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Pacific Region

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Science Advisory Report 2023/008

BIOLOGICAL BENCHMARKS AND BUILDING BLOCKS FOR AGGREGATE-LEVEL MANAGEMENT TARGETS FOR SKEENA AND NASS SOCKEYE SALMON (*ONCORHYNCHUS NERKA*)

Sockeye Salmon adult spawning phase. DFO Website.

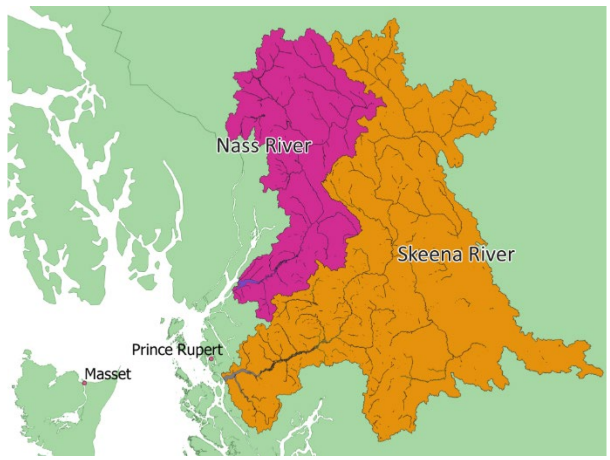

Figure 1. Skeena and Nass River watershed basins in Northern British Columbia, Canada.

Context:

Under the renewed Pacific Salmon Treaty (PST) previsions, Canada has agreed to complete a comprehensive escapement goal analysis for Sockeye Salmon returning to the Skeena and Nass rivers. Aggregate escapement goals are used to set Annual Allowable Harvests for US and Canadian fisheries. To align with the Wild Salmon Policy (WSP), support Canadian fishery management, and Indigenous treaties, escapement goals must incorporate stock specific considerations for the component stocks within the Skeena and Nass aggregates. An analysis framework, including alternative productivity scenarios and approaches for developing aggregate biological reference points, is needed to support upcoming planning and engagement processes.

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.

This Science Advisory Report is from the April 26-28, 2022 regional peer review on Biological Benchmarks and Building Blocks for developing Aggregate-Level Management Targets for Skeena and Nass Sockeye Salmon (Oncorhynchus nerka). Additional publications from this meeting will be posted on the [Fisheries and Oceans Canada (DFO) Science Advisory Schedule](#) as they become available.

Canada

SUMMARY

- This research focuses on comparing methods for developing alternative aggregate-level biological reference points (including aggregate escapement goals) for Skeena and Nass Sockeye Salmon and evaluate advantages and disadvantages of each.
- This research provides an analytical framework to develop aggregate biological reference points for wild Skeena and Nass Sockeye Salmon, including both a single stock and Hierarchical Bayesian Model (HBM) spawner-recruit models and alternative approaches for developing aggregate biological reference points.
- This framework is intended to support the development of escapement goals for implementation of the Pacific Salmon Treaty, Wild Salmon Policy (WSP), Section 35, Part II of the *Constitution Act, 1982*, fisheries, and Indigenous treaties.
- This work does NOT provide recommendations for setting formal escapement goals. Formal recommendations for aggregate escapement goals are expected to be developed based on subsequent work and engagement processes that explicitly take management objectives, trade-offs between aggregate yield, and stock level conservation objectives into consideration.
- The analysis of spawner-recruit relationships focuses on wild-origin spawners, but also explores model fits for enhanced stocks in Babine Lake. While relevant biological information on enhanced (e.g., artificial spawning channels) returns is provided, further research is required to address the interaction between enhanced and wild stocks.
- Both the single stock and HBM analysis show overall productivity decline for many stocks in recent years (including the largest wild stocks).
- Changes in productivity for component stocks within each aggregate appeared to differ substantially based on the single stock analyses.
- Setting aggregate reference points should consider information on differential productivity of wild stocks across different life history types and trends in productivity over time (e.g., habitat change and declining fecundity based on available data [i.e., lower egg production as size of spawning females declines]).
- The analyses explore alternative approaches to develop biologically based aggregate reference points for Skeena and Nass stocks, with results summarized in Table 4.
- A clear positive relationship exists between fry production and seaward migrating smolts from Babine Lake; however, the benefits of increasing smolt production to adult returns are less clear, with high variability in smolt to adult survival.
- The relative contribution of non-Babine stocks to the aggregate Skeena abundance had already declined before enhancement and continued to decline after the start of the Babine Lake Development Project.
- This analysis is not meant to provide a formal stock status assessment; however, one of the illustrated aggregation approaches depends on multi-criteria status assessment applied under the Wild Salmon Policy.
- Although some preliminary simulation analyses were provided, a Management Strategy Evaluation is recommended, which would evaluate trade-offs between different objectives under potential productivity regimes.

- The simulation analyses provide examples of candidate management objectives and associated results based on potential productivity scenarios.
    - Although more thorough evaluation is needed that includes observation and outcome uncertainties and covariation among stocks, the results of a simple forward simulation suggests that a steady decline in the largest stocks (i.e., Meziadin and Babine Late Wild) is likely for fixed exploitation rates greater than 50% based on recent productivity levels.
    - Even a simple forward simulation helps identify potential interactions between the component stocks of the aggregate. For example, these analytical results suggest that under a fixed aggregate escapement goal, with exploitation rates responding to abundance, the individual stocks within the Skeena and Nass aggregates are more likely to meet conservation objectives under recent low productivity (compared with historical higher productivity) because lower aggregate run sizes result in reduced aggregate exploitation rates.
- Several required improvements to the proposed analytical framework were identified: (1) exploration of the sensitivity of spawner-recruit model fits to alternative prior assumptions (e.g., capacity priors and common shared year effect within the HBM), (2) assessment of model sensitivity to estimation biases, and (3) exploration of the effect of using longer time periods to define the recent productivity scenario (e.g., 10+ years).
- Several key priorities for future work were identified, including: Formal simulation testing to explore sensitivity to alternative spawner recruit model forms (e.g. capacity priors, HBM with common shared year effects), include additional data treatment steps (e.g. uncertainty on infilled estimate), assess model biases, explore integration of a shared year effect that accounts for separation between wild and enhanced stocks, account for changes in fecundity related to decreasing body size.
- This data preparation and analysis provide the groundwork to support a formal multi-criteria status assessment as applied under the Wild Salmon Policy.

