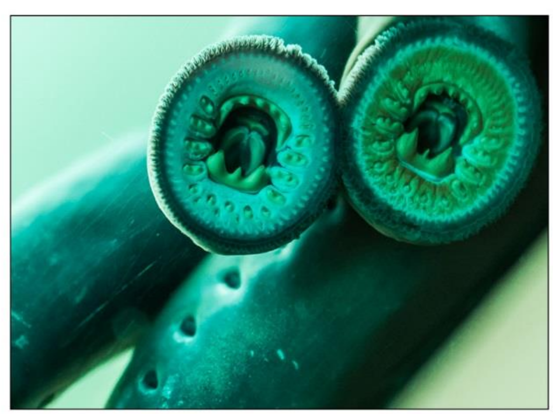
INDEPENDENT SCIENTIFIC ADVISORY BOARD

Review of the 2014 Columbia River Basin Fish and Wildlife Program

ISAB 2018-3 MARCH 23, 2018



Cover design by Eric Schrepel and photos by Tony Grover

ISAB

Independent Scientific Advisory Board
for the Northwest Power and Conservation Council,
Columbia River Basin Indian Tribes,
and National Marine Fisheries Service
851 SW 6th Avenue, Suite 1100
Portland, Oregon 97204

Kurt D. Fausch, Ph.D., (ISAB Vice-chair) Professor Emeritus of Fisheries and Aquatic Sciences, Department of Fish, Wildlife, and Conservation Biology at Colorado State University, Fort Collins, Colorado

Stanley Gregory, Ph.D., Professor Emeritus of Fisheries at Oregon State University, Corvallis, Oregon

William Jaeger, Ph.D., Professor of Applied Economics at Oregon State University, Corvallis, Oregon (also serves on IEAB)

Cynthia Jones, Ph.D., Eminent Scholar and Professor of Ocean, Earth, and Atmospheric Sciences; Director of the Center for Quantitative Fisheries Ecology; and A.D. and Annye L. Morgan Professor of Sciences at Old Dominion University, Virginia

Alec G. Maule, Ph.D., (ISAB Chair) Fisheries Consultant and former head of the Ecology and Environmental Physiology Section, United States Geological Survey, Columbia River Research Laboratory

Peter Moyle, Ph.D., Distinguished Professor Emeritus at the Department of Wildlife, Fish and Conservation Biology and associate director of the Center for Watershed Sciences, University of California, Davis

Katherine W. Myers, Ph.D., Research Scientist (Retired), Aquatic and Fishery Sciences, University of Washington, Seattle, Washington

Laurel Saito, Ph.D., P.E., Nevada Water Program Director, The Nature Conservancy of Nevada, Reno

Steve Schroder, Ph.D., Fisheries Consultant and Fisheries Research Scientist (Retired), Washington Department of Fish and Wildlife, Olympia, Washington

Carl J. Schwarz, Ph.D., Professor of Statistics and Actuarial Science at Simon Fraser University, Burnaby, British Columbia, Canada

Thomas Turner, Ph.D., Professor of Biology and Associate Dean for Research at the University of New Mexico, Albuquerque, New Mexico

ISAB Ex Officios and Manager

Michael Ford, Ph.D., Director of the Conservation Biology Program at the Northwest Fisheries Science Center, Seattle, Washington

Nancy Leonard, Ph.D., Manager, Fish, Wildlife, and Ecosystem Monitoring and Evaluation, Northwest Power and Conservation Council, Portland, Oregon

Zach Penney, Ph.D., Fisheries Science Manager at the Columbia River Inter-Tribal Fish Commission, Portland, Oregon

Erik Merrill, J.D., Manager, Independent Scientific Review, Northwest Power and Conservation Council, Portland, Oregon

ISAB REVIEW OF THE 2014 COLUMBIA RIVER BASIN FISH AND WILDLIFE PROGRAM

CONTENTS

LIST OF FIGURES

LIST OF TABLES

ACKNOWLEDGMENTS

Numerous individuals and institutions assisted the ISAB with this report. Their help and participation are gratefully acknowledged. Council staff including Tony Grover, Patty O'Toole, John Harrison, and Nancy Leonard provided useful briefings on the history, development, and implementation of the 2014 Fish and Wildlife Program. Jim Peterson (USGS Cooperative Fish and Wildlife Research Unit, Oregon State University) presented on adaptive management and structured decision making. Robby Fonner (NOAA Fisheries) presented on cost-effectiveness analysis to inform prioritization of habitat restoration actions. Michelle Wargo Rubb (NOAA Fisheries) and Brandon Chasco (Oregon State University) presented on marine mammal predation research. Eric Schrepel (Council staff) improved the quality of the report's formatting and graphics, and Kendra Coles helped with citations. The Council's administrative staff supported our numerous meetings.

I. EXECUTIVE SUMMARY

The Northwest Power and Conservation Council (Council) requested that the Independent Scientific Advisory Board (ISAB) evaluate the scientific merits of the Council's 2014 Columbia River Basin Fish and Wildlife Program (Program) in time to inform amendments to the Program during 2018. In its review, the ISAB used previous ISAB reports, including earlier reviews of the Program, and other documents including the Council staff's Program Implementation Assessment Report (NPCC Staff 2017). Overall the ISAB found that most sections of the 2014 Program provide sound scientific guidance for actions to mitigate for hydrosystem impacts and move toward recovery of fish and wildlife resources in the Columbia River Basin. The Council asked the ISAB to answer seven questions as part of the review. Those questions and answers can be found below (page 7) and are not summarized in this Executive Summary.

The ISAB found many strengths in the Program. Among these is Mainstem Hydrosystem passage research, which focuses mainly on survival of anadromous salmonids, elucidating the relative abundance and survival of hatchery versus naturally spawned fish, and the effects of run times on survival. Most of this work is very thorough and well done. The ISAB also sees great value in the Program's Protected Areas, which currently protect over 44,000 miles of rivers and streams of the Northwest from hydropower development, and the potential for the Stronghold Habitat strategy to protect native, wild, and natural-origin fish. The ISAB applauds the Program's strategy for Anadromous Fish Mitigation in Blocked Areas as first steps toward reestablishing salmon and steelhead in one third of their original habitat. Public Engagement is also a strength of the Program as descriptions of strategy, rationale, principles, and general measures are straightforward and well-articulated. Although it is not a specific strategy of the Program, the ISAB also supports the Council's interest in life-cycle models, which the ISAB sees as key to evaluating many proposed changes in the system—both before and after. The ISAB hopes the Council will continue to support life-cycle modeling efforts.

As indicated above, the ISAB found many strengths in the Program and the strategies are scientifically based. Several major weaknesses include the majority of Program goals need corresponding objectives, key Program strategies lack monitoring or evaluation plans or funding, and the Program provides limited guidance and use of adaptive management. Approaches are available to improve strengths and address weaknesses. The following are summary highlights of some ISAB recommendations to advance the scientific rigor of the Program. Follow the link at the end of each topic to fully examine the ISAB review of a specific strategy.

Program-wide Strategies

Adaptive Management. The Program provides limited scientific guidance for adaptive management for projects. The Program should develop rigorous decision-making processes based on regional strategies, address quantitative project objectives, develop coordinated monitoring and evaluation, and incorporate outcomes (i.e., lessons learned) into decision-making cycles that include project leaders, regional technical teams, and local stakeholders. (Pages 16 and 30)

Scientific Principles. The principles in the Program are scientifically sound. However, the ISAB recommends that these be reduced to four principles and be revised to aim at management of the Columbia River Basin power-generating and irrigation-supporting ecosystem —principles that imply that certain actions and conditions are needed to restore salmon, steelhead, and other native fish and wildlife in the Basin. (Page 24)

Goals and Objectives. A fundamental problem is the spatial scale at which goals and objectives are developed. For example, the objective of achieving 5 million salmon and steelhead in the entire Basin by 2025 is quantitative, but may not be useful if this leads to attempts to reach this goal primarily with hatchery salmon. Goals for salmon and steelhead abundance will be useful if they are based on inherent productivity, biological capacity, genetic and life-history diversity, and density-dependence relationships for specific subbasins. Objectives for most characteristics of salmon, steelhead, and other fish and wildlife populations, and key aspects of their ecosystems, are most useful if set at the subbasin scale for specific species, stocks and, in some cases, life-history stages. Objectives specific to subbasins can then be aggregated to derive overarching goals of, for example, abundance or escapement that are based on biological capacity and productivity, and reflect density-dependence. (Page 27)

Research. The ISAB and ISRP previously reviewed Program-funded research projects in their Critical Uncertainties report (ISAB/ISRP 2016-1), which was used in the development of the Council's Research Plan. The ISAB believes that the recommendations in the Executive Summary of the Critical Uncertainties Report will be useful as the Program amendment process goes forward. (Page 31)

Monitoring and Evaluation. Key Program strategies and measures, such as those for habitat and wildlife, lack monitoring and evaluation plans and adequate funding to address these important components of adaptive management. The Program needs information that can help refine actions and maximize the efficient use of scarce resources. Monitoring and evaluation provides information on whether projects such as habitat restoration, use of life-cycle models, and fish propagation, have been implemented effectively. At a time when information needs are growing, habitat monitoring needs support. The need for critical information for habitat protection and restoration remains a central requirement of the Program. (Page 30 and throughout the report)

Specific Strategies

Ecosystem Function. It is important for this portion of the Program to maintain focus on the entire Columbia River ecosystem, rather than focusing on habitat, for which there is a separate strategy. An ecosystem is a coupled physical-biological system that provides the environmental conditions (i.e., habitat) and biological production (i.e., food) required to sustain restored populations of fish and wildlife. This ecosystem includes riparian habitats, as well as upslope terrestrial habitats, groundwater sources, the estuary, plume, and ocean. (Page 36)

Habitat. The Program is a "habitat-based" plan, because restoration of salmon, steelhead**,** and other native fish and wildlife populations cannot be successful without adequate suitable habitat. The Program, however, does not mention a landscape perspective and does not have a landscape or subbasin context, despite the ISAB's ongoing focus on this point (see ISAB 2011-4). Neither the Principles nor General Measures of the Habitat strategy address research, monitoring, or evaluation. (Page 37)

Climate Change. The scientific evidence is unequivocal that human actions (i.e., the use of fossil fuels that increase CO_2 in the atmosphere and ocean) are driving climate change and ocean acidification. Indeed, the Council should increase its efforts to promote public awareness, convene science/policy workshops, and encourage the development of alternative energy. (Page 47)

Mainstem Hydrosystem Flow and Passage. Program work on passage and survival of anadromous salmonids has been thorough and well done. Hydrosystem operations, however, change the carrying capacity of mainstem habitats and impact ecosystem function and species other than salmonids. The Program needs to address mainstem habitat conditions and floodplain connectivity as elements in density-dependent regulation of fish. (Page 49)

Estuary. The ISAB recommends updating this strategy to focus on the most important information gap limiting the evaluation strategy—the lack of quantitative estimates of survival of juvenile salmon, steelhead, and other focal species in the estuary. (Page 50)

Plume and Nearshore Ocean. Most ocean mortality of salmon occurs in the initial phase of entry into the plume and nearshore ocean. Considering recent advances in scientific understanding of the effects of ocean conditions on Columbia River salmon, this strategy should be updated to guide projects and actions aimed at filling large gaps in population-specific information on these effects (including hatchery/wild interactions) in an ecosystem and life-cycle context. (Page 53)

Fish Propagation. The potential success of this Program strategy is dependent on: (1) fish possessing genetic and phenotypic characteristics well-suited for the natural environment, and (2) the capacities of the environments receiving the fish to accommodate these new recruits. The Program should also examine the total impact of fish releases made by diverse programs. For instance, do cumulative releases of juvenile salmonids overwhelm available food resources in subbasins, the mainstem, estuary, or ocean plume? (Page 56)

Wild Fish. A revised strategy should include measures to increase habitat quality, increase the number of restored habitats across watersheds, and increase connectivity throughout the hydrosystem. (Page 57)

Improving Cost-Effectiveness Evaluation. Despite Program guidance, cost-effectiveness analysis has not been undertaken to rank and prioritize projects. Prioritization should involve choosing actions that have the greatest expected benefit per dollar and the highest likelihood for generating those benefits in the shortest period. Cost-effectiveness analysis involves measuring both the effects of a range of actions (in comparable quantitative units such as increase in fish abundance or increase in smolts/redd) and the costs of those same actions. (Page 74)

Besides the recommendations described above, the ISAB's review contains additional points of emphasis for the Council's consideration. These can be found in the reviews of the Program's non-native fish, water quality, wildlife mitigation, lamprey, sturgeon, and eulachon strategies, and elsewhere throughout the report. The ISAB encourages readers to peruse the report for these and other recommendations. The ISAB recognizes that the Program is a living document, one that is evolving to incorporate new information and to meet ever changing conditions in the Basin. The ISAB hopes that its recommendations will prove useful to the Council, its staff, and others in the Basin as they develop the next Fish and Wildlife Program.

II. REVIEW CHARGE AND PROCESS

In a September 2017 letter, the Northwest Power and Conservation Council asked the Independent Scientific Advisory Board (ISAB) to evaluate the Council's 2014 Columbia River Basin Fish and Wildlife Program on its scientific merits in time to inform amendments to the 2014 Fish and Wildlife Program and before the Council requests recommendations from the region.

In an October 2017 message, the Council provided additional information and questions for the ISAB to consider. The Council observed that over the most recent amendment processes much of the Program content has remained consistent with most change occurring in a few distinct areas. Consequently, the Council is considering an amendment process that, while responding to all recommendations, would target a key set of issues that would benefit from focused attention, for example, wildlife mitigation including accounting for losses and gains, the Program's investment strategy and priorities, data management and reporting, and general Program accountability.

The Council also noted that while the Program's scale of implementation and funding level has increased steadily over the years, concerns have recently been expressed that financial uncertainties for Bonneville may result in reductions in Bonneville's investment in the Fish and Wildlife Program, at least for a period of time. Consequently, the Council asked the ISAB to provide any guidance to help streamline and increase the effectiveness of the Program's implementation in protecting and mitigating for hydrosystem effects.

The Council offered the following questions:

1. *What changes should be made in the Program strategies and measures to ensure that past, current and future mitigation investments addressing hydrosystem impacts perform as intended over-time in the face of existing and future threats, such as from non-native invasive species and climate change?*

2. *The Council and its partners are working on completing an extensive inventory of existing quantitative objectives, consisting of many different types and scales, for a subset of focal species and their habitat (see completed salmon and steelhead inventory on Council's website). What guidance can the ISAB provide for identifying the type and scale of objectives and related reporting indicators that are best suited for assessing and reporting on the Council Program?*

3. *The ISAB noted in their review of the 2009 Program that it did not appear to be on a trajectory to achieving the Program's basinwide objectives. Does the 2014 Program improve upon this? Is the 2014 Program a valid scientific basis from which to achieve basinwide Program objectives?*

4. *If life-cycle models can contribute to improving the Program and its implementation, what specific guidance can be provided in the Program to ensure that the appropriate models are developed to address specific Program needs?*

5. *Based on current scientific understanding, how can the Council strengthen the Program's Mainstem hydrosystem flow and passage operations strategy to improve juvenile and adult fish survival?*

6. *Based on current scientific understanding what further improvements in fish survival, productivity and capacity are possible through additional off site mitigation such as by investing in habitat improvement and artificial production actions in the tributary, mainstem and estuary?*

7. *The 2014 Program encourages the region to consider the ISAB's recommendation to refine the Program's 2-6% SAR objective for different species and populations and some work has been done to compile existing SARs through the Coordinated Assessments effort (see website). What approach should be used to refine the Program's SAR objectives to better meet the Program needs for assessment and reporting?*

Review Process: Our review of the 2014 Program for its scientific merit was tailored to meet a six-month deadline and relied on overview briefings and recent ISAB, ISRP, and Council staff reports. Specifically, our understanding of the Program greatly benefited from briefings from Council staff and others at our October, December, and January meetings. We considered past ISAB and ISRP reports relevant to the various Program components and strategies. The ISAB and ISRP's Critical Uncertainties Report (ISAB/ISRP 2016-1), the ISAB Density Dependence Report (ISAB 2015-1), the ISAB Review of NOAA's Life-Cycle Models (ISAB 2017-1), and the ISAB's Review of the 2009 Program (ISAB 2013-1) were particularly relevant. We also found the Council staff's Program Implementation Assessment Report (NPCC staff 2017) extremely useful. Our review of the 2014 Program coincided with our review of Spring Chinook Salmon in the Upper Columbia River (ISAB 2018-1), and that review proved to be an excellent example of how the Program is applied to mitigation and recovery efforts—the opportunities and challenges. Although our review applies many of the findings from those reports, we recommend that the Council, Council staff, and entities that develop recommendations for the Program amendments also explore those reports.

Report organization: In our report below, first we address the Council's seven questions. Then we provide comments on the sections of the 2014 Program that are most amenable to scientific review; for example, we provide comments on the *Habitat* sub-strategy section but not on the *Legal and social context of the program* section. Our comments on the Program sections (framework and strategies) begin with a general statement on the scientific merit of the sections, and then we identify gaps and make suggestions for modifications to improve scientific aspects of the sections.

III. SUMMARY ANSWERS TO THE COUNCIL'S SEVEN QUESTIONS

1. *What changes should be made in the Program strategies and measures to ensure that past, current, and future mitigation investments addressing hydrosystem impacts perform as intended over-time in the face of existing and future threats, such as from non-native invasive species and climate change?*

The ISAB addresses the Council's first question throughout this review by suggesting needed changes to the Program's framework, vision, objectives, strategies and measures, and research, monitoring, and evaluation. The 2014 Program's Investment Strategy focuses largely on financial needs for mitigation investments over a relatively short (1-20 year) time frame. This is unrealistic given long-term projections for the effects of existing and future threats and the highly altered state of the Columbia River ecosystem, such that performance of mitigation investments over the same long time scales is necessary and expected. Overall, there is a high level of scientific uncertainty about existing and future threats to the performance of the Program's mitigation investments. Thus, intended performance of mitigation investments cannot be ensured. First and foremost, a comprehensive strategic plan for monitoring and evaluating biological and ecological performance of mitigation investments is needed. The ISAB considers the Council's guidance to Bonneville to "implement adaptive management (including prioritized research on critical uncertainties) throughout the Program" to be the most important program priority needed to address this issue.

However, the Program provides limited scientific guidance for adaptive management for projects and actions. We provide a revised definition of the adaptive management process for the Program that includes rigorous decision-making based on regional strategies, quantitative objectives, coordinated monitoring and evaluation, and incorporation of outcomes into decision-making cycles that include project leaders, regional technical teams, and local stakeholders. Given the many critical uncertainties about existing and potential threats to performance of mitigation investments, measures for both short- and long-term monitoring and evaluation are essential to Program success. Monitoring and evaluation results are required for providing and adjusting estimates of uncertainty to aid decision-making. However, key Program strategies and measures such as those for habitat and wildlife lack monitoring and evaluation plans and measures or adequate funding to address these important components of adaptive management. Consequently, there is an urgent need to explicitly support the monitoring and evaluation component of adaptively managing mitigation investments to ensure intended performance over time.

The Program has also made little use of quantitative cost-effectiveness analysis to set priorities at multiple levels of Program decision making. The systematic use of explicit cost-effectiveness ratios to select projects and set priorities has been shown in other contexts to significantly improve the biological outcomes of conservation investments. Our view is that cost-effectiveness analysis should be incorporated into multiple levels of Program decision making.

2. *The Council and its partners are working on completing an extensive inventory of existing quantitative objectives, consisting of many different types and scales, for a subset of focal species and their habitat (see completed salmon and steelhead inventory on Council's website). What guidance can the ISAB provide for identifying the type and scale of objectives and related reporting indicators that are best suited for assessing and reporting on the Council Program?*

Objectives for most characteristics of salmon, steelhead, and other fish and wildlife populations, and key aspects of their ecosystems, are most useful if set at the subbasin scale for specific species, stocks and, in some cases, life-history stages. Objectives specific to subbasins can then be aggregated to derive overarching goals of, for example, abundance or escapement that are based on biological capacity and productivity, and reflect density-dependence. It will be critical, however, to set goals and objectives for productivity, diversity (genetic and life history), and spatial structure specific to subbasins and fish stocks, and that can be aggregated to larger spatial scales. In particular, the diversity of life-history types is likely to be a critical objective to prevent extinction of salmonid stocks in the face of climate change. Although objectives that are quantitative and time-bound are ideal, for some attributes where information is still rudimentary, qualitative goals can also be highly useful. Diverse teams of experts in each subbasin are best suited to develop specific, measurable, achievable, relevant and time-limited (SMART) objectives at this scale. The Columbia Basin Partnership Task Force is in the process of producing quantitative goals that reflect self-sustaining salmon and steelhead populations that adequately supports all needs within the basin (e.g., harvest).

3. *The ISAB noted in their review of the 2009 Program that it did not appear to be on a trajectory to achieving the Program's basinwide objectives. Does the 2014 Program improve upon this? Is the 2014 Program a valid scientific basis from which to achieve basinwide Program objectives?*

The 2014 Program includes basinwide objectives that are indirect (protect and enhance habitat) as well as ones that are direct (ensure survival to promote abundance, diversity and adaptability). The Program supports many projects and actions to address these multiple objectives as evident in project reporting (e.g., cbfish.org); tracking of general, regional progress through the Program's High Level Indicators; and the ISAB and ISRP's Critical Uncertainty Report's (2016-1) evaluation of progress toward addressing key research questions to inform fish and wildlife management.

In this report, we do not delve deeply into all of those resources nor conduct an evaluation of the trajectory of the Program toward meeting its numerous objectives. However, one of the basinwide objectives identified in the ISAB's 2009 comments was the interim objective to increase total adult salmon and steelhead runs to an average of 5 million annually by 2025 in a manner that emphasizes the populations that originate above Bonneville Dam and supports tribal and non-tribal harvest. Additional data available for 2011-2017 do not indicate further progress toward that objective. Favorable ocean conditions and river flows contributed significantly to higher adult returns in 2014-15; otherwise adult returns since 2010 at Bonneville Dam have been similar to the previous decade. The ISAB review of the 2009 Program called for making this 5 million fish objective more specific with respect to wild and hatchery fish, but updated estimates on the composition for most runs or a basinwide aggregation are unavailable. The ISAB does not believe the 5 million fish is a realistic goal. In a recent report the ISAB estimated that the original runs (i.e., pre-European influence) of salmon and steelhead were 5 to 9 million fish (ISAB 2015-1) and at least one-third of salmon and steelhead habitat has become unavailable in the Basin. Furthermore, even with today's lower number of returns, density dependent population regulation has been documented in many subbasins (ISAB 2015-1). Therefore, even 5 million salmon and steelhead is likely an unattainable goal. If the Program continues to set a Basin-wide numerical goal for adult returns, this goal needs to account for recent large variations in climate and ocean conditions that are affecting survival of juvenile fish. Especially during periods of poor ocean conditions, releasing large numbers of juvenile hatchery fish in an attempt to boost adult returns to a static numerical goal is not scientifically valid and could negatively impact endangered wild populations.

In addition to these basinwide goals, which are discussed critically elsewhere in this review, the Program's subbasin plans also included 89 quantitative targets with timelines (i.e., 25 years) for anadromous salmon and steelhead, but analysis is currently insufficient to evaluate progress in these cases. It should be noted, however, that in NOAA-Fisheries' recent status reviews of the Snake River ESUs (NMFS 2016a) and the upper Columbia River ESUs (NMFS 2016b), ESA-listings were not changed.

The Program also includes mitigation objectives in terms of habitat units or acres for wildlife losses attributed to construction of dams and inundation. This type of mitigation objective is relatively easier to track than biological objectives, and significant progress has been made toward meeting construction and inundation objectives covering 22 of 27 Federal Columbia River Power System dams listed in the 2014 Program for mitigation responsibility.

On the second part of the Council's question, most sections and strategies of the Program have a valid scientific basis. However, some of the Program's quantitative objectives have not been similarly based on these underlying scientific principles or relationships. Elsewhere in this report, issues are raised about possible improvements to establishing both quantitative and qualitative Program objectives.

4. *If life-cycle models can contribute to improving the Program and its implementation, what specific guidance can be provided in the Program to ensure that the appropriate models are developed to address specific Program needs?*

Many life-cycle models have been developed for the Columbia Basin, and there have been several reviews by the ISAB, including ISAB 2013-5 review of life-cycle models developed under the auspices of NOAA; ISAB 2017-2 which has a chapter on a life-cycle model developed as part of the Comparative Survival Study (CSS); and ISAB 2018-1 which contains information on life-cycle models for the Upper Columbia River.

Life-cycle models are important tools for considering management actions towards Program goals, and their development and refinement should be continued. As all models are simplifications of reality, consideration should always be given to model assumptions and uncertainties, especially when used to estimate future impacts. Models should be incorporated into the adaptive management cycle of the Program, so that as knowledge and data about the Columbia Basin are gathered, the models can be improved to provide better estimates and evaluations of alternative management actions.

There are two major goals for life-cycle models. First, the models are used to develop a deeper understanding of the current system and the role of limiting factors in each life stage of the current system. Second, and more importantly, the models can explore the impacts of potential management actions (e.g., improvement of habitat, adding nutrients, removing dams) on the long-term performance of the system. The following highlights of life-cycle modelling are covered in greater depth in Appendix 2.

- Life-cycle models provide an opportunity to incorporate cost effectiveness in choosing among management actions.
- The temporal and spatial resolution and complexity of a life-cycle model must match the management question of interest.
- All life-cycle models will be in a continual state of refinement and improvement.
- A successful life-cycle model will typically follow a path from coarse resolution to finer resolution, from using external information on values of parameters to fitting the model to actual data, and from understanding the current system to predicting consequences of future management actions.

- To the extent that downstream effects operate approximately equally on fish affected by upstream changes, the life-cycle models may only be useful to rank management actions in terms of their relative effect.
- All life-cycle modelling should include a sensitivity analysis to identify the stages of the life-cycle where system changes or uncertain parameter variables may have the largest impact on the response variable (e.g., smolt to adult returns [SARs] or adult abundance).
- Models that are fitted directly to observable data will likely provide predictions closer to actual outcomes. Model calibration where parameters are tuned in the models to match observed patterns (rather than fitting the model directly to the observable data) is not always successful—model output may match the pattern of observed changes over time but still have noticeable bias.
- The resolution of life-cycle models varies spatially and temporally.
- Both deterministic (e.g., those on the Upper Columbia) and stochastic (e.g., the CSS and many NOAA models) formulations are used in the Basin.
- Simpler models will provide relative rankings of the outcomes from different management actions but may not provide good predictions of the actual performance measure because of hidden non-linearities (e.g., density dependence both within a single stock and competition across stocks) or missing relationships.

5. *Based on current scientific understanding, how can the Council strengthen the Program's Mainstem hydrosystem flow and passage operations strategy to improve juvenile and adult fish survival?*

Work on examining effects of mainstem hydrosystem flow has focused mainly on anadromous salmonids and their survival through the hydrosystem and how changes to operations and flow management can improve survival and returns. This information is essential for understanding and developing recovery actions for salmon and steelhead. Among actions taken are improvements to juvenile passage via bypass systems or improved understanding of fish behavior and survival during spill. The work is generally informative and should be continued.

However, hydrosystem operations impact species other than salmon. For example, the effects on lamprey and sturgeon are less well understood. Rather than trying to change hydrosystem operations and flow to optimize responses for each species, an ecosystem function approach may be more fruitful. This approach must also address impacts on other species (e.g., non-native fish). For example, a proposed change to operations may benefit productive populations of salmonids, lamprey, or sturgeon but also benefit non-native species even more, and so the net benefit is actually negative. Similarly, primary and secondary production that sustains target species will be affected by flow, temperature, and water quality. The Program also needs to address mainstem habitat conditions and floodplain connectivity as elements in the effects on anadromous and resident fish.

Many of the changes in the past have assumed that capacity in the river is much larger than needed for each individual species, and so density dependent effects were assumed to be negligible. However, the ISAB (ISAB 2015-1) indicated that density dependence may be significant in many subbasins of the Columbia Basin. Many of the proposed actions provide immediate benefits to a specific part of the life cycle (e.g., juvenile passage survival), but the benefits may not be realized if there are limiting factors later in that life cycle. Consequently, proposed actions must be placed into context of a life cycle to identify the actual net benefit.

Similarly, current actions are implemented one population at a time, and there appears to be little consideration of the impacts of improvements on the aggregate of populations (e.g., improved habitat may increase the survival of each sub-population). However, when the populations migrate through the hydrosystem, benefits are again reduced if the aggregate population exceeds capacity. While individual population life-cycle models have been and are under development, multi-population or species aggregates have received little attention. The interaction of hatchery fish with non-hatchery fish needs additional research both because of density dependence factors and domestication effects on mixed-parentage stocks.

Finally, a cost effectiveness approach may be useful to help prioritize where to spend money given that life-cycle models are now at the stage where the impact of different management actions on the returns can at least be ranked (and potentially estimated with high confidence) for some responses.

6. *Based on current scientific understanding what further improvements in fish survival, productivity and capacity are possible through additional off site mitigation such as by investing in habitat improvement and artificial production actions in the tributary, mainstem, and estuary?*

Based on our current scientific understanding, possible gains in survival, productivity, and capacity via combined habitat and fish culture efforts cannot be estimated because of data limitations. A few subbasins (e.g., Upper Columbia, Yakima, Snake River) have the kinds of information and analytical tools needed to start to answer the question. Other subbasins, however, lack details on basin-wide abundance, productivity, survival, density dependence, genetic diversity, and responses to recovery actions that are required.

Four major sources of information are necessary to fully answer this question. First, population-specific estimates of current capacity, productivity, and survival of fish occupying habitats within the Basin are needed. Ideally, data on population-specific spawner-recruit relationships at three discrete life history phases (adult-to-fry, adult-to-smolt, and adult-to-adult) are required to estimate these parameters. These analyses will generate population-specific escapement goals and provide baseline capacity and productivity values at different life stages. Second, comprehensive habitat assessments within subbasins on a reach scale must be performed to determine if opportunities to expand capacity, productivity, and spatial structure are possible via habitat protection and restoration. The ultimate goal of such assessments would be to determine the amount of habitat within each subbasin that: (a) is relatively pristine, (b) was formerly utilized but is now inaccessible due to passage barriers, (c) will permit reconnections to floodplains and side channels, (d) is amenable to restoration through the re-establishment of ecosystem processes, and (e) cannot be restored due to existing uses.

