populations are separate stocks and therefore methods of addressing wild and enhanced stocks together do not apply. An author showed that the SR data for the enhanced populations are so variable that there is no clear density dependent signal and SR parameter estimates are highly sensitive to both data subsetting (i.e. excluding individual brood years) and prior assumptions used in the Bayesian estimation. It was decided that the authors will include SR analyses for the channel enhanced stocks in the Research Document with appropriate caveats of the data and results.

Genetic swamping: A participant was concerned about the reduced productivity for wild Babine Sockeye stocks being connected to increased harvest of the smaller stocks in mixed stock fisheries and potential straying from surplus enhanced stock. Another participant added that many streams within the main basin of Babine Lake are ephemeral and there is uncertainty as to where the spawners from those streams go when they cannot access their spawning grounds. They noted that small Babine stocks in the early timing group may be one large amorphous population. An author indicated this is a concern given there is little data on straying within Babine stocks, however another author pointed to evidence provided by a participant indicating the stocks that rear in Babine Lake are geographically separated which may indicate limited straying.

Increase channel loading: Authors did not provide results from SR analyses for the enhanced stocks since the loading target is fixed and they were not certain how any S_{MSY} estimates could be actioned. A participant said that if the SR analysis results indicated the channel loading targets could be increased that this might be worth considering since the reduced fecundity of the spawners has not been accounted for. Another participant was concerned that if loading targets for the enhanced populations were increased it may lead to redd superimposition. They thought that smaller fish might not necessarily have smaller or shallower redds. Another participant responded that current loading targets may be below the capacity of the channel and managed creek and river habitat could be increased. They pointed to the loading target in Fulton River being doubled in the early 2000s to mitigate for potential disease and temperature related pre-spawn mortality, which resulted in increased fry production but at a lower egg-to-fry survival rate. They also noted that the managed river sections have more fringe area to accommodate additional enhanced spawners that has not been accounted for in the area of available spawning habitat, which only includes areas of “ideal” spawning habitat. Participants noted that the goal of this enhancement project is unclear as in recent years the surplus channel-enhanced returns have exceeded the total harvest for the aggregate.

Hierarchical Bayesian Models: The authors of this Appendix highlighted a sensitivity analysis which removed the channel-enhanced stocks and indicated there were no significant changes in the posterior distribution of the alpha parameter.

Future work:

- More up-to-date estimates of lake productivity are needed, the most recent limnological survey for Babine Lake occurred in 2000.

- Explore the effects of increased fry production on smolt production and smolt-adult survival.
- Explore the trade-off between numerous smaller smolts and fewer larger smolts.
- Consider the interactions between the wild and enhanced stocks in terms of lake and ocean competition, as well as harvest management of the wild and enhanced aggregate stock. A reviewer suggested building life-stage models or capacity-based approaches to better understand the enhanced-wild interactions.
- The degree of straying and genetic distinction of the Babine Lake stocks requires more research.

TERMS OF REFERENCE OBJECTIVE FOUR

Compare alternative approaches for choosing aggregate-level biological reference points for Skeena and Nass Sockeye Salmon, and evaluate advantages and disadvantages for each approach.

New summary table: In response to reviewer comments, the authors will add a new table to the Research Document outlining various evaluation characteristics for each of the aggregate-level biological reference point approaches presented in the paper. Approaches have very different characteristics, yet in the Working Paper they were presented as equals. Participants provided ample input on headings the authors could consider when characterizing each approach. This table will also be included in the Science Advisory Report, so participants will be able to provide feedback on it prior to its inclusion in the Research Document.

Follow up meeting for new summary table: A follow-up meeting occurred on June 3, 2022 via the online meeting platform Zoom to review the new summary tables. Eleven volunteers from the RPR attended the follow up meeting. In addition, there were four written reviews given to the authors, two of which provided by people unable to attend the follow up meeting. “Bias estimate” was added to the table as a criterion. An importance column listing whether the criterion was critical, according to the Science Advisory Report (SAR) summary bullets, was added to the table. Although there was further discussion of preferred approaches given the summary table, there was no recommendation for any single approach in the SAR because it was not agreed to at the original RPR. Nevertheless, the participants decided that it would be helpful to include an example as a paragraph to frame how the summary tables could be used to determine the best approach, given specific management objectives. An example of Skeena aggregate equilibrium plots was also shared and participants recommended label terminology improvements.