INTRODUCTION

Under the renewed Pacific Salmon Treaty (PST) provisions, Canada agreed to complete a comprehensive escapement goal analysis for Sockeye Salmon (*Oncorhynchus nerka*) returning to the Skeena and Nass rivers (Pacific Salmon Commission 2020). 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 implementation of the Nisga'a Treaty (British Columbia, Canada, and Nisga'a Lisims Government 2000), 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 ecologically and genetically distinct smaller stocks, some of which are depressed and are considered stocks of concern. Several stocks are data-limited, as a result the status of these stocks is uncertain. In addition, enhanced-origin Sockeye Salmon from artificial spawning channels and flow-controlled sections of 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).

This research document analyzes spawner-recruit (SR) models to assess the productivity of the component stocks identified in Table 1 based on both long-term average and recent productivity. Based on these component stock specific spawner-recruit models, several different approaches to developing aggregate biological reference points for wild Skeena and Nass Sockeye stocks are explored. In addition to the component stock specific spawner-recruit models, a Hierarchical Bayesian Model (HBM) is explored for spawner-recruit relationships and as an aggregation approach. Although this analysis focused on wild origin spawners, spawner-recruit model fits are also explored for enhanced stocks in Babine Lake on the Skeena River. These model fits will need further research to address the interactions between enhanced and wild stocks, particularly for assessing mixed-stock fisheries.

The intent of the analysis framework provided through this research is to support the development of escapement goals that incorporate individual and aggregate stock considerations under varying productivity scenarios. This framework lays the groundwork to inform both a multi-criteria status assessment under the Wild Salmon Policy and the evaluation of trade-offs among management objectives within a Management Strategy Evaluation. These future framework uses are intended to support implementation of Pacific Salmon Treaty provisions, Canadian domestic commercial and Section 35 of the *Constitution Act, 1982*, fisheries, and Indigenous treaties.

Population Structure and Life History of Skeena and Nass Sockeye Salmon

Skeena and Nass Sockeye Salmon consist of numerous small stocks that are delineated into at least 33 distinct Conservation Units (CU), 25 in the Skeena River basin and 8 in the Nass River basin. These 33 Nass and Skeena Sockeye Salmon CUs were organized into 31 modelled component stocks for this analysis (Table 1).

Beacham and Withler (2017) describe three alternative life history strategies observed in the juveniles of sea-going (anadromous) Sockeye Salmon:

- lake-type Sockeye Salmon spawn in lakes or lake tributaries, and rear in the lake for at least 1 year after hatching.
- sea-type Sockeye Salmon spawn in tributaries or mainstem side channels, and the juveniles rear for several months in estuarine waters after hatching, or a total freshwater residency of one year including incubation.
- river-type Sockeye Salmon spawn in tributaries or mainstem side channels, and the juveniles rear in the river environment for at least one year before migrating to the ocean.

Most Sockeye Salmon spawning in the Skeena and Nass follow the lake-type life history, but there are river-type populations that spawn throughout both basins, and there are also at least two sea-type populations that spawn in the lower Nass River in Gingit and Gityzon creeks (Beveridge et al. 2017). While these river-type and sea-type populations are persistent, they usually account for a small part of the total abundance in each stock aggregate and most are inconsistently surveyed.

The Lower Nass sea-type population, for which the most abundant spawning population (Gingit Creek) has been surveyed regularly since 2000 (Beveridge et al. 2017), contributed about 31% of the Nass Sockeye Salmon return in 2019 (Nisga’a Fisheries and Wildlife Department 2020).

The population structure of river-type spawners in the Skeena watershed is unclear, with few samples in the genetic baseline and poor differentiation between some Skeena and Nass river-type populations. It is not known whether Skeena river-types should be assigned to one or multiple populations, or a single population for Skeena and Upper Nass river-types.

With respect to survival at different life history stages, the analysis of both fry to smolt and smolt to adult survival suggests that a significant source of uncertainty in productivity estimates may be associated with smolt to adult survival. Based on a smolt production assessment of Babine Sockeye Salmon by a mark and recapture program at the outlet of the Nilkitkwa Lake, a clear positive relationship between fry production and seaward migrating smolts (Figure 2) was identified. However, this positive relationship did not necessarily result in an increase in adult returns with the smolt to adult survival relationship being highly variable.

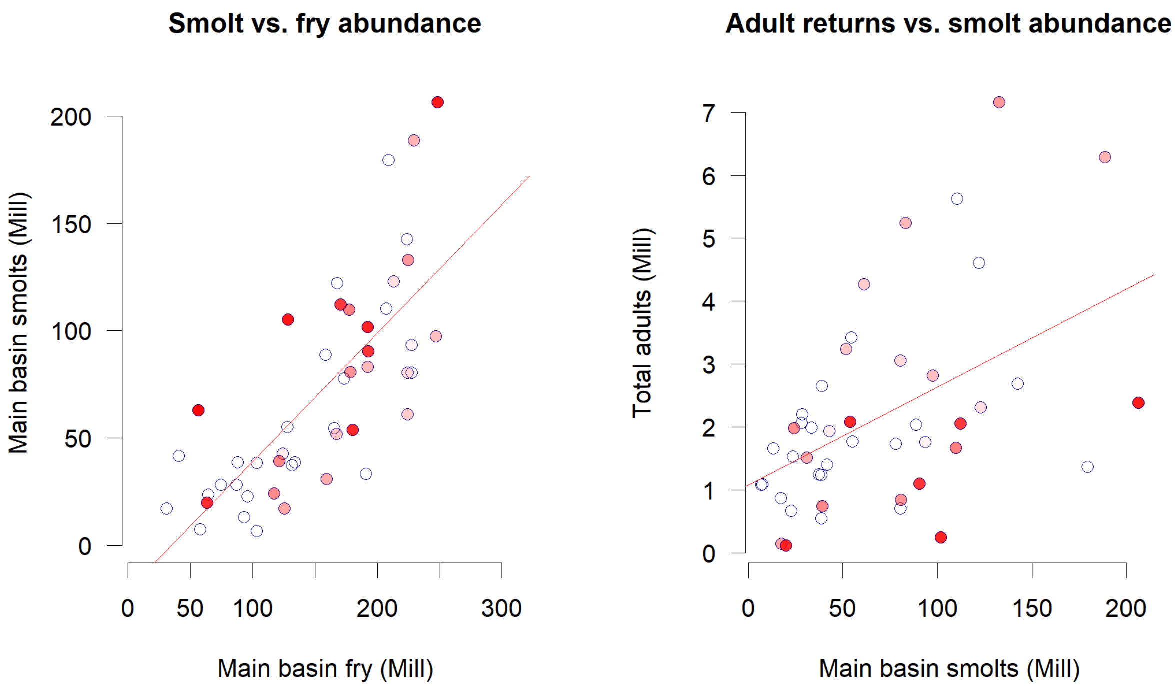

Figure 2. Patterns in fry to smolt and smolt to adult abundance. More recent observations are shaded darker red in both panels.

