Review of Upper Columbia United Tribes' Fish Passage and Reintroduction Phase 1 Report: Investigations Upstream of Chief Joseph and Grand Coulee Dams (Reintroduction Report)

INDEPENDENT SCIENTIFIC ADVISORY BOARD

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Photos clockwise from top left: Grand Coulee Dam forebay, Sanpoil River, Chief Joseph Dam tailrace, and Grand Coulee Dam tailrace

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The ISAB Ex Officio members helped define our review, organized briefings, provided context, and commented on drafts: Mike Ford, Zach Penney, and Nancy Leonard.

ISAB Review of the Upper Columbia United Tribes' *Fish Passage and Reintroduction Phase 1 Report: Investigations Upstream of Chief Joseph and Grand Coulee Dams* (Reintroduction Report)

Executive Summary

The Northwest Power and Conservation Council (Council or NPCC) asked the Independent Scientific Advisory Board (ISAB) to review the Upper Columbia United Tribes' (UCUT) *Fish Passage and Reintroduction Phase 1 Report: Investigations Upstream of Chief Joseph and Grand Coulee Dams* (Reintroduction Report) and supporting documents. The Reintroduction Report was a broad analysis of key decision factors and potential outcomes to determine whether reintroduction of any of the historically present species of salmon and steelhead is feasible. The Reintroduction Report contained several habitat assessments, donor stock and risk assessment, a life-cycle model, description of options for adult and juvenile fish passage facilities, and recommendations for future investigations and implementation of reintroduction. The Council asked the ISAB to answer a set of questions about these various elements and to review the strengths, data uncertainties, and limitations of each element of the UCUT's report.

Brief answers to the Council's questions

1. *Strengths, data uncertainties, and limitations of each element of the UCUT's report and critical gaps in the analyses*

    a. *Donor stock and risk assessment*

    The Reintroduction Report prioritized donor stocks for reintroduction and concluded that summer/fall Chinook salmon is the preferred lineage for Chinook salmon in the blocked area. Kokanee from Lake Roosevelt and sockeye salmon from the Okanogan River are the highest ranked sources for sockeye. However, concerns about the abundance of kokanee and whether they would develop an anadromous life history led to a preference for Okanogan sockeye. The ISAB finds the process and recommendations for donor sources to be scientifically credible. Research, monitoring, and evaluation programs are needed to identify responses of donor sources and consequences of hatchery stocking, competition, predation, passage mortality and other factors.

    - *Disease risks*

      Future assessments of disease risk should consider possible interactions between water quality, disease resistance, and other factors such as predator avoidance. The ISAB advocates development of a parentage-based tagging (PBT) program for all adults released in the blocked area to identify donors with the greatest disease resistance and to assess other factors that influence the success of reintroduction.

- *Predation risks*

  The Reintroduction Report concluded that predation risk to juveniles of reintroduced salmon probably will be high overall but variable, depending on spatial and temporal overlap with potential predators. Numerous uncertainties about the abundance, distribution, and behavior of predators make more thorough evaluation of predation critical in the next steps. Bioenergetic models could improve the understanding of the role of fish predation, especially by nonnative northern pike, on survival of introduced salmonids. Future effects of expanding populations of nonnative predators and a warming and changing climate also should be assessed. Non-fish predators—such as birds, mammals, including pinnipeds—should be considered in the assessment of risks to reintroduced salmon and included in the life cycle models.

b. Habitat assessments

The Reintroduction Report's habitat assessments identified both current available habitat within the blocked area as well as habitat conditions above existing barriers that could be restored in the future. Data were provided in a format allowing consideration of reintroduction either solely within the United States or within the combined areas in the U.S. and Canada above Chief Joseph and Grand Coulee dams. The Report did not rely on future production from the Canadian portion of the basin but provided an assessment of Chinook salmon capacity in the Transboundary Reach.

The habitat assessments provided a reasonable set of hypotheses about the capacity of the habitat in the blocked area to support juvenile and adult salmonids, but the Fish and Wildlife Program will require additional information for future decisions. The methods used to evaluate habitat for steelhead, Chinook, and sockeye salmon help bound the potential number of fish that can spawn and rear in the blocked area but provided only rough estimates. Overall, the estimates of potential adult capacities for both Chinook and sockeye salmon had wide ranges and included great uncertainty about habitat relationships and other factors, such as predation, fish passage, and survival in the lower Columbia River and ocean.

The ISAB commends the Reintroduction Report authors for considering the potential effects of climate change on reintroductions, which should be considered in future planning and implementation. Ocean survival of anadromous salmonids in the face of climate change is one of the most critical uncertainties facing reintroduction efforts but was not addressed in the Reintroduction Report. The discussion of climate change considered only the positive effects related to the lower thermal stress in the blocked area compared to warmer regions of the middle and lower Columbia River. The Report did not consider factors related to climate changes that could negatively affect survival, such as interactions with other stocks of salmon, pathogens, survival during lower river migration, or predators throughout the system.

c. *Life-cycle modeling*

The Life Cycle Model provides a framework for integrating information on potential habitat and reproductive capacity and for identifying data gaps. The model is simple to use and update. It provides a useful tool for managers to explore uncertainties about harvest and escapement goals, and it can inform decision making. However, the model is deterministic and incorporates little or no stochasticity or density dependence. The model does not acknowledge interannual variation or regime shifts on ocean productivity.

Outputs of the model are directly influenced by the numerous uncertainties that include a wide range of estimates of habitat availability and variation in adult spawner capacity. Use of the lower end of the distribution of estimated habitat and spawner capacity in applications of the LCM would be more conservative and precautionary. Sensitivity analysis should be expanded to evaluate other components of the model and consequences of using estimates of the lower range of habitat and spawner capacity.

d. *Adult and juvenile fish passage*

The Reintroduction Report explored five possible options for adult passage and concluded that any of them could be used to pass adult salmon upstream over the two dams. However, potential costs are extremely high, so benefits should be weighed carefully. The proposed interim adult passage approaches appear to be reasonable. Collecting and passing juvenile salmon downstream over Chief Joseph Dam and especially over Grand Coulee Dam represents a much greater challenge. At Grand Coulee Dam, fluctuations of reservoir levels would make passage for both life stages difficult. The consequences of total dissolved gas supersaturated water were not considered in passage assessment but may reduce survival and limit passage alternatives.

- *Costs*

  The Reintroduction Report did not assess the costs of upstream and downstream passage options for salmon and steelhead. Specific donor stocks and passage systems have not been selected, thus only broad preliminary estimates of cost can be developed currently. More specific design elements and cost analysis will be possible after several preliminary experiments and cultural releases of adult fish are completed. Future cost estimates would inform decisions about timing, combinations of actions that could be more effective than the individual actions on their own (complementarity), and risks associated with the sequential, experimental nature of the reintroduction program. The incremental reintroduction actions and large number of uncertainties make it important to incorporate cost analyses in the initial stages of the reintroduction effort.

2. *In sum, how well do the report and its supporting documents address the biological and physical elements of Phase 1, as described in the Council's Fish and Wildlife Program?*

   The 2014 Fish and Wildlife Program (Northwest Power and Conservation Council 2014-12) identifies several key steps in a phased approach to reintroduction of anadromous fish above Chief Joseph and Grand Coulee dams to mainstem reaches and tributaries in the United States (P. 85). The Program specifically calls for 1) evaluation of information from passage studies at Grand Coulee and Chief Joseph dams and other blockages, 2) assessment of habitat availability, suitability and salmon survival potential above Grand Coulee, and 3) investigation of the scientific feasibility and possible cost of upstream and downstream passage options for salmon and steelhead. The Reintroduction Report addressed all of these elements except for cost of passage options and provided a general proof of concept. The Report additionally evaluated donor stocks, disease risks, predation, and climate change, which are not specifically included in the Fish and Wildlife Program.

   While it is reasonable to expect that reintroduction could be successful to some extent, there is great uncertainty about the numbers of adults that will return and the types of management that will be required to maintain them. A strategic plan for future steps and an adaptive management process will be needed to address these uncertainties. The ISAB encourages the UCUT and the Council to make decisions conservatively or with caution because of the very wide ranges of estimates of capacity and habitat availability. While the ISAB recommends careful development of future decisions and actions, it is clear the UCUT and their collaborators put a lot of thought and effort into this assessment and make the fundamental issues and management alternatives accessible to many stakeholders.

Review Charge

On July 17, 2019, the Northwest Power and Conservation Council (Council or NPCC) asked the Independent Scientific Advisory Board (ISAB) to review the Upper Columbia United Tribes' *Fish Passage and Reintroduction Phase 1 Report: Investigations Upstream of Chief Joseph and Grand Coulee Dams* (Reintroduction Report) and supporting documents. The Council's request included a set of questions, listed below, which were based on input from Council's state and central staff, the Upper Columbia United Tribes (UCUT), and ISAB Ex Officio representatives[1] and members. The request was reviewed and approved by the ISAB Administrative Oversight Panel.[2]

The Reintroduction Report is part of the assessments envisioned in the Council's 2014 Fish and Wildlife Program's science-based, phased approach to investigate the reintroduction of anadromous fish above Chief Joseph and Grand Coulee dams. The Program states that the first phase will:

- *"Evaluate information from passage studies at other blockages and from previous assessments of passage at Grand Coulee and Chief Joseph dams.*
- *Investigate habitat availability, suitability and salmon survival potential in habitats above Grand Coulee. This might include selective releases of salmon and steelhead. Investigate the scientific feasibility and possible cost of upstream and downstream passage options for salmon and steelhead. Before funding new investigations, provide the Council with a report for consideration of subsequent work to advance the fish passage planning process.*
- *As part of Phase 1, the Council will engage in discussions with tribal, state, and federal agencies and others regarding the purpose, scope and progress of reintroduction efforts above Chief Joseph and Grand Coulee dams."*

The Reintroduction Report contains several habitat assessments, a donor stock and risk assessment, a life-cycle model developed by UCUT with various scenarios and assumptions based on the results of the habitat and donor stock assessments, information on adult and juvenile fish passage facilities that could be used for reintroduction at Chief Joseph and Grand Coulee dams, and recommendations for future field studies and continued investigation and implementation of reintroduction. In reviewing these various elements, the Council asked that the ISAB consider the following questions:

1. *What are the strengths, data uncertainties, and limitations of each element of the UCUT's report and are there any critical gaps in the analyses?*

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[1] Ex officio members—Zachary Penny for CRITFC and the Columbia Basin Tribes, Michael Ford for NOAA Fisheries, and Nancy Leonard for the Council—are liaisons between their agencies and the ISAB, assist in the ISAB's operation and administration, help develop and support assignments, and provide scientific and policy context for reviews.

[2] The ISAB Administrative Oversight Panel consists of Jennifer Anders, Council Chair; Jaime Pinkham, Executive Director of the Columbia River Inter-Tribal Commission, for the Columbia River Tribes; and Kevin Werner, Science Director, NOAA-Northwest Fisheries Science Center.

  a. *Donor stock and risk assessment*
     - *What are the potential disease risks posed by an anadromous reintroduction to redband trout, for example from infectious hematopoietic necrosis (IHN)?*
     - *The ISAB's recent report on the likely broad adverse impacts of Northern Pike and other fish and avian predators (ISAB 2019-1) was released after the UCUT's report. Is there information in the ISAB's report regarding predation, particularly Northern Pike predation, that could inform the reintroduction assessment. In addition, what methods could be considered to estimate predator populations, including Northern Pike populations, in areas above Chief Joseph and Grand Coulee dams, and what is the feasibility of accurately estimating the predator abundance in Lake Rufus Woods, Lake Roosevelt, and the associated tributaries?*
  b. *Habitat assessments*
     - *Do the habitat assessments assume potential production from currently accessible habitat in its current condition or that future habitat restoration would be needed (i.e., fish passage at irrigation diversions, small hydropower dams, irrigation intake screens, instream flows, etc.)?*
     - *Does the report rely on future potential from the Canadian portion of the basin? What does the report assume about fish distribution in the Canadian portion of the basin?*
     - *Do the results from the compilation of the habitat assessments provide a reasonable set of hypotheses about the environment and provide enough information to satisfy the Fish and Wildlife Program's direction to assess the quantity and suitability of habitat in the blocked area?*
  c. *Life-cycle modeling*
     - *Are the modeling assumptions reasonable, do the variants and sensitivity analyses adequately account for variability and uncertainty, and are other appropriate parameter values for critical life stages considered?*
  d. *Adult and juvenile fish passage*
     - *The UCUT Report focuses on biological and physical assessments but does not address the 2014 Fish and Wildlife Program Phase 1 element to investigate the possible cost of upstream and downstream passage options for salmon and steelhead. Does this section cover the potential passage technologies and alternatives for upstream and downstream passage, their feasibility, and associated biological information that should be evaluated to inform an estimated cost? Is additional information on passage alternatives needed to provide a cost estimate; if so, what information?*
  e. *Future field studies and recommendations.*

2. *In sum, how well do the report and its supporting documents address the biological and physical elements of Phase 1, as described in the Council's Fish and Wildlife Program?*

In the report below, we reverse the order of the Council's question, and we first address the Council's second question, for which our answer is intended to provide an overview for decision makers and is essentially a summary of the findings from our answers to the Council's first question. We then provide answers to the Council's first question and associated sub-questions. Our detailed responses are intended to improve the reintroduction assessment effort.

Overall, the ISAB review examines whether the report and its supporting documents adequately address the biological and physical elements of Phase 1, as described in the Council's Fish and Wildlife Program. The ISAB bases its answers to the Council questions, conclusions, and recommendations on a review of the Reintroduction Report and supporting documents provided by the UCUTs, a targeted but not exhaustive literature review, and a tour of the blocked area of the upper Columbia River Basin that included invaluable discussions with UCUT and tribal representatives, regional scientists, and Council members and staff.

NPCC Question 2. Overall ISAB Conclusions on Biological and Physical Elements of the Reintroduction Report

The 2014 Fish and Wildlife Program (Northwest Power and Conservation Council 2014-12) identifies several key steps in a phased approach to reintroduction of anadromous fish above Chief Joseph and Grand Coulee dams to mainstem reaches and tributaries in the United States (P. 85). The Program specifically calls for 1) evaluation of information from passage studies at Grand Coulee and Chief Joseph dams and other blockages, 2) assessment of habitat availability, suitability and salmon survival potential above Grand Coulee, and 3) investigation of the scientific feasibility and possible cost of upstream and downstream passage options for salmon and steelhead. The Reintroduction Report addressed all of these elements except for cost of passage options and provides a general proof of concept. The Report additionally included evaluation of donor stocks, disease risks, predation, and climate change, which were not specifically identified in the Fish and Wildlife Program.

The Reintroduction Report is a broad analysis of key decision factors and potential outcomes, which provides a general proof of concept. Inherently, it takes general information from other locations and stocks of salmon and steelhead to determine whether reintroduction of any of the historical species of salmon and steelhead is biologically and physically feasible. While it is reasonable to expect that reintroduction could be successful to some extent, there is great uncertainty about the numbers of adults that will return and the types of management that will be required to maintain them. A strategic plan for future steps and an adaptive management process will be needed to address these uncertainties. The ISAB encourages the UCUT and the Council to make decisions conservatively or with caution because of the very wide ranges of estimates of capacity and habitat availability. While the ISAB recommends careful development of future decisions and actions, it is clear the UCUT and their collaborators put a lot of thought and effort into this assessment and make the fundamental issues and management alternatives accessible to many stakeholders.

The ISAB report discusses several portions of the upper Columbia River Basin. For clarity, we refer to the area of the basin above Chief Joseph and Grand Coulee dams as the blocked area and the mainstem Columbia River and its tributaries between McNary Dam and Chief Joseph Dam as the upper Columbia River (UCR) (Figure 1). Some text and results of analyses in the Reintroduction Report and the ISAB review distinguish the portions of the blocked area in the United States and Canada. We refer to the section of the Columbia River between Lake Roosevelt and Hugh Keenleyside Dam in British Columbia as the Transboundary Reach.

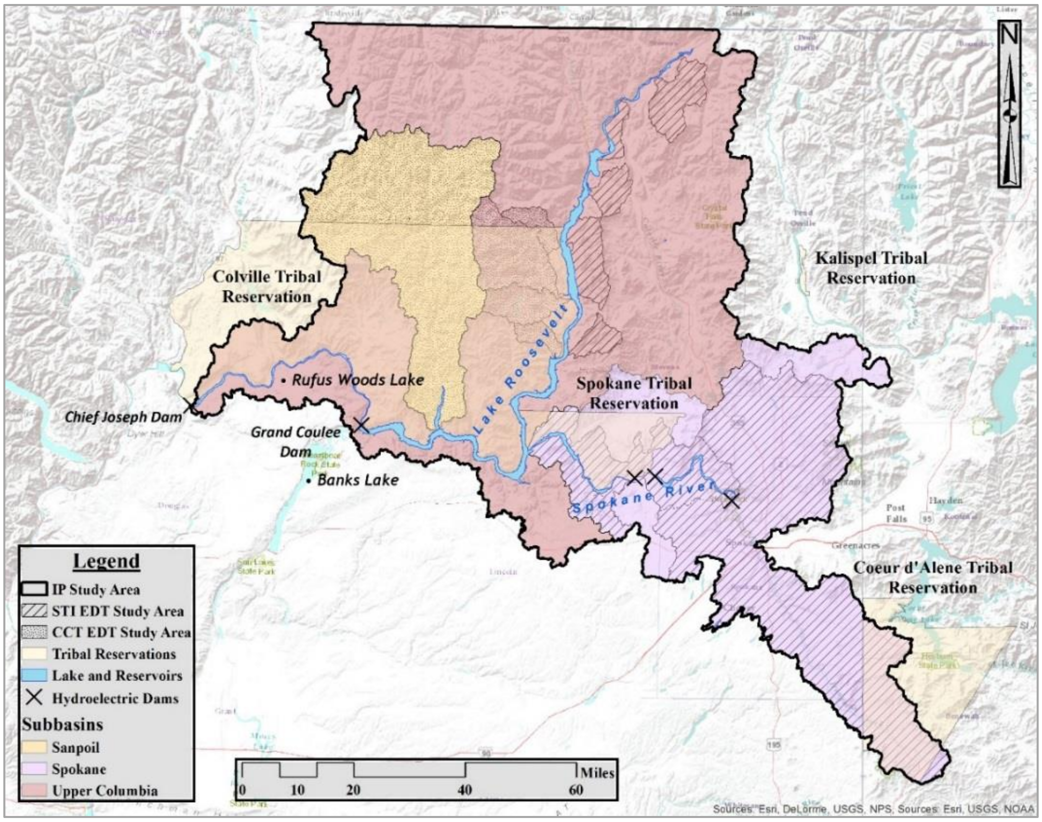
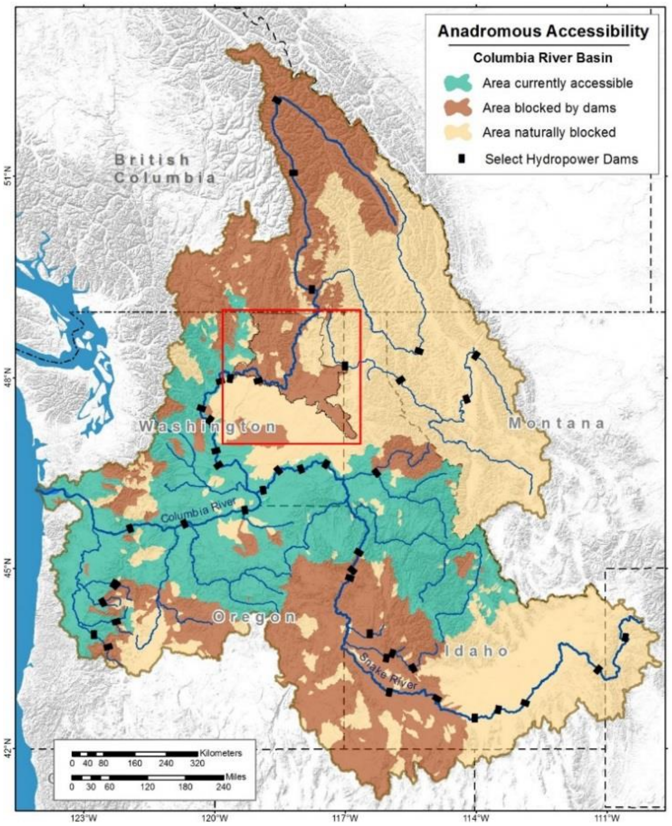


Figure 1. Blocked area of the U.S. portion of the Upper Columbia River Basin (above) shown in context (red box to the right) of the full Columbia River Basin, depicting anadromous accessibility. Sources: upper map, Conor Giorgi; map to the right, Pacific States Marine Fisheries Commission (from [ISAB 2015-1](), page 58).



Donor stocks: The Reintroduction Report prioritized donor stocks for reintroduction and concluded that summer/fall Chinook salmon is the preferred lineage for Chinook salmon in the potentially accessible blocked area. Kokanee from Lake Roosevelt and sockeye salmon from the Okanogan River are the highest ranked sources for sockeye, but it is not clear that kokanee will develop an anadromous life history. The ISAB finds the process and recommendations for donor sources to be scientifically credible. Hatchery-origin donor stocks are favored by the program because they are generally more accessible than natural-origin fish, but negative interactions between hatchery origin and natural origin fish could reduce fitness of re-established populations. Research, monitoring, and evaluation programs are needed to identify responses of donor sources, short- and long-term consequences of hatchery stocking, competition, predation, passage mortality, and other influences on survival.