Summing S_{MSY}: A few participants cautioned the authors against presenting this approach. They thought it was inappropriate since a mixed stock harvest is not maximized at the sum of the individual stock specific S_{MSY}. A participant did not want this method mentioned in the Research Document since some people may not read the paper carefully and think this approach is valid. The authors chose to include this approach at the recommendation of the Skeena Nass Sockeye Technical Working Group. They thought it was important to include this option if only to explain why it is not recommended and should not be explored in any future assessments. A participant indicated that the approach is only relevant to ensure escapement goals are at least as big as the sum of the individual stock S_{MSY}. In order to make it clear that this approach is not recommended, a participant suggested adding text to the figure and table captions in the Research Document indicating they are for illustration purposes only.

Forward simulations: In response to a request from a participant, the authors will clarify how they presented their forward simulations is more similar to what would be expected in a MSE, rather than what was proposed in DFO (2022) Guidelines for Defining Limit Reference Points for Pacific Salmon Stock Management Unit.

TERMS OF REFERENCE OBJECTIVE FIVE

Identify priorities for future work to support the development of stock-specific escapement goals (DFO 2009) and aggregate reference points.

In addition to the future work identified under the previous Terms of Reference (TOR) objective headings, the group also highlighted the following future work needs:

- Simulation work to explore consequences of correlations in interannual productivity within and between stocks. Covariation in productivity would affect the appropriateness of harvest control rules.
- Untangle how limited data, impacted habitat, or poor migration survival is resulting in the forecasted low probability of stocks exceeding the S_{MSY} benchmark goals.
- Participants agreed that developing a full implementation Management Strategy Evaluation (MSE) is the best approach for addressing the questions and uncertainties identified in the Working Paper and meeting discussion. This analysis should explore state-space models. State-space model approaches would help mitigate the assumptions that were made in this work (e.g., age composition, SR relationship assumptions, biological benchmark assumptions). An author noted that creating state-space models for 20 stocks is a large task and therefore not a direct extension of this working paper. A reviewer indicated that the data need to be available to properly run state-space models (e.g., the limited understanding of stock composition in the aggregate harvest). A participant pointed to a paper that explores the impact of limited SR data on management strategies (Adkison 2021). Potential genetic data exists, but would need to be analyzed. An MSE should also consider how bias and error flow through the analysis.

TERMS OF REFERENCE OBJECTIVE SIX

Examine and identify uncertainties in stock-level benchmarks by comparing outputs generated using alternative spawner-recruit model forms and datasets, and compare uncertainties in aggregate reference points generated using alternative approaches.

In response to reviewer comments, the authors provided a ranked list of uncertainties that will be added to the Research Document.

In response to a review comment the authors will provide more information on how the assumptions used when generating the data sets could produce errors throughout the SR modeling and aggregation approaches.

The utility of calculating stock-level escapement goals but harvesting based on aggregate-level reference points is unclear as harvest cannot be separated at the stock-level.

GENERAL COMMENTS

A reviewer asked for more clarification on how aggregate escapement goals are implemented in context of the international total allowable catch and in-season management processes. This context will help decision makers better understand the risks with various harvest control rules.

CONCLUSIONS

Meeting participants agreed the working paper satisfied all Terms of Reference objectives. The working paper was accepted with revisions (see Appendix E for a list of agreed upon revisions). A follow-up online meeting occurred on June 3, 2022 to review summary tables created for the

Science Advisory Report. Participants edited the summary tables and included an example paragraph on how to find an aggregate approach, given specific management measures.