Enhanced Population

The Babine Lake Development Project (BLDP) consists of a series of spawning channels and flow control structures which were constructed on Pinkut Creek and Fulton River starting in the 1960s to increase the production of Sockeye Salmon originating from Babine Lake. Although Sockeye Salmon returns to these enhanced systems have declined since the 1981 to 1997 run years, the enhanced returns have increased relative to wild spawning populations. The Pinkut and Fulton stocks, which contributed up to 40% of Babine Sockeye Salmon returns prior to the start of the BLDP have contributed over 75% of the Babine returns since 1975. It is important to note that the relative contribution of non-Babine stocks to the aggregate Skeena abundance had already declined before enhancement and continued to decline after the start of the BLDP.

*Table 1. Nass and Skeena Sockeye Salmon population structure. The 31 stocks fall into 7 distinct groups based on life history type and freshwater adaptive zone (LHAZ) and 21 watersheds. We use short stock labels (Label) for tables and figures throughout the report. Exploitation rate indicators (ERInd) are available for most of the stocks. Stocks match up with one or more conservation units (CU). Babine is currently designated as a single CU, but assessed and analyzed as five distinct stocks (marked with *).*

LHAZ	Watershed	Stock	ERInd	CU
Nass SRT	Lower Nass Tribs	Lower Nass Sea & River Type	Gingit+	1
U Nass LT	Meziadin	Meziadin	Meziadin	1
	Bell-Irving	Bowser	NA	1
		Oweegee	NA	1
	Kwinageese	Kwinageese	Kwinagees	2
	Damdochax	Damdochax	Damdochax	1
Nass RT	Upper Nass Tribs	Upper Nass River Type	BrownBear	1
L Skeena LT	Ecstall	Johnston	NA	1
		Ecstall	NA	1
	Gitnadoix	Alastair	Alastair	1
	Lakelse	Lakelse	Lakelse	1
	Kitsumkalum	Kitsumkalum	Kalum	1
	Zymoetz	Mcdonell	Zymoetz	3
M Skeena LT	Kitwanga	Kitwanga	Kitwanga	1
	Bulkley	Upper Bulkley Lakes	NA	2
		Morice	Morice+	2
	Kispiox	Swan/Stephens	Swan+	3
	Babine	Babine Early Wild	Babine-WE	*
		Babine Late Wild	Babine-WL	*
		Babine Mid Wild	Babine-WM	*
		Pinkut	Babine-P	*
		Fulton	Babine-F	*
U Skeena LT	Sicintine	Sicintine	NA	1
	Slamgeesh	Slamgeesh	Slamgeesh	2
	Motase	Motase	Motase	1
	Sustut	Bear	Bear+	2
		Asitka	Bear+	1
		Sustut	NA	3
	Kluatantan	Kluantantan	NA	1
	Kluayaz	Kluayaz	NA	1
Skeena RT	All	Skeena River Type	Swan+	2

ASSESSMENT

The assessment of Skeena and Nass wild Sockeye Salmon using both a single stock and a Hierarchical Bayesian Model (HBM) shows an overall decline in productivity for many stocks in recent years, particularly the largest runs in the Skeena (Babine Late Wild) and Nass (Meziadin) rivers. The productivity trends for 12 modelled stocks based on a single stock assessment are shown in Figure 3. As this figure shows, productivity of the individual stocks may vary substantially from other stocks within the same river basin and the associated stock aggregate.