Disease risk: The review of disease risk in the Reintroduction Report is based on regional experience and expertise with major fish pathogens. Future efforts should consider possible interactions between water quality, disease resistance, and other factors such as predator avoidance. The effects of total dissolved gas supersaturated water (TDGS) need to be considered more thoroughly, and the constraints on passage alternatives should be assessed. The ISAB agrees with the strategies to reduce the risk of serious pathogen impacts on resident fish as the result of reintroduction, but we also advocate development of a parentage-based tagging (PBT) program for all adults released in the blocked area to identify donors with the greatest disease resistance as well as to assess other factors that influence the success of reintroduction.

Predation risk: The Reintroduction Report concluded that predation risk to juveniles of reintroduced salmon probably will be high overall but variable, depending on spatial and temporal overlap with potential predators. Because so little is known about the abundance, distribution, feeding behavior, and spatial and temporal overlap of predators like northern pike within habitats likely to be occupied by juvenile salmon, predation risks should be evaluated more thoroughly in the next steps. If overlap of fish predators and salmonid prey is substantial, developing bioenergetic models would improve the understanding of the role of fish predation on survival of introduced salmonids. Assessment of predation risks would benefit from considering future thermal conditions and predator populations, as well as current predator populations and distributions. Non-fish predators—such as birds, mammals, and pinnipeds—were not evaluated. These predators should also be considered in the assessment of risks to reintroduced salmon and included in the life-cycle models.

Habitat assessments: The habitat assessments provided a reasonable set of hypotheses about the capacity of the habitat in the blocked area to support juvenile and adult salmonids. The five methods used to evaluate habitat for steelhead, Chinook, and sockeye salmon have strengths and weaknesses, but each helps bound the potential number of fish that can spawn and rear in river and reservoir habitat in the blocked area. Models of rearing and spawning potential for different species of salmon and steelhead provided only rough estimates with wide ranges of possible outcomes. Overall, the estimates of potential adult capacities for both Chinook and sockeye salmon had wide ranges and include great uncertainty about habitat relationships as well as other factors, such as predation, fish passage, and survival in the lower Columbia River and ocean. While it is reasonable to expect that reintroduction could be successful to some extent, there is great uncertainty about the numbers of adults that will return and the types of management that will be required to maintain them.

Climate change: The ISAB commends the Reintroduction Report authors for considering the potential effects of climate change on the success of reintroductions. Climate change should be considered in all future planning and implementation for salmon reintroduction. Ocean survival of anadromous salmonids in the face of climate change is one of the most critical uncertainties facing reintroduction efforts but was not addressed in the Reintroduction Report. It should not be assumed that ocean survival will be a constant, that most ocean mortality will occur during the early ocean life stage, or that the future range of interannual variability in smolt-to-adult survival will be similar to recent ranges for upper Columbia River populations. The discussion of climate change considered only the positive effects related to the lower thermal stress in the blocked area compared to warmer regions of the middle and lower Columbia River. It did not consider factors related to climate changes that could negatively affect survival, such as pathogens, survival during lower river migration, or predators throughout the system.

Life cycle model: The Life Cycle Model (LCM) provides a framework for integrating information on potential habitat and reproductive capacity and for identifying data gaps. The model is relatively easy to use and update as new data become available or parameter values change. It provides an accessible tool for managers to explore and better understand the many uncertainties surrounding catch and escapement goals from a reintroduction perspective. The model can be run in real time with various management and policy settings to address questions and aid discussions and decision making. However, the LCM is deterministic and incorporates little or no stochasticity or density dependence. Modelers used best guesses for parameter values based on other LCMs, published papers, and expert opinions. The model does not acknowledge that all parameters will vary from year-to-year or that there may be regimes of good and poor conditions, primarily affecting the survival terms between stages. Outputs of the model are directly influenced by uncertainties that include a wide range of estimates of habitat availability and variation in adult spawner capacity. Because ranges of these values are substantial and density dependence is not fully accounted for in the model, use of the lower end of the distribution of estimated habitat and spawner capacity in applications of the LCM would be more conservative and precautionary. The sensitivity analysis should be expanded to evaluate other components of the model and especially to assess consequences of using estimates of the lower end of the range of habitat and spawner capacity.

Adult passage: The Reintroduction Report explored five possible options for adult passage and concluded that any of these approaches could be used to pass adult salmon upstream over the two dams, separately or in combination. However, costs are extremely high if new structures are built as part of the solution, so benefits must be weighed carefully. The proposed interim adult passage approaches appear to be reasonable. These approaches, however, do have some challenges to overcome, such as how to collect and pass juvenile salmon downstream over Grand Coulee and Chief Joseph dams. Environmental conditions at Grand Coulee Dam, where reservoir levels fluctuate by up to 80 feet, are more challenging for juvenile and adult passage than those at Chief Joseph Dam. These fluctuations also often coincide with smolt and adult migration periods in spring and early summer, making passage for both life stages difficult. The Report presented several possible approaches for fish passage at each dam but emphasized that these are tentative solutions.

Cost: The Reintroduction Report focused on biological and physical assessments and did not assess the costs of upstream and downstream passage options for salmon and steelhead. Only broad preliminary estimates of cost can be developed at this stage because many aspects remain unresolved, especially those related to specific donor stocks and passage systems. More refined design elements and cost analysis will be possible after preliminary experiments and cultural releases of fish are completed. Future cost estimates would inform decisions about timing, complementarity, and risks associated with the sequential and experimental nature of the reintroduction program. The incremental nature of the reintroduction actions and the many uncertainties make it important to incorporate cost analyses in the initial stages. Lead times to develop and implement technologies are long and once started, costly to change and start over, so costs and cost effectiveness must be analyzed in a timely manner.

NPCC Question 1. ISAB Comments on each Element of the Reintroduction Report

This section addresses the Council's request for the ISAB to identify the strengths, data uncertainties, limitations of each element of the Reintroduction Report, and any critical gaps in the analyses. In addition, the ISAB answers the Council's sub-questions associated with each element.

A. Donor stock and risk assessment

Background

The Reintroduction Report identified two long-term goals pertaining to assessment of potential donor stocks for reintroduction upstream of Chief Joseph Dam. The program aims to restore naturally spawning and hatchery-based runs of sockeye and summer/fall Chinook salmon into the blocked area above Chief Joseph and Grand Coulee Dams, and to establish and increase harvest for all purposes (cultural, subsistence, sport, and commercial) in the blocked UCR.

To prioritize donor stocks for reintroduction, a set of metrics, qualitative rankings, and a decision-tree framework were established and evaluated in two workshops (Hardiman et al. 2017) that built on a previous framework developed for selecting Chinook salmon donor stocks for the Transboundary Reach (Warnock et al. 2016). The framework was used to prioritize donor stocks that maximize the probability of successful establishment in the blocked area, have highest availability, and minimize risks to genetic diversity and disease exposure to resident native salmonids (e.g., redband trout and kokanee). Goals and donor selection criteria for releases for harvest and cultural purposes are less well defined. The Reintroduction Report largely relied on the outcomes and recommendations from the workshops described in Hardiman et al. (2017) but provided additional considerations for donor stock choice based on other factors. The ISAB reviewed the logic, data, and qualitative and quantitative information provided in the Reintroduction Report to inform the choice of donor stock for reintroduction.

Of six potential species/lineages initially considered, the Reintroduction Report recommended summer/fall run Chinook salmon and sockeye salmon for a re-establishment program to be initiated in Phase II. Spring run Chinook salmon was not considered as a candidate because re-establishment could exert negative demographic effects on donor populations. Nonetheless, this lineage was recommended for possible cultural/harvest releases. Reintroduction of anadromous redband (steelhead) trout was rejected because of heightened disease risks to resident populations. Finally, coho salmon reintroduction releases were considered unlikely to succeed. However, if coho salmon was deemed a Tribal cultural priority, reintroduction strategies would be further considered in later phases of reintroduction, presumably as part of the harvest/cultural release strategy.

Strengths

Two independent evaluations were used to identify suitable donor populations for reintroduction above Chief Joseph Dam. In one (Hardiman et al. 2017), a panel of regional scientists used extant data and expert opinion to weigh risks and benefits of using different potential donor populations. Donor stock abundance, ancestral similarity to extirpated populations, life history compatibility, and pre-existing adaptations were criteria affecting the ranking of each candidate population. Risks, such as pathogen transfers, genetic effects (e.g., introgression and hybridization), competition for food and space, and predation on reintroduced fish by resident piscivores were also considered.

The second evaluation (Warnock et al. 2016) relied solely on existing data and was restricted to determining suitable donor populations of Chinook salmon that could be reintroduced into the Transboundary Reach. Four criteria were considered: evolutionary ancestry, adaptive potential (genetic diversity), environmental suitability, and potential risks (e.g., genetic, disease, ecological, and demographic) of each prospective donor population. One key aspect was an extensive appraisal that matched existing traits in potential donor populations to current environmental conditions in the Columbia River and the Transboundary Reach. Factors in the appraisal included adult migration timing into the Columbia River, potential for pinniped predation, spawn timing, energy or fat reserves in adults, water depth and potential dewatering of redds, incubation and emergence timing, food availability at emergence, thermal requirements for juvenile growth, emigration timing for juveniles (fry, subyearling, and yearling) and how these variables were related to hydrosystem operations, and predation on juvenile migrants by birds and fishes. Hypothesized consequences of climate change on the suitability of the donor populations were also considered.

The Reintroduction Report relied predominantly on results from the Hardiman et al. (2017) process when making decisions about potential donor populations. Hardiman et al. (2017) and Warnock et al. (2016) generally agreed on the use of summer/fall Chinook salmon as the preferred lineage for Chinook in the Transboundary Reach and for reintroduction into Lake Roosevelt and Rufus Woods Lake. Priority rankings were based on abundance, genetic diversity, spawn timing, spawning locations, and diverse juvenile life histories.

Hardiman et al. (2017) and the proponents' evaluation and selection process included more salmonid species than Warnock et al. (2016) and made recommendations on the suitability of individual donor populations for steelhead, Chinook (spring and summer/fall), coho, and sockeye. However, only decisions for summer/fall Chinook and sockeye were accepted. ESA listings, disease transfer concerns, and potential demographic impacts were cited as reasons to delay final selections of steelhead and spring Chinook donor stocks. Summer/fall Chinook returning to the Chief Joseph Hatchery were the highest rated donor stock for re-establishment. These fish are abundant, easily collected, have a high degree of wild parentage, and superior flesh quality compared to other possible summer/fall populations. In general, summer/fall Chinook originating from Priest Rapids to Chief Joseph dams had similar suitability scores.

Of seven potential sockeye donor populations (four anadromous and three kokanee populations), Lake Roosevelt kokanee was the highest ranked donor stock. This stock is considered to be locally adapted and exhibits low genetic and disease transfer risks. Low abundance, however, could make it impractical as a donor stock. Although some evidence indicates that Lake Roosevelt stock can adopt an anadromous life history, the extent to which life-history variation has been maintained is currently unknown (see section below). Okanogan River anadromous sockeye ranked slightly lower than Lake Roosevelt kokanee. This stock can be abundant in some years, is anadromous, and therefore was chosen as the preferred sockeye donor population.

Limitations, data uncertainties, and critical analytical gaps

The donor stock selection process outlined in the report was logical and largely defensible. Data and procedures used in Hardiman et al. (2017) were not as transparent or comprehensive as those used in the Warnock et al. (2016) report, but it was reassuring that they came to similar conclusions about the suitability of donor stocks. Nonetheless, there are uncertainties that could impact the reintroduction effort for these two species. These include 1) variation in the availability of donor stocks from year to year, 2) substantial uncertainties related to release strategies, 3) the need for planning to simultaneously achieve re-establishment, harvest, and cultural goals, and 4) potential conflicts with management of other species including non-native predators. Complex and potentially interacting factors affect re-establishment success or failure, and so stocking many individuals for a long time period may be required before the population becomes self-sustaining. These factors should be considered in an adaptive management plan as reintroduction proceeds in the future.

Data uncertainties and limitations

Both Hardiman et al. (2017) and Warnock et al. (2016) employed a ranking and prioritization system where scientists and managers sum their impressions/knowledge. The utility and validity of this approach depends on several things. First, were all of the important variables considered? Second, were variables appropriately weighted in importance? Third, were the data underlying ranking decisions sufficient to make the assessment? Fourth, were data interpreted correctly to yield a conclusion that would be widely accepted as valid, and ultimately be true? This includes consideration of the applicability of past data (e.g., abundance and ancestry) to build predictive models for future re-establishment success.

Were the most important variables considered?

1. Relative wild and hatchery influences of proposed donor stocks were considered, but it was not clear how this factored into ranking or in what category these effects were considered.
2. ESA status was considered, as shown in Figure 4-1 of the Reintroduction Report, but seems to have been essentially treated as a filter that prevented any listed unit from further consideration, rather than integrated with other factors. Additional assessments for the reintroduction program might consider the potential role of ESA-listed stocks once lessons have been learned from early-phase research outcomes, but this approach would require careful planning and support among stakeholders.
3. Future donor stock selection should consider genetic data on Chinook lineages that existed in the upper Columbia River within the blocked area prior to the closure of Grand Coulee Dam. UCR stocks were more genetically diverse than any single proposed Chinook donor stock (e.g., Johnson et al. 2018).

4. The ranking and selection process did not consider issues that could arise if salmon from one stock begin to be produced in the newly accessible region as well as the current (donor) location. Might genetic stock genetic identification of donor and re-established populations be compromised?
5. The Reintroduction Report did not indicate whether the assessment considered if stocks currently exist in the UCR that were historically in the blocked area or whether those genetic lineages still exist somewhere in extant wild or hatchery stocks.

Were weightings appropriate?

Contemporary populations of UCR Chinook salmon are less genetically diverse than were those prior to Euro-American colonization, which included runs in areas currently inaccessible (Johnson et al. 2018). Lowered genetic diversity in Upper Columbia populations creates fewer populations with local adaptations and less ability of existing populations to adapt to climate and other changes. Preservation of existing diversity in populations should thus remain a goal and guiding principle for re-establishment (ISAB 2018-1), though evolution is an ongoing process and adaptation to local conditions is needed.

Suitability ranks for donor stock to support re-establishment of sockeye salmon in the blocked area depend critically on the evolutionary provenance of the Lake Roosevelt kokanee stock. Although not discussed or assessed in the Reintroduction Report, to adequately assess genetic risks of stocking, it is important to know whether the Lake Roosevelt stock is native and ancestrally kokanee or sockeye that residualized and are now called “kokanee.” If the Lake Roosevelt stock is genetically distinct as kokanee, then the likelihood of producing viable sea-run sockeye salmon may be lower, and genetic interactions with sockeye stocks might matter. Alternatively, if Lake Roosevelt fish are sockeye that were recently trapped (e.g., by closure of Grand Coulee Dam), then genetic interactions with Okanogan River, Lake Wenatchee, or Penticton Hatchery stocks could be less of a concern. This suggests that stock selection and interaction with existing kokanee populations may also be an issue for stocking the blocked area.

Were the data adequate?

Without access to background information that led to conclusions in the Reintroduction Report and Hardiman et al. (2017), it is difficult to determine what data were available and to what extent local expertise was relied upon. This does not imply that these data do not exist, only that they were not accessible in the reports provided. For example, under the category of abundance/viability, were annual redd counts and estimates of the proportion of wild and hatchery origin fish considered by the panel of regional scientists? Were these validated capture-recapture estimates, aerial surveys, or counts at dams below the sites? Viability implies some data on trends in abundance or productivity (e.g., brood tables, fishery interceptions). There are many data sets on Columbia River salmon, but it would be useful to know, at least for the highest ranked stocks and the closely ranked alternatives, what data were available and what they indicated.

Risk Assessment and Reintroduction Plan Elements

Factors considered by Hardiman et al. (2017) and Warnock et al. (2016) to assess the suitability of potential donor populations (e.g., genetic diversity, environmental suitability) are important. Yet, the ultimate goal of an individual reintroduction effort also helps determine and guide appropriate choices of donor populations. At this point, determination of the types of reintroduction efforts that will be implemented for each species and lineage is needed. Identifying the goals of these programs (harvest, conservation, or conservation with some harvest) will further refine donor population choices. For example, the consideration of flesh quality for human consumption is obviously pertinent only to harvest, not conservation *per se*.

Overall plans for how reintroductions will occur for each species need to be developed. Should reintroduction efforts be broadly and simultaneously implemented? For instance, should summer/fall Chinook reintroductions occur in Rufus Woods Lake, Lake Roosevelt, and in the Transboundary Reach at the same time? Or does it make more sense to re-establish a population of summer/fall Chinook in Rufus Woods Lake and then use adults returning to that location as donors for Lake Roosevelt and Transboundary populations? A roadmap that considers short- and long-term goals of the re-establishment program would help clarify alternate reintroduction strategies.

Some components to consider in developing a reintroductions strategy are outlined below. One reintroduction approach, focused on releases of juveniles, was reviewed by Fedorenko and Shepherd (1986) who provided insight into the scale of effort that might be needed for successful reintroduction of Chinook salmon into new habitats. These authors recommended that the reintroduction effort be closely linked to a hatchery program that could provide annual releases of one million or more juveniles for ten or more years. If this approach is adopted, it may constrain how many reintroduction efforts can take place for the same species and run because of the need for large numbers of juveniles and possible scarcity of donor adults. Furthermore, heavy stocking of hatchery-origin juveniles presents risks of negative impact on fish spawned naturally by re-established adults. If adopted, the proponents may wish to consider a “stepping stone” approach of progressively establishing reintroduction programs from lower to upper regions in the anadromous blocked zone to allow for research on potential impacts of juvenile releases.

A study of adult (including jack) spring Chinook salmon reintroduction in an area blocked by a high-head dam on the McKenzie River, Oregon, indicated that released fish spawned naturally upstream of the dam (Sard et al. 2015, 2016). From 2008 and 2011, annual releases of adult Chinook salmon ranged from 731 to 1386, plus 5 to 107 jacks, passed upstream of the dam by trap and haul. The study used genetic parentage analysis to evaluate reproductive success of natural-origin returns (NOR) and hatchery-origin returns (HOR). Release date affected reproductive success of reintroduced adults, but release location did not in any year evaluated. The latter result was attributed to dispersal of adults from release locations. Jacks contributed to overall juvenile production and mediated gene flow among generations for the reintroduced population. HOR males exhibited lowered reproductive success than NOR males, but no differences in reproductive success between HOR and NOR females were observed. Much of the variation in fitness was related to body size at release, which differs significantly with origin. Overall, the study demonstrated that reintroduction of Chinook salmon above dams by active transport can increase natural production, but that sex, origin, and release date influenced Chinook reproductive success and, therefore, population productivity. It is important to note that in neither cohort year (2007 and 2008) did the population replace itself (Sard et al. 2016), so reintroduction efforts may take many years of sustained stocking to succeed.

Another key component for reintroduction success is to incorporate fish returning to the project into the broodstock. Adults produced from the reintroduction effort represent individuals that possess traits that have proven to be successful in the new environment (i.e., the "favored founders effect" described by Quinn et al. 2001 for the introduction of Chinook salmon to New Zealand). Using them as parental fish helps to reduce unsuitable variation and further promotes adaptation to the area being colonized. Consequently, the ability to identify adults produced by the reintroduction project will be an important aspect of the proponents' monitoring and evaluation programs. There may be several ways to intercept project adults. Visible marks (fin clips) and/or detectable tags (e.g., Visible Implant Elastomer Tags, CWTs in different body locations, PIT tags) could be applied to smolts for project-specific identification. One approach would be to have adult collection sites adjacent to acclimation or release sites. If injury, stress, and pre-spawning mortality during upstream migration are major impacts on adult salmon, it also may be possible to intercept project adults at lower river dams—like Priest Rapids, Wells, Rock Island, and Chief Joseph—from which they could be transported to holding areas prior to spawning to maximize the number of project-origin adult fish available to the reintroduction effort. These and similar issues will need to be carefully thought out as the reintroduction effort moves forward.

Besides these overarching planning needs, assumptions about prospective donor populations should be examined in research projects in the future. For example, the capacity of native redband trout and Lake Roosevelt kokanee to produce anadromous migrants should be examined and quantified. It also may be helpful to examine the genetic diversity of functional genes in some of the potential donor populations. Results from such a survey may prove useful when selecting donor stocks for individual restoration projects (Warnock et al. 2016). Moreover, no information is currently available on the proclivity of donor stocks to residualize in freshwater. Chinook and steelhead may adopt this life history strategy in environments that promote fast growth (Vøllestad et al. 2004, Larsen et al. 2006, Shearer et al. 2006), and the relatively low flow and rich food in Lake Roosevelt might provide such an opportunity. Having comparative information on potential residualization rates on a donor-specific basis would be useful information for managers.