ACKNOWLEDGEMENTS

We appreciate the time contributed to the RPR process by all participants. In particular, we thank the reviewers, Toshihide (Hamachan) Hamazaki (Alaska Department of Fish and Game) and Mike Hawkshaw (DFO Science) for their time and expertise. We also thank Nicholas Komick as Chair of the meeting and Jill Campbell as the Rapporteur.

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APPENDIX A: TERMS OF REFERENCE

BIOLOGICAL BENCHMARKS AND BUILDING BLOCKS FOR DEVELOPING AGGREGATE-LEVEL MANAGEMENT TARGETS FOR SKEENA AND NASS SOCKEYE SALMON, BRITISH COLUMBIA

Regional Peer Review Process – Pacific Region

April 26-28, 2022
Virtual Meeting

Chairperson: Nicholas Komick

Context

Under the renewed Pacific Salmon Treaty (PST) provisions, Fisheries and Oceans Canada (DFO) has agreed to complete a comprehensive escapement goal analysis for Sockeye Salmon returning to the Skeena and Nass Rivers. An aggregate escapement goal for Skeena and Nass Sockeye Salmon is used to set Annual Allowable Harvests (AAH) for U.S. and Canadian fisheries targeting both stock aggregates. In addition to renewed PST provisions, biologically based escapement goals for Skeena and Nass River Sockeye Salmon are used for Canadian fishery management including the Nisga'a Treaty (British Columbia et al. 1999), First Nations and other fisheries in the Skeena and Nass Rivers.

Aggregate Sockeye Salmon returns to the Skeena and Nass Watersheds are comprised of numerous genetically distinct smaller stocks (Pestal et al., in prep[1]), of which many are data-limited, and some are depressed and are considered stocks of concern. In addition, enhanced origin Sockeye Salmon from artificial spawning channels in two tributaries to Babine Lake account for a large proportion of aggregate Skeena Sockeye Salmon production. Canada is seeking to maintain the future productivity of Skeena and Nass Sockeye Salmon returns by maintaining the genetically unique wild Sockeye Salmon populations that contribute to overall returns consistent with Canada's Wild Salmon Policy (DFO 2005).

The current aggregate escapement goals for Skeena and Nass Sockeye Salmon, based on previous estimates of aggregate spawner abundance to produce maximum sustained yield (S_{msy}) are 900,000 and 200,000 respectively (Bocking et al 2002, Shepard and Withler 1958, Ricker and Smith 1975, Cox-Rogers 2013), do not take into account the complex stock structure of each aggregate, or the enhanced component of Skeena Sockeye Salmon from the Babine spawning channels. Furthermore, the productivity of Skeena and Nass Sockeye Salmon stocks has declined considerably in recent years. For these stocks, escapement goals based on maximum sustainable yield, which assumes long term average productivity, do not account for these changes and may not reflect current or future conditions.

Fisheries and Oceans Canada (DFO) Fisheries Management has requested that Science Branch develop and evaluate stock and aggregate-level biological benchmarks for Skeena and Nass Sockeye Salmon stocks that consider stock-level diversity, spawning channel capacity, and time-varying productivity. The assessment and advice arising from this Canadian Science Advisory Secretariat (CSAS) Regional Peer Review (RPR), will be used to inform the

[1] Pestal, GP, C Carr-Harris, S Cox-Rogers, K English, R Alexander and the Skeena Nass Sockeye Technical Working Group. (in prep). 2021 Review of Spawner and Recruit Data for Sockeye Salmon (*Oncorhynchus nerka*) from the Skeena and Nass Basins, British Columbia. Can. 20 Tech. Rep. Fish. Aquat. Sci.

development of escapement goals for Skeena and Nass Sockeye Salmon through stakeholder engagement in a management strategy evaluation process that are consistent with the considerations described above, in addition to international obligations described in the Pacific Salmon Treaty (Chapter 2 para. 11).

Objectives

The following working paper will be reviewed and provide the basis for discussion and advice on the specific objectives outlined below.

Pestal, G. and Carr-Harris, C. Biological benchmarks and building blocks for developing aggregate-level management targets for Skeena and Nass Sockeye Salmon (Oncorhynchus nerka) CSAP Working Paper 2018SAL05.