Increases in survival, abundance, and productivity cannot occur unless the habitat attributes that limit these parameters have been relaxed by suitable restoration actions. Prioritization should be first given to protection, next to passage, then to reconnection of floodplains and side channels, and lastly to artificial restoration. Monitoring and evaluation will be required to determine the effectiveness of the various types of habitat strategies. Previous and ongoing monitoring, evaluation, and research (e.g., CHaMP, ISEMP, AEM, PIBO) in the Basin will provide needed guidance, insights, and results. Once expected benefits have been established for each type of habitat action, potential gains in capacity and survival can be estimated. Benefits from the same habitat action undoubtedly will vary annually, both within and across subbasins. Nevertheless, mean responses can be calculated over time and used to estimate benefits.

Potential benefits produced by changed habitat conditions will not be fully realized if fish that occupy those habitats do not exhibit effective life history traits. If artificial production is employed in conjunction with habitat improvements, careful screening of the fish to be used is required. Consequently, the third type of information needed is assessment of the genetic diversity and life history expressions of fish that will be used in conservation or supplementation programs. Early genetic evaluation must be accompanied by appraisals of juvenile and adult traits, such as abundance and migration timing, spawning in the wild, maturation timing, spawning location, and juvenile production. Whenever possible, fish native to the areas being restored should be used in artificial production programs as they likely possess adapted genetic and phenotypic traits.

No matter how extensive restoration may be or how suitable the fish are, survival, capacity, and productivity will be limited. These limits will occur at the subbasin level and also in other habitats throughout the remainder of the fish’s life cycle. This brings us to the fourth and likely most difficult information needed to estimate effectiveness of habitat alterations and artificial culture. This fourth type of information need is the cumulative effect of all the fish, hatchery and natural origin, on survival and productivity. Although we tend to think of each population as a separate entity, ultimately the survival of individuals within these populations is affected by the presence of fish (both con- and heterospecific) from other subbasins. Availability of food in the mainstem, estuary, and ocean plume, for example, can be affected by the simultaneous or previous occupation of these habitats by fish from other subbasins. Similarly, numerical responses of predators due to past or contemporary abundance levels may increase or decrease predation. Life-cycle models will need to be developed to coalesce the effects of multiple subgroups of fish passing through, occupying, and using resources across multiple habitats.

As previously mentioned, information needed to determine what further improvements in capacity, fish survival, and productivity can be brought about by combining habitat actions and artificial culture is not uniformly available across the Basin. Most subbasins lack much of the required information and do not have the technical capacity to conduct many of the analyses and data syntheses. The Program could identify sets of information required to identify the degree and types of improvements that are possible. The next step would be to develop and fund a program to organize that information into a centralized database (e.g., the Coordinated Assessments for Salmon and Steelhead). Data could be analyzed and synthesized in centers located within participating scientific entities or in a centralized group. Given recent experience with regional data syntheses, requirements for data summaries and consistent reporting should be established at the beginning of such a program. Without consistent data acquisition, analysis, and synthesis across the major subbasins, current and subsequent scientific understanding will likely be insufficient to identify improvements from coordinated habitat actions and artificial culture.

7. *The 2014 Program encourages the region to consider the ISAB's recommendation to refine the Program's 2-6% SAR objective for different species and populations and some work has been done to compile existing SARs through the Coordinated Assessments effort (see website). What approach should be used to refine the Program's SAR objectives to better meet the Program needs for assessment and reporting?*

The 2-6% SAR objective has undergone extensive analysis (e.g., CSS 2017, Chapter 5) and been extensively reviewed (e.g., ISAB 2017-2). Generally speaking, SARs less than 1% consistently resulted in generation decreases in abundance while SARs greater than 2% resulted in generational increases in abundance (CSS 2017, Chapter 5). Historical productivity was generally associated with SARs in the 4%+ range (CSS 2017, Chapter 5). Hence the SARs objectives provide a readily measured, first-order objective for restoring stocks.

Key issues remaining are:

- dealing with discrepancies in SARs between PIT-tagged and non-PIT-tagged fish (are the reported estimates biased by these discrepancies?);
- information on how age at maturation affects SARs (if a shift to earlier ages of maturation occur, will this impact the SARs?),
- the contribution of mini-jacks to SARs (is a jack or mini-jack returning equally valuable as a mature adult?)
- the relationship between SARs and biomass of adult returns (is the "quality" of fish returning related to the SARs?)
- the causes of the variation in the SARs particularly in relation to uncontrollable factors at the Program's basin level (e.g., climate change) and controllable factors (e.g., hydrosystem operations and transport).

IV. COMMENTS ON THE 2014 FISH AND WILDLIFE PROGRAM BY MAJOR SECTION

FRAMEWORK

Scientific merit

The overall framework presented in the Program section is sensible and generally has scientific merit. Adaptive management has been a major program element since 1982, and at a broad level, the Program's organization follows a logical adaptive management outline. It begins with a description of the legislation the Program addresses and follows with guiding scientific principles; vision, goals, and objectives (linking biological performance and environmental conditions); strategies to achieve those goals; and research, monitoring, evaluation, and reporting to assess progress and the effectiveness of the strategies. However, some important details are missing and guidance should be improved.

Gaps and suggestions for modification

The Program provides limited scientific guidance for adaptive management for projects and actions. The Program should develop rigorous decision-making processes based on regional strategies, address quantitative project objectives, develop coordinated monitoring and evaluation, and incorporate outcomes (i.e., lessons learned) into decision-making cycles that include project leaders, regional technical teams, and local stakeholders. We also recommend using a more effective illustration of the adaptive management framework that clearly shows the importance of providing feedback to continue to improve the process.

The adaptive management cycle

The currently titled "Adaptive Management" section of the 2014 Program focuses mostly on research, monitoring, and evaluation (RM&E) and provides a set of principles useful in developing a project and monitoring its results, but it is vague on the adaptive part (i.e., feedback aspect) of adaptive management. The ISAB believes that the Framework section generally covers the full adaptive management cycle, but improved definitions and graphics in the Framework section would provide useful context for the Objectives, Strategies, and RM&E sections that follow. For example, in the Framework section (page 11, Program Figure 2's arrows about "guides" and "progress" do not clearly illustrate an adaptive management framework or feedback loop, so the "feedback loop" referred to on page 10 does not clearly connect to the figure. A better illustration would strengthen communication of adaptive management in the Program framework. Figure 1 below clearly shows the adaptive management cycle, and Figure 2 provides more detail on how the adaptive management cycle is applied to the Program. Figure 2 is modified from a graphic used by the ISRP in presentations to planners and project proponents to describe a logic path for subbasin planning and project proposal development. Also see Figure A.1 from the ISAB and ISRP's Critical Uncertainties Report ISAB/ISRP 2016-1.

Figure 1. Diagram of the adaptive management cycle

Source: www.reefresilience.org/images/Approaches_Adaptive-mgmt-cycle_large.png

Adaptive management definition

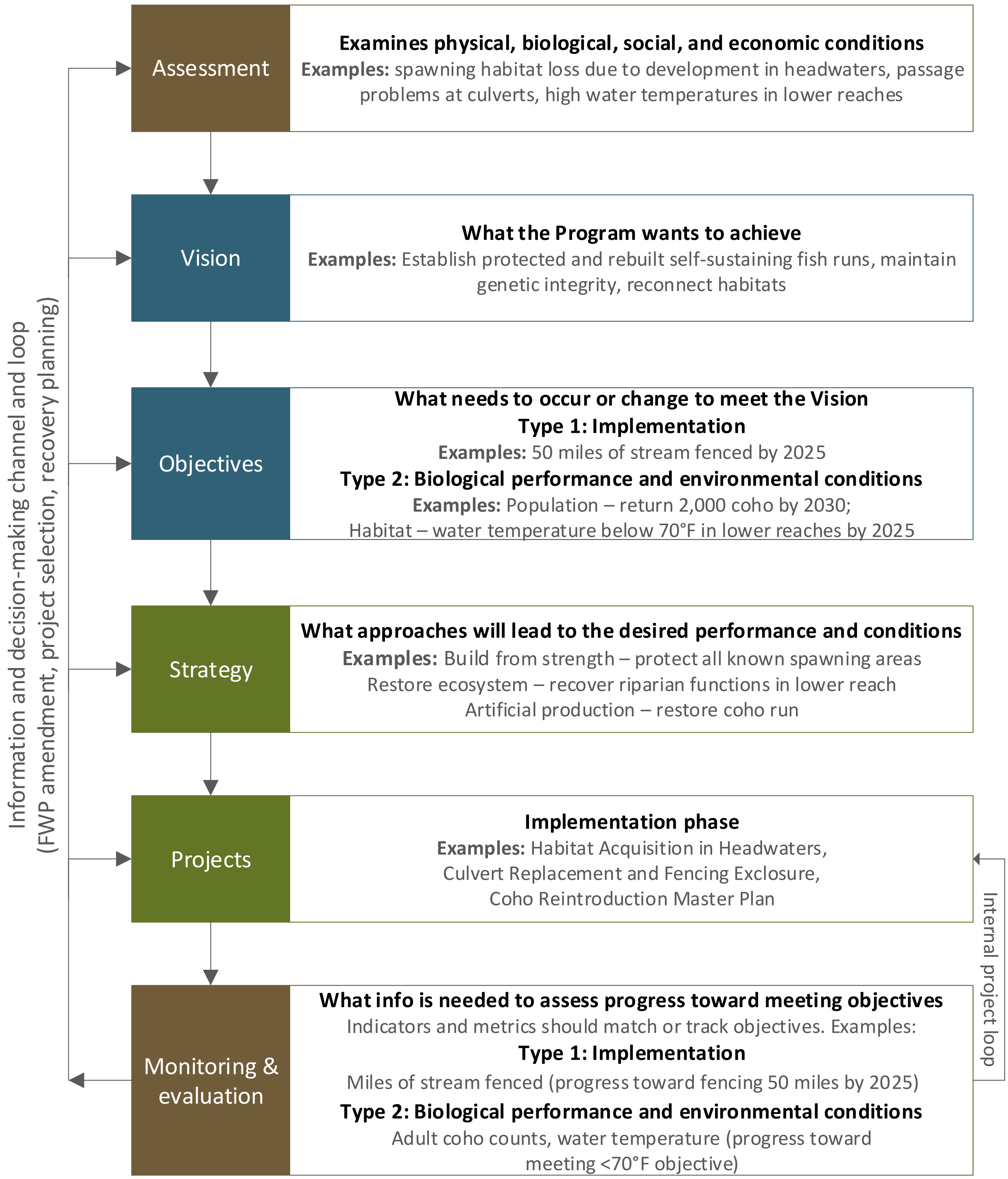
Although there is a definition of adaptive management provided in the Glossary of the Program, it does not describe the feedback portion of the cycle. Furthermore, because the term is used so widely throughout the Program, an expanded definition of adaptive management and inclusion of graphics, such as Figures 1 and 2, in the main body of the Program would clarify what is meant by adaptive management for the Program. Conroy and Peterson (2013) describe adaptive management as learning while managing; management decisions are made and monitoring data provide feedback to reduce uncertainty about how a system works. They emphasize that learning with adaptive management is not haphazard or trial-and-error.

An article published by Rieman et al. (2015), includes a succinct description of adaptive management as it applies in the Columbia Basin. The article is a synthesis of advice from the ISAB's Landscape Report (2011-4), the ISAB's Review of the 2009 Fish and Wildlife Program (2013-1), and the ISRP Geographic Review (2013-11):

> "Comprehensive restoration will require new and untried actions that must evolve with experience. Learning and using what is learned to modify future restoration actions are key. Adaptive management is a full-cycle process starting with the identification of quantitative objectives to fulfill agreements, policies, or laws. This is followed by an assessment of physical, biological, social, and economic conditions that need to be addressed to meet the objectives. Based on the assessment, actions are designed and implemented. Periodic monitoring and evaluation provide critical feedback. The results are then used to gauge progress toward objectives and ultimately to support or modify actions.
>
> Adaptive management ideally uses deliberate experiments to inform future decisions. It can still provide a useful path, however, where traditional scientific experimentation, replication, and intensive monitoring become difficult or impossible at very large scales. For example, models can be used to explore restoration scenarios and help managers and the public visualize the response of complex systems. The models can be integrated in a structured approach to making decisions, and the results can be updated periodically to focus new work and limited financial resources. Ultimately, learning and adaptation require sharing experience across watersheds, regions, and cultures so that each project becomes an observation for a larger collective evaluation of successes and failures. Active networking across groups with common interests must be part of the process."

Figure 2. Program Framework: Adaptive Management Loop

Guided by scientific foundation and principles



Guidance needed at program and project levels

Proper implementation of adaptive management has improved since the 2013 ISAB review, but the current program still does not clearly include measures that would ensure that lessons learned from the program are used to revise measures and projects. Cost is an additional constraint not mentioned explicitly in the Program. As DeFries and Nagendra (2017) point out, effective application of adaptive management can be costly and time-consuming, and monitoring systems often lack funding and leadership to coordinate essential data collection and management.

The Program or other Council documents provide no explicit guidance for developing adaptive management processes as part of projects. The recent review of the Umbrella Habitat Restoration Projects (ISRP 2017-7) found that 90% of the projects did not have time-specific, quantitative objectives, 70% lacked a formal adaptive management process, and 60% needed new or updated management plans. Projects lacked monitoring plans based on quantitative project objectives, systematic review of outcomes, and modification of management decisions based on the explicit adaptive management process. The 2013 ISAB review and previous ISRP reports (ISRP 2008-4, 2011-14) recommended use of Structured Decision Making, but such approaches are not implemented in most projects and the Program provides no guidance or assistance for developing adaptive management. Different programs and projects with different funding, staffing, analytical capacity, and consequences for recovery may require different levels of adaptive management processes. Program guidance is critical for future reviews of projects.

The conclusions of the 2013 ISAB review of the 2009 Program (ISAB 2013-1) regarding adaptive management are still valid. Projects indicate they use adaptive management for decision-making, but the ISRP and ISAB have found few examples of adaptive management. The term has been used to apply to everything from simple trial-and-error to more sophisticated efforts to develop true adaptive management. One example of a project that describes adaptive management applications is a restoration project in Asotin Creek, an intensively monitored watershed (IMW) in Oregon (Bouwes et al. 2016a; 2016b). The investigators made adjustments to their restoration design in response to data on geomorphology (Bouwes et al. 2016a) and fish abundance (Bouwes et al. 2016b). Thus, this project is a good example of adaptive management for providing geomorphic complexity and improving fish recovery at the project level, with appropriate data collected to inform adjustments to restoration design. Other positive examples of adaptive management in the Basin have occurred within local projects that solicit, review, implement, and monitor the collective projects in a subbasin. In Appendix 3, we provide some examples of how adaptive management can be applied to recovery programs for fisheries management.

Acknowledging and addressing uncertainty

One of the reasons adaptive management is so important for the Program is because of the many uncertainties involved in fish recovery in the Basin (ISAB/ISRP 2016-1). With more and better data, uncertainty can be reduced and lead to better management decisions. Moreover, risks associated with uncertainty can be managed in the adaptive management framework. In the review of the 2009 Program, the ISAB recommended that all project proposals be required to acknowledge uncertainty by describing areas of uncertainty and what will be done to deal with uncertainties. This recommendation was not included in the 2014 Program as strongly as the ISAB recommended. The ISAB further recommends that reports on projects should indicate how projects addressed uncertainties and if any lessons were learned in dealing with the uncertainties to ensure that such efforts contribute to adaptive management. Conroy and Peterson (2013) provide an example of how monitoring results can be used to adjust estimates of uncertainty to aid in decision-making (see Chapter 7, Box 7.6). What is clear is that the appropriate results must be monitored (in the example in Conroy and Peterson [2013], this would be the abundance of redhorse suckers), which does not always appear to be the case in the Basin. Synthesis reports may also be excellent opportunities to provide feedback on uncertainties for the adaptive management framework.

Models as an adaptive management tool

Models are also important aspects of adaptive management, and the Program acknowledges the value of models where data are scarce. However, the role models play in adaptive management is not clearly articulated. Bouwes et al. (2016a) note that early calls for adaptive management encouraged “complex modeling” (e.g., Holling 1978, Walters 1986) and argue that such complex models are not useful for developing meaningful ecological information, suggesting that experiments with intensive monitoring can be more effective. The ISAB notes that models can be useful for investigating hypotheses and future management actions that are difficult to examine with on-the-ground experiments. When used with monitoring and experiments, models can be improved as part of the adaptive cycle, and results can be part of continuing to revise and update management decisions and program objectives. Life-cycle models are being applied in the Basin to look at reach, subbasin, and system level approaches, so the ISAB recommends elevating the incorporation of adaptive management to model development as well.

In conclusion, the programmatic guidance needed to implement adaptive management in the Program is lacking. It may be necessary for the ISRP or ISAB to formally address the implementation of adaptive management in the Program as was explored in 2008 (ISRP 2008-4). Prior to the next update, it is recommended that a meeting be convened by the Council to get input on the adaptive management process and progress on resolving or reducing uncertainties in the Program.

VISION

The 2014 Program's Vision [numbering added]:

> "[1] The vision for this program is a Columbia River ecosystem that sustains an abundant, productive, and diverse community of fish and wildlife, supported by mitigation across the Basin for the adverse effects to fish and wildlife caused by the development and operation of the hydrosystem. [2] This envisioned ecosystem provides abundant opportunities for tribal trust and treaty-right harvest, non-tribal harvest, and the conditions that allow for restoration of the fish and wildlife affected by the construction and operation of the hydrosystem.
>
> [3] The vision will be accomplished by protecting and restoring the natural ecological functions, habitats, and biological diversity of the Columbia River Basin. [4] Where this is not feasible, other methods that are compatible with self-sustaining fish and wildlife populations will be used, including certain forms of production of hatchery fish. [5] Where impacts have irrevocably changed the ecosystem, the program will protect and enhance habitat and species assemblages compatible with the altered ecosystem."

Scientific merit

The 2014 Program Vision originated in the 2000 Program, although earlier Programs included goal statements that were similar to the Vision. Many iterations of the Vision were recommended and discussed for the 2000 Program, and it has not changed substantively since then.[1] The Vision is largely a values and policy statement, but there are important scientific underpinnings and tradeoffs inherent in the language. Because the Vision has not changed from the 2009 Program, our 2013 review comments still apply: "This vision has merit in being comprehensive and ambitious, as well as flexible, depending on the interpretation of 'abundance' and 'feasible.' It is worth noting that the goal of 'abundant opportunities' for harvest sets expectations for ecosystem benefits and largely determines whether the fish and wildlife community can possibly be 'abundant, productive, and diverse' enough for the vision to be achievable and sustainable." (ISAB 2013-1)

[1] See Findings on the 2000 FWP process (page 36-~60)

Gaps and suggestions for modification

We offer suggestions for consideration in the 2018 Program amendment process:

- In the first sentence of the Vision [1], the wording “supported by mitigation” is at odds with the goals of the next sentence, which suggest that the envisioned ecosystem is one where fish and wildlife are restored so that they need little support. The ISAB suggests that the wording should support a vision well balanced between the current reality that many fish populations are on life support and a future where restoration has resulted in many more self-sustaining populations.

  Suggested wording: *The vision for this program is a Columbia River ecosystem that sustains an abundant, productive, and diverse community of fish and wildlife, and requires a minimum level of intervention across the Basin to mitigate for the adverse effects caused by the development and operation of the hydrosystem.*

- The ISAB suggests reversing the statements in the second sentence [2] to reflect that restoration should precede and lead to more abundant opportunities for harvest.

  Suggested wording: *This envisioned ecosystem provides conditions that allow for restoration of the fish and wildlife affected by the construction and operation of the hydrosystem, and ample opportunities for tribal trust and treaty-right harvest and non-tribal harvest of populations that are restored.*

  As noted in the 2013 review, the current ISAB questions whether the term “abundant” sets expectations that cannot be met and sustained. Can “abundant” be better defined?

- In the fourth sentence [4], are there other intensive management actions that should be included, such as assisted migration (e.g., placing wild fish above dams to spawn) to sustain connectivity and nutrient supplies? Also, what is meant by "certain forms" of production of hatchery fish? Can the language be more specific and include the point that hatchery fish should not be allowed to degrade the fitness of wild populations?

  Suggested wording: *Where this is not feasible, other methods that are compatible with naturally reproducing fish and wildlife populations will be used, including assisted migration above current barriers and certain forms of production of hatchery fish that do not degrade the fitness of wild populations.*

- In the fifth sentence [5], the statement “the program will protect and enhance habitat and species assemblages compatible with the altered ecosystem” raises many issues at the intersection of science and societal values.

Suggested wording: *Where impacts have irrevocably changed the ecosystem, the program will protect and enhance habitat and self-sustaining species assemblages compatible with the altered ecosystem and societal values, but with a focus on species native to the watershed.*

This raises what one might call a Faustian bargain, whereby we give up the goal of restoring native species for the goal of having any species at all. What criteria are used to determine that the altered ecosystem will not support native fish and wildlife and which native fish and wildlife are considered in this evaluation? If it is determined that the altered ecosystem cannot support native fish, should we then opt for self-sustaining fish populations (wild, but not necessarily native) and only choose fish supported by hatcheries as the last resort? The challenges of managing extensively altered landscapes and river networks often cause decision makers and managers to shift their focus to artificial replacement of fish through hatchery production, and goals for naturally produced native fish are viewed as secondary and unattainable. Each situation will involve complicated tradeoffs. Fausch et al. (2006, 2009) include a useful discussion considering the values of pure vs. hybridized vs. hatchery cutthroat trout and might be of value when considering similar tradeoffs with salmonids in the Basin.

SCIENTIFIC PRINCIPLES

Scientific merit

As described in the Program, the ISAB is “responsible for developing, reviewing, and recommending modifications to the Scientific Principles.” In the ISAB’s review of the 2009 Program, the ISAB recommended that the Program’s eight principles be simplified into six.[2] Specifically, the ISAB consolidated four 2009 principles into one summary principle, emphasized the theme of resilience, and added a new principle on socioeconomics and public engagement. In drafting the 2014 Program, the Council adopted the ISAB’s suggested principles but simplified them for readability by a broad audience.

The ISAB believes the principles recommended by the ISAB and included in the Program are scientifically sound (ISAB 2013-1). However, the ISAB recommends that the 2014 principles be reduced to four principles and be revised to aim at management of the Columbia River Basin power-generating and irrigation-supporting ecosystem—principles that imply that certain

[2] See this link for a table showing a crosswalk between principles in the 2014 Program, the 2013 ISAB Review of 2009 Program (ISAB 2013-1), and 2009 Program.

actions and conditions are needed to restore salmon, steelhead, and other native fish and wildlife in the Basin. This is a different tack than the principles in the 2009 and 2014 Programs. We continue to emphasize the 2014 themes of resilience, socioeconomics, and public engagement, but we also emphasize the importance of connectivity.

Suggestions for modification

Principle 1: To restore salmon, steelhead, and other native fish and wildlife in the Columbia River Basin, policy makers, resource managers, and restoration practitioners need to take the entire ecosystem into account, including freshwater, estuarine, and ocean components, and the linkages and feedbacks between the natural and human systems.

- Ecosystems include all living things in a given area, interacting with their physical environment.
- Ecosystems are hierarchical, so that large-scale physical conditions set the stage for physical and biological processes that occur at smaller scales of space and time.
- Natural disturbance and change are ecological processes that maintain, alter, and restore ecosystems.
- These natural processes, and their interactions with human-caused changes, determine the diversity, abundance, and productivity of plants and animals.
- To restore native fish and wildlife in the basin, managers need to consider the entire complex coupled natural-human system and understand the linkages and feedbacks that have reduced abundance of fish and wildlife.

Principle 2: To restore and sustain diverse, abundant, and resilient populations of native fish and wildlife, policy and management actions will need to provide the diverse array of habitats that these organisms require throughout their life cycles and the connections among them that allow access.

- Landscape perspectives provide essential physical and biological contexts for protecting and restoring river networks and the aquatic ecosystems that sustain native fish, wildlife, and plant communities.
- Although pollution and habitat degradation are important factors causing declines in fish and wildlife populations, much of the reason for the decline is that access to habitats critical to completing their life cycles has been reduced or blocked.

- In addition to anadromous fish that must migrate, many fish species considered "resident" also make long migrations (>50 km) to spawning and rearing locations, so removing barriers to movement will be required to restore their populations.
- Many habitats critical to native fish are used only during wet seasons and have often been degraded by human actions because they are either dry or are not considered suitable habitat during summer.
- Restoring salmon, steelhead, resident fishes, and other native fish and wildlife will require sustaining connections among all habitats that these species require in rivers, lakes, estuaries, oceans, riparian zones, and uplands at appropriate times throughout their life cycles

Principle 3: The diversity of genes, life histories, populations, and biological communities allows ecosystems to adapt to environmental change. Maintaining this diversity is the key to sustaining native fish and wildlife into the future, especially in the face of natural and human-caused changes in climate, water quantity and quality, extreme events, exposure to non-native organisms including pathogens, and other conditions.

- Genetic diversity provides the raw material that allows populations of salmon, steelhead, and other native fish and wildlife to adapt to changing conditions.
- This genetic diversity produces a portfolio of life history characteristics of fish and wildlife (e.g., different body sizes, timing of migrations), which provide many different options for their populations to thrive under changing conditions.
- In addition to diversity of fish and wildlife, a diversity of other aquatic and riparian animals, plants, and microbes is critical for sustaining the fundamental biological production and physical conditions that allow fish and wildlife to persist in the Columbia River Basin.

Principle 4: Fish and wildlife live within complex ecosystems dominated by humans, so to achieve system resilience and persistence, policy makers, resource managers, and restoration practitioners will need to understand societal values for these animals and their ecosystems and incorporate these in their decision making.

- Ecosystem conditions affect all species, including the well-being of humans.
- Human behaviors, values, and institutions, including diverse cultures, provide the structures and perspectives that allow society to adapt to changing ecosystem conditions.

- Managing ecosystems effectively requires managers to experiment, learn, adapt, and use a structured process for iteratively testing and revising management systems.

- Effective restoration will require policy and management actions that (1) are based on scientific principles, (2) reflect societal values, (3) recognize the strengths and weaknesses of decision-making processes, and (4) identify beneficial policy options.

Finally, because the ISAB is asked to develop and recommend the Scientific Principles, we welcome the Council to seek our input on potential changes, except for minor changes to wording made to ensure that the principles are easily understood by the broad audience at which the Program document is aimed.

GOALS AND OBJECTIVES

Scientific merit

The main section of the 2014 Program Goals and Objectives makes some useful points but is not well organized, overall. Moreover, this section appears to have incorporated little of the highly useful advice presented in the ISAB 2013 review of the 2009 Program (ISAB 2013-1, p. 50-54, see excerpt). For example, the first paragraph of ISAB (2013-1) is instructive:

> "The Biological Objectives section of the 2009 Program includes many good ideas, but considerable refinement is needed to identify quantitative objectives or benchmarks that implementation strategies can target and that monitoring programs can use to evaluate progress of the Program. More quantitative objectives would facilitate development of HLIs that can be used to inform government officials and the public. It is also important to include metrics for less quantifiable goals like diversity, spatial structure, and ecosystem processes (integrity) so that implementation of the Program is not biased in favor of efforts to achieve more easily quantifiable objectives like abundance and productivity."

Therefore, this section of the 2014 Program does not provide scientifically sound guidance on goals and objectives, and needs revision.

Gaps and suggestions for modification

Overarching problem: A fundamental problem is the spatial scale at which goals and objectives are developed. For example, a goal of achieving 5 million salmon and steelhead in the entire Basin by 2025 is certainly quantitative, but may not be useful, as discussed in the 2013 review, if this leads to attempts to reach this goal primarily with hatchery salmon released in certain subbasins or mainstem segments.

Goals for salmon and steelhead abundance will be useful if they are based on inherent productivity, biological capacity, and density-dependence relationships for specific subbasins. For example, in the 2013 review the ISAB recommended spawning escapement goals for each species and stock in each watershed. These could be summed to provide a total escapement goal for the Basin that has a strong basis in the biology of these species. We note that this goal should be defined as at least a 5-year average, because abundance is expected to vary from year to year as ocean conditions vary and different stocks have stronger or weaker years.

In addition to abundance, most other objectives are also best defined at the subbasin scale. For example, the ISAB in 2013 called for setting quantitative harvest objectives that vary depending on productivity and are set with stakeholder input, as well as specific productivity goals (i.e., SARs) for each species and life stage, stock, and subbasin. We urge the Council to review the excellent suggestions made by ISAB in the 2013 review (ISAB 2013-1, p. 50-54).

Several other overarching problems are more difficult to address. Genetic diversity and spatial structure of salmon and steelhead stocks, and populations of other fish and wildlife, are the key to their resilience under climate change, yet suitable data, metrics, and qualitative or quantitative objectives are lacking, as described in the 2013 review. Likewise, objectives for species other than anadromous salmonids, such as inland trout and charr, sturgeon, lamprey, and eulachon, are rudimentary or non-existent. Finally, objectives for environmental characteristics like flow regimes, land cover, sediment, and water quality are similarly lacking.

Recent work by the Council involves collating objectives from many reports and sources in a database, and this can provide a starting point, if it is organized by specific subbasins and fish species and life history groups. However, simply collating these will also not be sufficient. Setting specific, measurable, time-bound objectives will require that a group of qualified experts meet and distill goals and objectives into effective quantitative or qualitative statements. These can then be used to develop suitable metrics to monitor in an adaptive management framework. The Marine Fisheries Advisory Committee (MAFAC) Columbia Basin Partnership (CBP) Task Force may be such an organization as their goal is to make recommendations on common goals to define a path to long-term salmon and steelhead recovery (Z. Penney, CRITFC, personal communication).

Specific problems: In this section of the Program, Figure 4, lays out a fairly clear logic, starting with qualitative goals, which lead to quantitative objectives, strategies and measures to achieve those, and indicators of the success in achieving the goals. However:

- Readers can easily become confused by the five levels: goals, objectives, strategies, measures, and indicators. The adaptive management cycle (see Figure 1 under the Framework section of this report) includes a more logical framework: a) management objectives, b) desired outcomes, and c) management strategies and actions, and d) performance indicators. If these are the main elements, perhaps this terminology would be suitable.
- Adding "Themes for program goals and objectives" adds a different dimension, and it is difficult to reconcile these with the framework the ISAB proposes above. If these are overarching goals, then they should be stated as such, but only if they can be effective in restoring fish and wildlife.
- Describing objectives separately for salmon and steelhead, other non-anadromous fish, ecosystems/habitat/hydro, and public engagement adds yet another dimension, further confusing the framework.
- If themes or species groups are retained, it would be wise to describe goals and objectives for each using a consistent framework presented in this same order to help readers, even if each component is not discussed in each case. Instead, the current narrative discusses the framework out of order in various places, and is confusing as a result.