Ecological Limitations

The Reintroduction Report states that "competition for space likely will occur in tributary habitats, whereas competition for food is more likely to occur in reservoir habitats." Headwater streams can be relatively cold and nutrient poor. Food resources can be limiting in these sections of the stream network, and few studies actually measure differences in food availability and the relative influence of food or habitat limitation. Indeed, the limitations of food and space are closely related to each other, as salmonids in streams need more space as they grow, to meet their increasing food requirements (Keeley and Grant 1995). Lessons learned from Lake Roosevelt kokanee program should be incorporated in future assessments and actions (see ISRP 2013-7). For example, if the Lake Roosevelt kokanee program was abandoned, then what is the likelihood of a different result with sockeye?

Recommendations:

- Goals of re-establishing self-sustaining populations and providing cultural and harvest opportunities can be complementary or antagonistic, depending on how introduced stocks interact and activities are coordinated. Future efforts should develop a roadmap for co-implementation of various reintroduction plans. Possible complementarity of reintroduction and hatchery programs was discussed in Warnock et al. (2016).

- Future research efforts should plan for year to year variation in donor stock availability, as this is likely to occur.

- Release strategies are a large source of uncertainty. Life stage, body size at release, location, season, and changes in these factors with environmental fluctuation will influence program success. Interactions with other releases and resident stocks should be considered. Size and date of release can markedly affect the tendency to residualize and to stray at return.

- Interactions of hatchery origin and natural origin spawners were discussed, but not in sufficient detail to allow review. Hatchery-origin donor stocks appear to be favored in the Reintroduction Report because they are generally more accessible than natural-origin fish. Once hatchery stocks are selected, the potential for negative interactions between hatchery origin and natural-origin fish could reduce fitness of populations of naturally spawning adults that are re-established. Potential short- and long-term consequences of hatchery stocking should be considered, especially because donor populations are likely to vary in capacity to supply fish for reintroduction.

- ESA-listed stocks were excluded from the analysis purportedly because regulatory constraints could hamper their availability. Additional assessments for the reintroduction program might consider the potential role of ESA-listed stocks once lessons have been learned from early-phase research outcomes.

- It may be difficult to identify specific reasons for failure of re-establishment because many interacting factors (species, stock, abiotic, and biotic factors) can affect the outcome. Multi-factorial systems are inherently complex, and causation is difficult to infer. Research, monitoring, and evaluation programs are needed to identify influences of donor sources, competition, predation, passage mortality and other factors on juvenile and adult survival. Stochastic effects can affect establishment in a new habitat, so repeated stockings may be necessary even under good conditions. There is a long history of failed salmon transplant efforts (mixed with a few successes), as reviewed by Withler (1982).

- Metapopulation approaches, such as those developed in the Life Cycle Model for the Upper Columbia Basin (reviewed by ISAB in 2017), should be considered to better assess probabilities of re-establishment success.

- How may future actions related to reintroduction of salmon interact with other management goals and activities for Lake Roosevelt, Rufus Woods Lake, and their tributaries? For example, are other types of stocking (i.e., game fishes) currently conducted or planned in the UCR and blocked area? Is suppression of non-native fish predators planned? Stocking non-salmonid species might create risks for introducing pathogens.

1. NPPC sub-question on disease threats to resident species

The Council asked, *"What are the potential disease risks posed by an anadromous reintroduction to redband trout, for example from infectious hematopoietic necrosis (IHN)?"*

For the most part, the review of disease risk in the Reintroduction Report was thorough and based on regional experience and expertise with major fish pathogens, but it was brief, and the reader was primarily referred to Hardiman et al. (2017). Consequently, documents such as Hardiman et al. (2017) and the expertise of contributors should be included as appendices in future documents. For example, Hardiman et al. (2017) included Rachel Breyta, a fish virologist who has published extensively on IHNV. However, the Reintroduction Report did not consider possible interactions between poor water quality (i.e., total dissolved gas supersaturation and contaminants) on disease resistance and predator avoidance. The ISAB review of these topics is covered under adult and juvenile passage (section D.3).

At the workshop of regional fisheries scientists held to evaluate characteristics of potential donor stocks, attendees ranked potential pathogen risks to resident species as part of the decision support framework. Workshop attendees recommended excluding steelhead from consideration for initial reintroduction because of the genetic and disease risks from downstream sources.

The assessment of disease risk assumed that 1) diseases would not occur if the causative pathogen was not present, and 2) pathogen surveillance programs upstream and downstream of Chief Joseph Dam were sufficient to detect and exclude pathogens. Both assumptions are reasonable for ongoing reintroduction efforts, but monitoring will be important to detect early disease occurrence. Three primary factors were considered: 1) potential pathogen introduction, 2) increased pathogen burden, and 3) disease impact. Disease risk was ranked 1) low when pathogens are widespread in both resident (i.e., in the blocked area) and donor regions and effective control measures exist, 2) medium when pathogens are detected in both resident and donor regions and control measures have limited success, and 3) high when pathogens are either not detected in the resident region or effective control measures do not exist.

Ten pathogens were considered as part of the disease assessment. Infectious hematopoietic necrosis virus (IHNV) is particularly virulent for steelhead, and the primary control strategy is pathogen avoidance. Other pathogens of major concern were bacterial kidney disease (BKD) and bacterial coldwater disease (BCWD). Monitoring for pathogens will be critical for the duration of the reintroduction program and in following years if reintroductions are successful.

There is some lack of clarity in Hardiman et al. (2017) regarding the incidence and prevalence of diseases in the resident and donor stocks. They indicated that all fish pathogens of concern were found in resident fishes tested, but the pathogens were found in higher frequency in potential donor stocks. Conversely, they also stated: "All pathogens of concern were detected within the resident region except infectious hematopoietic necrosis virus (IHNV), which is highly virulent in steelhead." But then the report stated: "The Sockeye Salmon-specific form of IHNV (UP subgroup) is present at low levels in the resident region." The authors continue by explaining that the IHNV genogroup M, which is highly virulent to steelhead, is not present in the resident region but is in potential donor stocks. The Reintroduction Report eliminated steelhead from consideration for initial reintroduction because of the high risk of transmitting IHNV to resident salmonids, particularly redband trout. If, however, steelhead are to be reintroduced in the future, resident redband trout were selected as the first choice to use as a donor because they are likely the ancestral source of steelhead in the upper Columbia River. Part of the consideration in this selection was that redband trout from the Sanpoil River have been detected in the Columbia River estuary, suggesting that at least some members of the population have retained the capacity for downstream migration.

However, results from other studies may lessen the concern of IHNV impacting redband trout. Kurath and Winton (2011) reported that in most but not all cases, viruses are more likely to move from wild fish to domesticated fish than from domesticated to wild fish. The authors tempered that conclusion by stating that many more domesticated fish have been inspected for pathogens than have wild fish. When steelhead were exposed to IHNV in the laboratory, Brieuc et al. (2015) identified genetic selection based on total mortality and the number of days required to kill fish that died. Furthermore, they identified a genetic basis for a positive correlation between fish length and survival when steelhead were exposed to IHNV. Thus, there may be actions that could reduce concerns of IHNV transmission to wild redband trout, such as a breeding program to select IHNV-resistant brood fish and releasing larger fish. Furthermore, the Washington Department of Fish and Wildlife (WDFW) has developed a genetic-based tool that can detect the M subgroup of IHNV and is working closely with the Tribes. All Chinook salmon were tested for IHNV(M) prior to release above Chief Joseph Dam in August 2019 (Ken Warheit, Washington Department of Fish and Wildlife, personal communication).

For summer/fall Chinook salmon, the Chief Joseph Hatchery was the highest ranked donor stock, and the Entiat and Lyons Ferry sources were ranked as high disease risks. Seven sources for sockeye salmon or kokanee were considered, and disease risks were relatively similar among those sources. Kokanee from local lakes (Lake Roosevelt, Arrow Lake, Chain Lake) were considered to pose the lowest risk of disease. Though Lake Roosevelt kokanee were ranked highest overall as a source for sockeye salmon, the lack of a brood source makes them less useful for testing prior to reintroduction. The Okanogan natural-origin sockeye salmon was the second ranked donor but had a slightly greater risk of disease than the Lake Roosevelt kokanee.

The myxozoan parasite *Ceratonova shasta (C. shasta)* is a significant parasite of salmonids in the Pacific Northwest, but stocks that co-evolved with *C. shasta* tend to be resistant (Bartholomew 1998). Stinson et al. (2018) surveyed salmonid stocks for *C. shasta* throughout the Columbia Basin, but not above Chief Joseph Dam. There are three genotypes of *C. shasta* (Type 0 affects rainbow trout/steelhead; Type I affects Chinook salmon, and Type II affects coho salmon). It appears that barrier dams stop the movement of *C. shasta* as there is no genotype I above barrier dams that block Chinook salmon from upper reaches of the Deschutes and Klamath rivers (Stinson et al. 2018). *C. shasta* may not be a problem in the area above Chief Joseph Dam, but its presence has not been investigated (Jerri Bartholomew, Department of Microbiology, Oregon State University, personal communication).

The prevalence of bacterial kidney disease (BKD) in Snake River and mid-Columbia River hatchery stocks was declining in the 1990's (Maule et al. 1996, VanderKooi and Maule 1999), resulting in part from low fish densities in the raceways, erythromycin injections of adults to reduce vertical transmission and in feed for juveniles when needed to control horizontal transmission, and better husbandry (cleanliness, disinfection of raceways after use). The frequency of BKD, however, has been increasing recently, perhaps owing to changing hatchery personnel and practices (Susan Gutenberger, Pacific Region Fish Health Program, U.S. Fish and Wildlife Service [USFWS], personal communication).

After Hardiman et al. (2017) was published, the National Wild Fish Health Survey sampled wild fish populations in collaboration with four upper Columbia River tribes. A total of 27 sites were sampled in streams the tribes believed to be culturally important and that have the potential to accept spawning adult anadromous salmonids. The USFWS tested 60 fish from each site and detected no viruses or pathogenic bacteria. The majority of the fish were rainbow trout with a few brook trout as surrogates (Laura Sprague, USFWS, Pacific Region Fish Health Program Wild Fish Survey Coordinator, personal communication).

Hardiman et al. (2017) advocated three strategies to reduce the risk of serious pathogen impacts on resident fish as the result of reintroducing anadromous salmonids above Chief Joseph and Grand Coulee dams: (1) pathogen avoidance as the only viable control for IHNV, (2) antibiotic treatments for bacterial pathogens as appropriate, and (3) continued surveillance for the presence of pathogens.

We agree with these strategies but also advocate development of a parentage-based tagging (PBT, Steele et al. 2019) program for all adults released in the blocked areas. Holborn et al. (2019) used PBT to identify pathogen-resistant Atlantic salmon, and such a program could be useful to identify donors with the greatest disease resistance. PBT could also be used in assessing other management action in the reintroduction. The proponents also should explore the efficacy of IHNV vaccines (Salinas et al. 2015, Leong and Kurath 2017) for donor populations. There are currently no IHNV vaccines licensed for use in the United States; however, an IHNV DNA vaccine is licensed in Canada. Any vaccine should be used thoughtfully, and the risk assessed fully because if the vaccine protects against disease, but not against infection, there is a risk of driving pathogens toward increased virulence. If the vaccine does not prevent onward transmission of a virus from vaccinated hosts, then replication of the virus in vaccinated hosts could cause selection of vaccine-resistance IHNV (Gael Kurath, USGS, Western Fisheries Research

Center, personal communication).

2. NPCC sub-question on predation threats, particularly northern pike

The Council's review request letter to the ISAB stated: "*The ISAB's recent report on the likely broad adverse impacts of Northern Pike and other fish and avian predators (ISAB 2019-1) was released after the UCUT's report. Is there information in the ISAB's report regarding predation, particularly Northern Pike predation, that could inform the reintroduction assessment. In addition, what methods could be considered to estimate predator populations, including Northern Pike populations, in areas above Chief Joseph and Grand Coulee dams, and what is the feasibility of accurately estimating the predator abundance in Lake Rufus Woods, Lake Roosevelt, and the associated tributaries?*"

The ISAB's predator management report (ISAB 2019-1) and other documents include information that could inform the reintroduction assessment. In particular, northern pike are highly piscivorous, eating small and large fish of all species to more than half their own body length. All pike age-1 and older eat salmonids, but large pike eat more per capita, so a broad range of ages of pike contribute to the total population-level predation on salmonids (Courtney et al. 2018). When salmonids were available, they made up a quarter to half the diet of different sizes of pike, based on a synthesis of pike diets from waterbodies in Alaska (Cathcart et al. 2019). Pike are capable of collapsing native Chinook salmon populations (Sepulveda et al. 2015), but much depends on whether they overlap with salmonids in space and time (Dunker et al. 2018, ISAB 2019-1).

The Reintroduction Report stated that "Predation risk to introduced juvenile salmon probably will be high overall but will vary greatly depending on spatial and temporal overlap with potential predators. Smallmouth Bass, Walleye, and Northern Pike were identified as the primary predators of juvenile salmon in Lake Roosevelt and its tributaries." This may or may not be true, but more work will be needed to assess predation risk. Broad assumptions about mortality from predation were made in the Reintroduction Report, particularly in the life-cycle model, which will need to be addressed in the next steps.

For the reintroduction of salmon into the blocked area, the two key questions of interest are: 1) What is the abundance of the various predators that eat juvenile salmon, and 2) What is the total predation by these predators on juvenile salmon? The answers to these questions should be put in the context of both current and likely future conditions.

Question 1: Predator abundance

Direct estimates of predator abundance are difficult: Methods to estimate the abundance of northern pike and other predator populations reviewed in the ISAB's report (ISAB 2019-1) and elsewhere include capture-recapture estimates, virtual population estimates (cohort analysis: Ruzycki et al. 2003), catch-per-unit-effort (CPUE) methods, and eDNA.

Capture-recapture estimates: The large size of both Lake Roosevelt (124 miles^2, 323 km^2, about 80,000 acres) and Rufus Woods Lake (10 miles^2, 26 km^2; or 6400 acres) would make a direct, accurate estimate of the total abundance of these predators using a capture-recapture estimate at best very expensive, if not impossible. Nevertheless, one option might be able to mark fish early in the season and use a sport-reward system (or fishing derby) to provide the recapture sample, as is done with northern pikeminnow in several lower Columbia River reservoirs (reviewed in ISAB 2019-1). However, great care must be taken to develop a sampling design that fully addresses the required assumptions, such as equal probability of capture and recapture across time and the large expanses of space. Body size of predators would also need to be considered because their populations are age-structured (hence size-structured) and this can affect natural mortality.

Virtual population estimates: Another option is to age catches of predators and reconstruct an estimate of what abundance must have been in the past using Virtual Population Analysis (cohort analysis). For example, Ruzycki et al. (2003) used this method to estimate abundance of an expanding nonnative lake trout population in Yellowstone Lake and ultimately its predatory effects on native cutthroat trout. Samples of predators might be obtained from the standard Fall Walleye Index Netting (FWIN) surveys on Lake Roosevelt conducted annually by the Confederated Tribes of the Colville Reservation, Spokane Tribe of Indians, and Washington Department of Fish and Wildlife (Schmuck 2017). The FWIN is an integrative gill-netting protocol that involves setting 150 nets in Lake Roosevelt, covering the reservoir at a density of one net per 533 acres (2.2 km^2). It provides estimates of the relative abundance, spatial distribution, and size-structure not only of walleye but other predators including smallmouth bass, northern pike, and northern pikeminnow. This survey design could be modified to stratify sampling based on physical features important for northern pike (e.g., littoral vs. pelagic zones, and vegetated vs. rocky) and repeated in other seasons to also provide data for estimating predator distribution and diets needed for bioenergetic analysis (see below). This sampling also could be integrated with ongoing efforts to remove nonnative predators, to optimize costs and benefits.

Catch-per-unit-effort estimates: A third option is to use data from the FWIN or other netting surveys to provide CPUE estimates of relative abundance of predators. These estimates provide no estimate of total abundance but can be used to measure the distribution of predators across time and space, and to assess whether predators are increasing or decreasing in the reservoirs and adjacent tributaries. If appropriate gear is used and catches are corrected for their selectivity (e.g., Hansen et al. 1997, Sorel et al. 2016), the size/age distribution can be assessed, which would be important data to help determine the trajectory of the population.

eDNA methods: A fourth option reviewed in ISAB 2019-1 might be to estimate abundance from eDNA samples. However, this technology is still being developed, and it is unclear whether it would be sufficiently accurate or precise to be useful by itself (Doi et al. 2015, Mizomuto et al. 2018, Tillotson et al. 2018, Levi et al. 2019). Nevertheless, it might be useful when paired with other methods like CPUE, or perhaps used to expand capture-recapture estimates from circumscribed areas to whole reservoirs. As highlighted in the report on predation (ISAB 2019-1), eDNA monitoring throughout the basin could also provide important information about the spatial expansion of northern pike.

Question 2: Total predation on juvenile salmon

A key is to measure whether predators and prey overlap in habitat, and the importance of prey in predator diets: To estimate the effects of a nonnative predator such as northern pike on salmonids, one must 1) determine the spatial and temporal overlap of the predator and prey species, and 2) assess by direct diet sampling whether predation is important at certain life stages, seasons, and locations. Although it may seem obvious that a voracious predator like northern pike would eat salmon, interactions among predators in the food web may lead to unanticipated consequences where one predator reduces the abundance of another predator, and hence the total predation impact. In such cases the net effect of a new predator can be a reduction in overall predation.

For example, Sorel et al. (2016) estimated the potential for tiger muskellunge (the sterile hybrid between northern pike and muskellunge) to prey on age-0 Chinook salmon rearing in Merwin Reservoir on the North Fork Lewis River, Washington, where Chinook are proposed for reintroduction. Merwin Reservoir also had a large population of northern pikeminnow, which at larger sizes ($\geq$300 mm FL) prey on anadromous salmonids but are, in turn, preyed on by the tiger muskellunge. The authors found that tiger muskellunge preyed primarily on a large number of smaller northern pikeminnow but few salmonids, primarily kokanee stocked in the reservoir. Larger northern pikeminnow also were cannibalistic on smaller pikeminnow. Overall, predation on Chinook salmon is likely to be less than it otherwise would have been owing to predation by tiger muskellunge on smaller northern pikeminnow, which greatly reduced recruitment of the pikeminnow to larger sizes that prey on salmonids. Similar examples of counter-intuitive predator-prey interactions in communities with multiple species and trophic levels are common in the literature on fisheries ecology (e.g., Larkin and Smith 1954).

Bioenergetics is a useful method to estimate total predation by fish predators but has many challenges in large reservoirs: Bioenergetics models (Hanson et al. 1997) use an energy balance approach to estimate how much prey biomass an individual fish predator must have consumed each day to produce their observed growth over a year, given a known thermal regime. Diets are sampled to estimate what proportion of this prey biomass is supplied by different species. Bioenergetic models have been developed for most species of predatory fish, including northern pike (Bevelhimer et al. 1985) and northern pikeminnow (Petersen and Ward 1999).

Uncertainty in estimates of predator abundances across time and space in the two large reservoirs will increase uncertainty in estimates of total predation based on a bioenergetic model, but this should not deter efforts to generate these estimates. Gathering the necessary data for a bioenergetic model can clarify what uncertainties need to be resolved to generate reliable predation estimates. Such estimates, in turn, are likely required to develop management actions for successful salmon reintroduction.

These models require as inputs:

1. The average mass of predators at the end of each year of life. Samples of the predators are captured and aged with otoliths or other structures (often the cleithrum for northern pike, a bone forming the rear margin of the gill opening). The relationship between length and age is calculated, usually with a von Bertalanffy growth curve, and length is then converted to mass based on a length-mass relationship.

2. The thermal experience of the predator fish, often based on gill net catches throughout the body of water, and sampling of thermal conditions across time and space. Telemetry using radio or acoustic tags, or data loggers that measure temperature and pressure (depth), provide even better data on thermal experience. These data are important because temperature has a large effect on metabolism and digestion.

3. The composition of the predator diets, estimated for different predator age or size classes (and sex if warranted), seasons, and regions by direct sampling and analysis of stomach contents.

4. The energy density (calories, or Joules, per gram of body mass) of each prey type and the predator, which are generally available in the literature or can be determined empirically in the laboratory.

5. Estimates of the energy lost by predators of each age or size class during spawning, as eggs or sperm.

Based on these inputs, estimates of per capita prey consumption by predators of different species, age or size, and sex in different seasons and regions of the reservoir can be multiplied by the applicable abundance estimates to estimate the total biomass of prey eaten by the predator population (Ruzycki et al. 2003, Sorel et al. 2016). Typically, the abundance estimates are the most uncertain part of this estimate.

Conclusions on predation:

The Reintroduction Report makes broad assumptions about predation, which should be evaluated in the next steps. The report concludes that predation risk to juveniles of reintroduced salmon probably will be high overall but vary greatly depending on spatial and temporal overlap with potential predators. Information on spatial and temporal overlap of fish predators with juvenile salmon is the highest priority in the next steps. If there is little overlap, then simpler models of predation losses may be suitable, but if overlap is substantial and leads to high or variable predation rates then more sophisticated models will be needed.