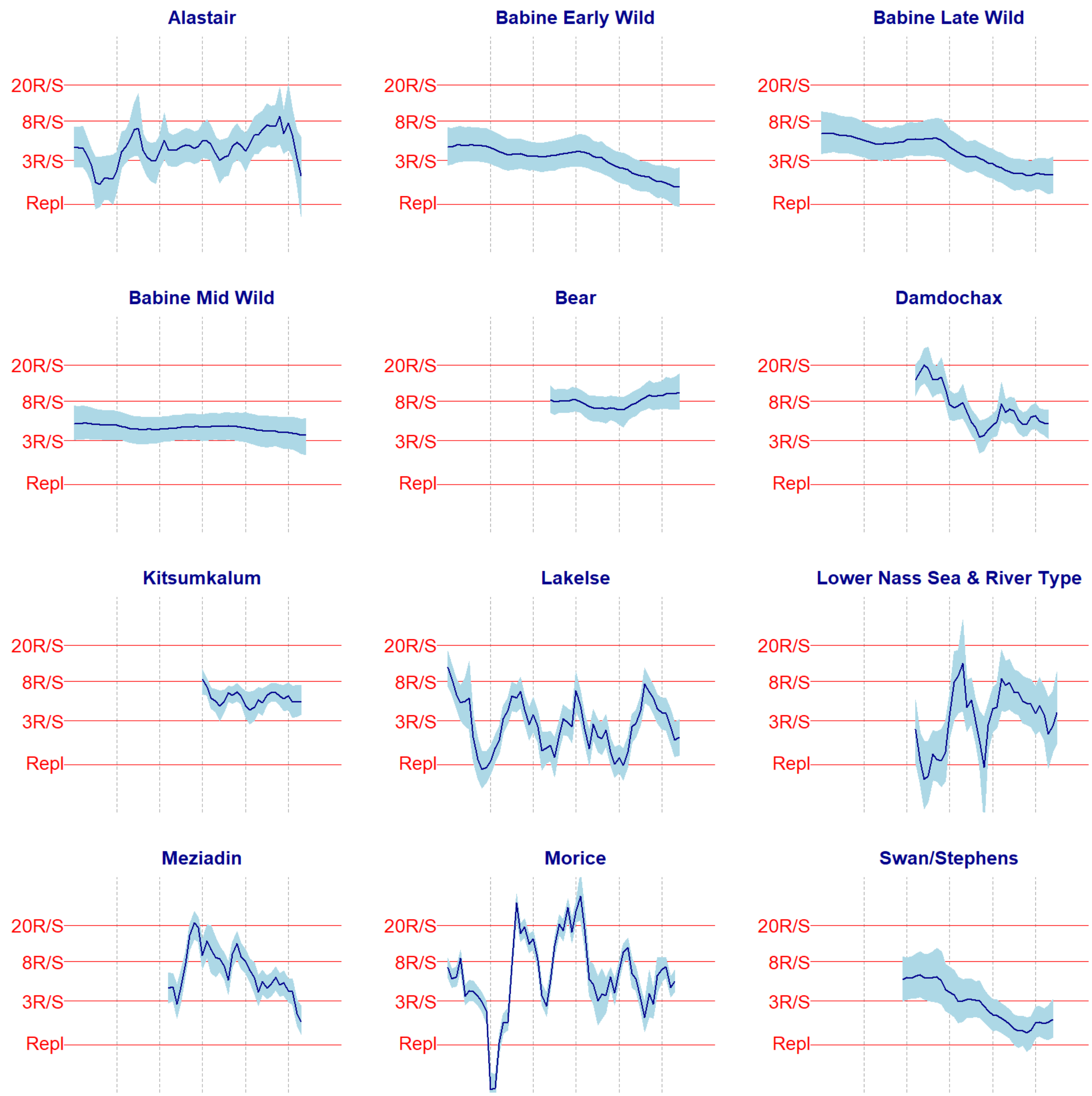

Figure 3. Time-varying productivity patterns for 12 stocks with complete time series. Each panel shows the median and 80% bounds of year-specific posterior distributions of ln.alpha for the SR model fit with time-varying alpha (TVA). Reference lines show the corresponding intrinsic productivity in terms of recruits per spawner (R/S) at very low spawner abundance (technically, at 0 spawners).

HBM analyses identified a shared year effect across the 18 Skeena stocks. This is shown in Figure 4, which includes a 4-year rolling average. The years showing the largest mostly positive common shared year effects included 1980-1992. The years showing the lowest mostly negative common shared year effects included 1999-2014. This effect could represent improved or diminished survival due to common environmental factors. There is currently no way to distinguish between authentic shared survival rate effect and run reconstruction error effects. Based on these findings future spawner-recruit analysis may be improved by the inclusion of a common shared year effect.

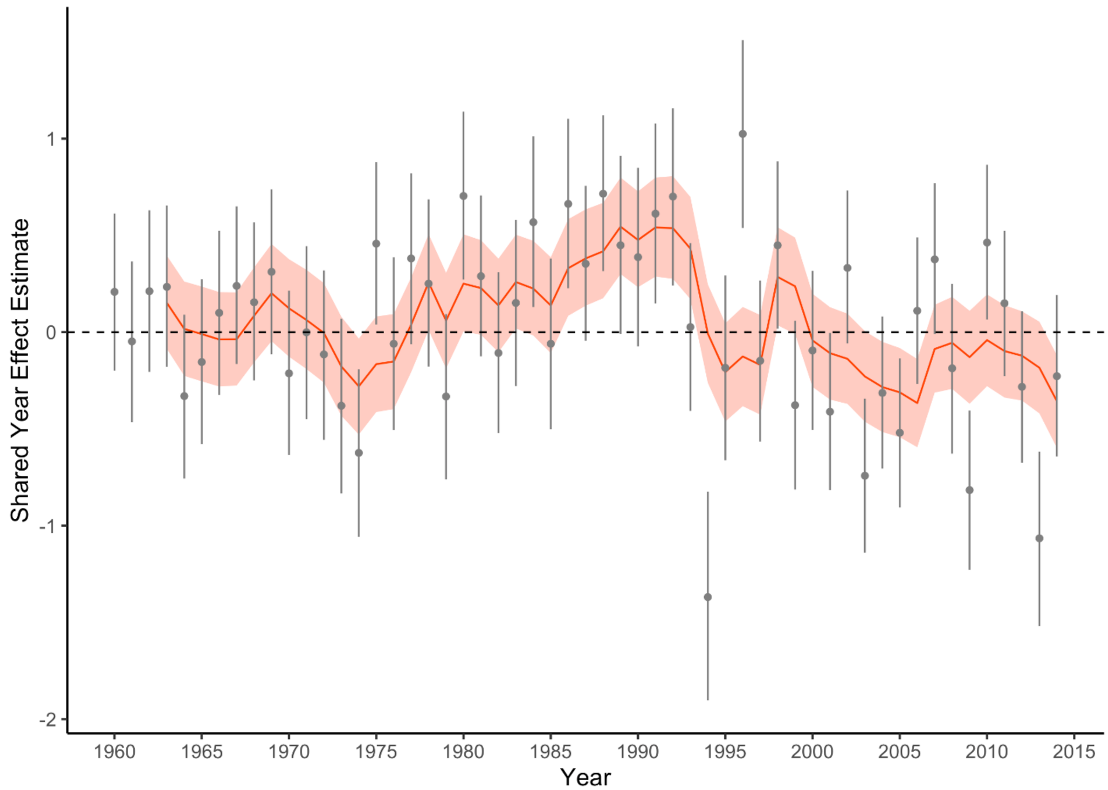

Figure 4. Estimated common shared year effect shared across the 18 Skeena stocks with a 4-year rolling average. Points indicate mean with error bars indicating the 95% credible intervals, while line and shading indicates the mean and 95% credible intervals for the rolling mean.

Comparing Alternative Approaches for Developing Aggregate Reference Points

The research document explored eight alternative approaches to combining component stock information into aggregate biological benchmarks. A summary of aggregation approaches explored is provided in Table 2. Each of these aggregation approaches were evaluated against criteria described in Table 3, with resulting ranks in Table 4. Further explanation on the criteria ranking is available in the research document.

Appropriate aggregation approaches can be selected depending on which criteria are identified as critical for a specific application. For example, if abundance-based aggregate escapement goals that consider stock level diversity are required, aggregate equilibrium tradeoff plots, logistic regression, and a forward simulation approach would be the only approaches that meet these criteria. Logistic regression has been determined to not be appropriate for Nass stocks, because past aggregate abundance is not correlated with stock-level performance measures. This leaves the aggregate equilibrium tradeoff plots and forward simulation as the only viable options within this example. Of these, only the aggregate equilibrium trade-off approach can be implemented within a relatively short time frame, while forward closed-loop simulations within a Management Strategy Evaluation (MSE) framework is the only aggregation approach identified that meets all of the criteria identified by Canadian Science Advisory Secretariat (CSAS) review committee.