The specific objectives of this review are to:

1. Develop an approach for the evaluation and selection of spawner-recruit model fits using alternative datasets and alternative model forms, including time-varying model forms, and apply this approach at the stock and aggregate levels for Skeena and Nass Sockeye Salmon.
2. Develop an approach to identify plausible alternative productivity scenarios (e.g., long-term average vs. current productivity) and corresponding spawner-recruit parameter sets.
3. Develop stock-level biological benchmarks using current datasets and appropriate methods for wild and enhanced Skeena and Nass Sockeye Salmon stocks including:
    a. Estimate and evaluate candidate biological benchmarks (e.g. S_{msy}, S_{max}, S_{gen}, U_{msy}) from model fits based on the plausible alternative productivity scenarios for wild Skeena and Nass Sockeye Salmon stocks.
    b. Review channel capacity and observed patterns in productivity for channel-enhanced Skeena Sockeye Salmon stocks originating from the Babine Lake Development Project.
4. Compare alternative approaches for choosing aggregate-level biological reference points for Skeena and Nass Sockeye Salmon, and evaluate advantages and disadvantages for each approach.
5. Identify priorities for future work to support the development of stock-specific escapement goals (DFO 2009) and aggregate reference points.
6. Examine and identify uncertainties in stock-level benchmarks by comparing outputs generated using alternative spawner-recruit model forms and datasets, and compare uncertainties in aggregate reference points generated using alternative approaches.

Expected Publications

- Science Advisory Report
- Proceedings
- Research Document

Expected Participation

- Fisheries and Oceans Canada (DFO) (Ecosystems and Oceans Science, Fisheries Management, Salmonid Enhancement Program)

- Academia (University of British Columbia, Simon Fraser University, University of Alaska Fairbanks)
- Indigenous communities/organizations (e.g. Gitanyow Fisheries Authority, Gitxsan Watershed Authority, Nisga'a Lisims Government, North Coast Skeena First Nations Stewardship Society, Skeena Fisheries Commission)
- Pacific Salmon Commission Bilateral Northern Panel and Northern Boundary Technical Committee
- Non-governmental organizations (e.g. Wild Salmon Centre)

References

Bocking, R.C., Link, M.R., Baxter, B., Nass, B., and Jantz, L. 2002. Meziadin Lake biological escapement goal and considerations for increasing yield of Sockeye Salmon (Oncorhynchus nerka). DFO Can. Sci. Advis. Sec. Res. Doc. 2002/124. 55 p.

British Columbia, Canada, & Nisga'a Nation. 1999. Nisga'a final agreement. Ottawa: Federal Treaty Negotiation Office.

Cox-Rogers, S. 2013. Summary derivation and stock composition of the 900,000 and 400,000 Skeena sockeye escapement goal. Fisheries and Oceans Canada.10 pp.

DFO 2005. Canada's policy for conservation of wild Pacific salmon. Fisheries and Oceans Canada, Vancouver, B.C.

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Pacific Salmon Commission. 2020. Treaty between the Government of Canada and the Government of the United States of America concerning Pacific Salmon. 145 pp.

Ricker, W. and Smith, H. 1975. A revised interpretation of the Skeena River Sockeye Salmon (*Oncorhynchus nerka*). J. Fish. Res. Bd. Canada. 32: 1369:1381.

Shepard, M. and Withler, F. 1958. Spawning stock size and resultant production for Skeena Sockeye. J. Fish. Res. Bd. Canada 15 (5) 1007-1025.