Bioenergetic modeling to assess losses from fish predation was considered for Phase 1 but not chosen for because the proponents believed the broad assumptions required to run such models with the data currently available would lead to imprecise estimates (Casey Baldwin, Colville Tribes, personal communication). Instead, the mortality rate of subyearling juvenile salmonid migrants not collected in the surface collector at the head of Lake Roosevelt was set at 0.25% per kilometer in the life cycle model (DJ Warren and Associates 2019). This value was based on a range of estimates for juvenile sockeye and Chinook salmon mortality from reaches of the Columbia River (Rock Island Dam to Bonneville Dam, Smith 2018). The ISAB concludes that if overlap of fish predators and salmonid prey is substantial, developing bioenergetic model estimates in the next steps will allow formalizing what is known versus what needs to be studied to understand the role of fish predation on survival of introduced salmonids.

Risk posed by different predators to candidate salmonid species considered for reintroduction was evaluated by regional fisheries scientists, and the rankings were used to select among donor stocks. Smallmouth bass and walleye scored high on the scale of risk as predators, but northern pike only moderate. This was surprising, given the rapidly expanding population of pike in Lake Roosevelt and the inability of control efforts to stop their spread (ISAB 2019-1). The predation threat posed by native northern pikeminnow was scored as low, despite their importance in the lower Columbia River reservoirs. Apparently, this was based on information about lower abundance of pikeminnow and low numbers of salmonids observed in their diets in Lake Roosevelt. Overall, more focus on these uncertainties is needed in the next steps because so little is known about the abundance, distribution, feeding behavior, and spatial and temporal overlap of these predators within habitats likely to be occupied by juvenile salmon.

The Reintroduction Report also did not consider future trends in the abundance of potential predators. For example, given recent increases in the abundance, size, and distribution of northern pike in Lake Roosevelt, future risks might greatly exceed current risks (ISAB 2019-1). Smallmouth bass are projected to increase their distribution owing to regional warming, further dispersal, and illegal introductions (Figure 2 from ISAB 2019-1 and Rubenson and Olden 2019). The assessment of predation risks would benefit from consideration of future predation risks reflecting thermal conditions and predator populations, as well as current predator populations and distributions.

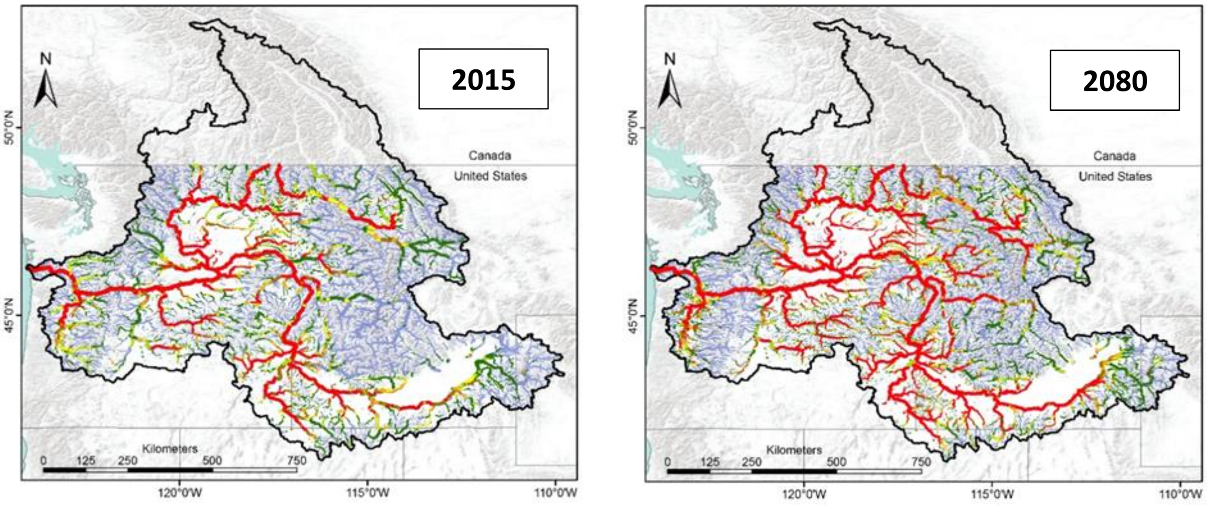


Figure 2. Modeled distributions of smallmouth bass in the United States portion of the Columbia River Basin ca. 2015 and 2080 based on a model of regional warming and dispersal probability (Rubenson and Olden 2019; figure from ISAB 2019-1). Current distribution circa 2015 is 17,660 miles, and projected distribution in 2080 is 28,818 miles, an increase of 69%. See interactive map.

Finally, non-fish predators on juvenile salmon, such as birds (e.g., Caspian terns, double crested cormorants, gulls, herons, kingfishers) and mammals (e.g., otters, mink, raccoon), were not considered or evaluated. Pinniped predators and timing of migration in the lower Columbia River also were not considered. These other predators could consume substantial numbers of migrating juvenile salmon from the reintroduction portion of the basin. Evans et al. (2018) estimated that colonial birds consumed 47% of the migrating steelhead between Rock Island and Bonneville dams during 2008-2017.

Pinniped predation of adult Chinook, sockeye, and steelhead in the lower Columbia River also could influence the success of the reintroduction program but was not considered explicitly in the evaluation of potential predators in the life-cycle model, nor was it in the discussion of climate change. Presumably, such predation is included in the smolt to adult return rates, but to the extent that estimates are based on past conditions, the recent increases in pinniped predation call such estimates into question (Rub et al. 2019). Lack of evaluation of other predators in the assessment of reintroduction risks is a major oversight. These predators should be considered in the assessment of risks to reintroduced salmon and included in the life-cycle models.

B. Habitat assessments

Background

The Reintroduction Report's habitat assessment focused on five models for assessing potential adult returns above Chief Joseph and Grand Coulee dams: 1) intrinsic potential, 2) Ecosystem Diagnosis and Treatment (EDT), 3) Chinook salmon spawner capacity, 4) sockeye salmon spawner capacity in the Sanpoil subbasin, and 5) juvenile sockeye salmon rearing capacity in Lake Roosevelt. In addition, the influence of climate change on habitat quality and productivity of introduced salmon was discussed briefly.

Two subsections pertaining to intrinsic potential modeling and EDT modeling describe findings of a BPA-funded habitat assessment project (#2016-003-00) to assess suitable and available habitat in the blocked waters above Grand Coulee. The project was a collaborative effort led by the Spokane Tribe of Indians with support from the Confederated Tribes of the Colville Reservation, Coeur d'Alene Tribe, Washington Department of Fish and Wildlife, U.S. Geological Survey Columbia River Research Laboratory, and NOAA Fisheries. The Independent Scientific Review Panel (ISRP) reviewed the project's final report and stated that the work provided useful estimates of available habitat quantity and quality. However, the ISRP commented that more detailed discussion of the limits of the assessment methods was needed, particularly for the intrinsic potential and EDT models, since they were based on highly uncertain data (ISRP 2018-8). We use the ISRP's comments as a starting point for a review of those two sections.

Responses to Council's sub-questions

- *Do the habitat assessments assume potential production from currently accessible habitat in its current condition or that future habitat restoration would be needed (i.e., fish passage at irrigation diversions, small hydropower dams, irrigation intake screens, instream flows, etc.)?*

Current natural and anthropogenic barriers were considered in the assessments of habitat and potential production of Chinook salmon, steelhead, and sockeye salmon. Data are available on habitat conditions within the basin to project potential capacity under current conditions and also the conditions if passage is provided above other existing barriers. The intrinsic potential and EDT models encompassed the full extent of tributary habitats within the blocked area of the U.S., but the intrinsic potential model presented results for both the blocked area and the currently accessible habitat. The models of large river spawning habitat, sockeye salmon spawning capacity in the Sanpoil River, and juvenile sockeye salmon rearing capacity apply to areas that are below natural or anthropogenic barriers.

- *Does the report rely on future potential from the Canadian portion of the basin? What does the report assume about fish distribution in the Canadian portion of the basin?*

The Reintroduction Report assessed potential Chinook salmon spawning habitat in the free-flowing Transboundary Reach, and some Life Cycle Model (LCM) analyses included scenarios assuming access to these habitats. Data were provided in a format allowing consideration of reintroduction either solely within the United States or the combined areas in the U.S. and Canada above Chief Joseph and Grand Coulee dams.

- *Do the results from the compilation of the habitat assessments provide a reasonable set of hypotheses about the environment and provide enough information to satisfy the Fish and Wildlife Program's direction to assess the quantity and suitability of habitat in the blocked area?*

The array of habitat assessments provided a reasonable set of hypotheses about the capacity of the habitat in the currently blocked reaches to support salmon at various life stages. The five methods used to evaluate habitat for steelhead, Chinook, and sockeye salmon include most methods currently available to analyze the potential for habitat to produce and support these salmonids at a river-segment scale. The Reintroduction Report provided estimates of habitat potential for steelhead, but the UCUT and Washington Department of Fish and Wildlife (WDFW) have decided to obtain more information about the disease risks to the native redband trout population before reintroducing steelhead. All the methods have strengths and weaknesses, but each helps bound the potential number of fish that can spawn and rear in river and reservoir habitats that would be accessible to them if reintroduced above the two dams.

Overall, the analyses suggested substantial potential for the habitat in the area blocked by the two dams to produce summer/fall Chinook and sockeye salmon (Table 1). Metrics for the potential outcomes of the reintroduction (e.g., miles or area of low to high quality habitat, numbers of spawners, number of redds, and number of smolts) differed substantially, but the projections of the different assessment methods generally were consistent with the baseline scenario of the LCM. Habitat-based estimates of summer/fall Chinook adults ranged from 9,565 to 32,489, which is lower than the LCM baseline scenario projections of 41,000 adult Chinook. The LCM baseline scenario estimated production of 76,000 adult sockeye salmon, which is within the range of the habitat-based estimates of spawner potential (34,066 to 216,078) in the Sanpoil River. The baseline LCM estimates of numbers of sockeye salmon smolts based on spawning habitat estimates (3.7 million below Chief Joseph Dam) were substantially lower than the minimum number of 12 million smolts that could rear in Lake Roosevelt. This difference largely reflects the potential difference between spawning capacity in accessible rivers and rearing capacity in the large reservoir. Overall, the estimates of potential adult capacities for both Chinook salmon and sockeye salmon had wide ranges and include great uncertainty about habitat relationships as well as other factors, such as predation, fish passage, and survival in the lower Columbia River and ocean. While it is reasonable to expect that reintroduction could be successful to some extent, there is great uncertainty about the numbers of adults that will return and the types of management (e.g., hatchery production, passage facilities, predator control, fishery management) that will be required to maintain them.

Table 1. Summary of ranges of estimates of habitat or abundance of spring Chinook, summer/fall Chinook, steelhead, and sockeye salmon from the Reintroduction Report. Estimates restricted to areas below known natural and anthropogenic barriers are reported as Adjusted for Barriers. Metrics or units of measure include miles of low to high quality habitat (adequate), numbers of spawners, number of redds, and number of smolts. The U.S. Blocked Area includes all habitat upstream of Chief Joseph and Grand Coulee dams within the U.S. The Transboundary Reach is a free-flowing section of the Columbia River between Lake Roosevelt and Keenleyside Dam in British Columbia, Canada.

Species	Stage	Area	Metric	Adjusted for barriers	Subbasin	Minimum estimate	Maximum estimate
Intrinsic potential model							
Spring Chinook	Juvenile/Adult	U.S. Blocked Area	Miles of Adequate Habitat	No	Sanpoil		82.2
					Spokane		214.4
					Upper Columbia		59.2
					Total		**355.8**
				Yes	Sanpoil		82.2
					Spokane		0.3
					Upper Columbia		53.6
					Total		**136.1**
Steelhead	Juvenile/Adult	U.S. Blocked Area	Miles of Adequate Habitat	No	Sanpoil		187.7
					Spokane		661.9
					Upper Columbia		311.9
					Total		**1161.5**
				Yes	Sanpoil		176.0
					Spokane		19.5
					Upper Columbia		256.2
					Total		**451.7**
Ecosystem Diagnosis and Treatment (EDT) model							
Su/Fall Chinook	Adult	U.S. Blocked Area	Number of Spawners	No	Sanpoil	1,684	2,206
					Spokane	7,291	9,535
					Lake Roosevelt Tributaries	303	397
					Total	**9,278**	**12,138**

Species	Stage	Area	Metric	Adjusted for barriers	Subbasin	Minimum estimate	Maximum estimate
Spring Chinook	Adult	U.S. Blocked Area	Number of Spawners	No	Sanpoil	374	498
					Spokane	407	543
					Lake Roosevelt Tributaries	120	160
					Total	**901**	**1,201**
Large River Spawning Habitat model							
Fall Chinook	Adult	Rufus Woods Lake	Number of Redds[1]	N/A		270	5,035
Fall Chinook	Adult	Transboundary Reach	Number of Redds[1]	N/A		1,705	20,351
					Total	**1,975**	**25,386**
Sanpoil Sockeye Spawning Habitat model							
Sockeye	Adult	Sanpoil	Number of Spawners[2]	Yes		70,585	756,272
Sockeye	Adult	Sanpoil	Number of Spawners[3]	Yes		34,066	216,078
Lake Roosevelt Sockeye Rearing Capacity model							
Sockeye	Juvenile	Lake Roosevelt	Numbers of Smolts	N/A		12,046,000	48,584,000

[1] Estimates of numbers of redds from three scenarios of low to high discharge (Q). Minimum is based on low discharge (90% exceedance probability), and maximum is based on high discharge (10% exceedance probability).

[2] Estimates of numbers of spawners without adjustment for redd size

[3] Estimates of numbers of spawners with adjustment for minimum and average redd size

Chinook salmon:

The intrinsic potential model projected 711 miles of habitat for spring Chinook salmon in the blocked area in the U.S. including areas above current barriers. Within the area immediately accessible below barriers, 356 miles would be of at least low habitat potential (as opposed to no potential at all). About 140 miles of adequate habitat quality are currently accessible above Grand Coulee and Chief Joseph dams without barrier removal or modification, mostly in the Sanpoil River. In the 82 miles of the immediately accessible reach of the Sanpoil River, 28% was not suitable habitat, 20% was low potential, 21% was moderate potential, and 31% was high potential. EDT modeling estimated that the total potential habitat in the blocked area could support 901 to 1,201 adult spring Chinook.

The EDT modeling for summer/fall Chinook indicated that the habitat could support 9,000 to 12,000 spawning adults, primarily in the Spokane and Sanpoil rivers, depending on assumptions about juvenile and adult survival during migration (Table 1). This estimate assumed that habitat in the Spokane River and other areas that are currently blocked become accessible, an assumption that requires additional actions beyond initial reintroduction above Chief Joseph and Grand Coulee dams. The 60 miles of free-flowing river in the Rufus Woods Lake area and the Transboundary Reach would provide habitat for 1,975 to 25,386 redds for summer/fall Chinook salmon. Based on estimates of 3 spawners per redd, this would amount to 6,000 to 75,000 adult summer/fall Chinook salmon.

Sockeye salmon:

One model of spawner capacity for sockeye salmon in the Sanpoil River projected a median estimate of 375,000 spawners, and a second model projected 34,000 to 216,000 spawners. A simple Euphotic Zone model of rearing habitat in Lake Roosevelt estimated a capacity of 12 to 48.5 million smolts during May to October.

Projections of the effects of climate change indicated that habitat (i.e., flow and temperature) in the blocked area above the two dams will fare better than downstream basins and will be the most resilient to climate change. Other factors that may cause positive and negative outcomes associated with climate uncertainty should be considered. Warmer temperatures in the lower Columbia River may increase mortality of salmon and steelhead returning to the upper tributaries of the Columbia River even if thermal conditions are more favorable in streams and rivers in the upper basin.

Strengths and limitations of specific habitat assessments

1. Intrinsic potential for spring Chinook salmon and steelhead

Background

Intrinsic potential is a GIS-based landscape analysis of the potential of the physical habitat to support salmonid populations, developed for estimating the potential for habitat to support salmonid populations when data are limited. It is based on known relationships between salmon abundance and specific characteristics of the habitat, such as valley constraints, gradient, depth, width, velocity, large wood, and substrate. Digital maps containing contour elevations along with climate data are used to estimate reach scale attributes and create high resolution maps of stream networks.

The intrinsic potential model estimated that there are 711 miles of spring Chinook salmon and 1,610 miles of steelhead habitat within the blocked area, with 356 miles of spring Chinook salmon and 1,162 miles of steelhead habitat rated as having low, moderate, or high potential for spawning and rearing. Overall, 50% of the habitat for spring Chinook salmon and 72% of the habitat for steelhead were suitable for spawning and rearing. Approximately 49% of this habitat was high quality habitat for spring Chinook salmon, and 36% was high quality habitat for steelhead. The greatest length and area of total habitat was in the Spokane subbasin, which included more than half of the total habitat.

However, current anthropogenic barriers reduce access to roughly half of that habitat, especially in the Spokane subbasin. The tributary habitat currently accessible from Rufus Woods Lake and Lake Roosevelt includes 136 miles rated low, moderate, and high for spring Chinook salmon, and 452 miles rated from low to high for steelhead. Approximately 37% of this habitat was high quality for spring Chinook salmon, and 46% was high quality for steelhead. The greatest length and area of immediately accessible habitat were in the Sanpoil River and Upper Columbia portions of the blocked area.

Analysis of intrinsic potential by the Okanogan Alliance estimated that the suitable rearing habitat within the blocked area would be increased by 15% for spring Chinook salmon and 20% for steelhead by including the Canadian portion of the blocked area (reported in Giorgi 2018).

Strengths

The intrinsic potential model has been used to evaluate both historical habitat and the consequences of current land use and future recovery efforts (Burnett et al. 2017). The method provides preliminary estimates of the quality of available habitat without requiring expensive, detailed field measurements of fine-scale habitat characteristics. Estimates from intrinsic potential analysis can be compared to EDT analysis to examine areas where both approaches are consistent and identify critical information that may be required to improve estimates of potential habitat capacity. These estimates can be integrated with estimates of potential spawning habitat in large river reaches to provide a better overall assessment of potential adult Chinook salmon returns for the blocked area. The intrinsic potential model also could be used to prioritize potential barrier removal projects.

Limitations, data uncertainties, and critical analytical gaps

One of the greatest limitations of intrinsic potential model analysis is its focus on physical habitat alone. It largely assumes that the physical habitat is the only requirement for fish populations and that food resources, predation, disease, and water quality do not influence abundance and distribution of fish. This assumption clearly is not realistic, which is why the analysis is termed “intrinsic potential.” Current conditions such as riparian vegetation, solar radiation, bank stability, large wood, pool and riffle habitats, water quality, upland exposure to fire damage, and other factors are not considered. This creates great uncertainty that is not easily reduced through subsequent analytical approaches because of the enormous and costly field measurements required. These limitations strongly influence the assessment of possible salmon and steelhead populations within the blocked area based on intrinsic potential models because food availability, predators, and fine scale habitat characteristics for juvenile salmonids are not evenly distributed throughout the stream networks.

The analysis of intrinsic potential also does not account for use of reservoirs and lakes by juvenile salmonids. Giorgi (2018) acknowledged this limitation and cited studies by ODFW in the Willamette Basin where yearling Chinook salmon, rearing in part in reservoirs, now account for most returning adults (Monzyk et al. 2015). None of the additional habitat assessments or life cycle models incorporated this potential habitat for juvenile Chinook salmon, which may be an important limitation of the models that likely would underestimate capacity.

Another major limitation of intrinsic potential models is the coarse representation of physical habitat. The large spatial scale of the analyses requires enormous amounts of data to represent the large number of small-scale segments (200 m long). Such data are rarely available from field measurements, so coarse-scale approximations are used, primarily from remotely sensed or modeled data sources.

The intrinsic potential analysis also could not be used for assessing spawning habitat in the free-flowing portion of the upper Columbia River within the blocked area, alluvial fans within Lake Roosevelt, and the mainstem Spokane River. The Reintroduction Report used analyses by Hanrahan et al. (2004) and Garavelli et al. (in prep) to assess these large river sections of the blocked area.

2. EDT modeling of Chinook salmon and steelhead in select tributaries

Background

The EDT model estimates potential abundance of juvenile and adult salmonids, and EDT has been widely used in the Pacific Northwest to assesses environmental constraints on salmonid populations (Blair et al. 2009). The model characterizes attributes of the environment relevant to salmonids (e.g., physical habitat, water quality, food availability) on a reach scale at monthly intervals, relates them to life-stage specific survival, and uses a multiple-stage Beverton-Holt model to calculate capacity and productivity parameters for each life-history trajectory. These values are summed across spatial and temporal scales to compute the population abundance (Mobrand et al. 1997, Blair et al. 2009, ISAB 2018-1).