Another fundamental problem is that the specific goals and objectives laid out in Appendix D overlap, as though they were written by different groups and simply appended verbatim. The large number of Goals (n=22) could be condensed into far fewer and perhaps laid out in a hierarchy. Some of the goals may instead be strategies or measures that should be subsumed under broader goals and objectives, such as survival metrics needed to achieve goals of population increase or stability. Overall, most of the Objectives (for 13 of 22 Goals) in 2014 Program Appendix D "remain to be identified and adopted." Therefore, these goals and objectives do not provide the level of guidance needed for the Program, although in some cases this is because the relevant science is lacking.

Because some of the goals are overlapping and redundant, the list could be condensed and a stronger hierarchy created within certain goals to include quantitative objectives and strategies. For example, a goal might be to increase survival of juvenile anadromous salmonids. One of the quantitative objectives following this might be to achieve a specified percent survival during downstream passage, and one strategy to achieve this may be to maintain total dissolved gas (TDG) below a specified saturation level.

Finally, a distinction needs to be made about long-term vs. short-term goals, based on the statement "Where possible, the quantitative objectives identified through this regional process should be specific, measurable, attainable, relevant, time-bound." (2014 Program, p.31). For example, a long-term goal about habitat improvement may not be achievable in a short time period, so the planning horizon for various projects needs to be explicit. Thus, if a quantitative objective is 5 million salmon returning by 2025, then additional short-term objectives of, perhaps, 2 million by 2019, and 3.5 million by 2022 need to be set. Incremental objectives are needed for each 5-year step to achieve long-term objectives.

Some specific comments on this 2014 Program section and on Appendix D of the Program are included in Appendix 4 of this review.

ADAPTIVE MANAGEMENT SECTION OF 2014 FWP: RESEARCH, MONITORING, EVALUATION, AND REPORTING

OVERALL COMMENTS ON RM&E AS PART OF THE ADAPTIVE MANAGEMENT CYCLE

This section of the 2014 Program does not cover the full adaptive management cycle (see Figure 1) but focuses on research, monitoring, and evaluation (RM&E), which is a critical component of adaptive management. For more comments on the incorporation of adaptive management within the Program, please see the "Framework" section of this report. Here the ISAB comments on the RM&E aspect of adaptive management and its incorporation in the Program.

While centralized data management and access to data and project information have improved substantially, the ISRP has previously identified four requirements for evaluating progress through adaptive management that could assist project proponents (ISRP 2017-2):

- Evaluation at a landscape scale using quantitative objectives with explicit timelines that are expressed in terms of expected (hypothesized) outcomes.
- Evaluation at a landscape scale through appropriate monitoring, access to monitoring data, and an explicit plan for evaluating and documenting outcomes. Time-specific, quantitative objectives are informed by the assessment and can be tailored for specific actions selected for implementation.
- Having the technical capacity to conduct the needed analyses and processes. Importantly, insufficient technical capacity and evaluation inhibit corrective actions that could be undertaken through adaptive management. Efficient evaluation can make available and guide limited funds needed to restore habitats and target populations.
- Documentation of outcomes and lessons learned as well as sharing of knowledge gained collectively are essential.

In addition to using information to determine whether or not progress is being made toward program goals and objectives, the data should be used to inform changes to the Program, from goals and objectives to strategies and measures. For example, suppose a project wishes to restore habitat and will evaluate success of the effort by the number of smolts produced compared to a control stream. The principles in this section provide guidance on the level of monitoring and how the data will be stored for future use. But suppose that monitoring shows that the project does not provide the level of benefit intended. Is the project just abandoned? How will the project be modified in light of the new knowledge gained from the monitoring program? Was the monitoring program designed to help assess reasons for failure (e.g., perhaps the new smolts were preyed upon by introduced species)? How will new hypotheses on how to modify the project be generated from the monitoring program? These alternate outcomes must be anticipated in advance with conceptual models and monitoring established to measure the reasons for project failures.

The ISRP Wildlife Review (ISRP 2017-7) indicates a concern about lack of adequate funding for effectiveness monitoring and alludes to a 5% cap on project budgets for monitoring and evaluation. It was unclear if such a cap actually exists, whether that cap is appropriate, and what an alternative might be if a cap approach is not effective. Budgets should be reserved for monitoring and evaluation to ensure effective adaptive management occurs. The ISRP recommended collaboration between wildlife projects and regional monitoring efforts, perhaps to address this budget gap (ISRP 2017-7).

RISK UNCERTAINTY MATRIX

The risk uncertainty matrix is difficult to use as the ISAB learned when it tried to apply the matrix in the Critical Uncertainties Report. The bullet below Figure 5 says that the "Council will accept a reasonable level of confidence, guided by the risk uncertainty matrix," but it is unclear how the figure provides such guidance. The ISAB provided an alternative figure in the Critical Uncertainties Report, Appendix A (ISAB/ISRP 2016-1). If any such figure is to be applied, clear direction on how to apply the figure should be included.

Some specific editorial comments on the 2014 Program's Adaptive Management (RM&E) section are included in Appendix 4.

RESEARCH

Scientific merit

As called for in the 2014 Program, the Council completed a new Research Plan in June 2017 (NPCC 2017-4). It outlines expectations for research projects and identifies critical scientific uncertainties surrounding Basin fish and wildlife mitigation and recovery. In developing the Research Plan, the Council considered public comments and the ISAB and ISRP's Critical Uncertainties Report (ISAB/ISRP 2016-1). For that report, the ISAB and ISRP reviewed (1) the extent to which Program-funded projects addressed critical uncertainties listed in the Council's 2006 Research Plan (document 2006-3), (2) the 2006 Research Plan's uncertainties and other uncertainties raised in regional documents to develop a revised list of uncertainties.

Gaps and suggestions for modification

The ISAB suggests that our recommendations on "moving forward" provided in the Critical Uncertainties Report's Executive Summary would be useful to consider in the Program amendment process:

- "Improve communication on research issues and results among project proponents, the public, governmental entities, the Tribes, and others involved with the Basin's water, land, and fish and wildlife resources. Communication leads to partnerships, pooling of resources, spreading of innovations, public support, and solutions that would be difficult for one or a few organizations to achieve alone.

- Foster efforts to synthesize information generated by independent studies by improving the rigor, consistency and availability of annual reports, convening workshops or symposia, and funding special projects as needed to compile, analyze, and review progress in addressing uncertainties.

- Recognize that research on the expected impacts of climate change and human development in the Basin should be taken into account when setting future Program objectives.

- Support research to identify thermal refuges and ways to secure the availability and quality of water essential to achieving Program objectives.

- Recognize that toxic contaminants are pervasive in the Basin and support research to determine threats to fish, wildlife, and people because of their persistence and bioaccumulation in food webs.

- Support research to guide the management of non-native species. As conditions change, environments may increasingly favor non-native species, some of which are valued and can be managed.

- Continue supporting research on artificial propagation that will help to measure the benefits and risks to natural populations. Encourage research to help develop biological escapement goals for the Basin's salmonid populations and refine approaches for harvesting surplus hatchery fish.

- Expand research to identify and track changes in population structure and genetic diversity of focal species. Loss of genetic diversity may compromise the long-term production and resilience of fish and wildlife in the Basin.

- Continue to support and demand rigorous monitoring and evaluation programs that have well-established objectives and potential for basinwide synthesis. Such evaluation is needed to understand the benefits and risks of Program actions and to manage adaptively.

- Recognize that evaluating the effectiveness of conservation actions is complicated by natural variability and statistical sampling error. Many years of careful monitoring are typically required to confirm small but meaningful changes in ecological outcomes from habitat restoration or supplementation projects.

- Support research on ecological interactions in mainstem, lower Columbia River, estuary, ocean plume, and ocean habitats. Understanding the factors in each habitat that limit population growth will improve management of all four H's (habitat, harvest, hatcheries and hydrosystem)."

The ISAB also recommends that research projects—and monitoring and evaluation projects as appropriate—identify the critical uncertainties that they address and describe this relationship in statements of work, annual reports, and proposals. This information should then be linked to the Research Plan's database to facilitate progress in increasing knowledge and reducing the uncertainties, for example, see the Critical Uncertainties Database.

In addition, the 2014 Program calls for BPA to report annually on publications resulting from program research. However, a bibliography of publications from program research that is accessible to the public has not been developed since 2013 (NPCC Staff 2017). Such a bibliography would be useful and add transparency to the Program. The Program indicates that the time required for research projects should generally be three to five years (p. 104), but this is likely too short for habitat restoration projects. The ISAB suggests a 10-year time horizon may be more applicable.

MONITORING METHODS

In terms of monitoring, BPA has supported development of the monitoring methods and protocols database, MonitoringResources.org, and required projects to input methods into the database. However, it appears that workshops to review and prioritize methods have not occurred (NPCC Staff 2017). Such review and prioritization should occur with an explicit consideration of how the methods relate to adaptive management (i.e., how monitoring data collected contribute to adaptive management, what methods are present to make sure new knowledge feeds back to adjustment of Program objectives and measures).

EVALUATION

In terms of evaluation, the measures seem focused on habitat action implementation (which are covered in other sections of this report including Ecosystem Function and Habitat), whereas there are many other actions occurring in the Basin. For example, there should be measures for model evaluation (see comments in the Framework section on the connection of modeling to adaptive management).

REPORTING

Overall, reporting seems reasonable but could be strengthened by clearly specifying that project and program reporting provide feedback on uncertainties, how uncertainties were addressed, lessons learned, and recommendations for further work or revision to the program. In addition, the audience for the various reporting tools needs to be considered.

For example, consider the annual project progress reports. The second bullet points to reports that are written as scientific research articles. This will be suitable for reviews by the ISAB, but is this type of detail suitable for Council, the general public, and other interested parties? Progress has been made in creating a template for project reporting, but NPCC Staff (2017) notes that BPA has not yet separated research reports from monitoring reports, and also that use of the reporting template is not consistent. The ISAB is not clear about the need to separate research reports from monitoring reports, nor the information requested by the template. Whether it is a monitoring or research report, the template should include (as mentioned in the Framework section) a discussion of uncertainties, how they are handled by the project, and lessons learned that provide feedback for adaptive management. Measure 1 states that "as appropriate, action effectiveness should be reported." It is unclear if "action effectiveness" encompasses the explicit inclusion of discussion of uncertainties, how they are handled by the project, and recommendations for improvement for research or monitoring related to the project. The draft assessment also mentions that many reports using the template omit key sections; it would be useful to assess which sections are typically skipped and find out why those sections are skipped so that the form can be adjusted or measures taken to mandate project proponents to complete those sections.

HIGH LEVEL INDICATORS, DASHBOARD, AND FISH INFORMATION SITE

High level indicators and subbasin plan dashboards are useful for summarizing and visualizing data regarding fish and wildlife in the Basin. Substantial progress has been made for reporting high-level indicators and information on species and habitats through the Council Dashboard and High-Level Indicators websites. The Dashboards are relatively intuitive and easy to use, contain extensive information and background documentation, and can be queried by subbasin to obtain information on recovery targets, species abundance and productivity metrics, monitoring data, limiting factors, regional data, and project-level information. The high-level indicators report website provides nice visualization of data, but the High Level Indicators table is not easy to navigate to see how progress is occurring on these indicators. The Fish Information Site also includes data for the Columbia River Basin that can be searched in a different way than the Subbasin Dashboards.

The Program should recognize that before creating any indicator or website, the intended message and audience for the indicator or website must be considered. For example, graphs and charts are extensively used to present the information, but these assume a high level of technical ability in the reader. If the target audience is the general public rather than scientists, alternate graphical methods may be more appropriate. In addition, the structure needs to be consistent across indicator (e.g., similar types of displays should be used for similar types of data) to reduce “learning” time.

The Program has refined performance criteria for some high-level indicators, such as productivity. Other high-level indicators, such as biological diversity, remain poorly quantified or evaluated and should be developed to the same degree as other high-level indicators. The Program consistently emphasizes measures of productivity while devoting little attention to either life-history diversity of individual species or community diversity of other fish and wildlife species. The limited attention to life-history diversity in the Program focuses on ESA-listed anadromous salmonids for specific subbasins. Basin-wide patterns of either life-history diversity for individual species or community diversity have not been synthesized. The Program has not developed explicit quantitative objectives for either focal species diversity, fish or wildlife community diversity, or habitat diversity at the scale of the Basin or any major subbasin. We recommend broadening the use of high-level indicators to include other fish and wildlife species, and to quantify performance criteria beyond just productivity.

Council staff indicates the website for Fish and Wildlife Program Highlights will be online soon. If it reflects the utility and information content of the Council dashboard, it will be a valuable planning and management tool.

Some specific comments on High Level Indicators are included in Appendix 4.

STRATEGIES

ECOSYSTEM FUNCTION

Scientific merit

The Ecosystem Function strategy is "an overarching Program strategy that incorporates many other strategies which will be assessed for implementation separately" (NPCC Staff 2017). A primary focus has been the role of mitigation in tributaries (offsite) to offset losses to functions in the mainstem that cannot be fully mitigated.

This section of the 2014 Program makes useful points about: 1) the need to consider the Basin as a system, rather than isolated components, and 2) the need to regenerate natural processes rather than relying on technological solutions. The Core Strategy is relatively sound (i.e., "Protect and restore natural ecosystem functions, habitats, and biological diversity wherever feasible consistent with biological objectives in the Program"). However, continued research often reveals strong linkages between ecosystem processes and fish and wildlife populations that were not understood previously, so the phrase "consistent with the biological objectives in the Program" is not a fixed goal.

Nevertheless, a key shortcoming of this strategy is that the narrative for the Rationale quickly moves from consideration of basic ecosystem functions to habitat restoration for target species (specifically, starting in the fourth sentence of the Rationale).

Gaps and suggestions for modification

We argue that it is important here to maintain focus on the entire Columbia River ecosystem, rather than focusing on habitat, for which there is a separate strategy. An ecosystem can be defined as the coupled physical-biological system that provides the physical conditions (i.e., habitat) and biological production (i.e., food) required to sustain restored populations of fish and wildlife. This ecosystem includes terrestrial habitats upslope from aquatic habitats in which fish live, as well as the riparian habitats that lie between and connect uplands to aquatic habitat. It also includes groundwater sources that provide the physical habitat, as well as the estuary, river plume, and ocean, both nearshore and offshore.

Examples of key functions of this linked aquatic-terrestrial ecosystem include not only producing aquatic invertebrates to feed fish (i.e., secondary production, in the parlance of aquatic ecologists), but also adult aquatic insects that emerge from streams and rivers and their floodplain habitats to feed birds, bats, lizards, and other terrestrial wildlife (Baxter et al. 2005). It also includes terrestrial insects that fall into streams and rivers and feed fish. In headwater tributaries, for example, these terrestrial insects can provide fully half the energy budget of stream fish, including salmon and trout, and so are a key function of the terrestrial portion of the ecosystem in supporting fish populations (Wipfli and Baxter 2010).

If we ask the question, for this and most other fish conservation problems, “What are we trying to conserve?”, it is apparent that at least six key elements are important. This list is incomplete because it does not include the ocean/estuarine ecosystem that is critical for salmon, but it illustrates an overall framework. In short, we are trying to conserve:

a) Water quality and temperature
b) Physical habitat structure, including flow itself
c) Floods and other disturbance regimes (e.g., fire, sediment)
d) Linkages to the riparian zone (e.g., inputs of nutrients, groundwater, terrestrial invertebrates, leaves, wood)
e) Riverscape connectivity
f) Coevolved biota (including invertebrates, fish, birds, mammals).

Rewriting a shorter list of statements focused on key ecosystem components, processes, and linkages that are essential to conserve could improve the Ecosystem Function section.

See Appendix 4 for specific ISAB comments on the 2014 Program’s Ecosystem Function strategy.

HABITAT

Scientific merit

In general, this section of the 2014 Program provides sound scientific guidance. However, although this strategy includes many important elements, several are missing.

Gaps and suggestions for modification

- A primary point often made is that the Program is a "habitat-based" plan, because restoration of salmon, steelhead, and other native fish populations cannot be successful without adequate suitable habitat. This point could be highlighted up front in the Rationale and perhaps as the first Principle.

- Surprisingly, the Habitat Sub-strategy does not mention a landscape perspective and does not have a landscape or subbasin context, despite the recent focus by the ISAB on this point (see ISAB 2011-4, Rieman et al. 2015). This could be the second Principle. For example, the list of measures does not include assessment of upslope influences on aquatic ecosystems or actions based on those relationships.

- Even more surprisingly, the Habitat Sub-strategy does not provide links to the subbasin plans, unlike all other sub-strategies except Hydrosystem. The second recommendation of the ISAB review of the 2009 Program (ISAB 2013-1) addressed this, but there is no evidence the Council made any modifications based on the recommendation.

- The General Measures section of the Habitat Sub-strategy should refer to the syntheses needed to determine the effectiveness of habitat restoration in producing higher fish survival and abundance, or point to other relevant sections that do. This is a key uncertainty identified in the Critical Uncertainties Report (ISAB/ISRP 2016-1), and will require large-scale regional or subbasin integration. Recent work by the ISEMP/CHaMP team is a good example of research at appropriate scales and is demonstrating positive results of habitat restoration at the subbasin scale (e.g., Bouwes et al. 2016b).

- It is unclear whether there is a Basin-level framework to integrate restoration of both tributary and mainstem habitats. The NPCC Staff (2017) reports that "More focus could be placed on identifying mainstem habitat restoration opportunities," yet also expresses concern about the benefits of tributary habitat restoration. Despite a section devoted to Mainstem habitat measures, there is no matching subsection focused on tributary "off-site" habitat restoration even though this is a focus of the Program. A more logical framework should be developed that integrates habitat restoration in tributaries, the mainstem, and estuary and ocean, all within a landscape and ecosystem perspective.

- One of the five principles for the goals and objectives of the 2014 Program states that it will be "Implemented in a manner that allows sufficient monitoring and evaluation, and provisions for adaptive management, to ensure that progress toward objectives can be tracked, and that future management can respond to new information and strategies." Neither the Principles nor General Measures of the Habitat Sub-strategy mention anything about research, monitoring, or evaluation. At a time when information needs are growing, recent Program decisions have sharply reduced funding for habitat studies, such as ISEMP/CHaMP. Although these programs may have deficiencies, the need remains for gathering critical information for habitat protection and restoration. There is now an even greater need to explicitly identify the RM&E component of the Habitat Sub-strategy.

Although prioritizing habitat restoration requires careful analysis for each subbasin, empirical data and modeling from the upper Columbia River and other locations within and beyond the Columbia River Basin support ranking habitat protection as a high priority, followed by removing barriers, and reconnecting floodplains and side channels (ISAB 2018-1). Increasing habitat complexity using log and boulder structures is a useful short-term approach, but a long-term strategy is needed to restore processes that maintain channel complexity and supply and retain large wood in rivers.

See Appendix 4 for specific ISAB editorial comments on the 2014 Program's Habitat strategy.

STRONGHOLDS

Scientific merit

In a general sense, the section is scientifically sound. The sub-strategy focuses on stronghold habitats and their populations of native, wild, and natural-origin fish, as well as areas managed for wild fish. Acknowledging, identifying, designating and conserving strongholds is a linchpin strategy for long-term maintenance of demographic stability and genetic diversity of native, wild, and natural-origin fish.

Gaps and suggestions for modification

Despite the importance of strongholds as a strategy, the Council Staff Draft Assessment Report (NPCC Staff 2017) states, "no formal stronghold designations have been made in the Columbia River Basin under the Council's Program." This result is perhaps not surprising given the wording in the section (e.g., "request," "work with") and that a criterion for stronghold designation is that strongholds be designated by states and tribes "in accordance with state law in the state in which they are located." Could the language be strengthened for the Council to take a more active role working with states and tribes to improve progress toward stronghold designations? Could the Council itself develop objective criteria to identify strongholds in order to guide project prioritization and funding through the Program while not supplanting a state or tribal designation?

Another Program language issue is that a portion of the second principle is inconsistent with the concept of a stronghold. That is, if populations decline "to the point where supplementation efforts are appropriate to avoid extinction and stabilize native wild or natural-origin stocks," wouldn't that by definition remove the habitat and population from a "stronghold" designation? The Fish Propagation Strategy section of the Program describes the use of conservation practices for weak stocks that are at the risk of extinction.

Additionally, there is a risk of demographic and genetic isolation of strongholds that could diminish their value for long-term maintenance of genetic diversity and provisions of ecological resilience. Strongholds should be functionally connected to the geographic extent possible with other habitats within the subbasin, and to the ocean if the stronghold is designated for anadromous species. There may be trade-offs of functional connectivity and threats of exposure to nonnative species and straying hatchery-origin fish. In this case, threats should be managed in concert with activities to restore natural connectivity. The enormous conservation value of strongholds could be increased by:

1. Supporting and encouraging multiple, geographically distinct strongholds within and among subbasins of the Columbia River Basin.
2. Promoting strongholds that are sufficiently large to preclude risks of catastrophic demographic loss and losses of genetic diversity in the species each stronghold is designed to protect.
3. Working toward functional connectivity between strongholds and other habitats that could potentially hold fish, especially restored habitat areas. The stronghold could serve as a natural demographic source for recolonization of restored habitat by salmonids and other native aquatic species, similar in concept to Marine Protected Areas (MPAs).

NON-NATIVE AND INVASIVE SPECIES

Scientific merit

While the Program provides mostly sound guidance, it is more general than specific. Prevention of introductions of all non-native species (or even moving established species) should be the rule. This rule should include a general prohibition on introducing Columbia River native species outside their historical native range, unless it is carefully done for conservation purposes, and with no damage to other native species.

Gaps and suggestions for modification

Non-native species, some of which are invasive (i.e., damage the environment, human economy or human health), present a dilemma to managers of natural resources. First, they frequently have a symbiotic relationship with people. Often the relationship is complex. Smallmouth bass and channel catfish, for example, were originally introduced because of a mutually beneficial relationship with people: the people got a fishery, and the fish got expanded ranges and populations in reservoirs and altered streams. While this positive relationship still exists, these fish are also regarded as a having a negative relationship because they prey on endangered salmon, creating potentially large economic costs. A second problem is that only a small percentage of non-native species are invasive. Most settle into highly altered habitats and become integrated into the novel ecosystems that now dominate so much of the western United States. A third issue is that eradication or even control of an invasive species is very difficult, and often impossible. Thus, the best strategy is to prevent invaders from becoming established through a large-scale prevention program. Such programs are hard to fund because they must be continuous, and success is based on negative results. Control of a new invader in contrast can get major emergency funding even though such control programs rarely lead to eradication.

The invasive species section of the 2014 Program recognizes these realities, if not specifically, and the need for a science-based, systematic way of dealing with the issues. The Program Goals and Objectives mention non-native species in a few goals. This concern was carried over from the ISAB review of the 2009 Program (ISAB 2013-1). The guidelines in the Program, however, are very general, apparently because agencies and tribes have developed more region-specific measures.

A major problem, as stated in the ISAB/ISRP Uncertainties Report is: “Effects of non-natives on the native fauna are seldom well understood, are typically difficult to predict accurately, and may be recognized only after the native species are in steep and sometimes irreversible declines in abundance and recruitment” (ISAB/ISRP 2016-1). The third Principle in this section says, however, that introduction of a non-native species necessary for mitigation is acceptable with “a clear understanding of the threats to native species.” Having an understanding is not good enough—the stakes are too high given the ESA’s mandate and Program’s goals and efforts to recovery and protect native species. The fallback position for any proposed introduction should be prohibition, except in the extremely unlikely case that it can be unequivocally demonstrated, through a wide array of scientific studies, that it will do no harm, now or in the future.

The list of General Measures is an unorganized set of overlapping ideas. Rewriting this section to flow logically from the most effective measures, which are profiling the most likely invaders and developing a public information campaign to prevent their introduction, to the least effective, which address eradication and control, would be a great improvement.

Another gap in the section is the failure to specify support for research to understand impacts of introduced species more fully. This may be an extension of the first gap mentioned above and, perhaps, with more research the first gap would be mitigated.

The order of priorities for preventing, controlling, and eradicating nonnative species is very important but is not clear in this section. Fisheries managers often elect to do the least effective action, which is to attempt eradication, first, whereas addressing the socioeconomic factors needed to prevent introductions is not. Fausch and Garcia-Berthou (2013) present a useful hierarchy, with actions ranked from highest to lowest priority (see Table 1 below). A key point of their first priority is to prevent stocking of nonnative species into any system, even ones thought to be closed (e.g., floodplain lakes), because flooding and human (often illegal) transport are key vectors for nonnative species.

Table 1. The problem of invasive species in river ecosystems (Table 8.2 from Fausch and García-Berthou 2013).

1. Profile and prevent	Estimate which species are most likely to arrive, by which vector and where. Assess which species are most likely to do damage if they spread.
2. Educate public and limit vectors	Educate the public about preventing arrival or spread of dangerous invaders, and develop methods to reduce risk of human or natural spread.
3. Reduce propagule pressure	Even after species have arrived, seek ways to reduce propagule pressure (i.e., the number of organisms released), a primary driver of nonnative species establishment and spread.
4. Manage habitat and flow regimes to favor native species	Habitat change is a powerful force that hampers native species survival and provides niche opportunities for invasions. The converse, that restoring natural flow or other disturbance regimes will reduce nonnative species invasions, is not always true but deserves more study.
5. Consider tradeoffs in social values and management options	The public may value some invaders while considering others noxious pests. This perception may change with more information, which deserves research.
6. Understand establishment and spread	Once invaders have arrived, understanding what allows them to establish and spread may allow developing management actions to limit these stages, or suggest stronger policies to reduce propagule pressure.
7. Eradicate or control	Eradication may be possible at the early stages of invasion when the spatial extent is limited, and should be pursued with all means possible. Control is often difficult and entails large and long-term costs.

The existing directives in the 2014 Program would seem to provide an adequate basis for looking at the impacts of invasive species on the 2-6% Smolt-to-Adult Ratio. Presumably, each species and population has a unique combination of non-native species to face, ranging from brook trout in the headwaters to bass in the reservoirs. It is important to determine how much, if any, impact invasive species have and whether it is growing. It is also important to identify potential invaders, including fishes. The fish fauna of the Columbia Basin is regarded as being far from saturated with species, so it may be especially susceptible to introductions (e.g., McGarvey 2012).

PREDATOR MANAGEMENT

Scientific merit

The rationale, principles, and general measures specified in the Predation Management section are for the most part scientifically sound, justified, and fairly comprehensive. Important strategies for managing altered predation regimes on anadromous salmon are identified. Most importantly, the 2014 Program recognizes that novel predator regimes are linked to habitat alterations that result from changes to, and management of, the hydrosystem. Habitat restoration is appropriately identified as a key strategy to reduce predation pressure at various life stages in the salmonid life cycle. Nevertheless, the ISAB suggests that some of the Council's guidance for projects and actions needs to be updated and important gaps in implementation addressed.

Gaps and suggestions for modification

The second principle of this sub-strategy is based on the assumption that predator management is necessary to improve the survival of salmon and steelhead, sturgeon, lamprey, and native resident fish species in the basin. However, this assumption has seldom been evaluated quantitatively (ISAB/ISRP 2016-1). The goal of developing a single common metric to evaluate predation is not supported because a single metric cannot address all management concerns (e.g., short-term effects of predation on harvest opportunity and spawner abundance or long-term effects on population viability and ecosystem resilience and sustainability (ISAB 2016-1), and the goal should be modified in the plan revision. The ISAB recommended two types of metrics be used in the context of life-cycle models: adult equivalence-factor and population-growth metrics. Compensatory mortality is the most important uncertainty for the technical work group to address when evaluating the effectiveness of predator-management actions (ISAB 2016-1).[3] The ISAB noted considerable uncertainty regarding compensatory mortality over the life cycle that can change the demographic outcome of predation.

Pinniped predation on returning adult spawners is likely to have the largest impact on salmon and steelhead survival, and more research is needed on the efficacy of predator control to protect returning adults in the estuary and lower Columbia River. The estimated consumption of combined populations of Chinook salmon by pinnipeds in the Columbia River increased sharply over the past decade, likely exceeding removals by fisheries, and additional sea lion predation on Columbia River Chinook salmon in the ocean may be larger than previously documented (Chasco et al. 2017). Better information is needed to evaluate how actions in the Basin such as hydrosystem spill and flow, large releases of hatchery fish, habitat alterations, and harvest affect pinniped predation in the Columbia River plume and nearshore ocean.

The 2014 Program does not consider evolutionary effects of predation. The revised plan should both identify threats to phenotypic (e.g., life-history variation) and genetic diversity, and a plan to mitigate these effects. For example, preliminary research indicated pinniped predation risk for adult Chinook salmon is much more acute for spring-run compared with summer-run fish (Sorel et al. 2017) and thus could exert strong selection on run timing. Strong selection in this context is expected to decrease genetic diversity and life history variation in Chinook salmon as a whole.

Important questions remain regarding the role of other native and nonnative fish species, especially with their roles as competitors (i.e., density dependence) or predators at some life stages. The rationale for potential expansion of northern pikeminnow removals to other mainstem dams in the lower Columbia River should be identified clearly. Such actions should be based on quantitative studies of the possible consumption of juvenile salmon and steelhead and the interactive responses with other species of prey and predators. Fish species with life histories that coincide with salmon could dilute apex predator effectiveness by increasing overall prey densities at particular life stages. The revised plan should include provisions to study interactions of nonnative and native fish at all relevant life stages, but particularly at the egg through smolt stages. Research on interaction of native and nonnative species and

[3] Compensatory mortality occurs when predation mortality at one life stage is offset to some degree by decreased mortality at the same or subsequent life stages. Examples of potential mechanisms driving compensatory mortality include (1) density-dependent survival due to factors other than predation, (2) selective predation based on fish size and condition, and (3) prey switching behavior of predators, which may be caused by a change in abundances of alternative prey species or when secondary predators increase predation on salmon following control of the primary predator (ISAB 2016-1).

incorporation of interactions into life-cycle models that evaluate salmon survival are needed. Trade-offs of hydrosystem operations, cost effectiveness, public perception and support for non-native and predator control and removal should be further studied in the context of an integrated salmon life-cycle model.

According to the Council staff's progress report on Program measures (NPCC Staff 2017), progress has been made on 10 of 14 Program measures for the predation sub-strategy. One notable gap in implementation is that the Council has not proceeded with its general measure under this sub-strategy to form a technical work group to determine the effectiveness of predator-management actions in the Basin. As discussed in more detail above, however, the Council's goal of developing a single common metric to evaluate predation is not supported (ISAB 2016-1).