APPENDIX B: WORKING PAPER ABSTRACT

Under the renewed Pacific Salmon Treaty (PST) provisions, Canada has agreed to complete a comprehensive escapement goal analysis for sockeye salmon (*Oncorhynchus nerka*) returning to the Skeena and Nass rivers. The biological and policy setting for this review is evolving rapidly (e.g., observed changes in productivity, new *Fisheries Act*). Given these rapid changes in requirements, process, and biological reality, our analyses focused on developing robust methods and agile tools to support current and future decision processes. Here, Skeena and Nass sockeye are grouped into 31 stocks with a range of life histories and observed productivities. We tested alternative spawner-recruit model fits, developed guidelines for choosing alternative productivity scenarios based on the model fits, and calculated biological benchmarks for the selected scenarios. We also illustrate several alternative approaches for combining stock-level estimates of biological benchmarks into aggregate reference points (e.g., sum of stock-level estimates, equilibrium yield profiles, status-based reference points, projection-based reference points). Sensitivity of biological benchmarks to variations in estimation method differed between stocks. Estimates were stable for stocks with long-time series of high-quality estimates and a clearly observed density-dependent relationship, but highly sensitive for stocks with poorer data, missing data, or lack of contrast in the data. Estimated productivity patterns varied across stocks, but recent productivity has been generally lower than long-term average productivity for most stocks, including the largest wild stocks from each aggregate (Meziadin on the Nass, Babine Late Wild on the Skeena). A large proportion of sockeye salmon returns to the Skeena originates from the Babine Lake Development Project (BLDP), a low-intensity enhancement program that consists of a series of spawning channels and managed river sections on two Babine Lake tributaries (Pinkut and Fulton). We summarized and assessed trends in BLDP production data as part of this review. While loading densities for these systems have remained relatively constant across time, that the overall productivity for the enhanced component of Skeena sockeye has declined considerably during the past 20 years.

APPENDIX C: AGENDA

Canadian Science Advisory Secretariat

Centre for Science Advice Pacific

Regional Peer Review Meeting (RPR)

Biological benchmarks and building blocks for developing aggregate-level management targets for Skeena and Nass sockeye salmon, British Columbia

April 26-28, 2022

Virtual Meeting

Chair: Nicholas Komick

DAY 1 – Tuesday, April 26

Time	Subject	Presenter
0900	Introductions Review Agenda & Housekeeping CSAS Overview and Procedures	Chair
0915	Review Terms of Reference	Chair
0930	Presentation of Working Paper	Authors
1030	***Break***	
1045	Overview Written Reviews	Chair + Reviewers & Authors
1200	***Lunch Break***	
1300	Overview Written Reviews	Chair + Reviewers & Authors
1445	***Break***	
1500	Identification of Key Issues for Group Discussion	Group
1600	Adjourn for the Day	

DAY 2 – Wednesday, April 27

Time	Subject	Presenter
0900	Review Agenda & Housekeeping Review Status of Day 1 (*As Necessary*)	Chair
0915	Carry forward outstanding issues from Day 1	RPR Participants
1030	***Break***	
1045	Discussion & Resolution of Introduction and Methods	RPR Participants
1200	***Lunch Break***	
1300	Discussion & Resolution of Results & Conclusions	RPR Participants
1445	***Break***	
1500	Develop Consensus on Paper Acceptability & Agreed upon Revisions (TOR objectives & Revisions table)	RPR Participants
1600	Adjourn for the Day	

DAY 3 – Thursday, April 28

Time	Subject	Presenter
0900	Introductions Review Agenda & Housekeeping Review Status of Day 2 (*As Necessary*)	Chair
0915	Carry forward outstanding issues from Day 2	RPR Participants
1030	***Break***	

Time	Subject	Presenter
1045	*Science Advisory Report (SAR)* Develop consensus on the following for inclusion: • Summary bullets • Sources of Uncertainty • Results & Conclusions • Figures/Tables • Additional advice to Management (as warranted)	RPR Participants
1200	***Lunch Break***	
1300	*Science Advisory Report (SAR) cont'd*	RPR Participants
1445	***Break***	
1500	Next Steps – Chair to review • SAR review/approval process and timelines • Research Document & Proceedings timelines • Other follow-up or commitments (*as necessary)*	Chair
1545	Other Business arising from the review	Chair & Participants
1600	***Adjourn meeting***	