Table 2. Alternative Approaches for Developing Aggregate Biological Reference Points

Approach	**Label**	**Description**
Aggregate S_{MSY} Estimate	Agg S_{MSY}	Calculate S_{MSY} for aggregate data set (total Nass, Total Skeena Wild).
Sum of stock-level S_{MSY} Estimate	Sum S_{MSY}	Calculate S_{MSY} for each stock with SR data, and sum the estimates. Meeting participants emphasized that this approach does not produce aggregate biological reference points consistent with the definition of MSY. This method is not recommended for developing aggregate reference points, it has been included here for completeness.
U_{MSY} Comparison	U_{MSY} Comp	Calculate U_{MSY} for each stock with SR data, and compare the estimates to identify a target ER for the stock aggregate from available stock-level U_{MSY} estimates from stocks with SR data (i.e., may choose to use the lowest stock-level U_{MSY} or the U_{MSY} for the largest stock, depending on management objectives).
Single-stock Equlibrium Profile	Equ. Prof	For each stock, calculate the proportion of parameter samples that meets a specified objective at increments of spawner abundance, such as prop (yield > 60% of MSY), under equilibrium conditions (i.e., on average over the long-term).
Aggregate Equilibrium Trade-off Plots	Agg TradeOff	Calculate summary performance measures across stocks (e.g., proportion of stocks meeting an objective vs. aggregate harvest, harvest rate, or escapement), under equilibrium conditions (i.e., on average over the long-term).
Stock-level Status Considerations	Status	Calculate status for each stock with data, and then identify aggregate reference points (LRP, harvest triggers) based on number of red/amber/green stocks (DFO 2022).
Log-regression	Log Reg	Classify past years as success or failure based on-stock-level performance measure (e.g. 80% of stocks above median S_{GEN}), then plot a logistic regression of success vs. aggregate abundance to identify an aggregate reference point from the fitted regression as the aggregate abundance associated with a required threshold of the stock-level performance measure.
Forward simulation (Mgmt Strat Eval, MSE)	Sim	Beginning with recent spawner abundances, simulate stocks forward under alternative assumptions about productivity, harvest, and other sources of mortality to identify aggregate abundances associated with appropriate levels of probability of meeting specified objectives. In practice, the focus of these analyses was to evaluate the performance of a variety of escapement goals and exploitation rates under a set of simple assumptions about stock dynamics.

Table 3. Description of proposed criteria for evaluating the utility of alternative approaches for developing aggregate biological reference points (Table 1). An initial list of criteria was identified during the peer-review meeting, then modified as the evaluations were being filled in. Criteria can be grouped into three distinct types: Estimation criteria are relevant to SR model fitting or simulation model scoping. Outcome criteria relate to the type of end-product generated by the aggregation method. Implementation criteria relate to how the end-product can be used, and when it could be available.

Type	Label	Description
Estimation	Time-varying parameters?	Can incorporate time-varying parameters (e.g. fecundity, capacity, variance, productivity).
Estimation	Uncertainty in SR model fits?	Explicitly accounts for uncertainty in SR model fits that arises from natural process variation and observation (i.e., measurement) error.
Estimation	Outcome uncertainty?	Can explicitly incorporate differences between target and actual escapement or exploitation rates?
Estimation	Productivity covariation?	Can explicitly incorporate observed or alternative future covariation in productivity among stocks?
Estimation	Bias in parameter estimates?	Can bias in S_{MSY}, U_{MSY}, the Ricker alpha, and the Ricker beta parameters be explicitly evaluated? For example, as a function of number of data points, average stock productivity, time variation in productivity, and previous harvest rates (the last two variables affect contrast in data), etc.
Outcome	Can get abundance-based Agg RP?	Can produce an abundance-based aggregate reference point?
Outcome	Can test state dependent Harvest Control Rules (HCR)?	Can this method produce and test harvest control rules that respond to changing conditions?
Outcome	Data-deficient stocks?	Can this method account for stocks currently without SR data?
Outcome	Allows taking into account component stocks?	Explicitly provides estimates of current or future biological status of component populations and other stock-specific information so that decision makers can evaluate trade-offs?
Implementation	Can be easily operationalized?	Easily operationalized in bilateral and domestic management setting. For example, does it align with Limit Reference Points under the Fisheries Act (DFO 2022)?
Implementation	Time requirements	Implementation time frame *after data review and SR model fitting.* Short = short-term is possible (can calculate from SR parameters immediately), Medium = medium-term process required (at least 6 months), Long = multi-year process required.

Table 4. Summary of characteristics of 8 alternative methods for developing aggregate reference points. The peer-review process compared alternative approaches for developing aggregate reference points (Table 2) based on a set of 10 criteria (Table 3). A YES/NO/MAYBE ranking was assigned for each criterion to provide a comparison of aggregation methods. YES identifies that the aggregation approach meets the criterion. MAYBE means that current approach could be modified or expanded to meet the criterion, depending on time and resources, but the research document analysis does not meet this criterion. NO means that the criterion cannot be met with this aggregation approach. For the time requirement, SHORT means that it can be applied immediately to the SR parameter estimates. MEDIUM means that at least 6 months will be required for either process (e.g., choice of quantitative objectives) or method developments (e.g. pending publication of guidelines, followed by review of implementation). LONG means that a multi-year process is likely needed for full implementation. The Critical column values are provided by the review participants and identify criterion that are critical (Yes) or not evaluated by review participants and to be determined (TBD).The research document has an appendix that provides a short rational for each rating in this table.

Criterion	Critical?	Agg S_{MSY}	Sum S_{MSY}	U_{MSY} Comp	Equ. Prof	Agg Equ. TradeOff	Status	Log Reg	Sim
Time-varying parameters?	**Yes**	**MAYBE**	**MAYBE**	**MAYBE**	**MAYBE**	**MAYBE**	**MAYBE**	**MAYBE**	**MAYBE**
Uncertainty in SR model fits?	TBD	**YES**	**YES**	**YES**	**YES**	**YES**	**YES**	**YES**	**YES**
Outcome uncertainty?	TBD	**NO**	**NO**	**NO**	**NO**	**NO**	**NO**	**NO**	**YES**
Productivity Covariation?	TBD	**NO**	**NO**	**NO**	**NO**	**NO**	**NO**	**MAYBE**	**YES**
Bias in parameter estimates?	TBD	**MAYBE**	**MAYBE**	**MAYBE**	**MAYBE**	**MAYBE**	**MAYBE**	**MAYBE**	**YES**
Can get abundance-based Agg RP?	TBD	**YES**	**MAYBE**	**NO**	**NO**	**YES**	**NO**	**MAYBE**	**MAYBE**
Can test state-dependent HCR?	TBD	**NO**	**NO**	**MAYBE**	**NO**	**NO**	**NO**	**NO**	**YES**
Data-deficient stocks?	TBD	**NO**	**NO**	**NO**	**NO**	**NO**	**MAYBE**	**MAYBE**	**MAYBE**
Account for component stocks?	**Yes**	**NO**	**NO**	**MAYBE**	**MAYBE**	**YES**	**YES**	**YES**	**YES**
Can be easily operationalized?	TBD	**YES**	**YES**	**YES**	**YES**	**YES**	**YES**	**YES**	**YES**
Time requirements	TBD	**Short**	**Short**	**Short**	**Short**	**Med**	**Med**	**Med**	**Long**