PROTECTED AREAS AND HYDROELECTRIC DEVELOPMENT AND LICENSING

Scientific Merit

This section of the 2014 Program provides scientifically sound guidance and is an important landscape strategy that protects over 44,000 miles of rivers and streams in the Pacific Northwest from the adverse effects of future hydroelectric project construction and operations. A map of those areas is available online. The ISAB has not commented on this aspect of the Program before, and coverage of Protected Areas would have been beneficial in the ISAB's Landscape Report (ISAB 2011-4).

Gaps and suggestions for modification

The ISAB supports the possible actions described in Council's staff assessment report (NPCC Staff 2017) and believes that Council staff should continue tracking proposals for new hydropower projects in protected areas. The Council may want to consider the merits of deliberately tracking the additional elements of this strategy.

The ISAB encountered difficulties accessing the Council webpage on Protected Areas and the Protected Area webpage in StreamNet. Thus, the ISAB recommends including the Protected Areas database, geographic information, and species of concern within each Protected Area in the Council Dashboard. Information on the Protected Areas also could be provided in an education and outreach module so more people would know about these areas and how they fit into the Basin conservation strategy.

WATER QUALITY

Scientific Merit

The section provides scientifically sound guidance, but very little has been accomplished outside of monitoring total dissolved gas (TDG) and water temperature. In terms of water temperature, there have been some operational modifications at the fish ladder at Lower Granite Dam to reduce temperature. In addition, Basin partners, including the Council, merged data from multiple agencies to create a publicly available map of polycyclic aromatic hydrocarbon (PAH) contamination in the Basin, and a map of cool water thermal refuges is being prepared along the mainstem Columbia (NPCC Staff 2017). Regional and local studies of water temperature impacts have been completed in some segments of the Basin (e.g., Cristea and Burges 2009 for Wenatchee River; Shultz and Johnson 2017 for Lower Snake River; Weber et al. 2017 for impacts of beaver dams on stream temperatures in John Day basin).

Gaps and suggestions for modification

Language in this Program section includes phrases such as "support and promote." It does not appear that funds outside of the Accords have been forthcoming. The Program states, "The Council urges Congress…" to fund Columbia River water quality work through the EPA. Has this action been taken beyond being printed in the Program? Can the Council be more insistent by acting through the Congressional representatives of the four states to get action?

Although titled "Water Quality," this section primarily discusses just water temperature, TDG, and toxic contaminants. Other water quality such as nutrients and contaminants that are not toxic can also affect habitat and health of fisheries, and measures should be included to monitor and assess impacts of these aspects of water quality.

In December 2016, Congress passed and the President signed the Columbia River Restoration Act, but as yet no EPA funds from this Act have been forthcoming to address water quality issues in the Columbia River. In addition, the EPA and other agencies, including the NPCC, underwent a US Government Accountability Office (GAO) investigation on current work efforts to reduce toxics in the Columbia River and the need for toxics reduction work. That investigation began in late 2016 and when the GAO report is released, it may point out the need for the Council, EPA, and others to take coordinated actions to reduce toxics and other contaminants in the Basin.

There is a recommendation in the 2014 Program to support the EPA-sponsored Columbia River Basin Toxics Reduction Action Plan (EPA 2010), but it appears that the interagency committee for this plan has not had any meetings since October 2015 according to their website. The

Council staff's draft program assessment report (NPCC Staff 2017) states that NOAA-Fisheries, USGS, USFWS, EPA, and BPA are conducting research and monitoring on the effects of toxic contaminants (e.g., Rounds et al. 2009). In addition, NOAA Fisheries included a chapter on toxics as an obstacle to Columbia River salmon recovery (Lundin et al. 2017) in their life-cycle model report. While little or no actual modeling has been completed, NOAA Fisheries outlines the actions needed to address the issue of toxics in salmon recovery.

CLIMATE CHANGE

Scientific merit

The measures in this section (including Appendix G) provide sound scientific guidance for projects and actions, but information on warming rates and changes in precipitation need to be updated based on the most current literature. Additional actions are also needed by the Council to ensure that the seriousness of limiting the advance of climate change is relayed to project sponsors and the general public. The Council and action agencies should insist that project sponsors include planning and monitoring climate change effects in their research and restoration activities.

Gaps and suggestions for modification

While some progress has been made on many of the measures in the Program, much of the progress has been fairly passive (i.e., support for actions by others or plans for action). The scientific evidence is unequivocal that human actions (i.e., the use of fossil fuels that increase CO_2 in the atmosphere and ocean) are driving climate change and ocean acidification. Indeed, the Council should increase its efforts to (1) promote public awareness of the causes and effects of climate change, (2) convene science/policy workshops on climate change in the Columbia Basin and (3) encourage the development of energy sources generated without the release of greenhouse gases as recommended in the ISAB Climate Change report (ISAB 2007-2).

Using hydropower operations to mitigate climate change has been partially addressed (NPCC Staff 2017). Selective withdrawal has been implemented at Lower Granite Dam and is being designed for some high-head Willamette subbasin dams. Such approaches can take advantage of reservoir stratification to release water of specific temperature at desired times of the year with appropriate management and water supply. The ISAB stresses that appropriate natural flow and thermal regimes are the goal. Compensation for climate change by artificially creating flows and temperatures of the past may inadvertently make aquatic ecosystems even more vulnerable to future changes when expensive artificial measures cannot be maintained. Focuses on restoring natural processes that maintain cooler temperatures (e.g., riparian shade, floodplain function, hyporheic exchange) are of greater importance than relying on technological fixes to solve problems exacerbated by those technical alterations of the river network in the first place. Nonetheless, the large number of dams and reservoirs in the Basin at varying elevations and with different storage and discharge capacities may provide options to mitigate climate change impacts on flows, water temperatures, and water quality (Null et al. 2013).

Given the Program's current emphasis on estuarine habitat restoration to improve juvenile salmon survival, the Climate Change sub-strategy should be updated to reflect the latest scientific evidence and uncertainties regarding climate change effects on estuary, plume, and nearshore ocean habitats. For example, sea level rise due to climate change in combination with hydrosystem effects (reduced sediment loads) and sand removal may result in substantial changes to lower Columbia River estuary habitats (Jay et al. 2016). However, the action agencies have not investigated the feasibility of mitigating climate change impacts in the estuary and plume through hydropower operations. One of the ISAB recommendations in the review of the 2009 Program is not included in the 2014 Program: Develop a comprehensive strategic plan on the potential impacts of climate change on the entire system, including the estuary and ocean, and develop a suite of strategies within the amended Program.

There is increasing evidence that climate change is driving rapid evolution of salmon life history traits and phenology, for example, shifts in migratory timing due to directional selection during the oceanic life stage (Manhard et al. 2017). Additional research and monitoring to guide restoration actions, hatchery practices, and hydro operations are needed to ensure that the maximum possible life history diversity is maintained. Diversity of life histories is key to resiliency of fish and wildlife populations. Focusing on sustaining a "portfolio" of the entire range of life history strategies may not produce the most salmon in the near-term but may mean the difference between losing all stocks of certain species in certain areas after extreme events versus retaining fragments from which stocks might be rebuilt.

In addition, extreme events may have strong effects out of proportion to their magnitude, and not only cause high mortality but also shift ecosystems into different phases that may be less desirable for salmon and steelhead. The Critical Uncertainties report (ISAB/ISRP 2016-1) noted that climate change impacts could affect not only flow, but also water quality and aquatic ecosystems. Few research or monitoring projects in the 2014 Program appear to be addressing such impacts directly. Projects listed in ISAB/ISRP (2016-1) involve restoration actions that are not directly related to climate change research, but which could build resilience in fish populations that could help to mitigate climate change. In addition, the Program's current research, monitoring, evaluation, and adaptive management planning for the preservation of life history diversity does not adequately consider and account for variation in plume and nearshore ocean life histories of salmon and steelhead.

The ISAB reviewed Crozier et al. (2017 in Zabel et al. 2017) in which climate change conditions were examined in relation to life-cycle models for spring/summer Chinook salmon in the Salmon River. The ISAB noted that although a lot of work had gone into the assessment, the chapter did not provide enough details to verify the approach (ISAB 2017-1). Honea et al. (2016) also did a modeling study using global climate models (GCMs), a hydrology model (DHSVM), and Shiraz life-cycle models to examine potential impacts of climate change on Chinook salmon in the Wenatchee River. Their modeling indicated that water temperature could be more challenging for Chinook salmon spawning with climate change but that the percentage of fine sediment in gravels during incubation could continue to limit spawner abundance, a similar finding to their study without climate change (Honea et al. 2009). This type of modeling provides information about the types of restoration that could have beneficial impacts on climate resilience for salmon. More modeling of climate change conditions is needed with acknowledgement of uncertainties associated with such modeling.

MAINSTEM HYDROSYSTEM FLOW AND PASSAGE

Scientific merit

The section on Mainstem and Hydrosystem provides scientifically sound guidance. However, the implementation of that guidance is inadequate in several respects. The section primarily addresses activities affecting anadromous salmonids, but actions to improve conditions for other fish, such as white sturgeon, eulachon, Pacific lamprey and bull trout are limited.

Gaps and suggestions for modification

Research on the effects of mainstem hydrosystem flow have centered mainly on anadromous salmonids and their survival, on elucidating the relative abundance and survival of hatchery versus naturally spawned fish, and the effects of run times on survival. Most of this work is very thorough and well done. However, hydrosystem operation has impacts on species other than salmon and on ecosystem function. The broad goals of the Program are to provide river and reservoir conditions to promote productive populations. However, any such proposed conditions must take an ecosystem view and address impacts on other species (e.g., non-native fish). For example, a proposed condition may benefit productive populations of salmonids, lamprey, or sturgeon but also benefit non-native species even more and so the net benefit is actually negative. It is not clear if such considerations have been taken into account.

A topic raised in the ISAB report on density dependence (ISAB 2015-1) is the role of changes in mainstem habitats on the carrying capacity of the Basin. Primary and secondary production that sustains target species will be affected by flow and temperature. The Program needs to address mainstem habitat conditions and floodplain connectivity as elements in density dependent regulation of anadromous and resident fish. Many of the proposed actions provide immediate benefits to a specific part of the life cycle (e.g., juvenile passage survival), but if there are limiting factors later in that life cycle, the benefits may not be realized. Consequently, any proposed actions must be placed into the context of a life cycle to identify the actual net benefit. Similarly, current measures are undertaken one population at a time, and there appears to be little consideration of the impacts of improvements on the aggregate of populations (e.g., improved habitat may increase the survival of each sub-population). But when the populations migrate through the hydrosystem, if they exceed carrying capacity, benefits are again reduced. While individual population life-cycle models have been and are under development, little work appears to have been done on multi-population or species aggregates.

Pacific lamprey are getting more attention through Accord projects. However, of all fish species in the Basin, the status of white sturgeon is most strongly tied to conditions in the mainstem, which are directly affected by the hydrosystem. In addition, the relationship between hydrosystem operations and sturgeon passage and reproductive success needs more investigation. These issues were raised by the ISAB in its review of the 2009 Program (ISAB 2013-1). It should be noted that elements of this section are integrated or linked with other sections such as sturgeon, lamprey, climate change, and water quality.

ESTUARY

Scientific merit

Overall, the ISAB considers the Council's guidance for estuary projects and actions sound, and there has been progress on implementation of most measures. There have been actions on five of six general measures, some with partial implementation (NPCC Staff 2017)**.** However, we suggest that the Council's guidance to the Corps and Bonneville and other partners could be strengthened by emphasizing the need for quantitative estimates of juvenile and adult salmon and steelhead survival in the estuary in order to evaluate the effectiveness of habitat restoration measures throughout the Basin, including those in the estuary.

Gaps and suggestions for modification

The estuary is a pivotal area that historically has had less attention than areas upstream. Only in about the past 20 years has the estuary received the attention it deserves, considering its importance for migratory life stages of all anadromous fishes (including all runs of salmon and steelhead, sturgeon, eulachon, Pacific lamprey, and even the non-native American shad). Little attention is paid to non-migratory or non-native fishes in the estuary despite potential for interactions with the migratory fishes.

The ISAB has reviewed various programs affecting the estuary, especially restoration activities, working with Columbia Estuary Ecosystem Restoration Program (CEERP)[4] (ISAB 2012-6). By and large, the reviews have been positive, noting steady increases in attention and resources being paid to the estuary. Some of the key issues that are being addressed to varying degrees include:

- Effectiveness of restoration programs, especially floodplain restoration, mainly for salmonids.
- Effects of hatchery juvenile salmonids on juveniles of wild origin. There is some concern that hatchery fish dominate open-water estuarine habitat to the detriment of wild fish. Could hatchery fish be exceeding the salmonid carrying capacity of the estuary?
- How do anadromous non-salmonid fishes use the estuary? What are limiting factors?
- Predation issues, especially by birds and marine mammals (see *Predator Management*).
- How do hydrosystem operations (and other factors) affect estuarine functioning, especially food webs?

The enormous spatial extent of the estuary exacerbates the challenges in mapping habitat use quantitatively and in evaluating species use of peripheral habitats. Because of the difficulty in matching surveys to the timing of species passing through or residing in the estuary, measurements of abundance to evaluate mortality are complex. A variety of modeling techniques have been used to address these shortcomings. For example, life-cycle models and proxies for mortality such as growth at age or stage are commonly used approaches. Increased survey effort in the estuary would better refine food-web modeling and, as a consequence, refine the evaluation of potential carrying capacity and its variance. Monitoring the physical environment may cost less but often is of less value compared with investing in biological monitoring. This is an ongoing challenge for action-effectiveness, status and trend monitoring, and research in the estuary.

---

[4] The Columbia Estuary Ecosystem Restoration Program (CEERP) is the collective habitat restoration and research, monitoring, and evaluation (RME) effort in the Lower Columbia River Estuary (LCRE) conducted by Bonneville Power Administration, U.S. Army Corp of Engineers, and others to direct implementation of estuary actions in the Federal Columbia River Power System Biological Opinion (FCRPS BiOp) under the Endangered Species Act.

The ISAB recommends updating this sub-strategy to better focus the Council on resolving the most important information gap that limits the ability to evaluate the success of this sub-strategy—the lack of quantitative estimates of survival of juvenile salmon, steelhead, and other focal species in the Columbia River estuary. The current state of knowledge of the effects of habitat restoration on the estuarine survival of juvenile salmon is largely descriptive (Krueger et al. 2017). According to Krueger et al. (2017), "reliable information describing the effects of restoration on salmon survival would ameliorate much of this uncertainty, and the Survival Benefit Unit (SBU) assignments could measure absolute mitigation rather than relative progress." An ISAB review of the process used to calculate SBUs concluded that the "capability of [habitat restoration] projects to actually succeed in increasing the survival of salmon through their residence and migration in the Columbia River estuary cannot be determined from the Scoring Criteria" used to calculate survival benefit units (ISAB 2014-1). Previous ISAB advice from the Columbia Estuary Ecosystem Restoration Program CEERP review (ISAB 2012-6) is still relevant:

> "A highly focused RME approach that estimates stock-specific survival rates in all major habitat types in the estuary and identifies habitats/locations where there are survival bottlenecks for species and stocks that migrate through Federal Columbia River Power System (FCRPS) is needed. Once these estuary bottlenecks are identified, it will be much easier to determine the most cost-effective approaches to habitat restoration that will be of benefit to Columbia River fish and wildlife."

An important gap is that monitoring for Pacific lamprey in the estuary has not been implemented (see *Lamprey*). There is a general need for lamprey studies to determine how much of the predatory marine-phase of the lamprey life cycle is spent in the estuary (including the ocean plume) and what fishes are their major prey. Does predation by sea lions affect adult lamprey population or help buffer salmon from predation?

A measure calling for a March 2015 summary report by Bonneville and the Corps on results of action-effectiveness, status, and trend monitoring, and research uncertainties has not been provided to the Council (NPCC Staff 2017). The information for this report was requested by the Council "to help improve and substantiate the effectiveness of habitat actions implemented in the estuary by parties that do not monitor their own habitat actions." It is not clear to the ISAB why this report is so long overdue and how the Council can evaluate the effectiveness of the estuary sub-strategy without having a thorough synthesis of results to date.

PLUME AND NEARSHORE OCEAN

Scientific merit

The Council's guidance for projects and actions is sound and substantial progress is being made. However, some of the guidance could be updated and improved. The ISAB's previous reviews state that substantial progress is being made to address the effects of ocean and plume conditions on growth and survival of target species (ISAB/ISRP 2016-1). This is also well addressed in the Council's Ocean and Plume Science and Management Forum, which summarizes ongoing research progress. On a broad scale, predictions of survival based on ocean conditions have been correct. The NOAA's PICES program has resulted in peer-reviewed science that evaluates linkages between ocean conditions and food web responses.

Gaps and suggestions for modification

Not enough effort has been directed at the effects of pollution (particularly plastics and nanoparticles) in the plume/nearshore ocean, although pollution may have a measurable effect on target species survival. The ISAB did not find any mention of pollution on the Council's Ocean Forum website. Our past reports also noted that the effect of harvest in the ocean on survival of anadromous species has not been quantified (for example, ISAB 2013-3, ISAB 2015-1, ISAB/ISRP 2016-1, ISAB 2017-1), perhaps in part due to the difficulty in obtaining solid measures of harvest or bycatch of Columbia River fish in distant-water marine fisheries.

Language in the Program needs to clarify which species are included in this sub-strategy by listing focal species in the sub-strategy statement. The current language is vague, referring only to "salmon" and "Columbia River fish," thus, for example, it is not clear if "fish" includes steelhead and other fish species that use plume and nearshore ocean habitats such as Pacific lamprey, sturgeon, and eulachon.

Considering recent advances in scientific understanding of the effects of ocean conditions on Columbia River salmon survival, this sub-strategy should be updated to better guide projects and actions aimed at filling large gaps in population-specific information on these effects (including hatchery/wild ecological interactions) in a full ecosystem and life-cycle context.

Regarding all active measures in the Program, the work should be expanded to include monitoring of returning adult salmonid survival in the Columbia River plume/nearshore ocean. To date, projects and actions have largely focused on juvenile (subyearling/yearling) Chinook salmon during their first few months at sea, a life stage generally accepted by scientists as critical to ocean survival. However, the effects of ocean conditions at other potentially critical life stages are largely unknown. For example, we do not understand how local ocean conditions and associated hydrosystem effects influence the survival or predation mortality of adult Columbia River salmon and steelhead near the river mouth.

ISAB members have participated in the Ocean and Plume Science and Management Forum and consider the Forum to be a success. If the Charter is renewed (it expired in 2017), the ISAB suggests that an important collaborative goal for scientists and managers participating in this forum would be to develop subbasin- or population-specific ocean modules such as that developed by NOAA for ESA-listed Snake River anadromous species (NOAA 2014). In particular, identification of important information gaps, potential management implications, and priorities for future ocean research would be valuable.

The ISAB considers the measure to develop an annual index of salmon ocean survival (smolt-to-adult), as measured at Bonneville Dam (BON to BON index), important—smolt counts at BON were identified as a large information gap that needs to be filled. However, a BON-to-BON index cannot be used to distinguish between estuarine and plume/nearshore ocean effects, and thus does not conform to the first principle of this sub-strategy, which is "Identify the effects of ocean conditions and distinguish from other effects." This measure should be expanded to guide development of an annual index of smolt survival between BON and the mouth of the Columbia River so that BON-to-BON survival effects can be apportioned to major habitat components (estuary and plume/ocean). Current efforts by the action agencies to estimate adult salmon survival from the Columbia River mouth to BON should be continued and expanded to steelhead.

WILDLIFE MITIGATION

Scientific merit

The Wildlife Mitigation section of the 2014 Program provides sound guidance. There are, however, several deficiencies in how that guidance is applied. The Program should directly address these deficiencies identified by Council staff (NPCC Staff 2017).

Gaps and suggestions for modification

The Council's Staff Assessment Report (NPCC Staff 2017) identified several challenges or unresolved issues for Wildlife Mitigation in the Program, summarized here:

1. Five of 27 FCRPS dams listed in the Program for wildlife mitigation remain under-mitigated for construction and inundation (C&I) losses; separate settlement agreements were made for Hungry Horse, Libby, the Willamette system, Albeni Falls (IDFG) and

Dworshak dams, and with IDFG for Southern Idaho. The 2014 Program endorsed a 2:1 mitigation for habitat units for unaddressed losses since 2000, but BPA is using acreage totals for their agreements and disputes 2:1 mitigation as a principle for wildlife mitigation.

2. There is lack of agreement on the level of monitoring funding needed for measuring habitat and species benefits though the Program. One potentially effective approach is regional pooling of monitoring funds (such as recent efforts by the tribes of UCUT). Projects monitor some habitat characteristics, but most projects do not monitor species responses.
3. Benefits to both wildlife and fish are limited in current projects and crediting for dual benefits is inconsistent and unresolved.
4. C&I losses have been mitigated for 22 of 27 FCRPS dams, but there is no agreement on methods to assess operational losses. One project of the Kootenai Tribe has worked with Montana Fish, Wildlife and Parks to develop an operational loss assessment, but other projects have not applied the approach. BPA has developed principles to consider in mitigating for operational losses, but the managers do not agree with these principles.
5. The Program indicates BPA and the agencies and tribes will complete wildlife loss mitigation agreements for the remaining construction and inundation losses by 2016, but these are not yet completed.
6. There is no agreement on how fish mitigation projects would or would not count toward addressing wildlife losses.

The ISAB review of the 2009 Program (ISAB 2013-1) recommended integration of wildlife mitigation projects with fish mitigation projects, consistent with an ecosystem approach. The lack of integration of wildlife and fish projects identified above indicates this continues to be a Program need.

The ISRP review of the Wildlife Projects (ISRP 2017-7) recommended basin-level analyses and summary of the overall effects of BPA's wildlife mitigation efforts. ISAB recommendations in the Comprehensive Landscape Approach Report (ISAB 2011-4) are consistent with the ISRP review. Few of the wildlife mitigation reports described relationships between habitat restoration activities and status and trends of habitat or fish populations at a landscape scale. The Program has not identified appropriate levels of funding and technical capacity for monitoring or landscape-level evaluation, thus wildlife mitigation projects differ greatly in their landscape contexts for assessing progress. The ISRP pointed out that upstream and upslope processes were not addressed in many wildlife mitigation projects, and the Program should make it clear that such basin-level factors should be addressed explicitly. Lastly, most of the wildlife programs are designed to mitigate for past habitat losses. The Program should call for the wildlife mitigation programs to consider climate change, human population impacts, and contaminants in developing their strategies and designing their mitigation actions for the future.

FISH PROPAGATION INCLUDING HATCHERIES

Scientific merit

Overall, the Program has done a good job providing sound scientific guidance for how artificial propagation of salmonids should occur in the future. Approximately 130 million juvenile hatchery salmonids are released annually into the Columbia River. Many of these fish are produced for harvest augmentation, but a substantial proportion support supplementation, conservation, and reintroduction programs. Each type of hatchery application carries with it management obligations and challenges.

Gaps and suggestions for modification

The upcoming Program amendments offer an opportunity to put special emphasis on two areas. First, the potential success of conservation efforts such as supplementation, reintroduction, and safety-net programs is dependent upon two factors:

1. Fish used in conservation programs must possess genetic and phenotypic characteristics that are well-suited for the natural environments they will eventually encounter. This consideration not only pertains to recently released juveniles but also to returning adults and the offspring those fish are expected to produce in nature.
2. The capacities of the receiving environments the fish are expected to inhabit must be great enough to accommodate the new recruits produced from conservation efforts.

This second factor is often overlooked, or assumptions about capacity are made but not evaluated. Careful evaluations of the habitats that will receive fish produced from conservation programs needs further emphasis in the Program.

The second area that can be emphasized has to do with state, federal, PUD, and tribal organizations all operating hatcheries in the Basin. There is a natural tendency for agencies to only consider their own hatchery operations. Additionally, legal requirements (e.g., treaty obligations and mitigation agreements) are often in place that establish production goals for single hatcheries. These legal constraints plus isolated views of ongoing hatchery programs reduce management flexibility. The 2018 Program should emphasize that the total impact of fish releases made by diverse programs needs to be examined. For instance, do cumulative releases of juvenile salmonids overwhelm available food resources in subbasins, the mainstem, estuary, or ocean plume? Coordination among the organizations operating hatcheries throughout the Basin is needed to ensure that deleterious interactions among hatchery fish, natural origin conspecifics, potential predators, competitors, and prey species are minimized. This will be quite challenging. However, the Council could play an important role in facilitating this type of coordination.

Genetic and habitat suitability and cumulative effects of multiple hatchery programs also need to be considered in the artificial propagation programs for white sturgeon, Pacific lamprey, kokanee, resident trout, burbot, and non-native fishes. Other principles related to artificial propagation that should be considered in the Program amendments include:

1. As an overarching guiding principle, the best available science should be used to evaluate short- and long-term risks and benefits of hatcheries.
2. Mandate collection of tissues for genotyping all hatchery fish along with the physical tagging requirement already specified in the General Measures section of the 2014 Program. Genotypes and tag identities should be deposited in an accessible database with appropriate metadata. These data are critical for understanding impacts of hatchery-origin fish on natural-origin fish at a broad scale as recommended by the ISAB (2013-1).
3. Guiding principles, strategies, and measures for integrated vs. segregated hatcheries should be in separate sections of the Program.
4. Recognize the value of thermal otolith marking and environmental DNA (eDNA) as tools that can also be used to monitor and evaluate salmonid hatchery programs

WILD FISH

Scientific merit

The 2014 Program appropriately identifies all native wild fish (anadromous and non-anadromous) and their habitats as critical resources for the Basin. The plan specifically refers to genetic, but not phenotypic diversity as a valuable biological resource that can buffer demographic losses against changing environmental conditions. Genetic and phenotypic diversity are linked, and variation in both should be distributed within and among restored native fish populations.

Gaps and suggestions for modification

A revised strategy should include measures to increase habitat quality, increase the number of restored habitats across watersheds, and increase connectivity throughout the hydrosystem. The following goals should be considered in the upcoming Program amendments:

1. Restoration of self-sustaining, genetically and phenotypically diverse populations of native fishes within and among watersheds.
2. Restoration of functional lateral connectivity (between river and floodplains) and longitudinal connectivity (via passage, active transport, etc.) throughout the hydrosystem for restored habitats occupied by anadromous and non-anadromous fish species.
3. Recognition and avoidance of impacts of hatchery-origin salmonids on natural-origin fish, including competition for limiting resources, straying, genetic effects, and loss of diversity.

Principles: It is important to clearly define priorities for mitigating fish losses through reintroductions to restored habitats. The priorities in terms of benefits and risks to recovery currently seem to be the use of (1) native anadromous donor populations, (2) native resident donors, (3) hatchery-origin donors and (4) nonnative species. Ideally, reintroduction efforts should focus on fishes with historical association to restored habitats and should include multiple species when possible, including native non-salmonids. The revised Program should mandate development of a separate document that describes the restocking plan for each restored habitat. The plan should identify and prioritize species to be restored, sources for reintroduction, and contingencies.

Rationale: The 2014 Program appropriately recognizes that provision of habitat for fishes with complex life histories requires a Basin-wide ecosystem approach. This requires simultaneous restoration of critical spawning, rearing, mainstem, estuary, and ocean habitats such that self-sustaining populations can complete their life cycles. Restoration of multiple watersheds and connectivity among them permits meta-population dynamics that provides additional resilience to environmental change.

General measures: Measures are sufficiently broad to encompass issues of genetic/phenotypic diversity, connectivity, and effects of hatchery-origin and nonnative species. Measures should be integrated and consistent with other aspects of the revised Program, especially those that relate to hydrosystem operations, toxics, habitat restoration, and fish propagation.

THE USE OF HATCHERIES FOR REINTRODUCTION

Scientific merit

In its review of the 2009 Program (ISAB 2013-1), the ISAB agreed that using hatcheries as a tool to reintroduce salmon was acceptable. The ISAB also concurred with the 2009 Program that the ultimate goal of reintroduction programs should be the establishment of self-sustaining natural populations. To achieve this goal the 2009 and 2014 Program revisions presented two general measures. First, that Bonneville will "locate and operate hatcheries to re-establish salmon and steelhead where they have been extirpated." And second, that "the goals, objectives, timelines, benchmarks and experimental framework for reintroduced populations will be developed by the agencies and tribes and submitted to the Council." The idea behind the second measure was to use the Three-Step Review or other procedures to sequentially evaluate the scientific merits of each proposed reintroduction effort. This lets the Council continually assess each project and allows projects to progressively incorporate new approaches as needed.

There is wisdom in letting local experts develop reintroduction programs. They have knowledge about possible donor stocks and conditions in recipient watersheds. At the same time, it also makes sense for the Program to provide some general guidance on the factors that are known to affect reintroduction efforts. These guiding principles are designed to protect existing genetic diversity and enhance the likelihood of creating successful reintroduction efforts. Additionally, in order for adaptive management to occur, timelines, biological objectives, and metrics that can measure project effectiveness must be established. The latter point was raised in the 2013 ISAB review of the 2009 Program, although no recommendations were proposed at that time. Because each reintroduction effort is unique, control over how reintroduction takes place cannot be by formula. It must be flexible enough to accommodate the idiosyncratic factors that exist in any reintroduction attempt.

Results of previous scientific reviews (e.g., Withler 1982; Fedorenko and Shepherd 1986; Lusardi and Moyle 2017) made on salmonid reintroduction efforts point to four key components: (a) selection of donor populations, (b) characteristics of recipient locations, (c) fish culture methods including broodstock sources, incubation, rearing, release protocols, and project duration, and (d) the presence of monitoring and evaluation programs that can determine how reintroduction is progressing.

Gaps and suggestions for modification

In terms of general guidance, the following principles and rationales originating from reviews by Withler (1982), Fedorenko and Shepherd (1986) and Lusardi and Moyle (2017) are suggested for inclusion in the 2018 Program.

Donor Populations:

1) Preference should be given to donor stocks in close proximity to the receiving system; ideally, donor and recipient locations should not be more than 100 km apart. If donor and recipient populations reside in the same watershed, upstream populations should be favored over downstream donor populations.

    a. Rationale—

        i. Geographically close river systems often have similar environments, so better adaptability may be expected from local transplants.

        ii. Fish from geographically close river systems will reduce the risks of strays from the project interbreeding with neighboring populations. Strays from such systems are likely already occurring naturally.

        iii. Local transplants also reduce the risk of introducing foreign pathogens or parasites.

        iv. Straying is expected to be less when upstream donors are used. Additionally, these fish are expected to have adequate energy stores during the adult migration to reach recipient locations.