APPENDIX D: PARTICIPANT LIST

Last Name	First Name	Affiliation
Addison	Angela	North Coast Skeena First Nations Stewardship Society
Adkison	Milo	University of Alaska Fairbanks
Alexander	Richard	LGL Consulting
Anderson	Erika	DFO Science
Campbell	Jillian	DFO Science
Carr-Harris	Charmaine	DFO Science
Challenger	Wendell	LGL Consulting
Cleveland	Mark	Skeena Fisheries Commission/Gitanyow Fisheries Authority
Connors	Brendan	DFO Science
Cox-Rogers	Steven	DFO Science (retired)
Davies	Sandra	DFO Fisheries Management
Davies	Shaun	DFO Science
Dobson	Diana	DFO Science
Doire	Janvier	Skeena Fisheries Commission
English	Karl	LGL Consulting
Fair	Lowell	Alaska Department of Fish and Game
Fernando	Alicia	Gitxsan Watershed Authority
Grant	Sue	DFO Science
Greenburg	Dan	DFO Science
Grout	Jeff	DFO Fisheries Management
Hamazaki	Toshihide (Hamachan)	Alaska Department of Fish and Game
Hawkshaw	Mike	DFO Science
Hertz	Eric	Pacific Salmon Foundation
Holt	Kendra	DFO Science
Holt	Carrie	DFO Science
Huang	Ann-Marie	DFO Science
Kindree	Meagan	DFO Fisheries Management
Komick	Nicholas	DFO Science
May	Chelsea	DFO Science
McAllister	Murdoch	University of British Columbia
Miller	Sara	Alaska Department of Fish and Game
Moore	Jon	Simon Fraser University
Pestal	Gottfried	SOLV Consulting
Peterman	Randall	Simon Fraser University
Piston	Andrew	Alaska Department of Fish and Game
Radford	Jeff	DFO Resource Management
Rosenberger	Andrew	Coastland Research
Warkentin	Luke	DFO Science
West	Cameron	DFO Salmonid Enhancement Program (retired)
Wor	Catarina	DFO Science

APPENDIX E: AGREED UPON REVISIONS TO THE WORKING PAPER

Type	Topic	Revision
Background material	Effect of enhanced surplus	Include expanded description of how the surplus is estimated, and summarize previous work on effects of surplus spawners (original assumption was that they would spawn on the lake shore, but snorkel surveys found no evidence of that). This is a summary of material from the Data Report.
Background material	Enhanced production review	Work with Cam West to identify and incorporate clarifications and additional context on the enhanced production data (BLDP smolt program description, survival and fecundity data) and how their on-going review is described in the paper. Incorporate Charmaine Carr-Harris' Babine slides for Day 2.
Communication	Document Structure	Include section at the beginning explaining the structure and scope of the paper, based on the section "Working Paper Organization" in the written response to Hamachan Hamazaki's response.
Communication	Editorial fixes	Work through detailed editorial comments from Randall Peterman's written review (plot layouts, captions, typos).
Communication	Editorial fixes	Work through editorial comments from Hamachan Hamazaki's written review.
Communication	Table of objectives	Table listing implied and explicit objectives for each of the examples of alternative aggregation approaches. (slide in presentation into paper)
Communication	Model Fitting Flowchart	Revise based on discussion (show infill, num obs threshold, etc.)
Conclusions & Recommendations	Changes in body size, fecundity etc.	Include discussion of observed trends and recommend future work on formally incorporating changes in body size into the analyses (pointing to recent Yukon Chinook paper by Connors et al. 2022).
Conclusions & Recommendations	Correlation in productivity / returns	Include a discussion of observed correlation in raw R/S and Basic Ricker residuals for all stocks with SR data (from Data Report). Add a pairwise correlation plot of Kalman Filter ln.alpha estimates for those stocks where KF model could be applied. Discuss which aggregation approaches are influenced by correlation (past correlation: log regression, assumed future correlation: forward sim) and which are not (status-based aggregate limit reference point (LRP), Sum of Smsy, upper bound on exploitation rate (ER) based on Umsy). ALSO: Include example of forward sim with one version of covariation (See specific item) ***Empirical evidence clearly shows positive