EDT analysis requires information on the potential distribution, age composition, life stage timing, and behavior of salmonid populations within the blocked area. Habitat features in the model include hydrologic characteristics (flow), physical habitat attributes (channel morphology, barriers, substrate composition), water quality (temperature), and biological community influences (interactions with competitors, predators, pathogens, and macroinvertebrates). EDT also considers the prevalence of key habitats (pools, glides, riffles) within each reach and includes a food availability factor (Blair et al. 2009, ISAB 2018-1). Ideally, data on life-stage survival at specific locations and times from field studies are used to populate the model. This often is not possible, in which case the model uses expert opinion or hypotheses about the effects of various environmental conditions (ISAB 2018-1). Estimates of possible future characteristics within the blocked area were created though expert opinion in a workshop conducted by the Confederated Tribes of the Colville Reservation (Colville Confederated Tribes or CCT). Three scenarios were created to account for possible survival of juvenile salmon migrating downstream and adult salmon moving upstream through both dams: 1) Biological Opinion survival: 95% juvenile downstream, 98% adult upstream survival at both dams, 2) moderate survival: 90% juvenile downstream, 97% adult upstream survival at both dams, and 3) low survival: 85% juvenile downstream, 95% adult upstream survival at both dams.

The EDT models estimated that approximately 2,300 adult steelhead may be supported in blocked area tributaries under current habitat conditions and Biological Opinion passage scenarios, assuming that all anthropogenic passage barriers are resolved. The Spokane and Sanpoil subbasins contain the majority of potential steelhead production. Approximately 8,500 summer/fall Chinook salmon may be supported in blocked area tributaries under current conditions and the BiOp passage survival scenario, 1,600 in the Sanpoil River, and 6,700 in the Spokane River. Under the lowest hydrosystem passage survival scenario, the model predicted an equilibrium abundance of nearly 6,000 adult summer/fall Chinook spawners. The analysis also indicated that current thermal refuges and holding habitat are limiting and could be improved through restoration. Approximately 600 spring Chinook salmon may be supported in blocked area tributaries under current conditions and the BiOp passage survival scenario, most of which would be produced in the Sanpoil and Spokane rivers. Many model inputs were based on expert opinion (particularly in the Spokane model), resulting in a wide range of estimates. Nevertheless, the models indicated that existing habitat likely could support viable populations of both summer/fall Chinook salmon and summer steelhead in the blocked area.

Strengths

The EDT model has a number of strengths. It addresses most of the Viable Salmonid Population parameters (productivity, abundance, diversity, and spatial structure; McElhany et al. 2000), and it is comprehensive. Some 46 different reach level habitat attributes are used to link habitat and fish performance. Additionally, model outputs identify specific habitats and habitat attributes that can be restored to increase habitat suitability for salmonids (see EDT application).

The EDT model for the Sanpoil subbasin and adjacent tributaries was based on a previous model for resident fish. To complete it, a panel of resident experts defined expected age compositions, life-stage timing, distribution, and behavioral traits of summer steelhead, summer/fall and spring Chinook salmon.

Assumptions about juvenile and adult survival over Grand Coulee and Chief Joseph dams, and through the mainstem, and ocean were used to develop estimates of potential returning adults. A new EDT model was produced for the Spokane River and for the tributaries entering the Spokane arm of Lake Roosevelt. A panel of experts also helped parameterize this model. ICF, the consulting firm that assembled and ran both EDT models, acknowledged that many freshwater environmental parameters, particularly in the Spokane River model, were not known. Expert opinion was used to complete the model.

Limitations, data uncertainties, and critical analytical gaps

The major limitation of EDT assessments is the enormous amount of data required to run the model. Information is needed not only on physical habitat characteristics and barriers but also distribution, age composition, life stage timing, behavior, and productivity of salmonid populations (McElhany et al. 2010). In this case, the EDT assessment also assumed that all manmade passage barriers would be removed or resolved, which is unlikely and would require considerable time for implementation. In addition, EDT requires estimates of the effects of other factors throughout the full life history of the fish, which are generally represented in survival estimates. These generalized estimates of survival do not allow assessment of specific relationships in the lower Columbia River or Pacific Ocean (e.g., effects of avian, fish, or pinniped predators, TDG), nor address their variability.

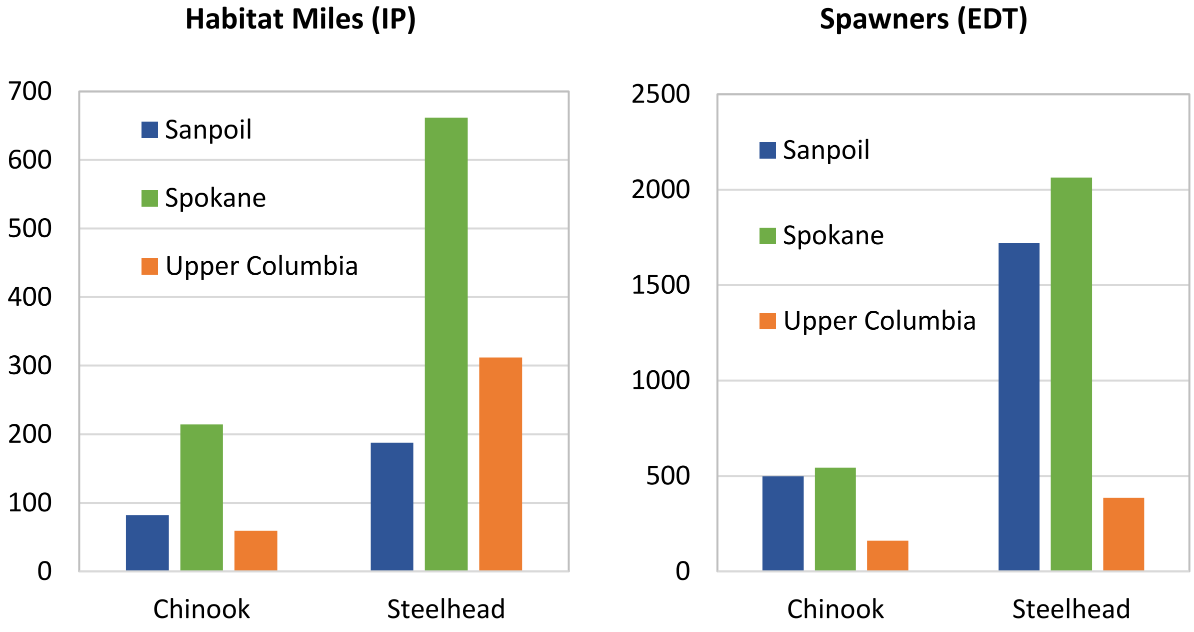
The complexity of the EDT model can obscure the importance of the assumptions that are being employed (see EDT application). McElhany et al. (2010) concluded that uncertainties in data placed into EDT and the model's internal parameters can lead to large prediction intervals around estimates of high priority reaches, productivity, and population abundance. They recommended that sensitivity analyses be conducted to identify the parameters for which the model is most sensitive and least sensitive.

The types of data included in these EDT analyses of the Sanpoil and Spokane rivers were not identical, and the EDT assessment of the Spokane subbasin is less detailed. Uncertainties are created in the EDT analyses where missing habitat parameters or gaps in spatial coverage were filled (e.g., 3rd party models, aerial imagery interpretation, interpolation from comparable watersheds). The Reintroduction Report noted that the EDT analysis of the Spokane subbasin and east tributaries to Lake Roosevelt used the best available information. It concluded that the model relies heavily on sources with high degrees of uncertainty and that future monitoring would be required to improve the model.

Another major question about the EDT assessment is the likelihood of the survival estimates for passage of juveniles and adults though Chief Joseph Dam and Grand Coulee Dam. The lowest survival estimates used in the assessment were 85% for juvenile downstream survival and 95% for adult upstream survival at both dams. The juvenile collectors and adult passage facilities have not been designed, much less constructed or tested. Their performance may not meet even the lowest survival scenario, but the Reintroduction Report does not address this in the discussion of adult spawners estimated by the EDT models. This critical uncertainty could be addressed after reintroduction when PIT-tagged fish migrate through the system, providing data for empirically estimating dam/reach survival, but this management adjustment would occur after substantial investment in passage facilities and other modifications. This management challenge is one reason the ISAB recommends a sequential or “stepping stone” approach to the reintroduction effort (see also ISAB comments related to Donor Stock Assessment).

The relative ranking of potential equilibrium abundance of adult spring Chinook salmon and steelhead estimated by the EDT models differed substantially from the relative ranking of available habitat (i.e., length and area) by the intrinsic potential models (Figure 3). The total habitat area for spring Chinook salmon within the blocked area estimated by the intrinsic potential analysis was greatest for the Sanpoil as compared to the Spokane and Upper Columbia portions of the blocked area (as defined in the Reintroduction Report). However, the EDT model projected that maximum potential equilibrium adult abundances of spring Chinook salmon were approximately equal in the Sanpoil and Spokane subbasins. The total habitat area for steelhead within the blocked area estimated by the intrinsic potential analysis was two to three times greater in the Spokane subbasins, but the EDT model projected that maximum spawner abundances of steelhead were roughly equal in the Sanpoil and Spokane subbasins. The EDT analyses considered other factors in projecting the abundance of adult salmon, but these differences between the intrinsic potential analysis and EDT models and the implications for reintroduction decisions were not addressed in the Reintroduction Report.

Figure 3. Comparison of estimates of potential spawning habitat for spring Chinook and steelhead in the Sanpoil, Spokane, and Upper Columbia subbasins (as defined in the Reintroduction Report) based on the intrinsic potential model with the estimates of maximum numbers of adult spawners for each species and subbasin from the EDT model.



3. Large river Chinook salmon spawning and habitat and redd capacity

Background

EDT models and intrinsic potential analysis were not considered appropriate for evaluating adult spawning habitat and capacity in large rivers. Consequently, habitat and population analyses were used to estimate spawning habitat and capacity in a 17-mile portion of Rufus Woods Lake downstream of Grand Coulee Dam (Hanrahan et al. 2004) and several sections of the Transboundary Reach between Lake Roosevelt and Hugh L. Keenleyside Dam in British Columbia, Canada (Bellgraph et al. in review, Garavelli et al. in prep). In both areas, a two-dimensional hydraulic model (Modular Aquatic Simulation System in 2 dimensions or MASS2) was used. The Reintroduction Report authors noted, however, that the methods used to estimate the quantity and quality of spawning areas in Rufus Woods and the Transboundary Reach differed slightly.

In Rufus Woods Lake, geomorphic analyses were used to identify two potential spawning areas. The MASS2 model "uses a structured, multi-block, boundary-fitted, curvilinear computational mesh that allows the simulation of very complex riverine or estuarine networks" (Perkins and Richmond 2004). In Rufus Woods Lake, 3 x 3 m cells represented the mesh size. Attributes within each cell were evaluated as suitable or not suitable for spawning based on criteria for Chinook salmon that included depth, velocity, substrate, and channel slope. Once areas with suitable habitat had been established, a "suitability index" ranging from 0 (poor) to 1 (optimum) was applied to estimate the extent of possible spawning areas. Afterwards, redd capacity was estimated by using four different methods that employed average redd size and inter-redd spacing.

For the Transboundary area, a logistic regression model that used spawning habitat attributes from Geist et al. (2008) was used to estimate available spawning areas. As in the Rufus Woods area, redd size and inter-redd spacing data were used to estimate redd capacity. The probability that spawning would occur at specific sites was estimated at three exceedance flows (10%, 50%, and 90%). Because flows in this reach vary substantially, the incremental flow analysis is valuable for projecting potential ranges of available spawning area. The model did not account for the effects of gas supersaturation, which could be a serious issue in both reaches (see section D.3. on reservoir passage and survival).

The analyses estimated habitat for 270 – 5,035 redds in Rufus Woods Lake and 1,705 – 20,351 in the Transboundary Reach. Based on an assumption of 3 fish per redd, the Reintroduction Report estimated spawner capacity of both reaches combined of 6,000 to 75,000 adults, depending on flows.

Strengths

Large river habitats are likely to provide the greatest spawning capacity for summer/fall Chinook in the blocked area. Assessment of this spawning habitat is critical for consideration of reintroduction and design of potential stages in implementation. Both approaches appear to provide estimates of redd locations and spawning capacity that will be useful in deciding whether to reintroduce Chinook into the blocked area.

Limitations, data uncertainties, and critical analytical gaps

The methods of analysis differed for the reaches in Rufus Wood Lake and the Transboundary Reach. The Reintroduction Report indicates that depth, velocity, slope, and substrate were used to model potential spawner capacity in both reaches, but the description of the analysis of the Transboundary Reach does not describe the use of substrate information and the manuscript (Garavelli et al. in prep) was not available. It is possible that the logistic regression model incorporated the substrate data, but that was not clear. The analysis of Rufus Woods Lake limited their summary to "high quality" habitat having greater than 75% probability of spawning, but the analysis of the Transboundary Reach included habitat with greater than 50% probability of spawning. Other differences between the methods were not fully described in the Reintroduction Report.

The Reintroduction Report concluded that the differences in methods and assumptions of the two studies prevents a useful comparison. The uncertainties of the two analytical approaches and the integration of the two studies is problematic. The 10-fold range of spawner capacities reported for the large rivers was extremely large. The Report states that "There is considerable uncertainty in selecting the best single estimate of capacity due to unknown direction and magnitude of the difference between the model prediction and the biological truth (which can only be evaluated after fish are reintroduced)." This statement is not explained further, but the "unknown direction and magnitude" of difference between the estimate and what might be realized after reintroduction are major uncertainties that should be carefully considered when making the decision to reintroduce Chinook salmon.

A "suitability index" was used to refine the spawning areas potentially available in Rufus Woods Lake, but details of the factors included in the index were not reported. Information on areas of known hyporheic upwelling were not available for either large river reach and were not included in the models of spawning habitat (Brian Bellgraph, Pacific Northwest National Laboratory, personal communication). Geist et al. (2008) emphasized the importance of upwelling hyporheic flows on redd site selection by Chinook salmon in the Hanford Reach. The ISAB acknowledges that measurement of hyporheic exchange is difficult and rarely available, but future assessment of spawning habitat in these reaches could be improved by information on hyporheic exchange.

4. Chinook salmon redd and adult spawner capacity estimates

Background

There is considerable variation in the estimates of Chinook salmon redd capacity, owing to estimates of redd sizes, spacing among redds, and variable flow rates. The authors projected potential spawner capacity by multiplying the range of redd capacities predicted by the two models by an estimate of adult spawners per redd. The estimate of spawners per redd (males and females combined) was based on data from the Methow and Okanogan rivers, which averaged 2.98 between 1989 and 2015 (Hillman et al. 2016). The product of adult spawners per redd (3 fish/redd) and the range of redd capacities (2,000 to 25,000) generates estimates of spawner capacities between 6,000 and 75,000 adults.

Strengths

Given the variation and uncertainty associated with these estimates, the proponents feel the models they used indicated that potential spawning habitat clearly exists but refinements on maximum redd numbers and capacity will need to wait until fish are allowed to spawn in these areas. As indicated for the EDT analysis, this information would become available only after substantial investment in passage facilities and other modifications, which is why the ISAB recommends a sequential or “stepping stone” approach to the reintroduction effort.

Limitations, data uncertainties, and critical analytical gaps

The number of fish per redd is a highly variable metric, and the value of 3 adults per redd was based on overall sex ratio at broodstock collection sites (Hillman et al. 2016). Thus, the validity of the estimate depends on the assumption that data on Chinook salmon at a broodstock site in the Wenatchee River system are representative of spawners in the blocked area in the future. One alternative would be to consider only females in the analysis. Spawner capacity is probably best measured by the suitability of the habitat to accommodate appropriate spawning locations and redd spacing. If reintroduction occurs, this capacity should be validated with direct, accurate counts of redds to be compared to counts of females.

Second, a temporal aspect of spawning behavior has not been considered in these estimates. Even though prospective spawning areas may have suitable locations for a given number of females, not all those locations may be used if female arrival is protracted. Depending upon water temperatures, territorial/spawning/guarding female Chinook salmon may live for 7 to 10 days or longer. After females die, their redd sites may be used by other females. Such later arriving females may spawn over recently vacated redds because hydrologic features (e.g., upwelling flows, clean gravel caused by female digging) make such sites favorable spawning sites. Consequently, the more protracted the spawning period of the population, the more the redd capacity may need to be adjusted to account for possible superimposition. On the other hand, if most females in a population mature at approximately the same time, their territorial behavior will more broadly distribute the population’s use of the spawning area. Female aggression will force the occupancy of unused habitat, some of which may be less than ideal.

A third issue is that Chinook salmon redd and spawner capacity are surrogates for fry production. Estimates in the Reintroduction Report assume that suitable conditions for spawning will also be appropriate during incubation or the egg-to-fry stage. However, post-spawning conditions can affect incubating embryos. Scour, excessive deposition of gravel, sedimentation, dewatering, low dissolved levels of oxygen, and other factors can affect egg-to-fry mortality, which may exceed 80%. The proponents may wish to evaluate whether redds deposited in locations that are suitable for spawning will also be suitable for incubating eggs and alevins.

5. Potential sockeye salmon spawning habitat in the Sanpoil subbasin

Background

Two methods were used to estimate sockeye salmon spawning habitat in the Sanpoil subbasin. One relied upon spawner densities whereas the other used average redd sizes. Wolvert and Nine (2010) estimated that there was 340,000 m^2 of potential spawning habitat for kokanee in the Sanpoil subbasin. Using literature values for kokanee that ranged from 0.7 to 5.0 spawning fish/m^2, they estimated the Sanpoil could support between 238,000 to 1.7 million kokanee. The proponents noted that Wolvert and Nine (2010) assumed that all the available habitat would be used and felt this probably would not occur. Instead, they hypothesized that a range (25% to 75%) of the habitat would be occupied and that adult sockeye densities of between 1.1 to 4.0 fish/m^2 would utilize this space. The analysis of sockeye salmon capacity in the Sanpoil subbasin across all ranges of habitat use and adult densities ranged from 34,066 to 216,078 spawners. A mid-range of density (2.96 fish/m^2) and 50% habitat utilization gave a capacity estimate of ~370,000 sockeye salmon.

The second method used redd sizes of sockeye (1.75 m^2 to 3.7 m^2) to estimate both redd and spawner capacity in the Sanpoil. The same range of habitat utilization (25% to 75%) was used and this approach yielded abundance estimates from 34,000 to 216,000 adults.

Strengths

The proponents stated that model estimates indicated relatively abundant spawning habitat for sockeye salmon in the Sanpoil subbasin, based on fundamental relationships between potential numbers of redds and numbers of spawners per redd.

Limitations, data uncertainties, and critical analytical gaps

The Reintroduction Report acknowledged that substantial uncertainties about redd sizes and the percentage of habitat used led to a wide range of abundance estimates. The Report did not indicate which estimate was more credible or would be used.

Spawning habitat for sockeye salmon was assessed only for the Sanpoil subbasin. The Reintroduction Report stated that habitat data are not available for other tributaries that are expected to support sockeye salmon. This seems inconsistent with the analyses for Chinook salmon and steelhead, for which habitat data in most tributaries were available for intrinsic habitat analysis and EDT modeling. One explanation could be that data on sub-habitat types used by sockeye salmon for spawning (e.g., glides, tailouts of pools) and used in the analysis of the Sanpoil were not available in the other tributaries, but the Report does not explain the specific limitation.

The range of estimates of potential sockeye salmon abundance for the Sanpoil River is very large because of uncertainty about habitat use and assumptions about redd size and spawner density. The habitat utilization multiplier (0.25, 0.5 and 0.75) represented a range because of the lack of knowledge about how much of the available habitat would be used. This major uncertainty should be considered cautiously in making decisions about potential for reintroduction of sockeye. Also, it is not clear if the estimates have been adjusted for the capacity for sockeye and kokanee (i.e., kokanee are smaller-bodied, use overlapping but somewhat different habitat within rivers, and spawn later than sockeye salmon where they are sympatric: Wood and Foote 1996).

The same concerns raised about estimates of redd and spawner capacity in summer/fall Chinook based on fish per m^2 are relevant for estimates of sockeye salmon. If that metric is going to be used, it should be converted to females per m^2. Clearly, all areas in glides, pools, riffles, and such will not be equally attractive to spawning salmon. Instead, spawners likely will select areas with upwelling, downwelling, or accelerating flows, and hyporheic seeps. All suitable spawning habitat likely will not be used, unless perhaps when densities are very high.

There are several reasons why the Sanpoil River may be important for sockeye salmon after reintroduction. It currently supports kokanee spawning, so it has proven to be suitable for the species, if not the anadromous form. Large reaches are within the Colville Reservation, with greater control on adjacent land use and opportunities for restoration actions than adjacent lands with mixed private and public ownership. However, several limitations were noted on the field tour. The river is relatively small, and flows could be limiting during droughts and stream temperatures could be limiting during warm periods; fires in the basin could increase erosion; and sedimentation could affect survival. Competition with resident kokanee in the Sanpoil River and in Lake Roosevelt could reduce productivity for sockeye (or vice versa), but such interactions were not addressed in either sockeye salmon model.

6. Sockeye salmon rearing capacity in Lake Roosevelt

Background

The carrying capacity of juvenile sockeye salmon in Lake Roosevelt was estimated by a Euphotic Volume (EV) model (Koenings and Burkett 1987). Euphotic Zone depth is defined as “the portion of the water column extending from the surface to the depth where one percent of ambient light penetrates. It represents depths where nearly all the primary production occurs in typical freshwater systems” (Giorgi and Kain 2018, first used in Koenings and Burkett 1987). The EV values were estimated for May, July, and October based on data from 1997 - 2006. Each of these months coincides with different lake volumes. May is the period of maximum drawdown. In July the lake is completely refilled, and in October late-season drawdown occurs. The EV method uses a correlation between carbon production and rearing capacity for juvenile salmonids and has been used in other reintroduction feasibility evaluations in the Yakima, Willamette, and Fraser watersheds (Giorgi and Kain 2018).