2) Infrastructure should be present in the donor system(s) to allow for the capture of adequate broodstock.

3) The donor population(s) should be robust enough to tolerate the extraction of broodstock for up to three generations. Alternatively, a release program could be put in place to return juveniles to donor stocks to ameliorate the effects of broodstock mining.

    a. Rationale—

        i. Receiving environments will differ from conditions in the donor watershed. Genetic diversity of adult broodstock needs to be sufficient to allow natural selection.

        ii. Ideally, three or more donor populations and all possible crosses among them) should be used. The use of multiple broodstocks and hybrids is expected to increase genetic diversity in the transplanted fish and lead to more rapid adaption to the new environment. Gametes from 300 or more adult fish (at a 50/50 sex ratio) should be used to create a robust effective population size and ensure adequate genetic diversity.

4) The donor populations should possess life history characteristics that are biologically compatible with the recipient location.

    a. Donor stocks should have migration and spawn timing, adult body sizes, ages at maturity, and length of juvenile freshwater residency deemed to be suitable in the recipient location.

    b. Stream elevation, temperature regimes, flow, stream gradient, and substrate type in donor and recipient streams should be similar.

    c. Migration route length, and for some species (e.g., sockeye) route orientation, should be similar between donor and recipient locations.

    d. Diseases present in the recipient location should be similar to those found in the donor populations.

Receiving Sites:

1) Habitat suitable for anadromous salmonids should be present, including characteristics such as stream elevation, gradient, current velocities, depths, temperatures, water chemistry, substrate type and composition, stream cover, and channel stability.

2) There should be adequate food supplies to support the juveniles produced from a reintroduction program.

3) Surveys should be conducted before reintroduction to determine the presence and abundance of possible competitors and predators.

4) Modeled effects of climate change on the temperature regime and hydrograph of the recipient watershed should indicate that the location will remain suitable for salmonids.

5) Suitable infrastructure should be available to capture adults and juveniles if the recipient location is above an impassable barrier.

Fish Culture:

1) Hatcheries used in conjunction with transplanting programs should be operated using well-established genetic principles.

2) Depending upon circumstances, use of translocated adults, eyed eggs, fry, parr, and smolts may be appropriate in reintroduction programs. Parentage-based tagging, otolith thermal marking, and other available marking and tagging tools should be used on all hatchery releases to enable system-wide monitoring and evaluation.

3) Relatively large releases of hatchery juveniles ($\geq$ 0.5 million; $\leq$ 1 million) are encouraged at the beginning of a reintroduction effort. Once adults return and are allowed to spawn naturally, release numbers should be based on expected capacity of the recipient freshwater habitat. Releases of hatchery juveniles may occur annually for up to three or more generations.

    a. Rationale:

        i. As mentioned under Donor Populations, genetic diversity enables populations to respond to changing environmental conditions.

        ii. If releases occur at the smolt stage, predation losses (%) of the released fish may be reduced due to predator saturation or prey size-selectivity.

        iii. The carrying capacity of the recipient location should be used to guide the number of adults and hatchery-origin juveniles released after adults produced from the program begin to spawn in nature. Continued releases of large numbers of juveniles and adults may result in low survival in the area where reintroduction is occurring and may also have negative impacts on adjacent wild populations

4) The use of multiple donor populations adjacent to the recipient location is encouraged as is the creation of hybrids among donor stocks.

    a. Rationale:

        i. Hybrids are expected to break down genetic homeostasis and greatly increase genetic variability. Stocks chosen for cross-mating should be geographically close and well-matched to the new environment. Although this strategy increases the risk of outbreeding depression, its effects are expected to be minimal if recommendations for release numbers are followed.

        ii. The use of multiple donor populations also reduces the number of adults that will be needed from each donor population to meet egg take or adult translocation goals.

5) Release timing of smolts should coincide with expected outmigration timing in the recipient location.

6) Acclimation sites or other methods (e.g., imprinting at the embryonic stage to waters from targeted spawning locations) should be employed to reduce straying and locate project adults in desired spawning and rearing areas.

7) To reduce straying and increase adaptation to the recipient location, adult progeny returning to the recipient location should be incorporated into hatchery broodstocks. The eventual goal is to cease the importation of outside fish and rely entirely on adults produced from the reintroduction effort. Initially, the inclusion of jacks or early maturing males is also encouraged, since they represent fish that successfully survived and returned to the new location.

Monitoring, Evaluation, and Adaptive Management Requirements:

1) Quantitative and time explicit project objectives are in place to track the results of a reintroduction program.

2) Both monetary and infrastructure resources are available to conduct implementation and effectiveness monitoring.

3) A formal adaptive management plan along with contingency options have been prepared.

Reintroduction efforts are designed to increase spatial diversity, increase overall abundance, and expand genetic diversity—VSP parameters. Those potential benefits have to be weighed against possible deficits caused by reintroduced fish on capacity in different areas (i.e., subbasins, the mainstem, estuary, or ocean plume), their conceivable genetic effects via straying on adjacent populations, and possible predaceous and competitive interactions with other fishes including salmonids. As recommended in the Fish Propagation section above, coordination among the organizations operating hatcheries throughout the Basin is needed to ensure that deleterious interactions are minimized.

ANADROMOUS FISH MITIGATION IN BLOCKED AREAS

Scientific merit

In general, the 2014 Program provides sound scientific guidance. The Program has proposed a three-phased approach for evaluating a potential reintroduction program. According to the draft assessment report (NPCC Staff 2017), progress is being made on all measures, although completion of Phase I is delayed.

Gaps and suggested modifications

In addition to the Program's phased approach for Chief Joseph and Grand Coulee, the Program calls for the US Army Corps of Engineers and Bonneville Power to support anadromous fish passage in the Willamette Basin to implement the Willamette Biological Opinion (BiOp). Lessons learned from that effort should be informative to other reintroduction efforts in the Basin. However, the Willamette passage effort is also behind schedule and the estimated total cost of current BiOp measures has more than doubled to $757 million by FY 2023 (NPCC Staff 2017). The measures seem fairly thorough, although they do not explicitly call out consideration of climate change when assessing potential habitat and ecosystems upstream of the dams. The Council Research Plan (NPCC 2017-14) raises this question.

Reintroducing anadromous fishes to areas blocked by impassible high-head hydro dams (Chief Joseph and Grand Coulee dams and dams on the Willamette River) is a huge task, with many uncertainties. Blockage of salmon and steelhead from large upstream areas represents a major loss to fisheries, especially tribal fisheries, which have traditionally been mitigated, partially, by hatcheries downstream of the dams and resident fish and wildlife enhancement projects above the dams. Reintroduction of anadromous fish above Chief Joseph and Grand Coulee to provide access to more habitat for spawning and rearing has the potential to considerably increase salmon capacity and productivity in the Columbia River Basin.

One general response to the 2014 Program recommendations was for Council staff to complete a report titled "Review of Fish Passage Technologies at High-Head Dams" (2016). This review is excellent and provides foundational information without making specific recommendations for Chief Joseph and Grand Coulee dams. This and other studies suggest that moving the outmigrating juveniles downstream past the dams is the biggest problem. After that, juveniles face the same problems of dam passage that all other runs face, which are also not trivial. Next steps include evaluation of habitat suitability above the dams. The habitat may no longer be hospitable considering that decades have passed without anadromous fish contributing marine-derived nutrients and that non-native species have become established. A final step includes pilot studies with introductions of fishes to blocked waters.

The current study of resident fish above Grand Coulee and Chief Joseph Dams (Proj. 1997-004-00) is a good example of how to develop an understanding of the ecosystem above the dams and for considering how reintroduced native species could interact with resident fishes. The USGS has also done several years of study of behavior and dam passage of juvenile Chinook salmon at Cougar Reservoir in Oregon (Beeman et al. 2012, 2013, 2014).

According to the Council staff's draft *Fish and Wildlife Program Implementation Assessments* (NPCC staff 2017), in 2016 the Upper Columbia United Tribes (UCUT) collaborated with federal agencies, Washington Department of Fish and Wildlife, and other Columbia Basin Tribes and First Nations in British Columbia on habitat investigations, donor-stock assessments, and life-cycle modeling. Also in 2016, the Spokane Tribe of Indians (STOI) received Program funds to begin a habitat suitability assessment. Nevertheless, according to the Council staff (NPCC Staff 2017), funding is largely lacking for these studies. However, restoration of anadromous fishes above the dams should be regarded as mitigating for their loss when the dams were built with insufficient consideration for fishes, which provides a strong scientific rationale for support with mitigation funds.

The scope of a blocked areas reintroduction project is so large that it has to be undertaken with a great deal of caution and an adaptive management approach. Such large-scale projects warrant modeling to examine uncertainties and potential climate and hydrologic conditions, as well as to consider alternative methods for reintroduction and juvenile fish passage. For example, Clancey et al. (2017) used a CE-QUAL-W2 model of Shasta Reservoir, California, to examine water temperature conditions in head-of-reservoir (where the river meets the reservoir) locations under different hydrologic conditions. The model was also used to examine the use of flexible temperature curtains to create better temperature conditions for juvenile Chinook salmon and steelhead that would need to pass downstream if adult fish are stocked above Shasta Dam. NMFS has done some modeling of options for restoring salmon habitat under climate change, including the removal of dams to open up habitat (Beechie et al. 2013).

Another example of an uncertainty that should be considered for juvenile dam passage is the timing of spawning, rearing and juvenile migration. Because anadromous fishes have not been present above the dams for decades, it is unknown if such life-cycle processes will occur at similar times as for fish below the dams. Genetic studies may provide insights into expected timing of these processes.

RESIDENT FISH MITIGATION

Scientific merit

This section provides mostly scientifically sound guidance for projects and actions. The ISAB has identified some changes to help clarify the goals and priorities of mitigation activities.

Gaps and suggestions for modification

Strategy: The focus of the strategy is resident native fish, and this should be included in the title and Strategy. This would be consistent with other sections of the 2014 Program that appropriately identify native wild fish and their habitats as a critical resource for the Basin.

Resident native fish are a valuable biological resource when they harbor sufficient genetic and phenotypic diversity to buffer demographic losses against changing environmental conditions. A revised strategy should prioritize mitigation measures, including property purchases, which will lead to a net increase in the number of restored habitats across watersheds and increase lateral and longitudinal connectivity throughout the hydrosystem. These actions could ultimately provide suitable habitat to resident native fishes.

Rationale: It is not clear whether the list of species included in this section is meant to be exhaustive, and some clarification should be considered in the revised version. This is important because species that are not included in the list may be perceived as non-eligible or of lower priority for native fish habitat mitigation activities. For example, several new species of sculpins in the interior Columbia are considered sensitive and in need of mitigation. Rather than a specific list, could a more comprehensive statement be substituted to encompass all species of concern?

More generally, the strategy section should recognize that provision of habitat for fishes with complex life histories requires a Basin-wide ecosystem approach. This requires simultaneous restoration of critical spawning, rearing, and mainstem habitats such that self-sustaining populations can complete their life cycles. Land purchases that maximize both lateral and longitudinal connectivity among purchased parcels should be considered high priority, for example.

Principles: The ISAB recommends clarification and reorganization of principles guiding resident fish mitigation activities. Activities should be consistent with other relevant sections of the Program, and reference them. For the first principle, the ISAB recommends listing the most effective and least invasive options first, which are habitat restoration and modifying hydrosystem operations, before harvest augmentation and hatcheries. However, an alternative first principle could be to determine the full life history of the species and to understand all the habitats and connections they need along the riverscape, throughout their life cycle (see Scientific Principle 2 in this report). Failure to determine this has led to much poor management in the past, and such understanding can better guide mitigation activities.

General measures: Measures are broadly defined and mostly sufficient to encompass issues of maintenance of genetic/phenotypic diversity, connectivity, and minimizing effects of interactions with hatchery-origin and nonnative species. Measures should be integrated and consistent with other aspects of the revised Program especially those that relate to hydrosystem operations, contaminants, habitat restoration, fish propagation, and nonnative species.

There are specific editorial comments on this 2014 Program section included in Appendix 4 of this review.

STURGEON

Scientific Merit

The sturgeon section of the 2014 Program provides scientifically sound guidance. Significant efforts and progress are being made on Kootenai white sturgeon recovery, larval collection for artificial propagation (e.g., Lake Roosevelt), artificial propagation in the mid and upper Columbia, population status reporting and sharing of research findings, and hatchery production master planning in the lower mid-Columbia and Lower Snake. However, little or no progress has been made in following much of the Program's guidance, including calls for dam passage effect and potential passage improvement studies, mainstem habitat restoration, harvest monitoring, pinniped predation monitoring and reduction, and comprehensive toxic contaminant studies (NPCC staff 2017). The Program relies on the Columbia River Planning Framework (CRPF 2013), which recognizes that sturgeon management is far behind that of salmon and steelhead and needs to accelerate to catch up. CRPF (2013) recognizes there are three sturgeon in the Columbia River—green sturgeon, white sturgeon, and Kootenai sturgeon. However, CRPF (2013) largely ignores green sturgeon and leaves management of the Kootenai sturgeon to the US Fish & Wildlife Service and the Tribes. The CRPF (2013) provides a basis for improved management and research in the future, as indicated by the Council (NPCC Staff 2017). The Program includes, and progress has been made on, the use of larval collection for use in artificial propagation. This technique should be emphasized for artificial production efforts.

Gaps and suggestions for modification

Of all fish species in the Basin, the status of white sturgeon is most strongly tied to conditions in the mainstem, which are directly affected by the hydrosystem. In addition, the relationship between hydrosystem operations and sturgeon passage and reproductive success needs more investigation. These issues were raised by the ISAB in its review of the 2009 Program (ISAB 2013-1) and guidance was included in the 2014 Program. The ISAB review of the 2009 Program also recommended that quantitative objectives be developed for non-salmonid species such as sturgeon. A topic raised in the ISAB report on density dependence (ISAB 2015-1) is the role of changes in mainstem habitats on the carrying capacity of the Basin for sturgeon. This is especially critical for sturgeon because most are unable to migrate upstream or downstream passed hydrosystem dams. The Program needs to address mainstem habitat conditions and floodplain connectivity as elements in density-dependent regulation of anadromous and resident fish. Additionally, sturgeon are a long-lived fish and thus accumulate contaminants. In addition to effects on fish health, contaminated fish may not be fit for human consumption, which is a central goal of mitigation efforts. These contaminant issues should be investigated and inform artificial production objectives and efforts. It should be noted that elements of this section have implications for other sections such as mainstem/hydrosystem, climate change, and water quality.

LAMPREY

Scientific merit

The Lamprey section of the 2014 Program provides scientifically sound guidance for projects. There is substantial interest in lamprey throughout the Basin, especially by the Tribes, and a great deal of work is continuing both in management and research. However, the causes of decline are multiple and complex, some rather general (e.g., dam passage), but others specific to watersheds or subbasins. The 2014 Program recognizes the large amount of ongoing work, based on the Tribal Pacific Lamprey Restoration Plan (2011), the Conservation Agreement for Pacific Lamprey (2012) and the Pacific Lamprey Assessment and Template for Conservation Measures (under revision). The Agreement was signed by all states, tribes, and federal agencies with concern for lampreys. The following are basic principles for Pacific lamprey management:

- Juvenile and adult lamprey should be able to safely pass dams in the Basin.
- The population size, distribution, and other limiting factors for lamprey related to the hydropower system need improved understanding.
- Lamprey throughout their historic range should be self-sustaining and harvestable.

Gaps and suggestions for modification

There are, however, several gaps that should be addressed by the Program in the future. First, more information is needed on the genetic structure of Pacific lamprey returning to the Basin. At present, it is widely assumed that Pacific lamprey returning to the Columbia River originate from a single panmictic population. Recent investigations, however, suggest that although philopatry in Pacific lamprey is much weaker than in Pacific salmon, it is strong enough to maintain local adaptations. This possibility needs to be incorporated into the lamprey translocation and artificial propagation efforts taking place in the Basin. Second, almost all attention has been focused on Pacific lamprey because they are conspicuous, important to tribal culture, and declining in abundance. Large population segments have been lost since the

1980s. River and brook lampreys, on the other hand, are small and poorly studied. More information on these lamprey species should be gathered. For example, information on non-anadromous brook lamprey may prove useful when identifying habitat characteristics suitable for ammocoetes (e.g., sediment attributes, effects of contaminants).

Third, the ISAB previously recommended the development of quantitative objectives for non-salmonid fish, including Pacific lamprey (ISAB 2013-1). Objectives for Pacific lamprey might include abundance levels for lamprey reaching Bonneville, Willamette Falls, and other locations where lamprey can be counted. Such objectives were not included in the 2014 Program.

EULACHON

Scientific merit

At the time of the 2014 Program's release, the section did not provide sound scientific guidance because all actions were delayed until NMFS released the recovery plan (September 2017), which was required because the eulachon was listed as a threatened species under the Endangered Species Act. Now that the plan is available, it should be critically reviewed and used to set priorities.

Gaps and suggestions for modification

The ISAB recommends that, after analysis, the Council adopt actions consistent with the Recovery Plan for eulachon (NMFS 2017). Prior to 2014, little attention was paid to non-salmonid fishes, such as eulachon, so actions were minimal. Here, the ISAB provides a basic introduction to eulachon and their management.

Like salmon, the eulachon is an anadromous fish that once was a prized food fish of lower Columbia River Indian tribes. Unlike the salmon, eulachon has received little attention from fisheries managers, although it supported commercial and sport fisheries through the mid-1990s (Wydoski and Whitney 2003). There was a sudden decline in the eulachon population in the Columbia and elsewhere about 1994. The southern Distinct Population Segment (DPS) of the eulachon was listed as a threatened species in 2010 by NOAA-NMFS. The recovery plan for southern DPS eulachon was issued in September 2017 (NMFS 2017).

Managers paid little attention to eulachon for several reasons, most important of which was that the populations seemed to do well without special attention, until recently. Their relatively small body size (mostly less than 20 cm) and ocean-dominated life history, make eulachon easy to overlook. Eulachon spend 98% of their life cycle in the ocean, and they are infrequently captured in sampling programs.

Eulachon enter fresh water only briefly to spawn and die. In the Columbia, they spawn mainly in tributaries below Bonneville Dam. They generally spawn in shallow sandy gravel areas, aggregating in large numbers for relatively short periods of time in February and March, with high variability in spawning numbers among years. Spawning runs are now greatly reduced in most years in Washington and Oregon and seem to be small or absent from California (Klamath River). Thus, the eulachon decline is a broader phenomenon than just occurring in the Columbia River, although it is likely the Columbia once supported the largest single population in the three Pacific coast states (NMFS 2017).

The ISAB recommends research to better understand the basic biology and ecology of this species in the Basin and California Current ecosystem, and effects of the hydrosystem on survival and ecological interactions among salmon, eulachon, lamprey, sturgeon, and their predators and prey in the river/estuary/plume/nearshore ocean ecosystems. This could be done through a combination of population dynamics, bioenergetics, and life-cycle modeling.

In the 2014 Program, there was recognition that eulachon needed attention, especially in regards to potential hydrosystem impacts, but the default position was to wait for the recovery plan to be issued by NMFS in 2017. As a result, recommendations were not implemented to (a) assess the effects of changes in the hydrograph on larval and juvenile survival, (b) monitor the population at Bonneville Dam, (c) study effects of sea lion predation, and (d) evaluate the importance of the tidal freshwater, estuary, plume, and nearshore ocean environment to eulachon.

Now that the recovery plan has been issued, its priority actions should be followed, as promised. Nevertheless, the main focus of eulachon measures here is “understanding the extent to which they are affected by the hydrosystem and what restoration actions can be taken to improve productivity and survival.” The recovery plan rates as high two threats to the Columbia River population: (1) climate change impacts on ocean conditions and (2) bycatch in ocean shrimp trawl fisheries. Factors rated as moderate threats were: (1) dams and diversions, (2) climate change impacts on freshwater habitats, (3) predation on spawners, (4) poor water quality, (5) shoreline development, and (6) dredging (NMFS 2017). Ocean conditions were the only factor rated high for all eulachon populations.

NMFS (2017) identified operation of the hydropower systems as a secondary threat to eulachon, perhaps interacting with conditions in the ocean and estuary. Now that the Recovery Plan has been issued, the Program needs to renew monitoring efforts to determine abundance and important spawning areas. It should contribute to efforts to understand how ocean conditions and climate change affect eulachon abundance and distribution, and it should develop and implement a plan to determine how (or if) the hydropower system affects eulachon. NMFS (2017) provides a good starting place for this analysis. According to NMFS (2017, p 66): "Overall, the available evidence indicates that shifts in the timing, magnitude, and duration of the hydrograph of the Columbia River via water management operations are likely to continue to affect the Columbia River subpopulation of eulachon."

PUBLIC ENGAGEMENT

Scientific merit

The 2014 Program's descriptions of strategy, rationale, principles, and general measures are straightforward and well-articulated. The principles were based on those recommended in the ISAB's Review of the 2009 Program (ISAB 2013-1). That review emphasized the need for early and extensive public engagement at all scales of social organization (e.g., homeowners, counties, subbasins, and larger spatial scales). The ISAB Review went on to specify six principles and three measures, including monitoring the success of the Council's outreach and involvement efforts.

Gaps and suggestions for modification

While there is strong evidence of the value and success of public engagement and outreach efforts, public engagement also involves costs and benefits, and it may be highly successful in some cases or fail in others. The literature on public engagement in environmental issues can provide guidance (see also ISAB/ISRP 2016-1). Promotion of more collaborative and participatory decision-making at multiple governance levels has gained attention in recent years. Adherents of this approach point to the need for more collaboration among non-governmental organizations (NGOs), governments, and businesses (Newig and Fritsch 2008). The actual benefits of public engagement are difficult to evaluate, however. Rigorous evaluation is both complicated and rare (Rowe et al. 2005), and the results are mixed (Newig and Fritsch 2008). One factor important to public engagement is community homogeneity—research has shown that public engagement is lower in more-heterogeneous communities (Costa and Kahn 2003).

Coordination and cooperation incur transactions costs, such as expending time and effort to establish channels of communication and to decide which among a multitude of potential cooperators represent sources of information and communication sufficiently valuable to warrant investments and continued expenditures (see Arrow 1974). These transaction costs can be high, and the benefits of cooperation must be sufficiently large relative to those costs for each entity to justify their continued involvement, otherwise collective engagement is unlikely to be sustainable.

In some cases, conservation and restoration actions appear to be working at odds with each other, but resolving the conflicts is not always straightforward. Adaptive problems, such as river conservation and restoration, are socially and ecologically complex, the solutions to these problems are not known, and even if they were, no single entity has the resources or authority to bring about necessary changes (Naiman 2013). Reaching effective solutions generally requires innovation, sharing new information, and learning by members of the public involved in the problems (Ostrom 1990, Lee 1994). Success can depend on the willingness of the public to change their behaviors in ways that are viewed as costly or simply contrary to habit, belief, or tradition (Ostrom 2014). International examples suggest that large-scale common pool resources (e.g., entire watersheds) can be successfully managed (Ostrom 1990). Such successes typically require coordination among governments with multiple overlapping jurisdictions and among multiple NGOs (e.g., Morton Bay, Australia; see Sarker et al. 2008 and Bunn et al. 2010). The challenges as well as successful examples have been well documented (Bromley and Cernea 1989; Ostrom 1990, 2009).

In addition to the kinds of public engagement emphasized in the 2014 Program, it is worth recognizing that one of the most direct and potentially valuable ways that the public engages with the Program is in promoting or protecting the interests of specific stakeholder groups. Lobbyists from energy rate payer organizations engage with the Program process in favor of actions that will limit the added costs imposed on energy customers. Proponents of fish and wildlife restoration are engaged in promoting and protecting their interests. As discussed elsewhere in this document, with increased transparency about the efficiency, cost-effectiveness, and estimated trajectory of fish restoration, these interest groups will have a common interest in lobbying for cost-effective actions (see section below *Implementation procedures and project review process: improving cost-effectiveness evaluation*).

SUBBASIN PLANS

Scientific merit

Subbasin plans provide fundamental information of varying levels on species, habitat conditions, hatcheries, harvest, human systems, the hydrosystem, and other factors that affect fish populations and aquatic communities. The subbasin plans include 10- to 15-year management plans, and most were finalized 13 years ago. The ISRP and ISAB reviewed draft plans for 58 subbasins in 2004 (ISRP/ISAB 2004-13), and the ISRP reviewed draft plans for the Bitterroot and Blackfoot subbasins in 2009 (ISRP 2009-46). The ISAB and ISRP reviewed each plan for its scientific merit following a comprehensive list of criteria. For the set of plans, the ISAB and ISRP also identified the strengths and areas needing improvement. The Council considered the ISAB and ISRP reviews and public comments in adopting 59 subbasin management plans in 2004-2005 and 2010-2011. Many of the ISAB and ISRP suggestions for improvement were addressed, but many persist regarding, for example, habitat and hatchery integration, human development impacts, RM&E, and climate change.

Gaps and suggestions for modification

The 2014 Program states that "the Council will identify subbasin plans most in need of an update." The Program implementation assessment (NPCC Staff 2017) indicates that no subbasin plans have been updated and that there is interest in updating the subbasins that have had significant habitat changes (e.g., dam removal). Since completing the subbasin plans in 2004, recovery programs and regional restoration strategies have been developed in many subbasins and often are more comprehensive and provide more up-to-date guidance. In such cases, subbasin plan revisions probably are unnecessary. Even in these situations, the subbasin plans still provide geographic contexts and resource descriptions that inform conservation planning.

Nonetheless, the Program does not discuss specific subbasins to be updated or a process to identify and initiate updating for specific basins. The Program should provide a description of the criteria that would trigger a subbasin plan update (e.g., substantial changes in the major characteristics of the subbasin, a designated time interval for all plans, new resource concerns that were not recognized in the subbasin plan) and identify candidate subbasins that will be considered for review by the Council.

PROGRAM MEASURES AND INVESTMENT STRATEGIES

Program measures

This section provides sound guidance. However, as discussed throughout our review, the Program measures lack some guidance for adaptive management feedback that promotes learning from projects to refine and modify actions. In addition, the guidance is directed at Bonneville and the action agencies as opposed to those directly involved in science or restoration work. Program measures are to "allow for" adaptive management (p. 112). However, given that the ISAB and ISRP continually find that project proposals and reports lack quantitative objectives, research hypotheses (where appropriate), experimental design, methods, data analysis, and an adaptive management framework, it seems that the language should be more forceful, e.g., "implementation will include…" This language may be more appropriate in the next section – Investment Strategy.

Investment strategy

This section guided the Council's focus on particular issues and strategies since 2014. In addition to these priorities, the Council continued to support the base Program functions, projects, and reviews. The 2014 Program's emerging priorities reflected advice from the ISAB and ISRP reports available at that time, for example, to consider contaminants, climate change, non-natives, floodplain restoration, adaptive management, and such. Progress has been made on many of the emerging program priorities, but most of those emerging priorities remain. The next Program should continue to address these and emphasize adaptive management feedback loops, addressing and reducing uncertainties, and considering costs for maintaining monitoring and infrastructure, as well as addressing potential impacts and mitigation for climate change.

The investment strategy contains language specifically detailing the allocation of funds to "anadromous fish (70 percent), resident fish (15 percent), and wildlife (15 percent)." The investment strategy should also include specific language ensuring that those funds are expended in a scientifically sound manner. That is, it should require project proponents to provide quantitative objectives, research hypotheses (where appropriate), experimental design (where appropriate), methods, data analysis, and an adaptive management framework. This might be an adaptation of item # 2 on page 116 of the 2014 Program.

IMPLEMENTATION PROCEDURES AND PROJECT REVIEW PROCESS: IMPROVING COST-EFFECTIVENESS EVALUATION

Scientific merit

This 2014 Program section provides mostly sound guidance for project review and implementation. This guidance is intended to ensure that appropriate methods are used to prioritize the use of limited funds, including requiring that the Council determine whether projects employ cost-effective measures. This second requirement is mandated by the Northwest Power Act that requires adoption of measures that minimize economic costs when choosing among equally effective alternative means of achieving the same biological objective.

Despite this Program guidance, cost-effectiveness (CE) analysis has not generally been undertaken to rank and prioritize projects or other actions. To cite one example, the recent ISAB review of the Upper Columbia River Spring Chinook program (ISAB 2018-1) found that although the project prioritization rubric being used included a category for cost-effectiveness, there was no explicit calculation of cost-effectiveness ratios.

The omission of CE analysis at multiple levels may reflect some misunderstanding both about what is involved in undertaking and using bona fide CE analysis, and also what can be gained by doing so. In addition, it may not be recognized that CE analysis can be done at different levels of decision making to ensure the Program achieves the greatest overall biological objectives at the lowest cost.

Gaps and suggestions for modification

The ISAB believes that a better understanding of what quantitative CE analysis involves and its derived benefits would foster the adoption of this essential tool for maximizing the biological return on Program investments. Additionally, because of its potential benefits, CE analyses should be incorporated at multiple levels of Program decision making. This section describes the method and illustrates its potential value, and also addresses challenges that are faced at different levels when it is applied.

Prioritization of projects or other actions involves making choices when time and resources are limited; otherwise everything could be done when wanted. Prioritization is also a challenge when there is great uncertainty. It still follows that prioritization should involve choosing actions that have the greatest expected impact per dollar and the highest likelihood for generating those impacts more quickly. An efficient trajectory for fish recovery that includes both abundance targets as well as other, less-easily quantified recovery goals, will achieve more impact sooner, and at a lower overall cost. By contrast, a less cost-effective Program will delay recovery and result in higher costs being passed on to Bonneville and their rate payers, running counter to the guidance in the Northwest Power Act. In several studies and examples described below, failing to make decisions on the basis of cost-effectiveness can produce outcomes that are an order of magnitude lower than the most efficient outcome.

Cost-effectiveness analysis involves measuring both the benefits of a range of actions (in comparable quantitative units such as increase in fish abundance, or increase in smolts/redd), and the costs of those same actions. Cost-effectiveness is the ratio of these two values or,

$$\text{Cost-effectiveness ratio} = \frac{\text{Expected biological improvement (biophysical units)}}{\text{Expected cost (monetary units)}}.$$

In the absence of other considerations, maximizing program performance (or biological return on investment) will compare CE ratios for all options where the associated benefits are comparable and select those projects or other actions with the highest ratios, up to the point where the available budget is exhausted.[5] To effectively use CE ratios, however, requires well-defined goals and assumptions, performance metrics, performance reviews, performance-based responsibility, and accountability (Atkinson 1999, Kerzner 2010, Kaplan and Norton 2001).