Type	Topic	Revision
		co-variation across stocks in productivity and that should be the default assumption***
Conclusions & Recommendations	Interaction between enhanced and wild stocks	Include a discussion of potential future work re: interactions between the wild and enhanced stocks, in terms of biology (e.g. competition in the lake and the ocean) and harvest management and outline future work that could explore this further. Include summary of Charmaine's presentation on enhances/wild Babine review
Conclusions & Recommendations	Productivity scenarios	Include discussion of limitations of current productivity scenarios (Fixed in time), and outline potential future work on alternative scenarios (patterns) including environment considerations and bound likely futures based on known relationships (potentially stock by stock relationship differences may be leveraged based on existing/ongoing work). Also include cautionary wording re: experience with past processes.
Conclusions & Recommendations	Productivity scenarios	Include reference to Rodionov papers on modelling alternative prod scenarios, and comment on similarities/difference in approach.
Conclusions & Recommendations	Ranked list of uncertainties	Draft list included in the presentation. Modify based on mtg discussions and include in the paper. Bias in parameter estimates (based on past research or evaluated using simulation, Brendan provides some text that supports this)
Conclusions & Recommendations	Recommended aggregation approach	Table of characteristics for each method included in the presentation for both WP and SAR. Modify based on mtg discussions and include in the paper. OPTIONS PRESENTED FROM THE MEETING: Add column for comments for advantages/limitations/prerequisites. And add how they are applicable for Nass/Skeena. Preference/priority notes could be included. Does the approach deal with the time varying productivity, conservation objectives, etc?
Conclusions & Recommendations	Table of recommended Biological benchmarks	Add a section clearly describing which biol benchmark versions are used in which subsequent analysis: (1) Sgen and 80% Smsy under long-term avg prod for status metric and in the illustration objective used in the forward simulation. (2) Sustainable exploitation rate (Umsy) under current productivity scenario to compare stock productivities, (3) Sgen from current prod scenario for the log-regression example, (4) Smsy and MSY from long-term prod scenario for the equilibrium probability profiles.

Type	Topic	Revision
Data	SR data sources	Include expanded description of the completed data review. This is a summary of material from the Data Report. ***Importance of data (e.g. age composition and literature around potential issues with assumption - Brendan, lack of harvest data and distribution differences at specific stock level, Milo paper on the importance of data)*** Consider future use of DNA data to inform harvest specific impacts on individual stocks?
Forward simulation	Covariation in productivity	Include an illustration of effect of covariation in forward sims: (1) Calculate cov in prod based on basic ricker resids for all stocks and Kalman filter ln.alpha pattern for subset of stocks where possible, (2) compare and generate a sample cov scenario, (3) run the forward sim with covar and incl. the summary output as a contrast to no-cov scenario.
Forward simulation	Outcome uncertainty	Clarify the intent of the simple example and discussion of limitations of current simplifying assumption. Also include cautionary wording re: experience with past processes. ***Need to note that outcome uncertainty is important to develop forward simulations***, ***Update captions to note that figure 50 to 53? are examples of ways to present simulation outputs***
Results	Benchmark comparison table	Comparison table of each biological benchmark showing ratio of LTAvg prod estimate / Current prod estimate, as requested in Peterman review.
Results	Productivity comparison table V1	Comparison table of ln.alpha for LT Avg and current prod scenarios requested in Hamazaki review. Have included draft table in response. Include this in the paper.
Results	Productivity comparison table V2	Comparison table of ln.alpha for different model forms requested in Hamazaki review. Have included draft table in response. Include this in the paper.
Results	Selected data sets and Model Fits	Include section that more clearly lays out which data sets and SR model fits were selected for subsequent analyses. (incl. explanation of %iles selected for stocks with only Basic Ricker fits).
Results	Productivity scenarios	Generate alternative "recent prod" scenario using 2 and 3 generations time window. Include cross-hairs comparison plot, but don't include alternate versions of all the subsequent results
Results	Trade-off plot	Implement multi-stock version of profile plot, based on Brendan Connors example (For long-term and current prod scenario) BRENDAN: My very specific recommendation re: tradeoff plot is: a four panel plot with top row = mixed stock yield and proportion of stocks below Sgen across range of mixed-stock exploitation rates for long-term average (left column) and