The aggregate equilibrium trade-off approach was recommended for evaluating alternative goals and harvest management rules for Skeena Sockeye Salmon in the report prepared by the 2008 Skeena Independent Science Review Panel (ISRP) (Walters et al. 2008). At the time, the ISRP report and preliminary trade-off analyses led to changes in the harvest rule for Canadian marine commercial fisheries for Skeena Sockeye Salmon implemented in 2009, which substantially reduced the harvest rate in these fisheries.

An MSE would require a considerable investment of time to develop (1) agreed-upon objectives, (2) agreed-upon model scope, and (3) agreed-upon scenarios for testing through a structured process. An MSE approach would identify management procedures (combination of harvest control rule and assessments) that adequately meet stated biological and socio-economic objectives, which extends beyond the current objective of identifying an aggregate biological reference point. This approach can be adapted slightly to identify aggregate abundance escapement that meet underlying biological objectives (such as all stocks being above Red or Amber zone status under the Wild Salmon Policy, 'projection-based reference points' described in DFO 2022); thus not requiring a full MSE and a complete set of biological and socio-economic management objectives. Depending on the available time to select an escapement goal, evaluating aggregate tradeoff plots may be the best option for developing an aggregate escapement goal in the short term. However, this approach does not account for covariation in recruitment dynamics among stocks or short term implications of spawner abundance.

If a full MSE is not feasible within the available time frame, the simple forward simulation approach can also be used to provide a complementary set of results for aggregate tradeoff considerations in a relatively short period of time, and has the advantage of being able to account for outcome uncertainty and covariation in productivity.

Although the research document identifies several approaches to developing aggregate reference points, subsequent research should take into account information of differential productivity of wild stocks across different life history types and trends in productivity. For example, productivity trends may factor in habitat changes and declining fecundity related to the lower egg production with declining spawning female body size. Future efforts to develop aggregate reference points should consider factors that may affect productivity, changes over time, and differences in those trends among stocks.

Examples of Candidate Management Objectives and Associated Results

In addition to evaluating different approaches for developing aggregate reference points, the research document provides examples of simulated performance against candidate management objectives. The simulation used the SR parameters from alternative productivity scenarios for 20 modelled wild stocks (4 Nass and 16 Skeena) to generate trajectories for each stock, under the simplifying assumption that each aggregate is managed based on a fixed strategy (either fixed exploitation rate, ER, or fixed aggregate escapement target), and that there is no operational uncertainty in the annual management. Additional simplifying assumptions included: no covariation in productivity of stocks and no changes in productivity over time (i.e., productivity was fixed within each scenario). Using the forward simulation and assuming a candidate management objective of "*80% probability that spawner abundance in the 3rd simulated generation is larger than the upper WSP benchmark for the relative abundance metric, set at 80% of the median posterior estimate of S_{MSY} for the long-term average productivity scenario*", three alternative productivity scenarios were assessed (Figure 5 below). The three productivity scenarios, which include long-term average (identified as LtAvg) productivity, recent productivity (identified as Recent), and a lower productivity scenario (identified as LowProd) are described in Table 5 for stocks with long SR data sets and stocks with short/incomplete SR data sets.

Table 5. Productivity Scenarios. Each scenario was generated by sampling parameter sets from Bayesian posterior samples for one or more SR model fit. Each cell in the table describes the parameter sampling.

Scenario	Stocks with long, complete time series of SR data and time-varying parameter estimates	Stocks with short and/or incomplete time series of SR data
Long-term Average (LtAvg)	Model fit to all years of data using AR1 Ricker model	Model fit to all years of data using Basic Ricker model (BR)
Recent	Last generation of the time-varying productivity SR model fit.	Subsample of the Basic Ricker fit to all years of data (median of subsample at x^{th} percentile, with stock-specific x selected based on pattern in observed Ricker residuals)
Low (LowProd)	Lowest productivity generation of the time-varying productivity SR model fit.	Lower end of the Basic Ricker fit to all years of data (median of subsample at 10^{th} percentile)

As the fixed Exploitation Rate approach using a simple forward simulation shows in Figure 5, under the recent productivity scenario and ERs less than 50%, most wild stocks will have greater than 80% likelihood of meeting the candidate S_{MSY} management objective. However, at 50% or greater ERs very few or none of the 20 modelled stocks are 80% likely to achieve the candidate objective with a steady decline in the largest stocks (i.e., Meziadin and Babine Late Wild) based on no change in recent productivity. When looking at a fixed aggregate escapement goal that meets the candidate management objective, the largest number of stocks met the objective at escapement goals at 75% or greater of the existing interim escapement goal of 500,000 for wild Skeena Sockeye Salmon and 200,000 for Nass Sockeye Salmon.

Although additional evaluation of different candidate management objectives and productivity scenarios is needed to better inform a management strategy, Figure 5 presents an informative summary approach to assessing the aggregate management approach on individual stocks. Furthermore, the simple forward simulation also helps identify counter intuitive interactions between the individual stocks within the aggregate. For example, under a fixed aggregate escapement goal, with exploitation rates responding to abundance, the individual stocks within the Skeena and Nass aggregates are more likely to meet conservation objectives under recent productivity because aggregate run size is lower (i.e., reducing the aggregate exploitation rate).