Basic cost-effectiveness measures are increasingly used in conservation programs. To illustrate why this can be so important, consider the hypothetical set of project options below:

Hypothetical set of project alternatives

Project	Effectiveness (change in adult returns)	Cost ($ thousands)	CE ratio (Effectiveness/cost)
A	7700	150	51
B	7600	150	51
C	7300	100	73
D	7300	60	122
E	6900	60	115
F	6800	50	136
G	5500	40	138
H	5000	40	125
I	4500	25	180
J	4000	25	160
K	3800	25	152
L	90	25	4
M	60	25	2
N	50	25	2
O	40	20	2
P	30	20	2
Q	20	20	1
R	10	10	1

If one had a budget of $300,000, and chose projects on the basis of highest benefits, one would choose projects A and B, for a total benefit of 15,300 more fish. However, if one simply chose the cheapest projects (i.e., those with the lowest cost and ignoring the benefits completely), one would choose projects G-R, for a total benefit of 23,100 fish. Ignoring benefits in this case would result in 50% more benefits than when selecting only those projects with the highest benefits. Finally, if one were to choose projects on the basis of the highest CE ratios, one would choose D-J, for a total benefit of 40,000 fish, or 2.6 times the benefits when choosing on the basis of highest benefits only. In this instance selecting projects on the basis of highest benefits is inefficient: more benefit could have been achieved with the same level of funding. The

[5] To the extent that the biological benefits or the costs are spread over multiple time periods, some form of present value calculation or "discounting" is needed to be able to compare projects or actions in comparable units. Also, in some cases where some projects are larger than others, completing the set of selected projects may involve passing up one (relatively large) project with a higher CE ratio in order to select two or more smaller projects with somewhat lower CE ratios, but which are able to be funded under the budget limit.

magnitude of the inefficiency can be even greater if there are actions or projects that are highly cost-effective but are not included in the set of projects being considered for funding. The mathematical reality is that the value of a CE ratio, which provides a measure of the relative efficiency or relative investment performance of alternative actions, is influenced as much by its denominator (cost) as by its numerator (effectiveness).

A number of recent studies of conservation programs demonstrate that prioritization based on ecological benefits *per dollar spent* can achieve significantly greater benefits than where programs ignore cost consideration (Naidoo et al. 2006). Gains from being guided by cost efficiency considerations are largely due to the identification of variation in estimated biological benefits gained per unit of cost (Boyd et al. 2015). The potential gains from choosing activities that maximize cost-effectiveness can be large. For example, a study of riparian buffer acquisition in New York (Ferraro 2003) found that a portfolio of riparian parcel easements selected only on the basis of their ecological benefits (i.e., reducing sediment and nutrient loading) generated only 16 percent of the sediment reduction benefits that were possible when both costs and benefits were considered. Although this example is for a smaller geographic area and pertains to a simpler issue, the principle is relevant to the Columbia Basin, especially if CE prioritization can occur within discrete portions of the Basin (e.g., subbasins).

Similarly, a retrospective analysis of a conservation plan in California found that the numbers of species that were protected under the plan would have been quadrupled had land costs been considered. Additionally, the number of threatened and endangered species protected would have been tripled (Underwood et al. 2009). Similar results have been found for vertebrate conservation, marine reserves, and salmon conservation (Boyd et al. 2015). Moreover, several studies have found that it may be at least as important, if not more important, for conservation programs to take account of variations in costs as it is to take account in variation in benefits (Polasky et al. 2001; Balmford et al. 2003). Naidoo and Iwamura (2007) show that “cost-only” prioritization of actions (making decisions based on the lowest denominator in the CE ratio) may conserve biodiversity at lower costs than a “benefit-only” prioritization (making decisions based only on the highest numerator in the CE ratio) in some situations. Much depends on whether conservation benefits are positively or negatively correlated with conservation costs, as well as the variability of the numerator and denominator in the CE ratio. Empirical evidence strongly supports the importance of taking costs into consideration to maximize the achievements of any program with a limited budget.

A study of this issue in the Methow, Entiat, and Wenatchee rivers indicated that significant cost reductions or performance improvements can be achieved on the basis of CE ratios (Newbold and Siikamäki 2009). A reserve site selection framework for prioritizing conservation activities in upstream watersheds was used, along with spawner return data and estimates of the economic costs of watershed protection provided by NOAA Fisheries. The relative cost-effectiveness of alternative prioritization criteria based on various combinations of biological and economic information were compared. When the prioritization method that maximized cost-effectiveness was used, Newbold and Siikamäki (2009) found that when selecting the watersheds on a cost-effectiveness basis, 79% of the total potential biological benefits (increase in stock persistence) could be achieved by spending only 10% of the costs that would be required to protect all upstream watersheds. Using habitat criteria alone, 62% of the total potential biological benefits could be achieved for that same cost.

Newbold and Siikamäki (2009) also noted that the Upper Columbia Salmon Recovery Board developed a set of recovery actions that would be expected to increase the probability to greater than a 70% chance that all stocks persist. Given the more limited portfolio of protection measures included in the Newbold and Siikamäki model – which increased the probability of all stocks surviving to a maximum of about 45% – they concluded that the cost-effectiveness approaches were a valuable addition and complement to habitat-based selection approaches.

Cost-effectiveness analysis is also valuable as a counterweight against competing interests which seek to spread funds broadly across activities, geographies, and interest groups. A study by Wu et al. (2003) showed that in cases related to aquatic habitats in the Northwest, decisions based on political acceptance or jurisdictional equity can lead to the lowest possible benefits for society. This risk was found to be particularly acute in a setting where habitat investments have cumulative effects. When this occurs there is a need for careful targeting to achieve the maximum benefits. For example, Wu et al. (2000) explored the importance of cumulative effects in establishing vegetated riparian corridors to restore steelhead habitat in Oregon. They compared the effects of two targeting strategies for Oregon's CREP (Conservation Reserve Enhancement Program) and EQIP (Environmental Quality Incentives Program) programs. In one scenario they targeted funds by choosing the locations with the worst stream bank conditions. In a second scenario, they targeted funds to maximize total steelhead numbers, taking account of cumulative effects or non-linear benefits related to temperature and other factors affected by conservation efforts. They concluded that distribution of funds according to the first approach, based on typical allocation guidelines, would not be efficient in the presence of cumulative effects (Wu et al. 2000). Similar issues have been found to be important for a range of riparian conservation programs (Watanabe et al. 2005).

To successfully maximize the biological benefits of the Program, CE analysis needs to be used at all levels of decision making, including: (1) to make resource allocation decisions internal to a specific project, (2) to prioritize funding decisions between potential projects, and (3) to make decisions about funding alternative actions or measures. If CE analysis is used at only one of these levels, it will not achieve the maximum possible biological success nor minimize the costs.

The potential for using CE analysis at broader Program levels or spatial scales is illustrated in Appendix 1 in the case of the basinwide objective of increasing aggregate adult returns of salmon and steelhead. The preliminary analysis presented in the Appendix provides one example of how "macro" scale restoration actions can be evaluated. The information gained from these and other different kinds of analysis, such as model simulations of augmented spill, harvest changes, or dam breaching, will make it possible to compare that information. These kinds of results will be complementary to the development and use of a range of model types (especially life-cycle or other system models as they become more fully developed and calibrated).

One challenge to wider use of CE analysis is less about the ability to compute the economic costs that make up the denominator of the CE ratio (which will be challenging in many cases owing to the uncertainty in future costs), but more about the challenges of estimating the numerator, the biological benefits of a given project or action. The 2014 Program references an IEAB analysis (IEAB 2014-1) to conclude:

> "Several factors make it difficult for the Council and the region to undertake a quantitative cost-effectiveness comparison among different fish and wildlife measures for the program. The most important has been the inherent difficulty of developing a single measure of ultimate biological effectiveness for different types of actions, so as to be able to determine if two measures "achieve the same sound biological objective" and then choose the one with the least cost. The complex life-cycles of fish and wildlife, especially anadromous fish, and the many human and environmental factors that affect their survival, make it difficult to isolate and determine the ultimate biological benefits of any particular activity or to compare the different biological effects of different activities in a rigorously quantitative manner" (2014 Program, page 211).

Current prioritization among subbasin projects is often undertaken without quantitative estimates of either the cost or the biophysical impact. This highlights the level of scientific uncertainty that exists, especially at small spatial scales. It is very challenging to estimate expected impacts on fish abundance for the many small projects that are often widely dispersed throughout subbasins, especially with incomplete knowledge of subbasin limiting factors and imperfect understanding of how these factors interact with limiting factors at the life-cycle level. Nevertheless, a quantitative estimate should be attempted. Although it is understandable why project sponsors and other decision makers are reluctant to estimate numbers for "expected project impacts on abundance," the practice of quantifying expected impacts would keep attention and discussion focused on the challenges associated with estimating performance metrics, and it is also a prerequisite for CE analysis.

The knowledge accumulated over the past 40 years in the Basin is substantial. New ways of making full use of existing research results, data, and Program actions may now be possible. For example, given improvements in data and models, there is more potential for incorporating results of subbasin-scale projects and actions with top-down statistical analyses of Program actions (as illustrated in Appendix 1), and life-cycle models. Each has different advantages:

1. Subbasin-scale actions: Many Program projects involve actions addressing habitat issues at river reach and subbasin spatial scales. It is very difficult to predict in advance, or detect afterwards, the impact on fish abundance for these kinds of individual projects, although progress is being made by programs such as ISEMP-CHaMP (e.g., Bouwes et al. 2016b).

2. Basin-scale empirical estimation: Statistical models (see Appendix 1) may have additional potential to make use of time-series data to study both biological impact and cost-effectiveness. Similar statistical modeling approaches could be conducted at somewhat less aggregated levels (e.g., for major subbasins; by species and life-history type).

3. Life-cycle models: Improvements in some of the life-cycle models (LCMs) recently reviewed by the ISAB (ISAB 2018-1) suggest that they can provide important insights into the effectiveness of Program actions. For instance, when adequately calibrated, LCMs coupled with basin-scale (i.e., top-down) and subbasin-scale (bottom-up) analyses could provide a powerful set of tools to validate the cost-effectiveness of multiple types of actions. Sources of uncertainty and appropriate confidence ranges, however, will need to be clearly indicated.

LCMs, basin-scale, and subbasin-scale analyses complement one another. Each can improve the potential insights from the other two. Importantly, the range of actions evaluated in this way could include all plausible actions that may be cost-effective. For example, recent analyses from LCMs indicate that increased spill and breaching the four Lower Snake River dams could result in a two- to three-fold increase in salmonid abundance (CSS-FPC 2017). Evaluation and comparison of a wide range of actions in terms of their cost-effectiveness would provide fuller information to the Council, policymakers, and the public. Life-cycle models may make it possible to evaluate the cost-effectiveness of individual actions and combinations of actions, and also to evaluate the scale and scope of potential actions in terms of what increases in fish abundance are possible over a given timeframe.

Taken together these observations highlight the conclusion that more biological benefits could be achieved at the same funding levels if cost-effectiveness analysis were explicitly and systematically used at all levels to prioritize Program decisions.

V. APPENDICES

APPENDIX 1. COST-EFFECTIVENESS ANALYSIS AND PROGRAM PERFORMANCE: AN ILLUSTRATION OF AGGREGATE-LEVEL APPROACHES

The 2014 Fish and Wildlife Program developed a vision for "a Columbia River ecosystem that sustains an abundant, productive, and diverse community of fish and wildlife, supported by mitigation across the basin for the adverse effects to fish and wildlife caused by the development and operation of the hydrosystem." The goals and objectives of the Program are designed to protect and restore the natural ecological functions, habitats, and biological diversity of the Columbia River Basin. As discussed elsewhere in this review, Program goals include promoting biologically diverse species that are resilient to environmental variability and restoring the widest possible set of healthy, naturally reproducing and sustaining populations of salmon and steelhead at each relevant geographic level. The quantitative objectives of the Program "serve as a benchmark to evaluate progress toward the vision and should be, as feasible, specific, measurable, achievable, relevant, and time-bound." (2014 Program, p. 137). These established objectives define the primary metrics for assessing the performance of the Fish and Wildlife Program, and analyses of salmon and steelhead populations and habitat conditions have been used to quantify performance measures. At the same time, the Program could be strengthened by effective prioritization of actions and efficient use of limited financial resources, but cost effectiveness has not been analyzed at scales greater than individual projects. In this Appendix, the ISAB provides a preliminary example of an approach that could be developed more thoroughly in the future.

It is challenging to analyze cost-effectiveness (CE) at larger spatial scales for Program actions, such as those related to spill or harvest. Simulated scenarios with life-cycle models represent one method for evaluating cost-effectiveness of broad-scale or basinwide actions. Another method involves analyzing basinwide data for relationships between Program spending and changes in basinwide metrics. This initial example illustrates such an approach using the 2014 Program objective of increasing total adult salmon and steelhead runs to an annual average of 5 million fish by 2025, with emphasis on populations that originate above Bonneville Dam and also support tribal and non-tribal harvest.

We emphasize that we are using this 5 million fish goal for illustrative purposes only. The ISAB does not believe the 5 million fish is a realistic goal. In a recent report the ISAB estimated that the original runs (i.e., pre-European influence) of salmon and steelhead were 5 to 9 million fish (ISAB 2015-1) and in the past 200 years at least one-third of salmon and steelhead habitat in the Basin has become inaccessible to anadromous fish. In addition, climate change, toxic chemicals, nonnative species, hydropower development, and land use have further diminished capacity of the available habitat. Therefore, even 5 million salmon and steelhead is likely an unattainable goal even if virtually all are hatchery fish—a solution which is not acceptable under the ESA and that the ISAB does not believe is tenable:

> "Hatchery releases account for a large proportion of current salmon abundance. Total smolt densities may be higher now than historically. By creating unintended density effects on natural populations, supplementation may fail to boost natural origin returns despite its effectiveness at increasing total spawning abundance." (ISAB 2015-1, page 1)

The relationship between salmon abundance and Program expenditures

In the case of the basinwide adult abundance measure, how can the overall performance of the Program over time be quantified? A natural approach is to use a conservation planning method for measuring the benefits resulting from a set of investments over a period of time. This is generally referred to as "return on investment" (ROI) analysis. In contrast to cost-effectiveness analysis which involves comparing in advance the expected benefits per dollar of alternative potential activities, ROI analysis involves *ex post* measurement of the benefits achieved for an entire program or complementary set of actions over a period of time. The two concepts correspond to each other in the following way: selection of the most cost-effective actions or projects should produce, over time, the highest possible ROI. ROI analysis represents an objective, analytically transparent, and data-driven approach to strategic planning and evaluation of conservation programs (Boyd et al. 2015). Both approaches promote efficiency for achieving biological or other objectives.

ROI analysis can help governmental and non-governmental organizations clarify both the technical and social rationales for conservation and complement other planning and strategic tools. The Program has some advantages over other conservation programs when it comes to using ROI analysis due to the extensive data available for some performance metrics and the existence of a range of options for investment alternatives.

The relationship between attributes of an ecosystem and the ecosystem services it generates can be represented empirically where conservation investments are translated into outcomes such as improved water quality or increased fish abundance. Such relationships are often referred to as "ecological production functions." The literature on ecosystem services now includes numerous empirical studies of these relationships (see Boyd et al., 2015). This literature includes studies that examine the relationship between conservation spending and the status of ESA-listed species (Ferraro et al. 2007, Kerkvliet and Langpap 2007, Langpap and

Kerkvliet 2010), as well as improvements in water quality correlated with spending by conservation organizations (Grant and Langpap 2017).

In many cases, obtaining data on ecosystem attributes and outcomes is difficult, as is establishing baseline conditions against which to evaluate investment impacts. The Program, however, has decades of data collected on fish abundance and other factors that could affect biological outcomes from Project investments. Detailed expenditure data on Program conservation investments are available, although some types of costs may be less straightforward to measure, such as opportunity costs (foregone benefits when resources are not available for other uses), or costs borne by individuals adversely impacted by Program actions, or when costs are incurred immediately versus over long time horizons. Also, allocating detailed costs to specific objectives is difficult in a multifaceted program with many objectives, only a few of which are quantitative with timelines. Among empirical conservation ROI analyses, a range of different approaches has been used, with an emphasis on different combinations of costs and using different methodologies and data sources (see Boyd et al. 2015).

The Program at its current stage could evaluate its progress and performance with a conservation ROI analysis. There are now 40 years of data on Program investments and outcomes. And there are also data on exogenous factors that may account for some of the high variability in fish abundance (e.g., Pacific Decadal Oscillation and spring Columbia River flows).

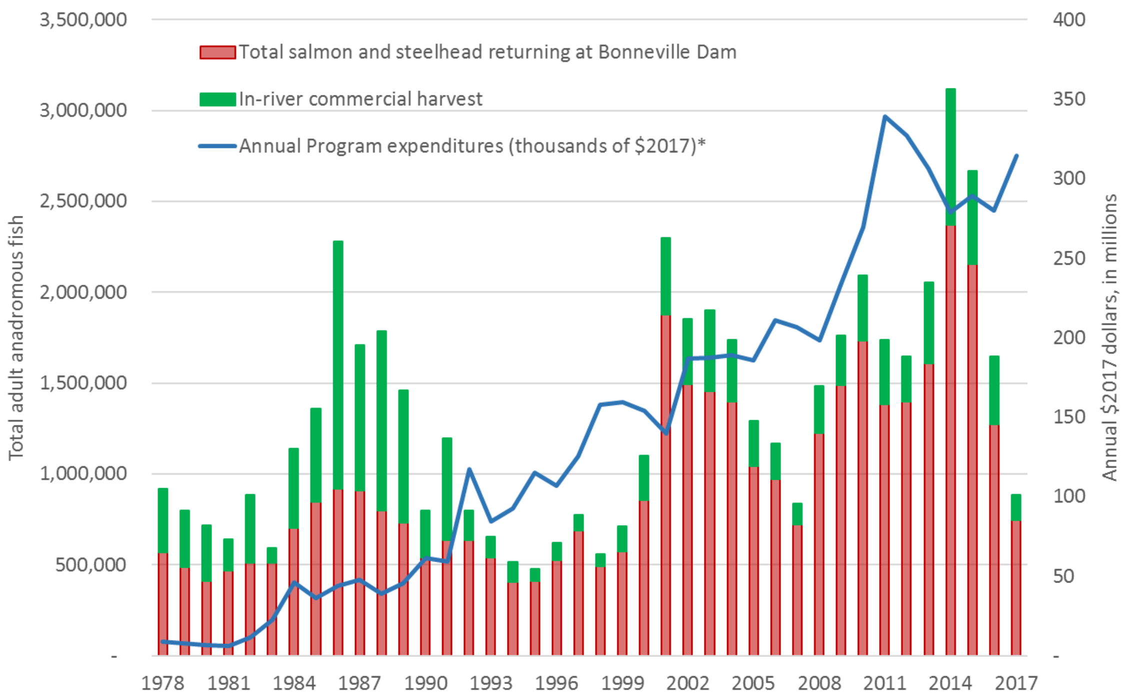
The questions to address are: what has been the relationship between Program expenditures and adult fish returns over the past 40 years? Does this relationship suggest that the Program has made progress in increasing salmon and steelhead abundance, and is on a trajectory to achieve its objective for 2025? If not, what kinds of program changes could be considered to help meet Program objectives, given the evidence on Program ROI thus far?

The Basin has a distinct advantage for measuring progress toward these conservation objectives because annual escapement of adult anadromous fish passing through Bonneville Dam are counted. When combined with harvest estimates, these data provide a reasonable approximation of abundance. Most conservation programs do not have a convenient way to inventory species abundance in this way (e.g., bird species). There is, nevertheless, high variability in anadromous fish returns from year to year due to exogenous as well as human-caused factors. Only after accounting for the natural variability is it possible to estimate the relationship between conservation expenditures and adult salmon and steelhead abundance.

Time series data are shown in Figure A1.1 for trends in adult returns and total Program spending including capital expenditures. By inspection we can see an increase in adult returns at Bonneville since about 2000 despite variability due in part to variable ocean conditions and

Columbia River flows (see Figure A1.2). A statistical modeling approach allows us to account for specific exogenous factors that may also influence adult returns (e.g., weather, climate, and some of the factors influencing ocean conditions) and identify evidence of a relationship between adult returns and cumulative Program spending ($5.7 billion [$2017] in inflation-adjusted direct project expenditures over a 40-year period).[6]

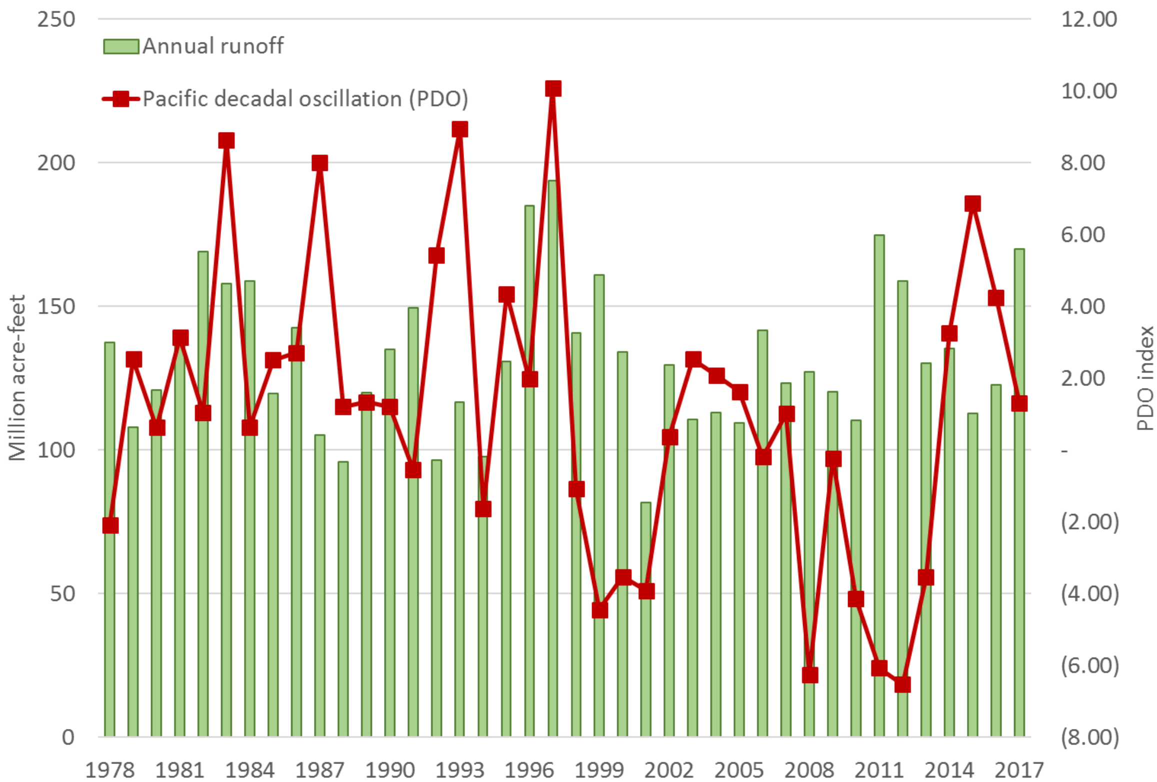
Figure A1.1. Columbia River adult salmon and steelhead returns and Fish and Wildlife Program direct program funding and capital expenses (inflation-adjusted)



* Includes direct Program spending and capital expenditures; 70-75% is for anadromous fish programs

[6] Data on program costs were obtained from the 2016 Columbia River Basin Fish and Wildlife Program Costs Report (https://www.nwcouncil.org/reports/financial-reports/2017-2/) and from Tony Grover, NWPCC. NOAA ocean conditions data for Pacific Decadal Oscillation (PDO) were obtained from the University of Washington (http://research.jisao.washington.edu/pdo/PDO.latest.txt). Columbia River total runoff by water year are from NOAA's Northwest River Forecast Center. Hatchery releases were obtained from the Fish Passage Center (http://www.fpc.org/) annual reports.

Figure A1.2. Variability in ocean conditions and Columbia River flows



A time series regression model was estimated for adult returns at Bonneville Dam as a function of Program expenditures, ocean conditions (PDO), and annual river flows (in million acre feet). Our prior expectations for the model were as follows: We expected to find a negative relationship between adult returns at Bonneville in a given year and the PDO occurring in the year of return or the three years previously (during the portion of each species' life-cycle that their survival is influenced by ocean conditions) (Mantua et al. 1997). We expected to find a positive relationship between adult returns at Bonneville in a given year and Columbia River flows occurring two to four years previously (to account for the varied life histories of different species) due to the effect of higher flows on reducing juvenile downstream travel times (Petrosky et al., 2010). We expected Program expenditures to have a positive impact on adult returns starting two years later (since Program benefits are mostly expected to occur during the early life stages, and the shortest life history is two years).

Program funding is split between short-term current spending and long-term capital investments. Some funds are dedicated to the operation and maintenance of previous investments. Even in the investment category, there will be large differences in the duration or longevity of the expected productivity impacts of different kinds of capital on fish and wildlife outcomes. Because of this, cumulative Program spending is better able to capture the impacts of the Program on abundance than annual expenditures.

With multiple ways to measure Program spending (direct, total, anadromous fish program only, BPA estimates of cost), readers must bear in mind the specific measure used when interpreting the results. The current analysis uses total direct Program funding and capital costs. As a result, the estimates derived using this measure of expenditures will overstate the cost of increasing fish abundance because not all Program spending targets increased abundance of anadromous fish. In recent years, about 70-75 percent of funding is for the anadromous fish program. By contrast, this estimate will understate the costs of increased fish abundance to the extent that not all Program expenditures are included in the model. Direct Program spending does not include program support and expenses by states and other federal agencies. They also do not include BPA's accounting of costs related to power purchases and estimated foregone revenue. There are additional caveats about interpretations and assumptions indicated in the text below that must be taken into account when interpreting analysis of this kind.

We also expected releases of hatchery salmonids to have an influence on adult fish returns. However, because hatchery costs are already included as part of Program expenditures, hatchery releases cannot be included as a separate variable in the model for statistical reasons. Hatchery origin fish have been estimated to make up more than two-thirds of returning adults, although recent estimates that distinguish between total hatchery and natural origin returns are unavailable. Adding harvest data to adult returns at Bonneville would also represent a more complete measure of abundance, but this was not possible due to incomplete data (see footnote below). In-river commercial (including tribal commercial) harvest data are shown in Figures A1.1 and A1.3.

This preliminary model was used to estimate the effects of six different combinations of explanatory variables on adult returns based on our prior expectations. The results are indicated in Table A1.1. The different model versions were used to allow for differences in: a) how Program spending is introduced in the model as either linear or piecewise linear (allowing the linear relationship to differ over different segments of the 40-year time series), and b) how ocean conditions and river runoff were introduced in the model with "lags" (to allow for their influences in years prior to the year adults return to Bonneville Dam) and averaged or disaggregated for individual prior years (e.g., last year's ocean conditions or from two years ago, etc.).

The results of the statistical model are consistent with the expected relationships between Program investments and abundance of returning adult salmon and steelhead, after accounting for ocean conditions and river flows.[7] The estimations are statistically significant and explain 70-72 percent of the variation in adult returns over the time period. The results are consistent with expected influences of ocean conditions and spring flows on adult returns when aggregated to include multiple lagged years. The evidence is also consistent with expectations for individual year effects for PDO with one, two, and three year lags; in the case of river flows the strongest relationship occurs with lags of three and four years. Program expenditures appear to be strongly related to abundance in the linear models; in the piecewise linear models, the most recent spending period (15 or 20 years) is strongly related to abundance.

[7] The model was estimated using regression analysis. The ordinary least squared estimation showed evidence of autocorrelation which will produce downward bias in the estimated standard errors, and potentially exaggerate the level of statistical significance in the model results. Thus, the Prais-Winsten generalized least squares regression method was employed to correct for this efficiency problem.

Table A1.1. Regression model for adult anadromous fish returns and direct program expenditures

Dependent variable: Columbia River adult salmon and steelhead returns at Bonneville Dam, 1975-2017

Variables	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6
Cumulative Program spending (lagged 2 years), millions of 2017 dollars	132***			122***		
	(36)			(40)		
Cumulative Program spending (lagged 2 years), years 1-25, millions of 2017 dollars		206*			185	
		(107)			(116)	
Cumulative Program spending (lagged 2 years), years 26-40, millions of 2017 dollars		138***			127***	
		(37)			(41.42)	
Cumulative Program spending (lagged 2 years), years 1-20, millions of 2017 dollars			41			96
			(186)			(220.68)
Cumulative Program spending (lagged 2 years), years 21-40, millions of 2017 dollars			129***			121***
			(37)			(41.30)
Pacific Decadal Oscillation (PDO), mean for t-1, t-2, t-3	-97,926***	-95,924***	-94,929***			
	(16,567)	(16,925)	(17,684)			
PDO, current year				-537.00	-183.04	-491.64
				(9518)	(9644)	(9681)
PDO, lagged one year				-16,565*	-16,248*	-16,284
				(9263)	(9384)	(9665)
PDO, lagged two years				-46,050***	-45,631***	-45,519***
				(9323)	(9456)	(10374)
PDO, lagged three years				-40,754***	-39,699***	-40,657***
				(9921)	(10198)	(10112)
Columbia River annual runoff, mean for years t-2, t-3, t-4	7,579***	7,250***	7,583***			
	(2,500)	(2,562)	(2,506)			
Columbia River annual runoff, t-2				2,108.12	2,056.00	2,164.30
				(1420)	(1439)	(1517)
Columbia River annual runoff, t-3				2,801.59**	2,822.13**	2,795.40*
				(1348)	(1364)	(1371)
Columbia River annual runoff, t-4				2,676.58*	2,489.33*	2,641.87*
				(1327)	(1380)	(1381)
Constant	-136,113	-129,586	-118,858	-120,225	-123,367	-116,968
	(337,055)	(340,137)	(338,974)	(353,851)	(357,963)	(359,823)
Number of observations	39	39	39	39	39	39
R-squared	0.70	0.70	0.71	0.72	0.72	0.72
Durbin-Watson statistic (transformed using Prais-Winsten GLS regression)	1.81	1.81	1.79	1.77	1.76	1.83
F-Statistic	26.8	19.8	20.4	8.4	8.3	9.0

Standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

The model indicated that Program spending was positively related to the average annual level of returning adult anadromous fish after accounting for PDO and river flows. This range includes linear estimates over the 40-year program period and estimates for the most recent 15-20 years from the piece-wise linear models. Based on these results, the overall productivity of the Program as of 2016 is estimated to have increased abundance by 690,000 to 790,000 returning adult fish.[8]

To further interpret the model results, some assumptions must be made about the underlying relationship of Program spending to productivity given the inclusion of current spending and capital investments with a wide variation in the durability of their relationship productivity. Is Program spending expected to influence adult returns for one year only, forever, or something in between? Statistically, it is only possible to estimate the biological response to cumulative Program expenditures rather than annual expenditures. This implies that the strong relationship between productivity and these expenditures lasts for a period of years. But how many years, on average? The actual period of time over which a given Program expenditure will influence adult fish returns varies greatly by expenditure type: capital expenditures and land purchases, research and monitoring, and operation and maintenance. The benefits from some actions may improve over decades as natural processes are restored; others may have no lasting benefits beyond one life cycle.