Because empirical data for smolt production per EV unit are not available for Lake Roosevelt, a range of possible relationships was represented by three different scenarios (high, moderate, and low smolts/EV). Estimates of average EV units increased from May (1,770), to July (3,515), and October (4,647). Data on smolts produced per EV in Lake Wenatchee (low = 6,780, moderate = 8,531, and high = 10,455 smolts/EV) were used to estimate the rearing capacity of Lake Roosevelt. These analyses projected that Lake Roosevelt could support from 12 to 48 million smolts depending upon the month and the smolt/EV parameter used.

Strengths

The method is simple but provides a first approximation of the capacity for a large lake to rear juvenile sockeye, when little empirical data are available. The method is acceptable and has been used in other areas of the Pacific Northwest.

Limitations, data uncertainties, and critical analytical gaps

The estimates of sockeye salmon rearing capacity (minimum = 12 million juveniles) were substantially lower than the LCM estimates of smolt migrants (3.7 million below Chief Joseph Dam). The LCM model estimates 7 million sockeye smolts if smolt and adult passage survival is set to 100% (Kevin Malone, D.J. Warren & Associates, personal communication). The LCM estimate of sockeye smolts was based on assumptions about adult spawning capacity and egg-to-smolt survival rate, not on the juvenile rearing capacity of Lake Roosevelt. In the LCM, egg-to-yearling smolt survival was set at ~4% based on input from Hyatt as the long-term average survival for 30 sockeye salmon populations (See Table 6-7 in Reintroduction Report). Yearling smolt capacity was set at near unlimited (10 billion) to ensure that density dependent effects were minimal, because the 4% egg-to-smolt survival includes density effects. Adult spawning capacity was set at 50,000 for the Sanpoil River and 5,000 for the Columbia River mainstem upstream of Lake Roosevelt. The spawner capacity for the Sanpoil used in the LCM was within the range (34,066 to 216,078) projected by the habitat assessment (section B.5). The difference between the models largely reflects the potential difference between rearing capacity in the large reservoir and spawning capacity in accessible tributaries, which is a major uncertainty in decisions about reintroduction actions to support sockeye salmon production in the blocked area.

Currently, single integrated stock models are not available for assessing the rearing capacity of lakes with juvenile sockeye, but the effects of food and temperature are well known and can be used to improve estimates of juvenile rearing capacity. Several methods use limnological data and food web information to determine carrying capacity, including the photosynthetic rate model, euphotic volume model, zooplankton production-consumption model, and an empirical juvenile sockeye biomass-to-numbers saturation model (Kim Hyatt, Fisheries and Oceans Canada, personal communication). Fundamentally, these models are based on assumption that the growth and survival of juvenile sockeye salmon are related to their food supply and environmental influences on growth. If the consumption of zooplankton by fishes and other predators exceeds daily zooplankton production rates, zooplankton biomass will decline. As a result, fish growth and/or survival will decline until the carrying capacity for planktivores has been reached.

A long-term study of sockeye and kokanee in Lake Osoyoos, British Columbia found that survival of sockeye and kokanee fry was positively related to zooplankton biomass, particularly two genera of large omnivorous cladocerans and copepods (Hyatt et al. 2018). Previous studies also demonstrated that abundances of fry measured in coastal lakes of British Columbia did not cause density-dependent reductions in fry growth rates and prey density, except at unusually high fry densities (Hyatt et al. 2011).

In other lakes supporting sockeye salmon, density-dependent reduction in growth has been documented (Burgner 1987, Schindler et al. 2005). These observations support the conceptual basis of the euphotic zone model but indicate that information on fish consumption rates, prey abundance, and temperature could provide more rigorous estimates of carrying capacity for juvenile sockeye salmon.

The estimated rearing capacity of Lake Roosevelt was based on limited limnological data. The lake has been sampled annually since 1988, and monitoring data on zooplankton, temperature, and other water quality parameters could be used to improve estimates of sockeye rearing capacity. A number of limnological monitoring reports for Lake Roosevelt provide data on temperature, oxygen, stratification, nutrients, phytoplankton, zooplankton, and fish communities (Stober et al. 1981, Vermeyen 2000, see series of reports cited in Lee et al. 2006). Future assessments could incorporate methods that integrate zooplankton data and temperature, such as Edmundson and Mazumder (2001), Hyatt et al. (2018), and other papers in Quinn (2018). The temperature patterns in lakes Wenatchee and Okanagan differ markedly, so the thermal regime will play an important role in growth and smolt timing. Peven (1987) reported larger size and later smolt migration from Lake Osoyoos than Lake Wenatchee. Historical data from Lake Roosevelt, such as limnological data and smolt information from studies in the 1970s (Stober et al. 1977), could be incorporated to provide a longer temporal context for the analyses.

The EV model assumes that primary production and subsequent zooplankton production are positively related to euphotic zone depth. This ignores vertical patterns in phytoplankton and zooplankton and potential behavioral responses to visual predators. Other factors that determine rates of primary and secondary production (e.g., nutrient concentrations, temperature, trophic cascades) are not considered.

The proponents recognized that their analyses might overestimate juvenile sockeye rearing capacity. The method was developed for Alaskan lakes where photosynthetic rates were positively related to EV units, which is not always reported. Giorgi and Kain (2018) cited a study of coastal and interior British Columbian lakes, which found a negative relationship between EV and photosynthetic rates and led to overestimation of sockeye salmon rearing capacities (Shortreed et al. 2000). The proponents also stated that parts of Lake Roosevelt differ in nutrient cycling and trophic dynamics due to reservoir operations. Abundance of smolts/EV unit undoubtedly varies temporally and spatially, which could reduce the capacity estimates.

Species composition of the zooplankton assemblage present in Lake Roosevelt should be regularly monitored after sockeye salmon are introduced. Juvenile sockeye salmon typically prefer to feed on *Daphnia* and other large, highly visible zooplankton. In recent decades, *Daphnia* represent approximately 60% of the zooplankton biomass in the lake (Lee et al. 2006). This percentage could be substantially reduced by juvenile sockeye salmon foraging. If the zooplankton abundance and/or community composition is altered, the lake's sockeye rearing capacity could be substantially lower (Koenings and Kyle 1997). A phased approach that incrementally increases the abundance of juvenile sockeye salmon into the lake may be prudent. The zooplankton community should be monitored to understand changes in smolt capacity as juvenile sockeye salmon influence key prey species of zooplankton, such as *Daphnia*.

7. Climate change

Background

The Reintroduction Report indicated that changes in water temperature, hydrologic regimes (e.g., snow-melt, rain-on-snow, or rain-dominated), and drought caused by climate change over the next century could beneficially influence the success of reintroduction and the importance of this portion of the Columbia River Basin. Areas in the U.S. portion of the upper Columbia River are snow dominated but are expected to become rain dominated to a greater extent in the future. This shift could profoundly affect flows, nutrient inputs, and water and air temperatures, all of which are likely to influence salmonid capacity, productivity, diversity, and spatial distribution. Parts of the upper Columbia River Basin in Canada, however, are expected to remain snow dominated. Maps from the Climate Impacts Group at the University of Washington indicate that this is likely. In the future, these regions may prove to be invaluable refuges for the basin's salmonids.

Strengths

The Reintroduction Report considered the potential impacts of climate change, which is important given the possible changes in habitat and potential salmon production. The Report argues that now is the time for reintroductions to occur. Reintroducing salmonids in the near future will allow lead time to conduct necessary research, build and test effective fish passage facilities, possibly establish artificial production facilities, and develop stocks adapted to warmer conditions prior to anticipated environmental changes. CRITFC geneticists (BPA project 2009-005-00 - Influence of environment and landscape on salmonid genetics) have determined that some salmonid stocks possess functional genes that provide increased tolerance for warm water temperatures. Such information may inform efforts to use more thermally tolerant fish to meet future conditions throughout the Columbia Basin. The ISAB commends the Reintroduction Report authors for considering the potential effects of climate change on the success of reintroductions. Climate change should be considered in all the sections of the assessment in future steps in assessing or implementing reintroduction of salmon above Chief Joseph and Grand Coulee dams.

Limitations, data uncertainties, and critical analytical gaps

The consideration of climate change effects was extremely brief and not spatially or temporally specific to the stream networks of the blocked area. It considered only the positive effects of climate change related to the lower thermal stress in the blocked area as compared to warmer regions of the middle and lower Columbia River. It did not consider how the changes in climate will affect pathogens or predators, nor how these factors will interact with other factors. Recent losses of adult sockeye salmon to prespawning mortality during migration and on the spawning grounds were neither discussed nor related to the potential negative impacts of climate change on reintroduced sockeye as they migrate through the lower Columbia River. Salmon from the upper Columbia River within the blocked area will be exposed to lower river conditions as smolts and returning adults, so the upper river will not be a refuge from the changing climate for all salmon life stages.

Predicting the long-term effects of climate change is challenging. Fortunately, climate forecasting models are becoming more sophisticated. Scenarios produced by these models should be routinely assessed by the proponents to help inform which stocks and areas should be used in reintroduction programs. Projections from these models should be incorporated in assessments of upstream migration and survival of adults on their return migration as well as production and survival of juvenile salmon during downstream migration (Hyatt et al. 2003). In both cases, the reintroduced populations would have longer migrations than extant populations in the upper Columbia River below Chief Joseph Dam.

A final consideration, with respect to climate, is the possible interaction with other stocks of salmon in the Columbia River system. If climate driven factors reduce the productivity of stocks in general, fishing pressure on the ones in the reintroduction reach might increase to a point where they are either not sustainable at all or not producing surplus salmon for the upper Columbia River user groups.

C. Life-cycle modeling

Background

This ISAB report section identifies the strengths and limitations of the life-cycle modeling assessment element of the Reintroduction Report and addresses the Council's sub-questions: "*Are the modeling assumptions reasonable, do the variants and sensitivity analyses adequately account for variability and uncertainty, and are other appropriate parameter values for critical life stages considered?"*

"The life-cycle model (LCM) was developed to help managers answer key management questions such as:

- What role can hatchery releases play in starting and sustaining the reintroduced population?
- What role can translocation of adult salmon play in starting and sustaining the reintroduced population?
- What might be the adult spawning escapement and harvest benefits from such reintroduction efforts?
- What are the key assumptions and research needs?"

This LCM is deterministic; that is, model output is completely determined by parameter values and initial conditions without stochasticity and with limited density-dependence (see comments below). Modelers used best guesses for parameter values based on other LCMs (e.g., the model in the Comparative Survival Study), published papers, and expert opinions from a working group. No actual model fitting to estimate parameter values was done because no data currently exist for this proposed re-introduction. The LCM was run for many years from its starting values, feeding the input from one year back into the next year until the model "converges" to an equilibrium solution which is then presented to the user.

The LCM produced estimates of the following parameters (Table 6-1 in the Reintroduction Report):

- Spring migrant (fry/subyearling), fall migrant (age-0), yearling migrant (age-1) and age 2+ migrant abundance, total numbers of smolts (natural and hatchery origin) migrating downstream below Bonneville Dam.
- Adult run-size at Bonneville Dam, harvest, adults arriving at Chief Joseph Dam, and escapement to spawning grounds.
- Number of fish harvested in marine and freshwater fisheries, including new fisheries upstream of Chief Joseph Dam.
- Smolt-to-adult survival rate.
- pHOS, PNI and pNOB.

The baseline scenarios estimated that reintroduction would result in an additional 2 million juvenile summer/fall Chinook salmon and 1.5 million juvenile sockeye salmon migrants at Bonneville Dam. This would result in an estimated 41,000 adult summer/fall Chinook and 76,000 adult sockeye before losses to harvest. Total harvest (ocean, estuary, and in-river) was estimated to be 24,000 summer/fall Chinook and 21,000 sockeye, and escapement would be 17,000 adult summer/fall Chinook and 55,000 adult sockeye.

Strengths

The LCM provides a framework for integrating the information on potential habitat and reproductive capacity for populations of summer/fall Chinook and sockeye salmon in the major subbasins of the blocked area. Additionally, the framework highlights processes for which data are lacking and thus can focus research on obtaining estimates of these parameters. The model is simple to use and simple to update (e.g., as new data become available, or as parameter values change for one reason or another). It provides a readily accessible tool for managers to explore and better understand the many uncertainties surrounding catch and escapement goals from a re-introduction. The model can be run in real time in management and policy settings to address questions and aid discussions and decision making.

This model incorporates the information developed for the major habitat assessments in the Report and accounts for differences in relative reproductive success of hatchery and wild fish, passage of juveniles and adults, and harvest in the river and ocean for both species. Sensitivity analysis included Monte Carlo simulations for some analyses and simple increases or decreases in parameters for other analyses.

Although the model is still under development (*see* K. Malone, response to ISAB Modeling Request, 7 August 2019 Memo to Erik Merrill from UCUT Modeling Team), preliminary results are being used to identify key information gaps and uncertainties to be addressed by future research, monitoring, and evaluation. The model contributes to an adaptive management process, which the ISAB considers very appropriate for this effort.

Limitations, data uncertainties, and critical analytical gaps

(a) Lacking stochasticity in parameters over time

This LCM is deterministic, with no variability in the parameters modelled (except for the sensitivity analysis). The model does not acknowledge that all parameters will vary from year-to-year, or that there may be regimes of good and poor conditions, primarily for the survival terms between stages. Ignoring such well-known forms of variation (Quinn 2018, and references therein) renders the model incapable of evaluating what might happen following reintroduction efforts. Recognizing that no data exist for the populations modeled here, scientific literature or otherwise “best guesses” could inform the expected values (as used for the baseline scenario) and ranges (as used in the sensitivity analysis) and then be used to obtain reasonable measures of interannual variability for some of the survival terms in the model. For example, data on variation in the numbers of smolts per female, and smolt to adult returns, could be incorporated.

The model projects the numbers of fish harvested and escaped, whereas the output should expressly include the uncertainty associated with these estimates. To accomplish this, variability needs to be included as a model feature. As a consequence of this aspect of the current LCM, the results must be viewed cautiously because natural variation in parameter values may drive a stock to extirpation (i.e., a series of years with lower than projected survival rates), especially if returning adult numbers are modest. The model should be explored to see how plausible variation in parameter values could affect the results. This would be similar to a sensitivity analysis where parameter values are driven to extremes until the population is below some threshold (e.g., below 100 returning adults).

Outputs of the model are directly influenced by the uncertainties and wide range of estimates of habitat availability and adult spawner capacity. Because these ranges are substantial and density dependence is not fully accounted for in the model (see below), use of the lower end of the distribution of estimated habitat and spawner capacity in applications of the LCM would be more conservative and precautionary.

Care must be exercised if randomness is included, because it must account for possible co-variation between parameters. Depending on the nature of mortality agents, survival at one life history stage may be correlated with that in another, magnifying the overall variation experienced by brood years. For example, climate conditions favorable for juvenile coho in fresh water were also favorable for marine survival (Lawson et al. 2004). Alternatively, density-dependence can result in a negative correlation (e.g., if high survival of embryos results in reduced survival of juveniles). In addition to such co-variation between life history stages, there may also be co-variation between species (Chinook and sockeye salmon) resulting from climate-driven conditions at sea or in the river during downstream or return migration, or other processes. Ignoring such co-variation can thus affect the range of projected outcomes in many ways, hence this possibility should be considered.

(b) Current sensitivity analysis has limited utility

The sensitivity analysis is still under development and not fully implemented in the LCM package, but the current iteration generates many scenarios by simulating a (user-) specified range of parameter values and reporting a range of outcomes. Instead, a sensitivity analysis should determine how much the inference depends on the assumptions made. The primary output from this model should be the probability of meeting or exceeding some escapement/harvest threshold deemed important to managers. The sensitivity analysis should then assess how much these probabilities change when different assumptions are made. The sensitivity analysis itself does not provide probabilistic statements, but rather it illustrates how those statements change based on the assumptions.

Because the range of input uncertainties have no statistical basis in this analysis and the analysis has not acknowledged covariation, the Monte Carlo sensitivity analysis in no way represents probability. It only describes how the assumptions about ranges of uncertainties in parameter values translate to ranges of uncertainty in predictions, not the probability of any particular prediction.

The use of triangle-shaped distributions in the sensitivity analysis will overweight the tails of the distribution and increase variation in the outputs, but the lack of covariation among parameters will reduce the variation in the outputs. Because density dependence is modelled only at the spawner-stage, the sensitivity analysis may be overly sensitive (i.e., because of compensatory behavior, changing a parameter may have relatively little impact on the spawner numbers). The net impact of these and other impacts is unknown.

The current sensitivity measure needs to be improved because it is affected by the number of simulation runs (more simulation runs will automatically increase the range of output values) and the user-specified range. It is possible to make the model appear to be sensitive to a parameter by simply using a wider range for the simulated values. A measure such as the ratio of the standard deviation (SD) of the output-values to the SD of the input-values may better reflect its sensitivity.

Furthermore, the report states "*For some analyses, instead of using the Monte Carlo feature modelers simply increased or decreased the parameter of interest by a set percentage and then reported the median value* (p. 72)." It is not clear how this demonstrates a sensitivity of the model to a parameter.

The sensitivity analysis should be expanded to evaluate other components of the model and consequences of using estimates of the low portion of the distribution of estimates of habitat and spawner capacity.

It is surprising that the model is not more sensitive to ocean conditions, given the large variation in marine survival routinely observed in salmonids (Bradford 1995, Quinn 2018). Perhaps the wrong metric is being used. For example, rather than calculating changes in the "steady state" value, it would be better to calculate the minimum number of returning salmon and determine if it is below a level needed to prevent quasi-extinction. One might also estimate the number of years in which given levels of catch are likely or even (less optimistically) the number of years when there might be no catch. The model could also be used to estimate the number of "bad" years of ocean conditions occurring required to collapse the population.

(c) Lack of information about certain assumptions

Tables 6-6 (Chinook salmon) and 6-7 (sockeye salmon) in the Reintroduction Report identify the basic assumptions for each life-stage. This is very helpful, but it is unclear what fecundity values were used. Supplemental information provided to the ISAB by the UCUT modeling team states that the LCM permits users to decide whether or not to calculate age-weighted fecundity (assumed age composition of the run, % females in the run and eggs/female at different ages) and provides fecundity values and sources.

The chosen values of 2% marine survival (Bonneville to Bonneville) for Chinook and 5% for sockeye seem high, and it is unclear if these estimates are comparable to what has been measured in recent years. Supplemental information provided to the ISAB by the UCUT modeling team gives more detail on marine survival values and sources. The source of estimates of 2% SAR for spring-migrating juvenile Chinook is the Hatchery Scientific Review Group (2009), as quoted in the CCT ISIT model. A SAR of 2.53% (Lower Granite to Lower Granite) was assumed for fall-migrating juvenile Chinook based on a 7/27/16 NOAA Memo from Zabel to Graves (2007-2012 September and October in-river migrating fall Chinook from Lower Granite). The ocean survival for yearling migrants (BON-to-BON SAR) was assumed to be similar to fall migrants (value used was 2.53%) because body size of spring and fall migrants is similar. The supplemental information notes, "Pg 18 of the 2013 CSS [Comparative Survival Study] report states that for Snake River wild spring/summer Chinook ocean survival rates have varied from 0.3% to 6.1%, with a geometric mean of 1.9%." The 5% value for sockeye is based on SARs from Okanagan sockeye and is highly variable, and so the supplementary information suggests that sensitivity assessment should consider 4% - 8% SAR (Source: 10/19/17 Bussanich e-mail that shows SARs of 7.29% and 4.65%. 5% chosen). In general, the ISAB considers the SAR estimates used in the LCM to be optimistic given that they were derived from a period of relatively good ocean conditions and do not reflect lower ocean survivals during the 2014-2016 juvenile outmigration years when a warm water mass called "The Blob" reduced ocean survivals of salmon in the Gulf of Alaska.

It was also not clear in the Reintroduction Report what assumptions are made about the potential for either or both species to residualize, given the potential problems posed by passing the dam.

The estimates of harvest in the Baseline Scenario amounted to 58% of the returning adult Chinook and 28% of returning adult sockeye. The supplemental information provided by the UCUT modeling team gave reach-specific harvest values and sources. The supplemental report notes that "UCR summer Chinook has been declared by NOAA to be over-exploited (Federal Register notice). CCT's annual review of harvest rates for ISIT confirms exploitation of about 75% currently." The model could be used to explore the influence of harvest management alternatives on the success of the reintroduction.

The report is silent about the assumptions made in the model with respect to the marine distribution of the fish. Sockeye salmon will presumably experience very little fishing pressure owing to their offshore distribution, but Chinook salmon can experience high or low pressure, depending on whether they are distributed along the coast or primarily in open water, and this is related to their population of origin (Sharma and Quinn 2012).