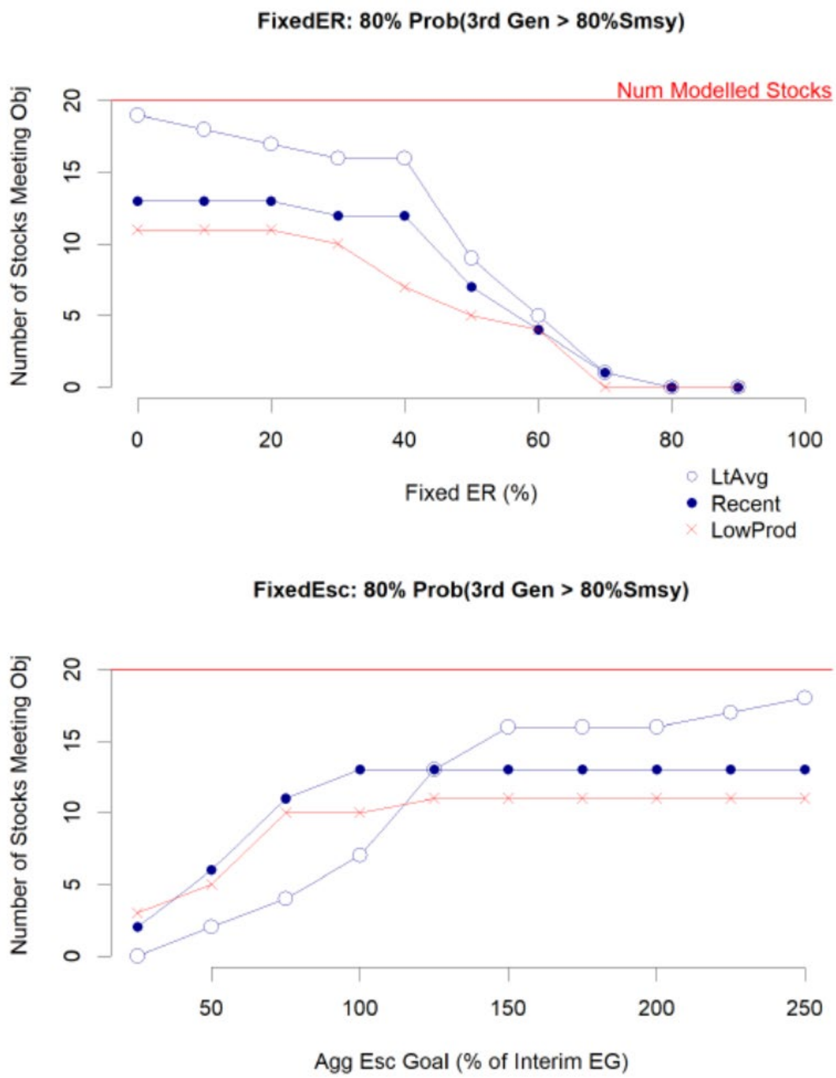

Figure 5. Examples of simple forward simulations – All variations. Panels show the number of stocks with at least 80% probability of meeting a benchmark set at 80% of median S_{MSY} for the long-term average productivity scenario. Results are shown under three alternative productivity scenarios for 10 levels of aggregate fixed ER and 10 levels of aggregate fixed escapement (expressed as % of the interim escapement goal for the two modelled aggregates, Nass and Skeena Wild).

Aggregate Equilibrium Trade-Offs

Using the approach by Walters et al. (2008), the equilibrium state for each component stock was calculated at different levels of fixed exploitation (i.e., calculate the spawner abundance and catch the stock would eventually settle down to, if each ER were applied for many years, in the absence of inter-annual variation). Equilibrium spawner abundances and catches were then summed across stocks to calculate aggregate equilibrium spawners and catch under the assumption that all component stocks are harvested at the same fixed ER and all are at equilibrium. This simplifying assumption allows aggregate trade-off profiles (Figure 6) to be derived directly from the spawner-recruit parameter estimates. Alternative stock-specific performance measures can be compared against the aggregate spawner and catch estimates. Figure 6 shows one example, the number of stocks where the aggregate ER exceeds the stock-specific estimate of U_{MSY}, the exploitation rate at MSY. This example was provided for consistency with Walters et al. (2008), however these figures can be modified to present alternative candidate management objectives, such as the number of stocks meeting 80% of S_{MSY}.