It is not possible to separate these categories and estimate separate influences for current expenditures and short-term and long-term investments. In many cases, these different kinds of spending are complementary, and the productivity of the Program overall is dependent on choosing the right mix of current and capital expenditures to maximize Program effectiveness. Nevertheless, one way to interpret these results is to think of an average duration of Program investments that would produce an estimated relationship comparable to what the model estimates. Based on the data and model results, one could ask: What coefficients for adult returns and estimated "average durability" of Program expenditures would be consistent with the trajectory of Program influences similar to the one estimated above (690,000 to 790,000 adult returns)? The model's estimated trajectory can be very closely matched to a given "average durability" of impacts in this way. For example, assuming a 20-year average duration adult returns produce a trajectory over the past 40 years that is nearly identical to the model's estimate.

---

[8] It was not possible to estimate the same model with harvest data added to adult returns at Bonneville dam. Given a lack of complete harvest data prior to 1986, and for ocean harvest after 2010, the time series on harvests is too limited to add to the model. Moreover, there are some anomalies in the data that would likely thwart the goal of estimating Program ROI with harvests included. For example, there were very high harvest levels from 1986-1991, before cumulative Program spending had reached high levels. See Figures A1.3 and A1.4. This period of high harvests also overlapped with a period of large releases from hatcheries below Bonneville Dam, larger than the combined releases from hatcheries above Bonneville Dam. These fluctuations in below-Bonneville hatchery releases (which do not influence adult returns above Bonneville), likely had significant influences on harvests, and these relationships would confound a model of above-Bonneville adult returns.

Interpreting results

Interpretation of these results requires placing them in context and clearly stating the key qualifications and caveats. In terms of context, an analysis of the Program costs for restoring salmon and steelhead should recognize the other side of the ledger, the Program's benefits, as well as the foregone benefits owing to the impacts of the hydrosystem on fish abundance historically. There are large social benefits to restoring the Basin's fish and wildlife, and additional delays in achieving that goal represent additional costs to society. The social costs resulting from the impacts of the hydrosystem are difficult to quantify due to the challenges of non-market valuation (see National Research Council 2005). The costs of delayed restoration are large and growing with every passing year; these include costs for species listed as threatened or endangered, other species under continued risk of extinction, and a wide range of foregone use and non-use (cultural) values in tribal and other communities.

Estimating these potential benefits could be accomplished using non-market stated preference. The most recent comparable study of this type in the Pacific Northwest estimated the social value for restoring fish populations in the Klamath Basin by taking actions that included removal of the four lower dams (U.S. Department of Interior and Commerce 2013). For a scenario involving an action plan expected to increase Klamath Basin Chinook salmon and steelhead by 30%, as well as a significant reduction in extinction risk for ESA-listed coho and suckers, the present discounted total economic value (use and non-use values combined) over 20 years had a mean value of $84 billion (pp. 217). Estimated values over a time horizon extended beyond 20 years would more than double those estimates. The number of additional adult fish anticipated in the Klamath scenario is significantly smaller than those reflected in the Program objectives analyzed here.

With that context in mind, the evidence presented in this initial analysis indicates that the Fish and Wildlife Program is not on a trajectory toward an average of 5 million adult salmon and steelhead by 2025. Our ability to project into the future based on any analysis of past trends is limited, however, so this conditional projection is subject to the following qualifications and caveats:

- Future Program spending levels may not be similar to recent levels.
- Future ocean conditions and river flows may differ from recent patterns.
- Outside influences on aquatic habitats will introduce new challenges to the Program's success, including non-native species, toxic contaminants, and climate change impacts such as increased flow variability and changes in the estuary with sea level rise that would likely adversely affect juvenile salmonids. Climate change is

likely to introduce additional adverse impacts on future levels of salmon and steelhead abundance. Overall, these factors would likely shift the future trajectory downward for adult returns, although some program restoration projects whose benefits could grow over time (e.g., riparian tree plantings) would have an upward influence on the trajectory.

- Future returns on investment and cost-effectiveness measures may be lower, or higher, than indicated by these data. Some high return investments have likely already been undertaken so that additional projects of some kinds will exhibit diminishing returns. There is some evidence to support the relevance of diminishing marginal returns for Program activities. For example, in the IEAB analysis of the water transactions program (IEAB 2011-2), water contracts to augment instream flows in early transactions had a lower cost per acre-foot than in more recent years. By contrast, if the recommendation in this review for more systematic use of cost-effectiveness analysis is heeded, average return on investment could increase.
- Some prior project investments are aging, according to BPA documentation (IEAB 2015-1), and so an increasing percentage of program funding may be needed simply to maintain previous investments, reducing the share of expenditures that add on new projects and additional returns on investment.

These preliminary estimates suggest that, with these caveats and qualifications in mind, the levels of returning adult salmon and steelhead would reach about 2.3 million for 2025 (including ocean and in-river harvests). Were those same conditions assumed to hold beyond 2025, the model indicates it would take an additional 80-90 years at an additional cost of $22-25 billion ($2017) in direct Project funding to reach 5 million salmon and steelhead. This conditional trajectory, of course, could be hastened to the extent that the average cost-effectiveness of actions could be increased. Also, if a regime of favorable ocean conditions were to return, this would be expected to result in increased adult returns, which would likely also increase the gains attributable to Program spending.

Further refinement of these models, and additional analyses of this kind, could provide useful insights and evidence of the extent of progress toward achieving Program goals at multiple levels of aggregation.

Figure A1.3. Harvests of Columbia River origin salmon and steelhead

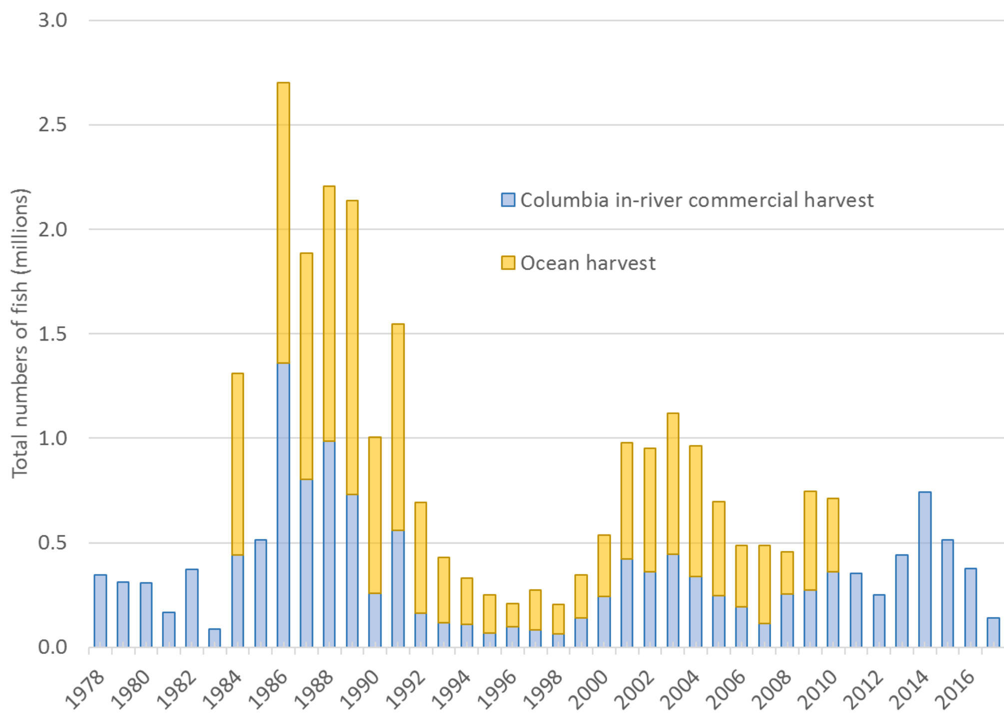
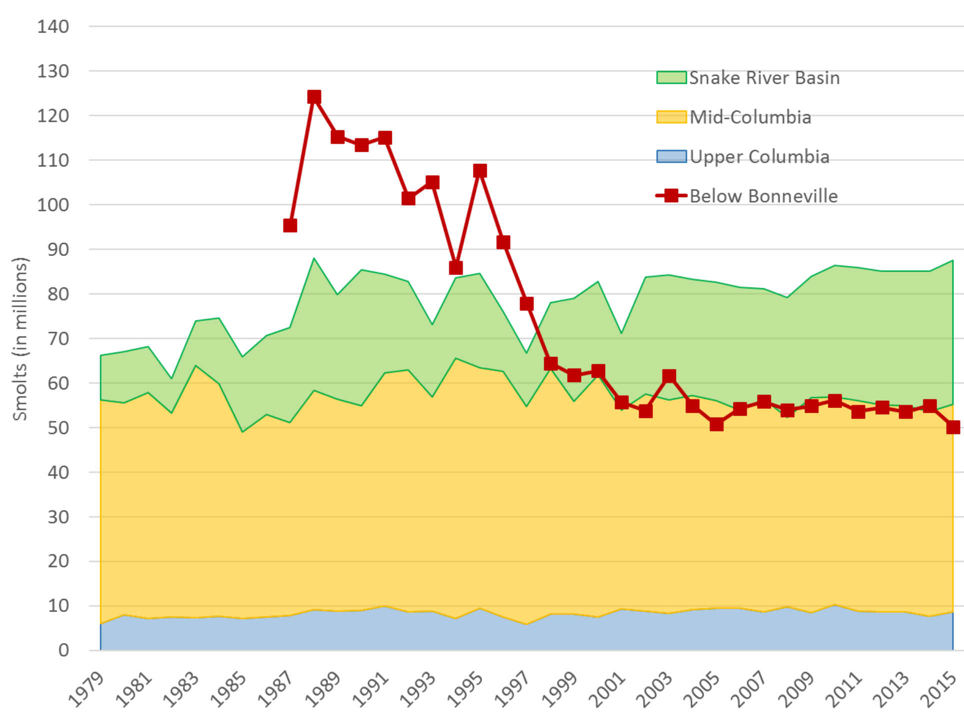


Figure A1.4. Columbia River hatchery releases by basin



APPENDIX 2. LIFE-CYCLE MODELS

Many life-cycle models have been developed for the Columbia Basin, and there have been several reviews by the ISAB, including ISAB 2013-5 review of life-cycle models developed by NOAA; ISAB 2017-2 which has a chapter on a life-cycle model developed as part of the Comparative Survival Study (CSS); and ISAB 2018-1 which contains information on life-cycle models for the Upper Columbia River.

Life-cycle models are important tools for considering management actions towards Program goals, and their development and refinement should be continued. As all models are simplifications of reality, consideration should always be given to model assumptions and uncertainties, especially when used to estimate future impacts. Models should be incorporated into the adaptive management cycle of the Program so that as knowledge and data about the Columbia Basin are gathered, the models can be improved to provide better estimates and evaluations of alternative management actions. All life cycle modelling should include a sensitivity analysis to identify the stages of the life-cycle where system changes or uncertain parameter variables may have the largest impact on the response variable (e.g., SAR or adult abundance).

Because life-cycle models can incorporate multiple life stages and environmental and management conditions, they can address the net effectiveness of management actions across a suite of potential actions. Life-cycle models provide an opportunity to incorporate cost effectiveness in choosing among management actions.

There are two major goals for life-cycle models. First, the models are used to develop a deeper understanding of the current system and the role of limiting factors in each life stage of the current system. Second, and more importantly, the models can explore the impacts of potential management actions (e.g., improvement of habitat, adding nutrients, removing dams, etc.) on the long-term performance of the system. To the extent that economic response and costs can be integrated into or combined with the life-cycle models, it will be possible to evaluate and compare the cost-effectiveness of alternative management actions. Before moving to the second goal, it is important that a particular life-cycle model provides realistic predictions of the current system; i.e., it needs to be fit to or calibrated against actual data.

The resolution of the life-cycle models varies spatially and temporally. For example, the CSS models have separate components for each of the major life stages (e.g., smolt production, in-river survival, ocean-entry, and ocean-survival), but the temporal resolution does not go below the life-stage resolution. Alternatively, the life-cycle models developed for the Methow River in the Upper Columbia model changes in growth of juvenile fish at a daily level, and the models for the Wenatchee and Entiat rivers use monthly time steps. Similarly, the spatial resolution varies from the individual stream (e.g., CSS models six populations in the Snake River without looking at the physical structure of the spawning areas) to 1 km segments of the stream in the Methow River models. The differences in resolution mesh with the different aims of the life-cycle models (e.g., broad effects of in-river hydrosystem and transportation for the CSS vs. impacts of habitat improvements on the food web for the Methow River).

Both deterministic (e.g., those on the Upper Columbia) and stochastic (e.g., the CSS and many NOAA models) formulations are used. Generally speaking, deterministic models will provide information about the mean response of the system but cannot be used to estimate probabilistic functions such as the probability of quasi-extinction. For large numbers of fish, both models will perform similarly because demographic stochasticity (e.g., variations in actual survival through the hydrosystem of individual fish) is only a small component of overall variability.

All of the models have parameters that describe movement of fish through the various life stages. Estimates of the parameters can be found in two ways. First, the actual life cycle can be fit to observed data about the system in various life stages, and the values of the parameters that provide the best fit are determined using likelihood or Bayesian methods. This is the approach used in the CSS model. Because the model is fitted directly to observable data, no additional tuning is needed and the model should generally match observed trends, unless the model is missing an important life stage.

Second, focused studies can be used to estimate the parameters for a particular transition in the life stages (e.g., estimating the survival through a dam/reservoir complex using radio telemetry studies) and these estimates are used directly in the life-cycle model without actually fitting the entire life cycle to the observed data. In this second approach, additional tuning or calibration is needed to match model output to typical data seen over multiple years. Because these life-cycle models are not fit to actual data from these systems, the model produces baseline runs that may match the pattern of changes over time, but results can suffer from noticeable bias (i.e., models that estimate parameters in this way typically under-predict abundance) as seen in the review of the Upper Columbia models. The advantage of the second method is that a model can be quickly developed and implemented based on the results of many individual studies without having to deal with the (considerable) challenges of implementing an appropriate overall fitting strategy.

Model fitting or calibration is not always successful. There are many reasons why model output may match the pattern of observed changes over time but still have noticeable bias. For example, density dependence in a later life stage may not have been modelled, which would limit actual increases in abundance through the actual life cycle which is not captured by the model. Increases in productivity in earlier life stages (e.g., from habitat improvements) could be less than projected by life-cycle models because of limitations outside the natal habitat.

To the extent that downstream effects operate approximately equally on fish affected by upstream changes, the life-cycle models may only be useful to rank management actions in terms of their relative effect. The assumption of approximately proportional effects would be tenable if upstream actions result in incremental changes to productivity, rather than dramatic changes, so that density dependence (and other effects) have approximately proportional impacts on improved productivity. Consequently, the models may be useful to rank the relative impact of different actions on (a limited set of) different life stages that are close together in the life cycle because different limiting factors elsewhere are assumed to be approximately equal. However, comparing the benefits of increased estuary survival to benefits of improvement in habitat restoration actions on the spawning grounds may be less useful because of the many intermediate stages between the spawning grounds and estuary that may not be well modelled by the life-cycle models.

In general, judging the validity and accuracy of a life-cycle model by comparing its prediction with observed outcomes from actual management actions is always challenging. For example, the model may predict that a management action should result in a 20% increase in the number of spawners, but only a 10% increase was seen. Did this discrepancy occur because the model was inadequate (e.g., model was too simple, key limiting factors were not included, interactions with other species were not modeled, etc.) or because of natural variation in the life cycle of the fish (e.g., marine survival was lower than predicted) even if the model is basically a reasonable representation? Evaluation of the actual benefit of on-the-ground restoration actions by comparing output from the life-cycle models against observed outcomes will be difficult because not all sources of variation are accounted for in the models.

Focused studies (e.g., fish-in [spawners] vs. fish-out [fry or smolts] studies of habitat improvements) provide information on the benefits of management actions over short time and small spatial scales but cannot be readily scaled up for incorporation into a model that represents larger scales. Initial life-cycle models can be used to scale up management actions to larger spatial (e.g., entire river) and temporal scales (e.g., entire life cycles), but rarely model non-linearities and feedback mechanisms (e.g., density dependence) in more than one stage. At this point, the models are useful for ranking the relative benefit of management actions at the population level but may not perform well when predicting exact benefits. These models are also useful to identify the stages on which the life cycle is most sensitive and identify potential scenarios for improvements. A side-benefit of developing a life-cycle model also lies in determining which data are missing about the population of interest and need to be collected, or where additional studies are needed to better understand relationships used in the models.

The next steps in life-cycle modelling are to better calibrate the models to actual life-cycle data both at fine and large temporal and spatial scales and to include more complex relationships in those stages where the model is most sensitive.

The temporal and spatial resolution and complexity of a life-cycle model must match the management question of interest. For example, adding nutrients to a stream operates at a very fine temporal and spatial scale, and the coarser models (e.g., CSS) could not readily model such impacts. Conversely, a fine resolution is not needed to model the impact of a dam removal. It is possible to incorporate both scales of resolution in a single model, but there are formidable computational challenges in doing so.

Simpler models will provide relative rankings of the outcomes from different management actions but may not provide good predictions of the actual performance measure because of hidden non-linearities (e.g., density dependence both within a single stock and competition across stocks) or missing relationships. This may be sufficient for deciding among several similar but different management actions (e.g., different types of habitat improvements). However, comparison of outcomes from management actions in different parts of the life cycle (e.g., estuary improvements vs. spawning habitat improvements) will require more complex models. Even the more sophisticated life-cycle models currently used in the basin rarely model among stock density dependence and other effects through the hydrosystem.

Whenever possible, life-cycle models should be fit directly to observable data rather than relying on past studies to provide values for the internal parameters and then trying to calibrate the model indirectly. Models that use direct fitting will likely provide predictions closer to actual outcomes.

All life-cycle models will be in a continual state of refinement and improvement. A successful life-cycle model will typically follow a path from coarse resolution to finer resolution, from using external information on values of parameters to fitting the model to actual data, and from understanding the current system to predicting consequences of future management actions. Consequently, implementation of life-cycle models should keep in mind this natural progression and use tools and methods that can be readily expanded and refined.

APPENDIX 3. EXAMPLES OF ADAPTIVE MANAGEMENT PROGRAMS

The key component to adaptive management designs is the structured decision-making that takes place through the iterations of the project or program. As new information is gathered, choices about moving forward may change. This implies that at each step in the cycle, a clearly defined set of alternative outcomes and consequences of the outcomes on future management decisions must be presented. The latter can be done informally or in a probabilistic framework (e.g., using Bayes rule to update decision paths based on prior and observed information). In this Appendix, we provide two examples of how adaptive management can be used effectively in recovery programs.

(a) Robust Redhorse (a sucker) Example (adapted from Conroy and Peterson 2013)

The robust redhorse (*Moxostoma robustum)* was believed to be extinct but was rediscovered in 1991. Initially there was scientific disagreement on the factors responsible for depressing the population, with opinion split between the impacts of hydropower generation and the impacts of predation. Let us assume for simplicity that a response to a management action could be seen in one year.

Using a life-cycle model, the impact of a change in flow (i.e., decreased power generation) or predator management is shown in Table A3.1. For example, if the actual limiting factor was the flow regime, and the flow regime was changed, the life-cycle model estimated redhorse abundance of 30. Whereas if predator control was implemented, an abundance of 15 redhorse was estimated.

Table A3.1. Estimated outcomes of alternative management options from a life-cycle model on improving redhorse populations. Numbers indicate the expected redhorse abundance in each scenario as predicted by the model.

Proposed change	Actual limiting factor	
	Flow regime effects	Predator effects
Change flow regime	30	15
Predator Control	15	25

Notice that the impact of proposed management actions is generated under both hypotheses of potential effects.

Now a series of decision rules can be established. Using a simple model of uncertainty where each actual limiting factor is given an equal weight or belief about its actual role in the ecosystem, it can be shown that the "best"[9] initial choice for a management action (but by only a slim margin) is to change the flow regime. If the observed population size after changing the flow regime is found to be 32 fish, this is "closer" to the outcome expected under the change flow regime. The beliefs (i.e., weights) about the limiting factor are updated (using Bayes rule) and the new flow regime would be continued the next year. Similarly, if the observed outcome was only 10 fish, this would provide information that the flow regime may not be the limiting factor and the experiment would then switch to predator control. If the observed outcome was 22 fish, then this outcome would be equivocal,[10] implying that this year's experiment was not very informative and the experiment could be repeated for another year, but perhaps the matrix would be updated to include another option where neither factor is the limiting factor (Table A3.2).

Table A3.2. Estimated outcomes of alternative management options from a life-cycle model on improving redhorse populations, with an option that neither management action is a limiting factor. Numbers indicate the expected redhorse abundance in each scenario as predicted by the model.

Proposed change	Actual limiting factor		
	Flow regime effects	Predator effects	Neither
Change flow regime	30	15	20
Predator Control	15	25	20

Again, depending on the outcome of this experiment, the beliefs in each limiting factor as a predictor of experimental outcome is updated. If a second year's results are again equivocal, then the updated beliefs about the limiting factor may show that neither of these management choices is suitable and a year with no control may be added to the decision matrix. In each year, the observed outcome is used to update the choices on how to proceed in the future and after a certain point, there is little doubt about the efficacy of an approach.

[9] Conroy and Peterson (2013) used the expected outcome, but other criteria such as min-max or max-min criteria could also be used.

[10] We are assuming that the experimental design has high power to distinguish between these two alternatives. If experiments have insufficient monitoring to distinguish between alternatives, there is no possibility of learning through different management actions.

(b) Pallid Sturgeon Example (adapted from Fischenich et al., in review)

The Missouri River Recovery Program for Pallid Sturgeon and Terns/Plovers uses an adaptive management (AM) framework to guide experimentation on the river.

The recovery of pallid sturgeon in the Missouri River is hampered because of a lack of knowledge of the limiting factors for this population. Fischenich et al. (in review, Chapter 4) developed an ambitious adaptive management plan for pallid sturgeon, and we quote heavily from their report below. As indicated in their report, there were 21 initial hypotheses that were the focus of conceptual and quantitative modelling linked to management actions.

> "Through life cycle models, expert opinion and workshops, these resulted in 30 working management hypotheses which were further reduced to 21 modeled hypotheses for Phase 1 of the Effects Assessment (EA). … The degree of uncertainty and risk associated with each hypothesis (risks to both pallid sturgeon and human considerations) will guide the level and sequence of experimentation. Hypotheses with the highest levels of uncertainty and risk will first be explored through research … Specific management actions can be taken for hypotheses with less uncertainty and risk, from limited implementation as field-scale experiments to full field implementation. Key outcomes and uncertainties from the EA can be conceptualized in a decision tree framework that highlights the possible management actions …. Decision trees are shown below for the Upper Missouri and Yellowstone rivers (Figure 63 [Figure A3.1 below])."

Separate decision trees were constructed for each of the hypotheses about limiting factors for this population. These decision trees are very useful in delineating how to proceed.

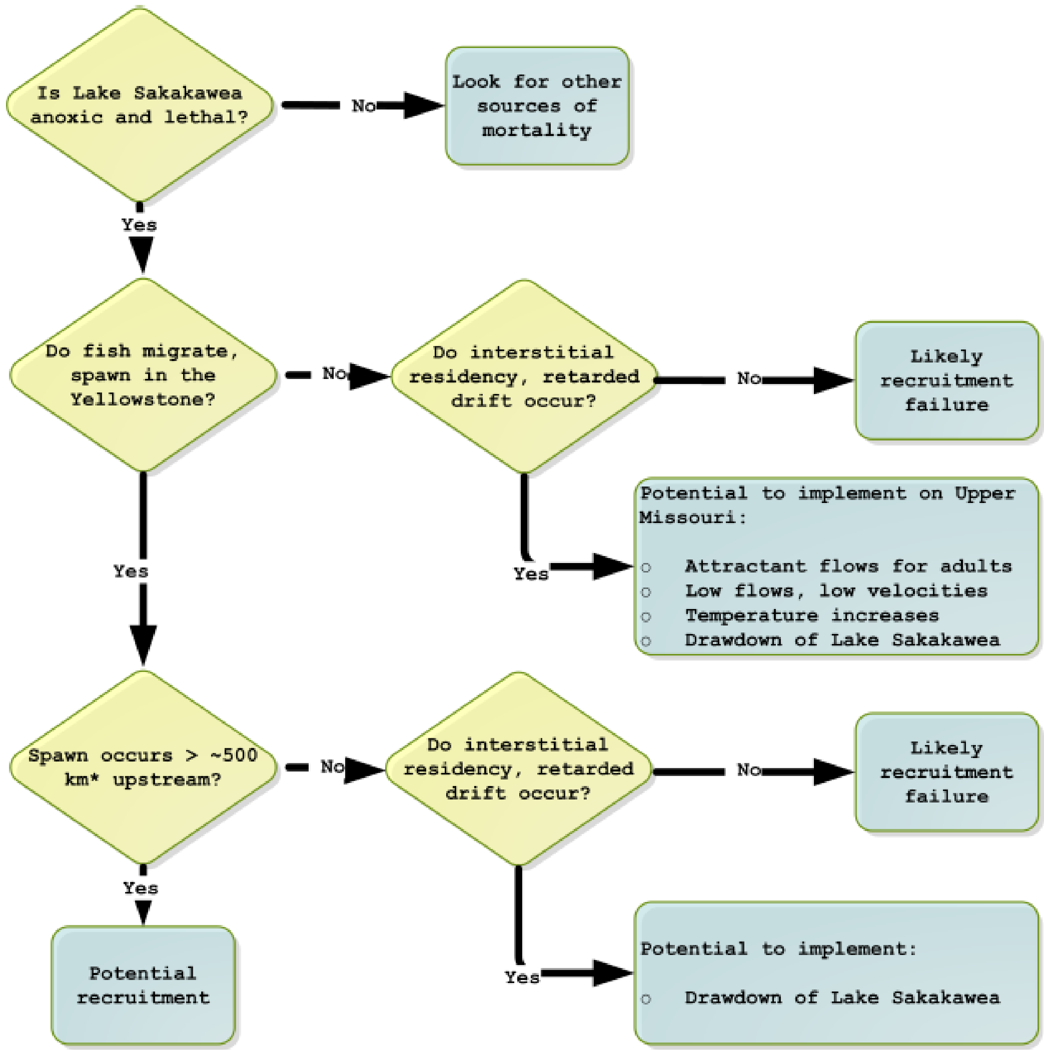
> "Focusing research studies and AM experiments on key decision nodes (i.e., the diamonds in Figure 63 [our Figure A3.1]) can simplify the decision process by rejecting some hypotheses and thereby eliminating certain branches on the decision tree. Such advances help to clarify that some actions are very unlikely to be successful, which helps to focus management attention on the remaining actions with potential benefit and reduces the number of possible future scenarios. Learning is not instantaneous. Various forms of variability (e.g., year to year variations in flows, temperatures and reproductive spawners; spatial and temporal variability in the distribution of free embryos within each year) require multiple years of observations to separate the signal from the noise, and draw reliable conclusions. Therefore, though information from pallid sturgeon studies will be analyzed and reported annually, major decisions on actions are likely to proceed based on several years of accumulated and carefully confirmed findings."

The report describes potential monitoring designs, sample size requirements, and decision trees for each of the hypotheses in turn. Learning progresses through four levels, where level 1 has great uncertainty, while level 4 is achieved when the results are unequivocal. For example, the report develops a series of questions to assess if additional experimentation is needed or if the experimentation should stop and implementation occurs (Table A3.3). Highest priority experiments are also listed assuming a decision is made to proceed.

This adaptive management plan is lengthy and required a great deal of resources to document because of the high degree of uncertainty about the causes of the problems and the consequences of management actions. It provides a clear path forward but is not cast in stone, and new hypotheses can be introduced rapidly into the existing framework as new data are collected.

Conclusion

These two examples illustrate how adaptive management can be used in a program framework so that the program is designed to capture new and useful information that helps to update management decisions towards the program goal. Having explicit decision pathways and monitoring the right response variables are critical so that the results and lessons learned are fed back to evaluate and update management options and decision-making.



* 500 km distance upstream is a coarse guideline because it would provide about 9 days for drift and development under purely passive drift assumptions.

Figure 63. Diagram of a decision tree for addressing contingent information for drift and dispersal related management actions in the Upper Missouri and Yellowstone rivers. In this diagram, drawdown of Lake Sakakawea (lower right) is to a level consistent with authorized purposes. The diamond in the upper left refers to the headwaters of Lake Sakakawea. Information exists to partially answer some of the questions in the diamonds, as discussed in the text. A more detailed decision tree, including other actions such as augmentation, is contained in Appendix F (Figure F2). Source: Jacobson et al. 2016a.

Figure A3.1. Diagram of decision tree for adaptive management in the Upper Missouri and Yellowstone rivers.

Key uncertainties related to a subset of the key hypotheses being evaluated in the AM plan are depicted by yellow diamonds and potential actions are depicted by blue boxes. The initial uncertainty, posed as a question, is listed in the top-left corner. The yes/no answer to this question is connected by arrows which either lead to another uncertainty (question) or a potential action. The directionality of subsequent decisions follows the life-stages in sequence, which would be the most systematic approach to understanding recruitment failure. Useful information can be generated outside of the sequence as well. For example, using age-0 shovelnose sturgeon as a surrogate species may generate insights about food limitations of pallid sturgeon and allow for an emphasis on other hypotheses. From Fischenich et al. (in review).

Table A3.3. Questions to decide when experimentation should be terminated and implementation occurs. From Fischenich et al. (in review).

Table 41. Supplemental lines of evidence strategy for triggering Level 3 implementation. See above text.