Type	Topic	Revision
		recent (right column) productivity. Bottom row same as above but for aggregate escapement instead of exploitation rate.
Whole Paper	-	Replace current productivity with recent productivity
SR Modelling	Alternative form of Capacity prior	Include in list of potential future explorations
SR Modelling	Capacity priors	Include clearer explanation of how the capacity priors were set up.
SR Modelling	Model Form	Add some text and comparison related to address concern with switching between model types for long term and recent S-R model form (what does the long term averaging....)
SR Modelling	Model fits	Include results from SR fits for Pinkut and Fulton in summary tables
SR Modelling	log-normal bias correction	Include the wording provided in Hamazaki and Peterman reviews, and the Subbey references listed in Hamazaki Review, as well as some linking this back to our approach: do not apply bias correction focus on medians estimates, use non-corrected parameter estimates for forward simulations. (note that use of medians are not consistent with past work and mean may be appropriate in particular circumstances...unbiased corrected versions of both median and mean may be appropriate dependent upon how the management objective is stated. Effect of bias correction is linked to data quality and associated uncertainty in the variance on parameter used in the bias correction...So biased correct and uncorrected mean values may provide bounds on statistically expected value)
SR Modelling	Minimum number of SR data points	Include reference to unpubl. Connors analysis re: minimum number, and show that the increased threshold does not affect our current SR modelling approach. Too few data points in the model fitting will potentially lead to bias output parameters)
SR Modelling	Non-Ricker model forms	Include a brief justification in the Methods section for focus on Ricker variations. Also include a clearer explanation of the proposed approach, which is specifically designed for easy testing of alternative model fits (and even model averaging if the planning process requests it). For Sockeye this is a common approach...
SR Modelling	Smoothing step for Kalman Filter ln.alpha estimates	In methods section state that original Peterman et al. implementation of Kalman Filter applied a smoothing step, but that we did not. In results section state that (1) several stocks have smooth ln.alpha patterns even without the smoothing step, and (2) our subsequent use of the Kalman

Type	Topic	Revision
		Filter estimates already samples across multiple brood years, so does a type of smoothing. Use fixed interval smoothing which is the statistically most defensable method. Also include smoothing step in list of potential future explorations. (OR: implement interval smoothing, and include plot comparing the smoothed/non-smoothed patterns, and then compare the subsample from last gen for the smoothed vs. non-smoothed). Future work should compare Kalman Filter Ricker Model (with fixed interval smoothing) and Recursive Bayes Ricker Model (both methods should be very similar if not identical) Wor pers Comm . ***All references to Kalman Filter should be changed to Recursive Bayes...need to reference past work eg. CSAS processes *** Recursive BAYES REFS: Freshwater et al.; Fraser Sockeye RPA: Science Advisory Report and Research Document.
SR Modelling	Infill test of Kalman Filter fits	As part of infill testing appendix: for those stocks with infill and Kalman filter fits, generate 2 alternative versions of the data set (infill value at 1/3 and 3), redo the Kalman filter fit, generate a comparison plot of median ln.alpha patterns (using Monte Carlo (MC) approach by using bootstrapping)
SR Modelling	Stochastic simulations of bias	Include as potential future work
Conclusions & Recommendations	Recommended aggregation approach	Characterize forward simulation differently in the pro/con table and highlight differences from Holt LRP work.
Communication	Editorial fixes	Change headings in 2.4 and 3.4 to reflect the topic of defining/generating productivity scenarios
Background material/SR Modelling	Enhanced production review	Summarize Pinkut and Fulton modelling decision making and background - taken from CCH slides. Present benchmark values for enhanced stocks
Conclusions & Recommendations	SR model form summary of "best use" scenarios	Include a flow chart of aggregation methods in terms of different circumstances. To build a concise framework that the paper is recommending- may also just be captured in the former pro/con table *** This includes addressed using criteria/characteristics table ****