Ocean conditions are parameterized using a single set of values, but these conditions are likely to have the largest impact on SARs. Are the values used for ocean survival the “average” of current values, and do they account for future climate change? Because no stochastic behavior is applied at the ocean stage, the “steady-state” values obtained from the life-cycle model may never be obtained. For example, a bad year could push the population into a state where it never recovers and eventually goes extinct.

At present the model does not separate parameters for ocean survival into age-specific estimates of survival and harvest, although the report authors note that this feature may be added to future versions of the model. This should be done.

(d) Density dependence modelled only at spawner-stage

Density dependence is modelled only at the spawner stage of the life cycle, but competition might also occur in freshwater habitats used by juveniles. If the reintroduced fish generate a large number of juveniles that migrate in common with juveniles released below Chief Joseph Dam, their smolts from the blocked area may experience density-dependent effects as well. The current model can incorporate density dependence (via a Beverton-Holt [BH] relationship) in all life stages. However, the capacity in other life-stages is set presently to a very large number, rendering density dependence moot. It is possible that the ocean habitat capacity is insufficient to accommodate the new (reintroduced) populations of salmon without negatively impacting other ESA-listed populations, but the increase in overall abundance from this effort is likely too small for this to be a major concern.

(e) Predator effect should be explicit

Sources of mortality outside the blocked area, other than passage and harvest, were not represented explicitly in the LCM (e.g., avian and marine mammal predation). Sources of mortality within the blocked area—such as predation from northern pike, smallmouth bass, and walleye—are included only implicitly in reach-specific survival rates in the LCM (see section on Predation above). Effects of predation are represented as part of the overall survival rates (e.g., probability of survival per kilometer of passage) for juvenile and adult salmon in reaches downstream of Chef Joseph Dam. Moreover, model runs should include scenarios where the distribution and abundance of these predators has increased due to regional warming. While this version of the LCM may be adequate for initial consideration of the feasibility of reintroduction, more explicit representation of sources of mortality should be included before making final decisions.

(f) Implementation concerns

The authors need to immediately check the implementation of the Beverton-Holt model. The Beverton-Holt relationship is presented on page 68, but the N + p in the equation should be N * p, as presented in the paper cited by the authors (Mousalli and Hilborn 1986)[3] It is not clear if this a typographical error or if the spreadsheet is incorrect. A review of the Excel spreadsheet by the ISAB was inconclusive because of the complexity of the formula in the relevant cells used in the spreadsheet.

Blocked areas cannot simply be treated as instantaneously available habitat—not from the perspective of fish behavior, at any rate. It could take many years before a theoretical carrying capacity becomes an empirical one. Reintroduced fish could take years to stray into unseeded areas and imprint for subsequent homing. With no perspective on the rate of population growth from model simulations (since they are presented as instantaneously reached equilibria) and with effective recruit per spawner numbers changing as larger fractions of the population utilize new habitat, the results presented make it difficult to gauge success from a temporal perspective, i.e., how long before the population fully uses the new habitat.

Some care is needed to ensure that enough years are run that the model has converged. There does not appear to be a model diagnostic to alert the user that convergence has not occurred. This should be added.

There are some (minor) differences between the documentation of the model and the actual spreadsheets. The screen shots should be checked.

- For example, page 16 of the user manual shows that the model results are “medians” (they are not), but the actual worksheet no longer has the incorrect captions.
- On page 18. The screen shot for the results of the sensitivity analysis in the documentation differs from the work. As well, the results are not “medians” and a better sensitivity measure is needed (see above).
- On page 19, the screen shots for the results of the sensitivity analysis are different than what is presented in the workbook (e.g., Y-axis is no longer labelled with number of simulated scenarios).

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[3] The incorrect function looks like a Beverton-Holt curve in that it rises steeply near the origin and asymptotes at high levels of the x-axis unit; however, it produces higher-than-appropriate y-axis unit predictions near the origin than the true Beverton-Holt function when the same parameters are used. Given the fact that several such Beverton-Holt functions are used sequentially, these errors could propagate and provide predictions far from those generated from the correct model.

D. Adult and juvenile passage

The success of the proposed project to reintroduce Chinook and sockeye salmon to waters above Chief Joseph and Grand Coulee dams depends on successful adult and juvenile passage over, around, or through the dams with acceptable survival rates and costs. These survival rates need to be high, given the many obstacles (e.g., other dams) that these fish face when going upstream and downstream. Survival also has to be sufficient for replacement and growth in the newly colonized habitat as well, including egg-to-fry and fry-to-smolt stages.

As discussed below, getting adults over the dams can be done using proven technologies such as fish ladders, passage ways, or perhaps some newly developed or future technology such as the new "Whooshh" technology. Successful juvenile passage through reservoirs and past dams is much more difficult to accomplish because of the small size and large numbers of juvenile salmon, the need for extremely high survival rates, and the difficulty of collecting them as they move downstream, especially when flows are high. Floating Surface Collectors (FSC) are discussed at some length, based on the reviews of NPCC (2016) and Kock et al. (2019), including where they can be placed at the two large dams. However, it is not clear whether the apparently successful collection of juvenile salmonids at smaller hydropower dams (e.g., Baker River, Washington) can be translated into success at the two large dams.

1. Adult passage facilities

Strengths

The Reintroduction Report indicated that successful adult passage requires an effective method of adult collection or attraction and rapid transit over the dams with minimal physiological impacts on the fish during the transit period. Five possible options for adult passage are presented: 1) trap and haul, 2) fish ladders, 3) fish elevators and locks, 4) the Whooshh Salmon Cannon, and 5) a natural fishway channel, or some combination of these approaches. The proponents concluded that any of these approaches could be used to get adult salmon over the two dams, separately or in combination. However, whenever new structures are built, costs are extremely high, so benefits of alternatives have to be weighed very carefully.

The Reintroduction Report acknowledged that final decisions about how to accomplish adult passage over each dam will require extensive planning and discussion with and by the dam owners and operators (Bureau of Reclamation, Army Corps of Engineers, Bonneville Power Administration). However, interim options were described for adult passage at each dam. One of the first factors considered was water temperature at the time of adult passage. Summer/fall Chinook are expected to arrive at both dams from late June through early November, and sockeye from mid-June through early September. Average river temperatures below the dams at those times of year will likely meet EPA standards ($\leq 20^{o}$ C). Consequently, thermal blocks to migration or mortality due to excessive water temperatures are not expected to occur, at least in the immediate future. The report cites the thermal barrier downstream of the dams in the Okanogan River as an example of Chinook and sockeye maintaining their populations despite high temperatures in late summer in that river because the cooler Columbia River, usually around 19° C, creates a refuge. However, both species must ascend the Okanogan River for spawning, so suitable temperatures in the river are still necessary. Temperatures in the Okanogan River are close to being too warm under present conditions, demonstrating that climate change models need to be consulted before major decisions are made about passage methods. Indeed, in parts of the Columbia River system, returning salmon have experienced significant *en route* and pre-spawning mortality in recent years (e.g., Bowerman et al. 2018).

The interim adult passage approaches proposed for each dam were similar. When the Chief Joseph salmon hatchery was built, a fish ladder leading into the hatchery was installed on the right-hand bank (looking downstream). Thousands of summer/fall Chinook, many of non-hatchery origin, are attracted to the ladder and can be intercepted there. The proponents suggested that fish captured at this site could be transported and released above the dam. They also suggested that another ladder could be built next to Foster Creek on the left-hand bank of the river (looking downstream), just below the face of Chief Joseph Dam. To further attract fish into this structure, a secondary entrance located in the tailrace was proposed, with water pumped from the tailrace. The ladder would not ascend to the forebay. Instead, after a relatively short gain in elevation it would end in an adult holding area that would be equipped with Whooshh systems to transport fish over the dam.

The Whooshh technology is still experimental; thus, the system should be viewed with caution given the untested aspects of the proposed operation (e.g., getting fish over the high dams). Some research has been performed on the potential effects of this new method on adult survival and reproductive success. No deleterious effects were reported (NPCC 2016-14). However, during the ISAB tour of facilities (August 27-28, 2019), Toby Kock (USGS) and the Whooshh representative indicated that in earlier trials the internal water misting system along the tubes failed, leading to mortalities as high as 100% in three of four trials. Therefore, more research on best approaches to employ the Whooshh Cannon (e.g., how to attract, aggregate, guide, and select fish of various sizes into multiple cannons) is needed to ensure high survival. Furthermore, both the Chief Joseph and Grand Coulee dams are high head structures, so trials should be performed that mimic the length and elevation gain needed in a Whooshh tube to get fish over these dams. In short, we do not know if the adult salmon can find the cannon entrance in a "real life" situation, how much elevation the tubes can overcome, how well they would operate under variable and less than ideal flow conditions, and whether there will be delayed or latent effects on the salmon even though they survive the passage. Such latent effects might depend on whether the fish are released into the reservoirs directly, trucked, or transported in some other manner after the Whooshh process. Presumably, the final solution to adult passage will involve multiple means of getting adult salmon over the dams, with or without Whooshh technology.

At Grand Coulee Dam (67 km upriver from Chief Joseph Dam), interim steep passage structures established on each bank of the river are proposed. As is the case at Chief Joseph Dam, these passage structures would terminate in adult holding areas after a moderate gain in elevation. Pumps would need to be installed to deliver water from the dam's tailrace into each passage structure. Whooshh systems are proposed for each terminus to transport adults into Lake Roosevelt. More conventionally (and more likely, given our current state of knowledge of Whooshh), captured fish would be transported by truck and released into the reservoir.

Limitations, data uncertainties, and critical analytical gaps

The proposed interim adult passage approaches appear to be reasonable. For example, little additional infrastructure would be needed if the Chief Joseph Fish Hatchery ladder is used as the capture point for adults. Fish hauling trucks would, however, be required to move fish into Rufus Woods Lake or perhaps into Lake Roosevelt as well. A greater financial commitment would be needed if a second ladder is constructed at the Foster Creek site. The ladder and adult holding area would need to be designed, built, and supplied with water pumps and, possibly, Whooshh systems. In 2002, the Army Corps (USACE 2002) examined the suitability and cost of installing a fish ladder, a natural channel, or a fish elevator and lock system for adult passage at Chief Joseph Dam. Among these, the natural channel option might also be used as a passage route for juveniles moving downstream.

No ladders or other infrastructure to facilitate fish passage are currently available at the base of the Grand Coulee Dam. If the steep passage option proposed as an interim solution for adult passage at this dam is adopted, permitting, engineering and construction design, and subsequent construction efforts should begin in the near future. If trucking is involved in moving fish over Chief Joseph Dam, presumably the fish could be released above Grand Coulee Dam, rather than above Chief Joseph Dam, given the relatively short distance between dams. However, such transportation should not preclude use of habitat between the dams such as in Rufus Woods Lake and tributaries.

2. Juvenile passage facilities

Strengths

The Reintroduction Report forthrightly admits that collecting and passing juvenile salmon over Grand Coulee and Chief Joseph dams represents one of the most significant challenges faced by the proposed reintroduction program. Each dam has different juvenile collection challenges. The proponents present several possible approaches that could be used for juvenile passage at each dam, which are summarized below. They emphasize, however, that these are tentative solutions. Comprehensive discussions with the Bureau of Reclamation, Army Corps of Engineers, and BPA are needed to select the best juvenile passage solutions for each dam. Uncertainties about how smolts approach the dams and their possible survival over spillways and through dam turbines need to be resolved. Additionally, information on the survival of juveniles while juveniles rear and migrate through each dam’s reservoir will need to be incorporated into any final passage solutions, including the potential for collecting juveniles above Grand Coulee Dam for release below Chief Joseph Dam.

The Reintroduction Report described environmental factors that would influence juvenile passage. Water temperatures, flows, and dam spill rates all appear to be favorable during periods when migration is expected to occur (March – June). For example, water retention (residence time) in Rufus

Woods Lake averages around five days, from which the proponents concluded that transit time by smolts through this reservoir will be rapid. Water retention times in Lake Roosevelt are much longer and typically range from 30 to 80 days. However, when most smolt migration is expected to occur the lake will be drawing down, so water retention at this time could be substantially shorter (14 to 30 days). The Report assumed that smolt migration rates are linked to water transit times and that, consequently, smolt transit times will be faster when water retention is low. However, juvenile sockeye and possibly some juvenile Chinook are expected to spend a year in the reservoir before migrating downstream as smolts. During extended rearing in the reservoir, juvenile salmon will be exposed to a number of physical and biological threats that potentially reduce survival rates. Among the threats are predation, fish pathogens, high total dissolved gas, and contaminants.

Floating Surface Collection (FSC) structures, equipped with guidance nets and pumps to create attraction water, were identified as methods to enhance juvenile passage at both dams. Smolts collected from these structures would be released below the tailrace of each dam, either by pipe or truck. A review that examined the use of FSCs indicated that the use of lead nets, size of the collector entrance area, relative size of the forebay, and interaction between the size of the collector entrance and forebay areas all influenced capture efficiency (Kock et al. 2019). A review of effectiveness of FSCs, mostly in smaller hydropower dams in the Columbia River Basin, concluded that evidence for success of FSCs in increasing adult salmon populations above dams was lacking (Lusardi and Moyle 2017).

The physical settings where the proponents have suggested siting FSCs at Chief Joseph and Grand Coulee dams have suitable forebay sizes and attraction flows. At Grand Coulee Dam, for instance, ~85% of the fish entrain over the dam at the site chosen for the FSC.[4] However, flows at FSC sites at both Grand Coulee and Chief Joseph dams are an order of magnitude greater (150 kcfs) than other locations where FSCs have previously been installed. The effects of such high volumes of water on guidance nets need to be determined. If guidance nets prove to be impractical, then other guiding structures will need to be evaluated. The proponents suggested that trash screens with narrow spacing could be tried if flows prohibit the use of nets because water velocity and/or volume are too high.

The configuration of Chief Joseph Dam and the small amount of annual variation in the surface elevation (though daily and hourly scale fluctuations should be considered) of Rufus Wood Reservoir would also allow a fish collection system to be built that is similar to the corner fish collector at Rocky Reach Dam, operated by Chelan PUD. It has an attraction flow of 6,000 cfs and survival rates for juvenile sockeye and Chinook are > 93%. While this seems like a viable possibility, Rocky Reach Dam is about one half the height of Chief Joseph Dam, so careful evaluation will be required. As mentioned previously, a stream channel built for adult passage could also serve as a secondary or primary juvenile passage route. The major obstacle for this option would be attracting fish to the site where the channel exits the reservoir. Like the FSC, guidance nets or other structures would probably be needed to get fish to enter a channel. As with the FSC, guidance nets for the natural stream would likely be affected by high flows, so

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[4] In some months, over 100,000 fish are entrained over Grand Coulee Dam (*see* e.g., Fig 7-17 page 121 in the Reintroduction Report). It is suggested that kokanee and trout collected by the FSC could be returned to Lake Roosevelt. Conversely, non-indigenous fish predators, e.g., walleye, bass, and northern pike, could be culled.

alternatives to nets would need to be considered. All of these features would be affected by dam operation as well, especially hourly/daily variation for power peaking.

Environmental conditions at Grand Coulee Dam for juvenile passage are more challenging than those at Chief Joseph Dam. To provide flood control, reservoir levels can vary by up to 80 feet and annually vary around 50 feet. Decreases in lake elevation coincide with smolt and adult migration periods in spring and early summer, making passage for both life stages difficult. Accordingly, any juvenile passage system installed at Grand Coulee Dam will need to function at varying lake elevations; an FSC can apparently be designed to do so. The Bureau of Reclamation (BOR) faced a similar challenge at Cle Elum Lake where a temporary passage structure for sockeye smolts needed to be replaced. Water level behind Lake Cle Elum's dam can vary up to 64 feet. A multilevel gated intake structure with a 7-foot diameter, 1,500 foot-long fish conduit that discharges below the dam is currently under construction (background). Plainly, the situation at Cle Elum is very different than that at Grand Coulee. Nevertheless, this passage structure was designed to accommodate a range of reservoir elevations and so may be of interest to the proponents, BOR, BPA, and USACE.

Three other possible juvenile passage options for Grand Coulee Dam were also mentioned in the Reintroduction Report. Spills often occur during the smolt out-migration period, even though reservoir levels are fluctuating. The proponents suggest that spill water could be re-routed to a secondary juvenile collector located at or adjacent to the spillway and thus serve as another fish collection point. Additionally, the report noted that fish may enter turbines that pump water into Banks Lake. A screening system could divert these fish into the Grand Coulee tailrace and Rufus Woods Lake and provide another juvenile passage route. Finally, the proponents hypothesized that a second FSC may be needed at the head of Lake Roosevelt. Because Lake Roosevelt's elevation varies substantially, this structure would not operate as a typical FSC but would more closely resemble a Merwin trap with long net guides. To improve survival rates, captured fish would be placed into net pens or barges and moved down Lake Roosevelt and liberated below Grand Coulee Dam.

The second FSC may not be needed if the survival of smolts migrating through Lake Roosevelt is high enough to support sustainable populations in the Transboundary Reach and in other upstream locations. Given the predation issues (see predation section of this report) in this reservoir, smolt survival may vary by species, smolt size, transit time, time of year, and such. The extent of these sources of variation will not be known until explicit studies designed to answer these questions can be conducted. The proponents have provided some reasonable options for juvenile passage. As they note, refinements or alternatives to these suggestions will be made in the future after consultations with BPA, BOR, and USACE. Research projects resulting from these discussions will also help to determine what passage options are ultimately used.

Limitations, data uncertainties, and critical analytical gaps

The proponents' assumption that the migration rate of smolts will be directly related to how fast water moves through the reservoir may not be correct. A study that examined the seaward migration of sockeye salmon exiting Babine Lake found that migrating sockeye smolts swam at peak rates (~30 cm/sec) from dusk to dawn and that directional tendencies of these fish were consistent with the shortest route out of the lake (Groot 1965). However, these smolts were genetically adapted to this very long, narrow lake, and the migration patterns there may not be replicated by salmonids in a new habitat. Nevertheless, assuming that the migratory rates of sockeye or other salmonid smolts are perfectly aligned with water transit times may substantially underestimate their true out-migration rates. Giorgi et al. (1997) reported variable relationships between discharge and travel rates of salmonids in the mid-Columbia River. Field evaluations in Lake Roosevelt will be needed to determine how rapidly sockeye, summer/fall Chinook, and steelhead transit through the lake, noting that sockeye are expected to take up residence in the lake for a year.

3. Reservoir passage and survival

Strengths

The proponents recognize that survival of juveniles through the reservoirs, especially Lake Roosevelt, will be a problem. A literature review was used to create hypotheses about juvenile salmonid growth and survival in lakes Roosevelt and Rufus Woods. Likewise, data from similar reservoirs were used to forecast possible survival rates of emigrating smolts. The proponents' review suggested that growth, survival, and emigration rates should be great enough to allow successful reintroductions to occur. Once introduced salmonids start to rear and migrate through these systems, these early estimates can be refined, in particular in response to the effects of predation.

Limitations, data uncertainties, and critical analytical gaps

A number of assumptions were made about the likely growth and survival of juvenile sockeye and summer/fall Chinook in lakes Roosevelt and Rufus Woods. One of these is that food supplies in the two reservoirs would be greater than in riverine habitats and therefore capacity and productivity are expected to be greater for summer/fall Chinook than if they were rearing in a typical large river. Lake Roosevelt was also assumed to have excellent rearing potential for juvenile sockeye. Limnological data collected in Lake Roosevelt support this assumption. However, a key factor that is not mentioned is the presence of northern pike and other non-indigenous fish predators such as walleye and smallmouth bass. If rearing salmonids occupy the same habitats as these predators, substantial reductions in salmonid abundance will likely occur. In Lake Washington, for instance, some smolting sockeye emigrated along shorelines prior to leaving the lake. If sockeye in Lake Roosevelt behave in the same manner, they may expose themselves to predation in littoral areas of the lake. Additionally, sub-yearling Chinook often feed in littoral areas in reservoirs, and if this occurs in Lake Roosevelt, substantial losses of these fish may occur due to predation.

Survival rates of smolts moving through lakes Roosevelt and Rufus Woods were estimated using information from other large reservoirs. This seems reasonable, although those other systems did not contain northern pike. A concerted effort to suppress northern pike is occurring in Lake Roosevelt. If their numbers can be reduced, then it is possible that the survival rates of salmon envisioned by the proponents can be realized. In addition, predation by other non-indigenous fishes may substantially reduce numbers of sockeye and Chinook smolts (see predation section of this report).

In addition, as of 2016 the Confederated Tribes of the Colville Reservation had a net pen rearing project for rainbow trout in Rufus Woods Lake. This program was scheduled to release 50,000 to 70,000 trout per year with perhaps 20,000 of them weighing as much as 1 kg (2.2 pounds). Such fish could be significant predators on rearing and migrating juvenile salmonids. It is not stated whether or not this program will be modified or terminated after reintroduction of sockeye and summer/fall Chinook.