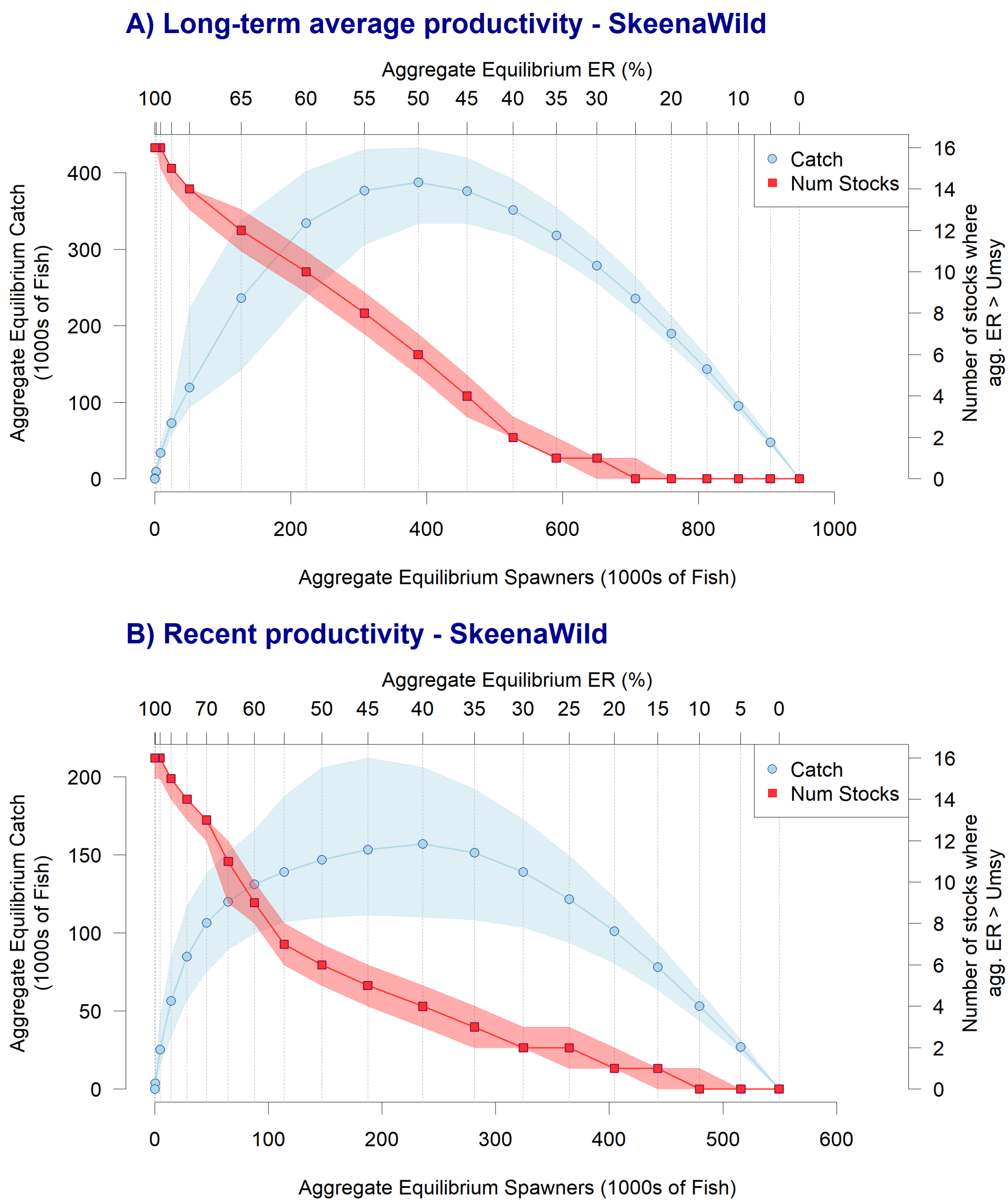

Figure 6. Example of aggregate equilibrium trade off plots for the SkeenaWild aggregate with 16 modelled stocks. For 5% increments of aggregate exploitation rate (ER; top axis), the figure shows median estimates (points) and interquartile range along the vertical axes (shaded area, p25 to p75) for aggregate spawner abundance (bottom axis), aggregate catch (left axis), and number of stocks where aggregate ER exceeds stock-specific median estimates of U_{MSY}, the exploitation rate at maximum sustainable yield. Note that the ranges of spawner abundances and catch levels differ substantially between long-term average productivity (Panel A) and recent productivity (Panel B), but the ranges of ER and number of stocks are the same in both panels.

Sources of Uncertainty

A reliable timeseries of data is critical to any spawner-recruit analysis. In this analysis, stock-specific age composition gaps were a potential issue within the analysis.

Future use of DNA data may better inform estimates of stock-specific harvest in different marine and in-river fisheries. Although estimating the impact on larger stocks may be effective, stock level precision on smaller stocks may be a concern.

Given changing and increasingly variable productivity (e.g., fecundity, habitat capacity, marine conditions), future uses of this analysis framework must update the SR parameter estimates regularly.

In addition to changes in productivity, variability in both data quality and quantity across component stocks can potentially impact the estimates of aggregate reference points. Future spawner-recruit analysis would benefit from consistent monitoring programs across component stocks.

Ranked List of Uncertainties

Below is a ranked list of uncertainties associated with developing aggregate reference points. The list was identified by the research document authors and the review committee participants in order of most important to least important:

1. Interaction between enhancement, aggregate abundance, marine harvest levels, tradeoffs between harvest rates on wild stocks, and enhanced surplus (Skeena aggregate and escapement to Pinkut and Fulton in excess of spawning capacity).
2. Alternative productivity scenarios, how they are specified and how they are considered in the aggregation approach (Both aggregates, potentially assumptions with co-variation in productivity).
3. Wild Stocks: Spawner-recruit parameter estimation:
    - Wild Stocks: Spawner-recruit parameter estimation:
    - Model form (Ricker, AR1, Kalman Filter)
    - Capacity prior
    - Estimation type (single-stock vs. Hierarchical)

CONCLUSIONS AND ADVICE

This research provides an analytical framework based on alternative spawner-recruit models to develop aggregate level biological reference points for wild Skeena and Nass Sockeye Salmon. The choice of objectives is an important driver in developing specific biological reference points (e.g., stock specific or aggregate escapement goals). The intent of this work was NOT to recommend formal escapement goals, but to develop an analytical approach to support subsequent work and engagement in considering specific management objectives used to illustrate trade-offs between yield and risks with component stocks. These analyses focused on spawner-recruit relationships for wild origin spawners, but also explored spawner-recruit model fit for enhanced stocks in Babine Lake. While relevant biological information on enhanced returns is provided, further research is required to address the interaction between enhanced and wild stocks.

Critical decisions required to account for when using this analytical framework include:

- Choice of aggregation approach, scoping decisions made when implementing the approach, and choice of quantitative objectives. (Both aggregates)

- Approach to define production targets for enhanced stocks and how it is integrated into aggregate escapement goal. (Skeena aggregate)
- Implications of the 1/3 of stocks that are assumed to be small but are currently data deficient. Depending on the choice of aggregation approach they are either critical considerations, or a rounding error in the aggregate abundance target. (Both aggregates)

Examples in the analysis show that outcomes are sensitive to definitions of productivity and future work needs to consider alternative assumptions.

To strengthen this framework, the analysis should improve the following elements:

- Formal simulation testing to explore sensitivity to alternative spawner-recruit model forms (e.g., capacity priors, HBM with common shared year effects);
- Include covariation in recruitment dynamics among stocks;
- Include additional data treatment steps (e.g. uncertainty on infilled estimate);
- Assess model biases;
- Explore integration of a shared year effect that accounts for separation between wild and enhanced stocks; and
- Account for changes in fecundity related to decreasing body size.

Although some preliminary analysis was provided, a Management Strategy Evaluation is recommended to evaluate trade-offs. The analysis provides some examples of candidate management objectives and associated results. Although more thorough evaluation is needed, even the results of a simple forward simulation suggests that under higher fixed exploitation rates (> 50%), a steady decline in the largest component stocks is likely, given recent lower productivity. Another simulation showed that when escapement is fixed and exploitation rates are variable depending on abundance, component stocks are more likely to meet conservation goals under recent productivity because removals are lower at lower aggregate run sizes. These results need further validation under simulations analyses with realistic assumptions (e.g., including observation and outcome uncertainties, and covariation in recruitment among stocks).

This data preparation and analysis provide the ground work to support a multi-criteria status assessment under the Wild Salmon Policy and evaluate trade-offs within a Management Strategy Evaluation.

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SOURCES OF INFORMATION

This Science Advisory Report is from the April 26-28, 2022 regional peer review on Biological benchmarks and building blocks for developing aggregate-level management targets for Skeena and Nass Sockeye Salmon, British Columbia. Additional publications from this meeting will be posted on the Fisheries and Oceans Canada (DFO) Science Advisory Schedule as they become available.

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