Other critical uncertainties not considered in the Reintroduction Report relate to reservoir water quality. The first relates to possible impacts on adult and juvenile salmonids from high total dissolved gas supersaturated water (TDGS). In response to high TDGS (> 140%) below Grand Coulee Dam in the mid-1990s, the BOR funded studies of the effects of high TDGS on fish in Rufus Woods Lake (Beeman et al. 2003) and also explored ways of minimizing TDGS by dam operations (Frizell 1998). Data from Columbia River DART (2019) indicated that in the past 10 years TDGS at the Canadian border has occasionally exceeded 130% (Figure 4) and was often over 115% in the Grand Coulee forebay (Figure 5). High TDGS continues to be an issue in Rufus Woods Lake where it is frequently greater than 130% and occasionally approaches 145% (measured six miles downstream of Grand Coulee Dam (Figure 6). In the Chief Joseph Dam forebay, TDGS continues to be high—often 120% to 135% (Figure 7).

Hydrostatic compensation protects fish to the extent that 1 m of depth compensates for about 10% TDGS. Thus, juvenile steelhead and Chinook that emigrate at 1.5 to 3.0 m depths (Beeman and Maule 2006) may be protected from gas bubble disease (GBD) when TDGS is 115% to 130%. Backman and Evans (2002) and Backman et al. (2002) collected adult and juvenile salmon (steelhead, coho, sockeye and Chinook) migrating in the lower Columbia and Snake rivers and reported that signs of GBD remained low until TDGS in the river exceeded 125%. In adult salmon, the most severe signs of gas bubble disease when TDGS exceeded 125% were seen in sockeye, followed by steelhead and Chinook (Backman and Evans 2002). Similar effects were seen in juveniles with the proportion of fish with severe signs of GBT increasing sharply when TDGS was above 125%. While Gale et al. (2004) found that acute exposures (< 125% TDGS) did not impair reproductive success of adult Chinook, information about the effects of TDGS > 130% is critical because we do not know if these levels can reduce predator avoidance (Mesa and Warren 1997) and increase susceptibility to fish pathogens (Weiland et al. 1999) in juvenile salmon.

Contaminants are another water quality uncertainty. Many fish in Lake Roosevelt have mercury and PCB levels that make them unhealthy for human consumption (see fish advisory). These contaminants can also reduce a fish's ability to survive and reproduce (Jørgensen et al. 2006).

In future documents, the proponents should provide an understanding of the importance of these water quality issues and propose means of tracking their possible impacts on the success of reintroductions. The proponents might consider designing an experiment to detect impacts of water quality on adult and/or juvenile salmonids using net pens similar to those in upper Klamath River (Maule et al. 2009). Net pens that can be lowered in the water column would provide an excellent control when examining the effects of high TDGS.

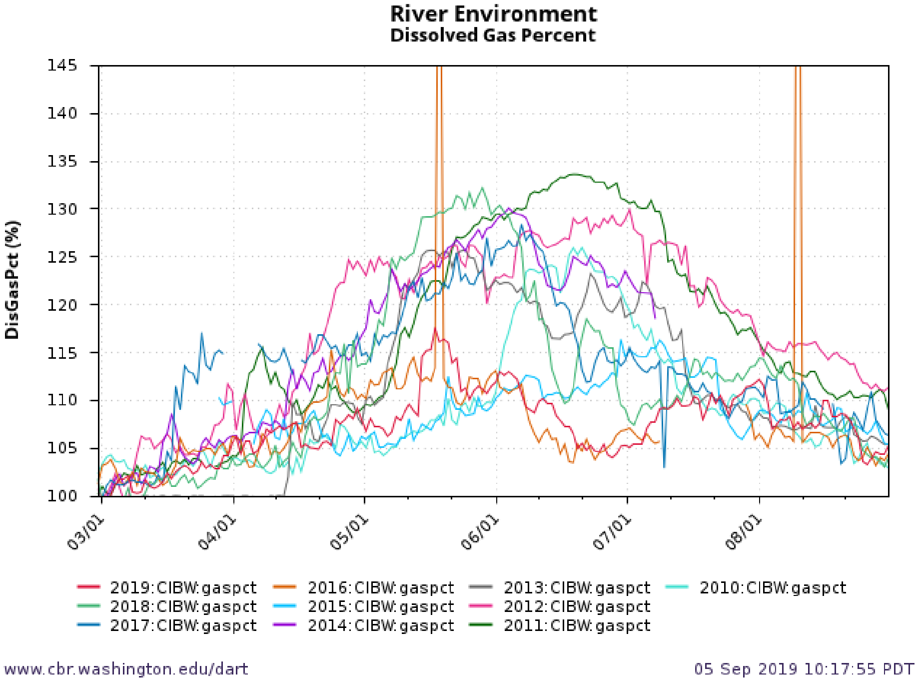


Figure 4. Total dissolved gas measured in the Columbia River at the Canadian border between 2010-2019 during the spring and summer (March 1 to August 31).

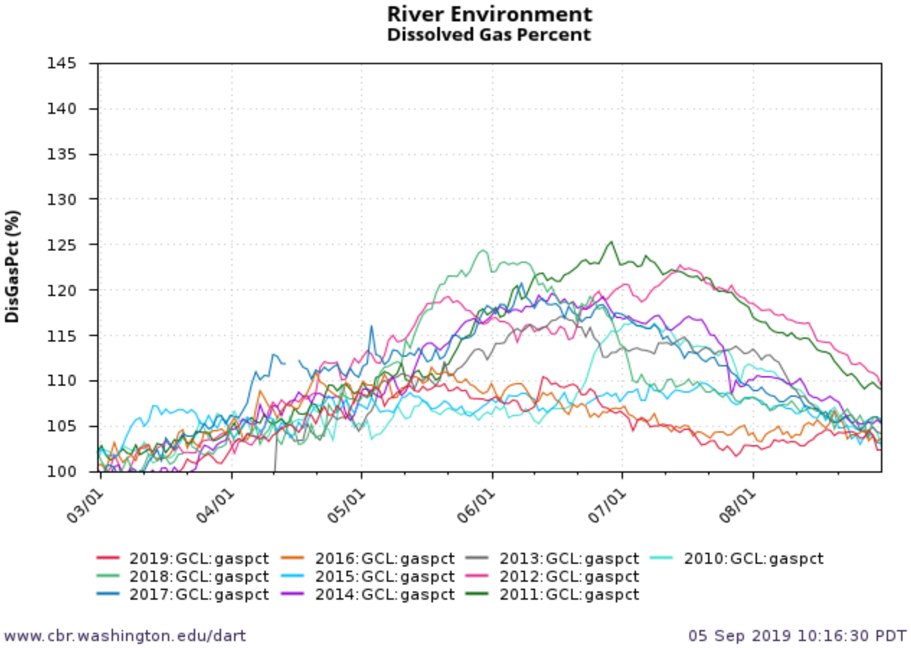
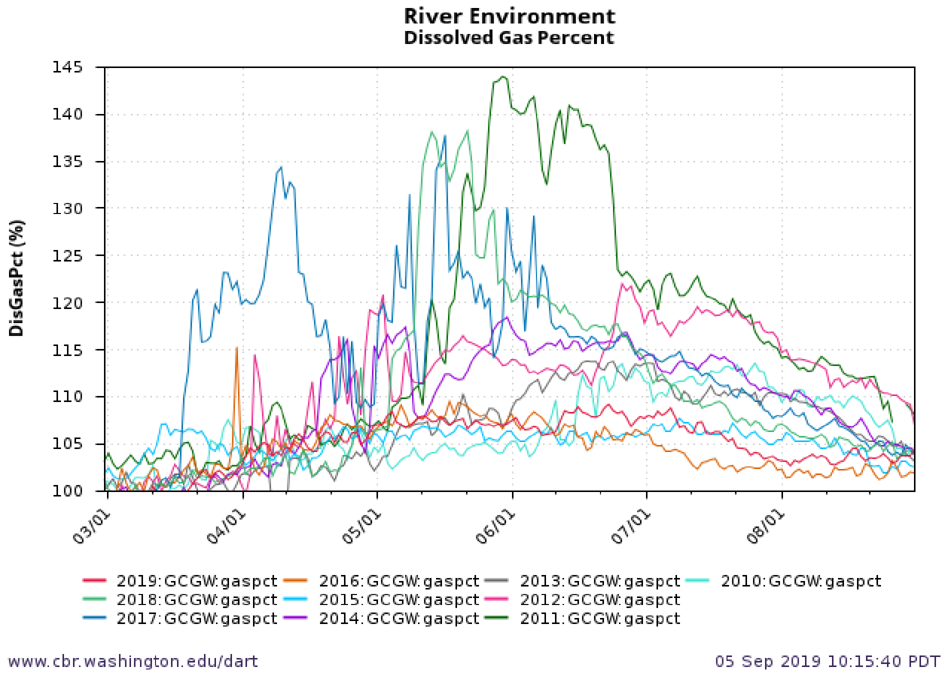


Figure 5. Total dissolved gas measured in the forebay of Grand Coulee Dam between 2010-2019 during the spring and summer (March 1 to August 31).



www.cbr.washington.edu/dart

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Figure 6. Total dissolved gas measured in Rufus Woods Lake about 6 miles downstream of Grand Coulee Dam between 2010-2019 during the spring and summer (March 1 to August 31).

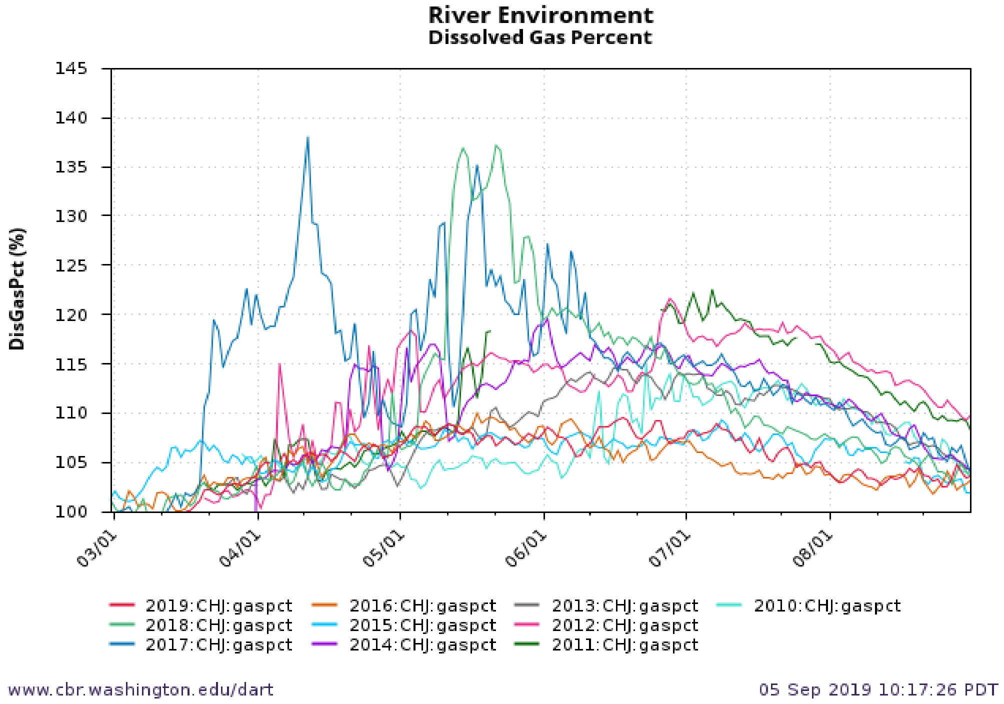

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Figure 7. Total dissolved gas measured in the forebay of Chief Joseph Dam between 2010-2019 during the spring and summer (March 1 to August 31).

4. NPCC sub-question on costs

As the Council's letter to the ISAB acknowledged, the Reintroduction Report focused on biological and physical assessments but did not address the 2014 Fish and Wildlife Program Phase 1 element to investigate the possible cost of upstream and downstream passage options for salmon and steelhead. The Council asked the ISAB to consider the following questions to help inform potential future cost evaluations. Regarding fish passage, the Council asked: "Does this section cover the potential passage technologies and alternatives for upstream and downstream passage, their feasibility, and associated biological information that should be evaluated to inform an estimated cost?" The identification of technologies and alternatives is of course needed to begin estimating costs, and the information on feasibility and associated biological information is needed subsequently to estimate cost-effectiveness. The Council went on to ask: "Is additional information on passage alternatives needed to provide a cost estimate; if so, what information?"

Additional information is needed to form the basis for a detailed economic study to estimate costs—both direct and indirect—associated with each technology under consideration. These estimates would also inform decisions about timing, complementarity, and risks associated with the sequential and experimental nature of the reintroduction program. Proximate costs will include interim actions, whereas final costs will depend on subsequent decisions and details of the final stages of re-establishment and fish passage construction. Moreover, interim studies and trials are likely to limit the scope of the ultimate program as uncertainties are resolved, additional information is acquired, and re-introduction scenarios are accepted or rejected.

In short, a roadmap is needed for implementation of Phase II through project completion. Qualified economists will be required to produce estimates of all relevant costs based on the best available information. Similar to the way that UCUT contracted with DJ Warren and Associates to develop the LCM, an economic study of the costs associated with each technology under consideration is necessary for making critical interim and final decisions about technology choices based on evaluations of the most cost-effective and highest performing set of actions to be taken. These cost and cost-effectiveness analyses should be initiated as soon as possible. The incremental approach and prototype choices will need to account for both biological effectiveness and cost effectiveness. Lead times to develop and implement technologies are long and once started, costly to change and start over, so costs and cost effectiveness must be analyzed in a timely manner.

The issues of cost, cost-effectiveness, and funding are mentioned numerous times in the Reintroduction Report. No specific cost information is included nor are there indications of how economic data and analysis will be undertaken in the next stage.

Further comments and observations to address the Council's questions:

1. (page 10) "The Council in collaboration with other relevant entities will decide whether and how to proceed to implement and fund reintroduction measures as a permanent part of the program."

This is an important point because the benefits of the program will depend on how funds allocated to this program impact funding for other programs. For example, if funds are drawn in part or in whole from existing BPA budgets in future years, then the net benefits suggested in the Reintroduction Report (e.g., basin-wide benefits including harvest and benefits to Southern Resident Killer Whale populations, etc.) may be overstated. This will depend on the relative cost-effectiveness of the Reintroduction Program activities versus the currently funded or proposed alternatives that would otherwise benefit these focal species in other ways. For a given budget level, if the cost-effectiveness of the reintroduction program is lower than ongoing projects it would "crowd out" existing programs, so the net effect regionally would be negative. Therefore, to evaluate the net effect of this additional activity, one must estimate the extent to which the funding is additional, and which are likely to be drawn away from other competing activities. In the substitution case, it will be important to estimate the reductions in net benefit for those other activities that will be curtailed.

2. (page 11) "Council staff began Phase 1 activities by reviewing regional fish passage facilities, their effectiveness and associated costs (NPCC 2016). This report effectively completed Task 1 of Phase 1 with partial completion of the cost's analysis called for in Task 2."

   The NPCC 2016 report is based on cost estimates provided by the Corps (U.S. Army Corps of Engineers 2002), which in turn were based on a study of fish passage at 16 hydroelectric projects (Francfort et al. 1994). The NPCC Staff Paper summarized those cost (NPCC 2016, pp 68-69), which was very useful.[5] Updating these summary cost estimates to 2019 dollars, they estimated costs for juvenile and adult salmon passage at Chief Joseph Dam (annualized over a 30-year period using a 4% discount rate) would be $32 million per year based on a basic set of passage system components (items 1, 4, 5, 6, 7 in Table 2). These figures are no doubt outdated and do not include some current technologies. Nevertheless, they are useful as a starting point for recognizing the levels of cost that may be involved, need for potential sources of funding, and kinds of economic analyses needed to update and improve these estimates. These estimates also provide an initial point of comparison for the baseline LCM estimates of increases of 41,000 adult summer/fall Chinook and 76,000 adult sockeye from the blocked area.

3. (page 14) "Whenever and wherever possible, methods that utilize existing riverine and reservoir habitats to rear and produce fish will be preferred. This approach is expected to reduce costs associated with the reintroduction effort."

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[5] The NPCC Staff Paper (2016, p. 10) quotes from an IEAB memo in a misleading way due to lack of context. The IEAB was not suggesting that cost comparisons about fish passage among projects was not useful due to the presence of too much variation in the site characteristics, different vintages, and such. The IEAB was commenting on what could be ascertained on the basis of the information provided to them at the time by NPCC Staff. With time and resources, much better data could be collected to estimate these cost relationships, as suggested by the estimates in Table 2, compiled on the basis of detailed comparative analysis by the U.S. Army Corps and Idaho National Engineering Laboratory.

To determine which methods are lowest costs, it will be necessary to evaluate the costs in the same timeframe with the evaluation of each method's effectiveness.

4. (page 64) [LCM discussion] "The variants also provide insights into the possible sequencing of fish passage facilities and propagation actions to optimize benefits and costs."

   We emphasize again that it will only be possible to have insights for possible sequencing to optimize benefits and costs (most cost-effective choices) if detailed cost analyses and cost-effectiveness ratios are developed simultaneously with the progress being made on all other fronts.

5. (page 93) [On LCM sensitivity analysis and SARS—improving juvenile survival rates as by 10% results in a 21% increase in adult production.] "This finding is important for it points out that if survival targets upstream of Chief Joseph Dam cannot be met, or the cost is prohibitive, then improvement at downstream dams may help achieve reintroduction goals while at the same time increasing abundance of downstream salmon populations."

   This rationale carries over to the economic analysis. Cost effectiveness is measured as a ratio of the change in cost to the change in impact (e.g., survival or population abundance). To approach this systematically will require consideration of how the performance of the program can be improved either by increasing survival (directly or indirectly) or by lowering the cost. Both the numerator and the denominator of the cost-effectiveness ratio have equal potential for increasing the performance or impact of the program over a given period of time and fixed budget (ISAB 2018-3).

6. (page 97) "The FSC technology continues to evolve and improve in function and cost as evidenced from designs installed at Puget Sound Energy's (PSE) Upper Baker Dam in 2008…"

   The observation that this technology is improving in function and cost is not documented with data either about cost or improved performance. This could be an important consideration if technology is changing rapidly, as frequently occurs with increased efficiency (Jaffe et al. 2003). Moreover, testing the FSC prototype system may be important to determine the likely success of a full system, but decisions about this sequencing will also depend on the relative cost of the prototype versus the full system (see also pages 136, 142).

Table 2. Cost estimates for fish passage at Chief Joseph Dam reported in NPCC 2016 (in millions of 2019 dollars)

		Capital cost	Annualized capital cost*	Annual operating cost	Annual generation cost	Studies (yearly for first 5 yrs)	Annualized study costs*	Annualized cost total
1	Single-fish ladder	59.3	3.4	0.3	1.2	6.6	1.8	7.1
2	Bypass channel for upstream and downstream passage	93.5	5.4	0.3	0.9	6.6	1.8	8.9
3	Fish lift or lock	39.5	2.3	1.1	1.7	6.6	1.8	7.3
4	Surface bypass collector for downstream passage	27.7	1.6	1.5	3.9	11.9	3.3	10.9
5	Traveling screens for gatewell turbine bypass for downstream passage	67.2	3.9	1.5	0.3	5.3	1.5	7.7
6	Passage collection and transportation facilities (downstream and upstream)	9.2	0.5					0.6
7	Annual generation loss for downstream spill passageway				5.3			5.7
	Total annualized costs excluding items 2 and 3							**32.0**

* Annualized costs reflect financially equivalent annual payments over 30 years (at 4%) based on the present value of a given cost in year 1.

Additional aspects of economic analysis needing attention and the involvement of economists:

Costs and risk: For example, rather than building an expensive facility at the start, it may be preferable to implement a less permanent structure or method to see if reintroduction is feasible. If reintroduction fails, then a “temporary” solution to passage can be dismantled and the costs of failure minimized. There may also be staging issues. For example, if it takes five years to construct a facility, what methods will be used in the interim? Cost analyses are needed that consider risks related to failure or investments that are then abandoned because other technologies prove to be superior on the basis of biological effectiveness or cost-effectiveness. This kind of risk modeling could be used to improve or optimize the timing of irreversible decisions about construction and technology selection. Also, understanding risks from stochasticity may influence design-decisions. For example, the LCM does not model variation in ocean survival probabilities, density dependence (except for spawners), or account for future climate change. Variation in ocean conditions, which may be a large source of mortality, could imply that a better solution is to “buffer” the system against stochasticity by other actions to increasing salmon productivity.

Differences in survival between technologies may be small or null. In that case, the comparisons of cost-effectiveness across differing technologies will depend on their differences in cost, and estimates of costs are likely to be reasonably estimated from existing studies, engineering estimates, and fish passage operations elsewhere. As such, a two-stage procedure is suggested. First, develop rough estimates of annualized costs based on the U.S. Army Corps of Engineers (2002) and Francfort et al. (1994) studies. This will allow for more detailed initial comparisons given the estimated survival rates (e.g., in terms of cost to achieve a given percentage increase in abundance). This would include information on the costs for a Whooshh system, which was not available for the previous analyses. Second, conduct an economic study to estimate cost for each of the technologies relevant for future passage alternatives.

E. Future field studies and recommendations

The ISAB does not provide specific comments on this brief Reintroduction Report section, but the ISAB’s answer to the Council’s Question 2 and comments for each Reintroduction Report chapter above provide recommendations related to future assessments and studies.

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