	Question	Y	U	N
1	Is this factor limiting pallid sturgeon reproductive and/or recruitment success?			
2	Are pallid sturgeon needs sufficiently understood with respect to this limiting factor?			
3	Do one or more management action(s) exist that could, in theory, address these needs?			
4	Has it been demonstrated that at least one kind of management action has a sufficient probability of satisfying the biological need?			
5	Have other biological, legal, and socioeconomic considerations been sufficiently addressed to determine whether or how to implement management actions to Level 3?			
	Criteria for Level 3 implementation			
	1 - A "Yes" to all five questions triggers Level 3 implementation			
	2 - A "Yes" to four of five, with an "Uncertain" for either #1 or #2 triggers a two-year clock to either reject the hypothesis or implement at Level 3			

APPENDIX 4. SPECIFIC COMMENTS ON 2014 PROGRAM SECTIONS

GOALS AND OBJECTIVES (INCLUDING APPENDIX D)

A. Program goals and quantitative objectives

Paragraph 2: Is it relevant to consider that the losses of salmon and steelhead may be somewhat less than originally thought, given the new estimates of original runs from the Density-Dependence report (ISAB 2015-1)?

The sentence describing other anadromous fish should include white sturgeon along with lamprey and eulachon. The Sturgeon section of the Program makes it clear that these fish have not received the attention required given the effect of dams on them.

Paragraph 3: The third paragraph on Goals and Objectives is disorganized. It is best to begin by discussing qualitative goals before quantitative objectives, in order to follow the same order as in FWP Figure 4. Likewise, it is best to place Figure 4 as near the front of this section as possible, and certainly on the first page of it. Also see ISAB Figure 2 above for an alternative.

It is unclear over what time period the goal of an average return of 5 million salmon and steelhead is computed. For example, is this a 5 year-average which would allow for a complete generation of salmon to be included in the average? The same question arises for the average SAR of 4 percent – over 5 years?

Placing the caveat about the ISAB refining the SAR goal near the front of this section on Goals and Objectives, rather than in a footnote or farther down, raises concerns about the adequacy of the SAR goal and might be better placed.

Principles guiding the program goals and objectives

It would be best to move the “Principles guiding the program goals and objectives” to near the front of the entire section, perhaps after the second paragraph. The third and fourth bullets are not as clear as they could be, and should be revised.

Themes: For “Theme Four: Engage the public” - This short title does not make it clear why the public is being engaged. Is there a better title that can suggest why?

Figure 4: Fig 4 is useful, because it shows a clear framework and linkages among the components. However, two descriptions could be improved.

- Better wording might be: Adaptive Management Strategy - how we assess progress of strategies and measures through research, monitoring, evaluation, and data management

- The first sentence of the caption is confusing, and should be reworded.

See ISAB Figure 2 above for an alternative Program framework flow chart/logic path.

1. Refining program goals…. This subheading is numbered, but there is no subsequent subheading number 2, which suggests that this one does not need to be numbered.

The ISAB understands that there has been an ongoing process by the Council Staff to "survey, collect, identify, and refine a realistic set of quantitative objectives for program focal species and their habitat related to the four broad themes and program goal statements." It seems like the status of that should be discussed here.

Under the second paragraph - Judicious editing, especially to remove jargon, would help in this paragraph.

a) Objectives for adult salmon and steelhead – The second paragraph will need to be updated, given that a 2015 deadline is included.

The second paragraph discusses quantitative objectives and the third discusses indicators. As described above, it seems wise to use subheadings to show this, and to link back to Figure 4 so the reader can keep track of the framework. For example, it is unclear why strategies and measures are also not discussed, as the intermediate step between objectives and indicators.

b) Other anadromous and resident fish objectives - Has progress been made on these "resident" fish objectives, so that this section needs major changes? The first paragraph begins by discussing indicators, rather than objectives which is what the reader is expecting. It needs to be organized better.

Step 1: Why delay producing objectives for these resident fish until the process is complete for salmon and steelhead? Is there a potential for "never finishing"? Why can't these start concurrently with salmon and steelhead?

Perhaps referring to "native rainbow trout and cutthroat trout" would be better. No doubt some hatchery-origin rainbow trout stocks were lost owing to hydrosystem changes.

c) Ecosystem function, habitat, and hydrosystem objectives

Step 1. The ISAB is unsure about the assumption here that new data on indicators of ecosystem health will be readily available. We doubt, for example, that measures of floodplain connectivity, large wood inputs, or nutrient cycling are readily available from throughout the Basin.

Likewise, does “The data needed … should be available” reflect the optimistic view that we have all the data we need, or that where data are not available then the objectives will not be developed?

The three bullets in Step 1 seem quite disparate, ranging from ecosystem health indicators to lamprey to indicators of habitat and biological diversity. This set of objectives seems like it needs to be modified. For example, are the lamprey numbers going up or coming down or both?

d) Public engagement - This set of objectives needs to be fleshed out, and coordinated with the Public Engagement section (2014 Program, p. 99).

Appendix D. Program goals and objectives (2014 Program p 153-162)

Theme One: Protect and enhance habitat

Goal 3: This could be worded better to discuss reestablishing natural regimes in hydrology, temperature, and sediment, all of which have fluctuations and affect fish and wildlife habitat and populations.

Goal 4. “Water quality” is more than TDG. What about water quality measurements such as temperature, contaminants, and others? Are these discussed later?

Goal 5. This goal is a subset of Goal 3, because it refers to flow regimes. Perhaps, instead, it is a strategy to achieve Goal 3?

Goal 6. This goal is very general, and unclear, although there are many linkages between terrestrial and aquatic ecosystems that are important. It is partly redundant with Goal 10.

Goal 7: Both this goal and its objective are qualitative; can the objective be stated in quantitatively? Granted, this is one of only two specific objectives stated to this point (the other being for TDG).

Goal 8: There is strong overlap between Goals 1 and 8, which both address restoring healthy fish populations.

Goal 9. This goal is not at all clear, and could be contentious if, for example, it means “importing” fish from strong populations to bolster weaker populations. Connections are important among habitats required by populations (i.e., connectivity), whether they are strong or weak populations. However, mixing stocks of salmon or steelhead which may interbreed does not seem like a good goal. Perhaps what is meant is to provide connections for populations such as bull trout and cutthroat trout, where small subpopulations may die out and be “rescued” by colonists from larger adjacent subpopulations (i.e., in a metapopulation). If so, this should be clarified.

Goal 10. This goal discusses connections among aquatic and terrestrial systems (see Goal 6 above), but does not indicate why this is important. Connections may be important for both aquatic and terrestrial habitats. For example, emerging adult aquatic insects flow into riparian landscapes and feed birds, bats, lizards, and spiders; and large wood is deposited from rivers to floodplains and benefits birds and small mammals in the riparian zone.

Goal 11. Is this part of water quality as well? See comments on Goal 4.

Goal 12. Will it be clear to a reader what a settlement agreement is? Is this discussed earlier in the Program?

Theme Two: Species survival via abundance, diversity, and adaptability

Goal 13. Does “full mitigation” have a specific legal meaning that is being used here? The public could read this as restoring runs to their historical status by removing dams.

Objective 13b. See earlier comments. A 5-year average of 5 million fish, or a 10-year average of 5 million?

Goal 14. This goal duplicates Objective 13b.

Objective 14b. A 4% SAR to be computed over how many years?

Goal 15. Environmental variation is likely to be different in the future than the past. So, does this goal consider environmental variability calculated from past data? Suppose that climate change makes it impossible for some stocks to persist as water temperatures rise or flows become too variable?

Does full mitigation refer to loss of both life history and genetic diversity? This is a laudable goal, but is this possible for most stocks (i.e., to recreate lost life-history diversity)? Is setting a goal for 100 years hence realistic, or useful?

Goals 16 and 17: These goals appear to overlap strongly with items in Goal 13, and should be revised so that they are coordinated. It is unclear whether the percentages in the second table are survival or something else.

Goal 18. Where is the harvest to be located? In the ocean or in terminal fisheries? It is better to harvest in terminal areas, which gives more control over the harvest in light of ocean conditions. How does treaty-rights-based harvest fit in here?

Goal 20. What type of involvement is envisaged? Is the program interested, for example, in strikes and protests? Does it seek public support for initiatives? It is not clear what is wanted here.

Goal 21. Who should consider the social and ecological context? BPA?

HIGH LEVEL INDICATORS

The High Level Indicators referred to here are not in the Program text document but are available online at: www.nwcouncil.org/ext/hli/background.php.

Graphs and charts are extensively used to present the information, but these assume a high level of numeracy in the reader. If the target audience is the general public (rather than scientists), alternate graphical methods may be more appropriate.

For example: Indicator 1a for salmon and steelhead returning to the Columbia River presents a stacked line graph with the top line representing the number of fish entering the Columbia River and the bottom line indicating Bonneville Dam counts. Many scientists will understand this graph without much trouble, but the general public is not as statistically literate. The graph shows an improvement starting in 2000, but how does this compare to historical numbers? How far away are we from the eventual goal?

Indicator 1a. It is hard to determine which points belong to which year. Vertical lines should be added (every 5 years) similar to the horizontal lines for abundance.

Indicator 1b. This appears to be a similar graph to 1a (i.e., two time series) but is presented differently than 1a. Why?

Indicator 1c. Why a bar graph rather than a line graph?

Indicator 1e. This is a different type of graph from 1b (two distinct species) but uses the same graph type? Why?

Indicator 1f. This shows a series of lines, but now the individual data points are shown (but the points were not shown in the graph for 1a). There is no link from this graph to an explanation of how the adult returns (over several years) are aggregated together. Presumably the bottom axis is brood year but is not labelled as such.

Indicator 2b. Because this is a percentage, the y axis should not exceed 100%

Indicator 2c. Some of the survival estimates exceed 100% - how is this possible?

Indicator 3a. The cumulative graph looks impressive but does this represent 10% of the total that needs to be improved?

Indicator 3g. Why is this a pie chart? More acres are created in 2017, and this will affect the size of all the other segments. A pie chart is not a suitable graphic here.

ADAPTIVE MANAGEMENT – RM&E

"Project sponsors must report the level of accuracy and precision …" Accuracy is defined as a combination of bias and precision. Precision can be estimated from statistical principles (e.g., standard errors), but the bias of a procedure is impossible to estimate without knowledge of the actual value (which of course can never be known). So, accuracy can never be estimated or reported. We suggest: "Project sponsors must report an estimate of precision."

p.104 "Statistical validity – yields statistically reliable results." Validity and reliability are different. Validity is a concept related to assessing if the measure actually measures the underlying construct; reliability implies reproducibility (i.e. precision). You can have very reliable results which are completely wrong!

p. 104 "…with the results published in peer-reviewed scientific journals." This may be too high of a bar. Peer-review is necessary, but this can be obtained outside of a scientific journal. This is especially true for large complex projects where a standard scientific article is not appropriate. So, peer review is necessary, but publication in a journal may not always be appropriate.

p.105 "Bonneville should contract for complete data products … and not only collaborative processes and preliminary data collection." The distinction between these two products is not clear.

ECOSYSTEM FUNCTION

2. Principles:

The first principle is circular. A better statement to describe the central role of ecosystem functions might be:

"Ecosystem functions are the primary physical and biological processes that shape basins and their river networks, create stream channels and their floodplains, create riparian forest corridors, maintain required water quality, retain nutrients, and sustain complex food webs and food resources. The landscape features are required to sustain healthy populations of fish, other aquatic communities, wildlife, and terrestrial plant communities.”

For the fourth principle, are these examples of restoration the key ones on which to focus? Also, the term "repair" seems awkward. A possible revision might be:

"Ecosystem function can be improved in the Columbia and Snake rivers and their tributaries by restoration and judicious management of: connectivity for organisms, riparian vegetation and large wood inputs, floodplain function, flow regimes, water quality and contaminants, and the land uses that potentially degrade these components."

3. General measures – these appear to be a rather unorganized list of concerns raised by specific interest groups and do not present a clear logic. For example, there is much overlap among the first four general measures. Another good example is the last measure, about recruits per spawner. It would be wise to reduce redundancy and write fewer and clearer statements, which will be more useful to policy makers and managers.

HABITAT

This Strategy includes important points for restoring and managing habitat throughout the Basin, but also suffers from unclear writing and redundancy in places. Specific points include:

1. Sub-strategy: Careful wording is important here. The logical order is Protect, Connect, Restore, and only then Enhance. That is, one would never consider enhancing habitat that fish could not reach (i.e., was not connected). Likewise, it is logical to protect and connect existing habitat before considering restoring degraded habitats, and to do these before enhancing habitats, which implies improving them beyond their natural condition.

The Habitat Sub-strategy does not have a landscape or subbasin context, either in its Principles or lists of measures. Upslope conditions and processes that influence aquatic ecosystems are omitted. None of the measures are linked to the subbasin plans, <u>unlike</u> all other sub-strategies except Hydrosystems. This sub-strategy more than any other should reflect the landscape perspectives endorsed by the FWP and repeatedly recommended by ISAB and ISRP.

2. Rationale:

   a. As described above, the Program is acknowledged as a habitat-based plan. Given this, it seems like this point and the fundamental importance of a landscape context should be highlighted at the opening of the Rationale, and perhaps as the first Principle.

b. It is important to define terms clearly to improve communication and to avoid confusion. For example, the term "Habitat mitigation" is unclear. Does this mean creating NEW habitat in one place to offset that lost in another place, or restoring tributary habitat as mitigation for degrading the hydrosystem with dams? Habitat restoration seems like the least ambiguous term.
c. Similarly, the term "habitat improvement projects" later in this Rationale is unclear. Is this the same as habitat mitigation, or habitat enhancement, or does it actually refer to restoring degraded habitat? We suggest using a minimum set of terms that are clear and unambiguous. Finally, the last sentence about toxic chemicals is quite specific, and does not fit with the overarching topics addressed by the Rationale.

3. Principles:

a. As described above, the first two principles could state that the Program is a habitat-based program, and that the Habitat Sub-strategy is underpinned by a landscape-scale perspective.
b. *Build from strength*. Clearer writing is needed here also. For example, the second sentence could be improved to read, "Restoration should be expanded to adjacent habitats." Avoid the term "improving habitat" if what is actually meant is restoring habitat. The focus on adjacent habitats also seems unnecessary, because fish and wildlife typically use all available habitat that is suitable.
c. *Restore ecosystems.* This principle links to the Ecosystem Sub-strategy, so it seems wise to actually make that link in the document.
d. *Use native species wherever feasible.* This principle makes very good points, but seems out of place in the section on Habitat. Is there a more appropriate section? Or, perhaps it would be better to phrase is as "Restore habitat to focus on native species, wherever possible."
e. *Address transboundary species*. Although focusing BPA funding on U.S. fish stocks seems appropriate, it would seem wise to discuss how the two countries could work cooperatively to restore the fish populations that benefit both countries, and importantly, benefit native people who occupied lands before either country was founded. For example, are not some Canadian-bound salmon (e.g., Okanagan River sockeye) caught in U.S. waters, or at least die there and contribute nutrients?
f. Isn't one of the fundamental principles to allow "sufficient monitoring and evaluation, and provisions for adaptive management, to ensure that progress toward objectives can be tracked, and that future management can respond to new information and strategies" (see p. 30 of 2014 FWP)? This principle is critical for the Habitat Sub-strategy.

4. *General measures.* This list is a bit disorganized, and might better be arranged as a logical list describing what aspects of habitat we are trying to conserve. A logical order could be: flow, temperature, physical structure (channel and wood), linkages with riparian habitat, connectivity among critical habitats, and landscape framework. RME efforts are included as measures for most other sub-strategies but are omitted in the Habitat Sub-strategy.

a. Given the interest in using log and boulder structures to increase habitat complexity, and the controversy over whether these are effective, should this topic be addressed in a general measure, near the end of the list?
b. First bullet: This might be improved by including "to allow fish and other aquatic biota free access to habitats needed to complete their life cycles."
c. Third bullet: We suggest revising this to refer to sediment runoff, or erosion, not "reduce sediments."
d. Fifth bullet: Referring to "improving geomorphology" sounds awkward. Clearer and more direct wording is needed here.
e. Last bullet: This is redundant with the 4th measure, so the two should be combined

5. *Mainstem habitat measures*. The subsection on Mainstem Habitat Measures makes excellent points, but then it seems like there needs to be a matching subsection to present basic principles for the strategy about Tributary habitat restoration, as described above.

a. The additional eight bullet points at the end are, in part, redundant with the more general points just above them. It would be wise to integrate them all into a clear but limited set of bullets, appropriate in scope and detail to the strategy presented at this point in the Program.

RESIDENT FISH MITIGATION

Rationale: The ISAB recommends that in the last sentence of the Rationale section, strategies be presented in a logical priority, from most to least effective, in promoting native resident fish. As for the Habitat strategy, the term "habitat mitigation" is unclear and needs clarification. Does this mean protecting and restoring habitat, or creating habitat elsewhere for habitat that was lost? Similarly, it is not clear what the term 'harvest augmentation' means. In the revised version, the same set of clearly defined terms used previously in the plan should be used in the revised section for consistency and clarity. The ISAB also raised these semantic issues in the Habitat section of the 2014 Program (see above).

Principles: In the sub-principle under the second principle, it is unclear how one might acquire (i.e., buy) new streams, as streams cannot be created? In the big picture, when a stream is inundated by a reservoir, a new stream cannot be created. This information seems best suited for the General Measures subsection rather than to be listed as a general principle. The third principle is more general than the second sub-principle, as related to resident fish losses, and so could be modified so that the longer description above could be deleted.

Principle 3, Sub-bullet 3 - The meaning is unclear about implementing projects to provide benefits for other wildlife. Is this owing to providing habitat for other wildlife, or perhaps runs of large adfluvial or fluvial bull trout or cutthroat trout used by bears, eagles, etc., or both?

General measures: Bullet 1 - This seems like a more general principle and might fit better in that section, perhaps as the first Principle. Rather than state “Where feasible”, state “As a guiding principle, Bonneville shall preserve, enhance, and restore….”

Bullet 2 – Interim fisheries should also prioritize native fishes. Problems arise when nonnative trout are stocked to create these fisheries. Those problem should be addressed briefly, and a linkage made to the Non-native species strategy here.

Bullet 3 - The third bullet is redundant with information presented in the “Principles” section but fits better here than there.

Bullets 4 and 5 - This bullet and the next are highly detailed, and reviewers wondered whether this detail was appropriate here.

Bullets 6, 7, and 8 - The last three bullets seem specific to interests of a certain group or agency. These items should be addressed as part of a more general principle or measure.

Appendix K: Land purchases as part of mitigation settlements should prioritize high-quality habitats, those that improve lateral connectivity between floodplain and stream habitats, and those that restore longitudinal connectivity.

Appendix K. General measures:

Bullet 1 – the phrase “mitigation based on resident fish is not feasible….” is unclear. If habitat were purchased that was occupied by resident native fish, wouldn’t this be an ideal form of mitigation?

The final bullet under Appendix K. General Measures appears to be redundant with the second bullet in this section.

ALTERNATIVE OPERATIONS AT GRAND COULEE (APPENDIX I IN 2014 FWP)

The section describes the operational guidelines, but the rationale for the guidelines is not clearly stated. The first bullet appears to be about traditional operations. Rationale for minimizing fluctuations and producing steady flows is not given. The next bullet does include the rationale (i.e., protecting kokanee access and spawning) for operations September to December. However, it also mentions “chum flows” and “operating to protect flows for the Hanford Reach,” neither of which are described, so it is unclear if those could conflict with protecting kokanee access and spawning, and if they do conflict, how they conflict. The table is not referred to in the text and is not explained with a caption, so its relationship to the alternative operations at Grand Coulee are unclear. It is therefore difficult to determine if the guidance provided in this section is adequate or appropriate.

VI. REFERENCES

Arrow KJ. 1974. The Limits of Organization. Fels Lectures on Public Policy Analysis. W.W. Norton & Company.

Atkinson R. 1999. Project management: cost, time and quality, two best guesses and a phenomenon, it's time to accept other success criteria. International Journal of Project Management 17.6: 337-342.

Balmford A, KJ Gaston, S Blyth, A James, and V Kapos. 2003. Global variation in terrestrial conservation costs, conservation benefits, and unmet conservation needs. Proceedings of the National Academy of Sciences 100 (3): 1046–50.

Baxter CV, KD Fausch, and WC Saunders. 2005. Tangled webs: reciprocal flows of invertebrate prey link streams and riparian zones. Freshwater Biology 50:201-220.

Beechie T, H Imaki, J Greene, A Wade, H Wu, G Pess, P Roni, J Kimball, J Stanford, P Kiffney, and N Mantua. 2013. Restoring salmon habitat for a changing climate. River Research and Applications 29:939-960. DOI: 10.1002/rra2590.

Beeman JW, AC Hansen, SE Evans, PV Haner, HC Hansel, and CD Smith. 2012. Passage probabilities of juvenile Chinook salmon through the powerhouse and regulating outlet at Cougar Dam, Oregon, 2011. Open-File Report 2012-1250. US Geological Survey. 26 p.

Beeman JW, HC Hansel, AC Hansen, PV Haner, JM Sprando, CD Smith, SD Evans, and TW Hatton. 2013. Behavior and dam passage of juvenile Chinook salmon at Cougar Reservoir and Dam, Oregon, March 2011-February 2012. Open-File Report 2013-1079. US Geological Survey, 48 p.

Beeman JW, SE Evans, PV Haner, HC Hansel, AC Hansen, CD Smith, and JM Sprando. 2014. Passage and survival probabilities of juvenile Chinook salmon at Cougar Dam, Oregon, 2012. Open-File Report 2014-1038. US Geological Survey, 64 p.

Boyd J, R Epanchin-Niell, and J Siikamäki. 2015. Conservation planning: a review of return on investment analysis. Review of Environmental Economics and Policy 9.1 (2015): 23-42.

Bromley DW, and MM Cernea. 1989. The management of common property natural resources: Some conceptual and operational fallacies. Vol. 57. World Bank Publications.

Bouwes N, S Bennett, J Wheaton. 2016a. Adapting adaptive management for testing the effectiveness of stream restoration: an intensively monitored watershed example. Fisheries 41(2): 84-91. DOI: 10.1080/03632415.2015.1127806.

Bouwes N, N Weber, CE Jordan, WC Saunders, IA Tattam, C Volk, JM Wheaton, and MM Pollock. 2016b. Ecosystem experiment reveals benefits of natural and simulated beaver dams to a threatened population of steelhead (*Oncorhynchus mykiss*). Nature Scientific Reports 6:28581 | DOI: 10.1038/srep28581.

Bunn SE, EG Abal, MJ Smith, SC Choy, CS Fellows, BD Harch, MJ Kennard, and F Sheldon. 2010. Integration of science and monitoring of river ecosystem health to guide investments in catchment protection and rehabilitation. Freshwater Biology 55.s1: 223-240.

Chasco BE, IC Kaplan, AC Thomas, A Acevedo-Gutiérrez, DP Noren, MJ Ford, MB Hanson, JJ Scordino, SJ Jeffries, KN Marshall, AO Shelton, C Matkin, BJ Burke, and EJ Ward. 2017. Competing tradeoffs between increasing marine mammal predation and fisheries harvest of Chinook salmon**.** Scientific Reports 7: 15439, DOI:10.1038/s41598-017-14984-8.

Clancey K, L Saito, K Hellmann, C Svoboda, J Hannon, and R Beckwith. 2017. Evaluating head-of-reservoir water temperature for juvenile Chinook salmon and Steelhead at Shasta Lake with modeled temperature curtains. North American Journal of Fisheries Management 37(5): 1161-1175.

Conroy MJ and JT Peterson. 2013. Decision Making in Natural Resource Management: A Structured, Adaptive Approach. First Edition. John Wiley and Sons, Ltd.

Costa DL and ME Kahn. 2003. Civic engagement and community heterogeneity: An economist's perspective. Perspectives on politics 1.01:103-111.

Cristea NC and SJ Burges. 2009. An assessment of the current and future thermal regimes of three streams located in the Wenatchee River basin, Washington State: some implications for regional river basin systems. Climatic Change. DOI 10.1007/s10584-009-9700-5.

Crozier L, ER Zabel, and B Burke. 2017. Themes of climate impacts on Columbia Basin salmon: multiple limiting factors, correlation in climate drivers, and cumulative life cycle effects. Chapter 9c in Interior Columbia Basin Life-Cycle Modeling dated May 23, 2017.

CSS-FPC (Comparative Survival Study Oversight Committee and Fish Passage Center). 2017. Comparative Survival Study of PIT-tagged Spring/Summer/Fall Chinook, Summer Steelhead, and Sockeye. DRAFT 2017 Annual Report.

DeFries R and H Nagendra. 2017. Ecosystem management as a wicked problem. Science 356:265-270.

EPA. 2010. Columbia River Basin Toxics Reduction Action Plan. U.S. Environmental Protection Agency Region 10. www.epa.gov/region10/columbia.

Fausch KD and E García-Berthou. 2013. The Problem of Invasive Species in River Ecosystems. Chapter 8. Pages 193-216 in S Sabter and A Elosegi (editors). River Conservation: Challenges and Opportunities. BBVA Foundation, Bilbao, Spain. (available online www.jbbva.es).

Fausch KD, BE Rieman, MK Young, and JB Dunham. 2006. Strategies for conserving native salmonid populations at risk from nonnative fish invasions: tradeoffs in using barriers to upstream movement. USDA Forest Service, General Technical Report RMRS-GTR-174. Rocky Mountain Research Station, Fort Collins, Colorado.

Fausch KD, BE Rieman, JB Dunham, MK Young, and DP Peterson. 2009. The invasion versus isolation dilemma: tradeoffs in managing native salmonids with barriers to upstream movement. Conservation Biology 23:859-870.

Fedorenko AY, and BG Shepherd. 1986. Review of salmon transplant procedures and suggested transplant guidelines. Canadian Technical Report of Fisheries and Aquatic Sciences No. 1479, 151 pp.

Ferguson JW. 2006. Estimation of Percentages for Listed Pacific Salmon and Steelhead Smolts Arriving at Various Locations in the Columbia River Basin in 2006. NMFS Technical Memorandum. Northwest Fisheries Science Center, Seattle, Washington.

Ferraro PJ. 2003. Assigning priority to environmental policy interventions in a heterogeneous world. Journal of Policy Analysis and Management 22(1): 27–43.

Ferraro PJ, C McIntosh, and M Ospina. 2007. The effectiveness of the US endangered species act: An econometric analysis using matching methods. Journal of Environmental Economics and Management 54.3: 245-261.

Fischenich JC, DR Marmorek, MA Nelitz, CL Murray, BO Ma, KE Buenau, G Long, JL Bonneau, CA Fleming, and CJ Schwarz. In Review, Science and Adaptive Management Plan: Missouri River

Grant L and C Langpap. 2017. Private provision of public goods: evidence from the effect of environmental groups on water quality. Working Paper, Oregon State University.

Holling CS. 1978. Adaptive environmental assessment and management. Chichester UK: Wiley.

Honea JM, MM McClure, JC Jorgensen, and MD Scheurell. 2016. Assessing freshwater life-stage vulnerability of an endangered Chinook salmon population to climate change influences on stream habitat. Climate Research 71: 127-137.

Honea JM, JC Jorgensen, MM McClure, TD Cooney, K Engie, DM Hozer, and R Hilborn. 2009. Evaluating habitat effects on population status: influence of habitat restoration on spring-run Chinook salmon. Freshwater Biology 54:1576-1592.

Idaho Supplementation Study. 2015. Idaho Supplementation Studies Project completion report 1991–2014. December 2015, IDFG Report 15-18. 135 p. https://nwcouncil.app.box.com/s/gsolcxk9nv1w3897am4th5nl7xe6108g

IEAB (Independent Economic Analysis Board). 2011-2. Cost–Effectiveness of Improved Irrigation Efficiency and Water Transactions for Instream Flow for Fish. Independent Economic Analysis Board, Northwest Power and Conservation Council. Task Number 211 September 12, 2015. www.nwcouncil.org/fw/ieab/ieab2011-2/

IEAB (Independent Economic Analysis Board). 2014-1. IEAB recommendations related to amendments for the 2014 Fish and Wildlife Program. Independent Economic Analysis Board, Northwest Power and Conservation Council. Task Number 207. March 20, 2014. www.nwcouncil.org/fw/program/2013amend/ieab2014-1/

IEAB (Independent Economic Analysis Board). 2015-1. Long-Term Cost Planning for the Fish and Wildlife Program. Independent Economic Analysis Board, Northwest Power and Conservation Council. Task Number 211 September 12, 2015. www.nwcouncil.org/fw/ieab/ieab2015-1/

ISAB (Independent Scientific Advisory Board). 2007-2. Climate change impacts on Columbia River Basin fish and wildlife. ISAB Climate Change Report. Northwest Power and Conservation Council, Portland, Oregon. Report ISAB 2007-2. 146 p. www.nwcouncil.org/fw/isab/isab2007-2.

ISAB (Independent Scientific Advisory Board). 2011-4. Using a comprehensive landscape approach for more effective conservation and restoration. Northwest Power and Conservation Council, Portland, Oregon. Report ISAB 2011-4. www.nwcouncil.org/fw/isab/isab2011-4.

ISAB (Independent Scientific Advisory Board). 2012-6. Review of the Columbia River Estuary Ecosystem Restoration Program. Northwest Power and Conservation Council, Portland, Oregon. Report ISAB 2012.6. www.nwcouncil.org/fw/isab/isab2012-6/

ISAB (Independent Scientific Advisory Board). 2013-1. Review of the 2009 Columbia River Basin Fish and Wildlife Program. Northwest Power and Conservation Council, Portland, Oregon. Report ISAB 2013-1. www.nwcouncil.org/fw/isab/isab2013-1.

ISAB (Independent Scientific Advisory Board). 2013-3. Review of the IEAB Fish Tagging Effectiveness Model. Northwest Power and Conservation Council, Portland, Oregon. Report ISAB 2013-3. www.nwcouncil.org/fw/isab/isab2013-3.

ISAB (Independent Scientific Advisory Board). 2013-5. Review of NOAA Fisheries' Life-Cycle Models of Salmonid Populations in the Interior Columbia River Basin. Northwest Power and Conservation Council, Portland, Oregon. Report ISAB 2013-5. www.nwcouncil.org/fw/isab/isab2013-5.

ISAB (Independent Scientific Advisory Board). 2014-1. Review of the Expert Regional Technical Group (ERTG) Process for Columbia River Estuary Habitat Restoration. Northwest Power and Conservation Council, Portland, Oregon. Report ISAB 2014-1. www.nwcouncil.org/fw/isab/isab2014-1.

ISAB (Independent Scientific Advisory Board). 2015-1. Density dependence and its implications for fish management and restoration programs in the Columbia River. Northwest Power and Conservation Council, Portland, Oregon. ISAB Report 2015-1. 246pp. www.nwcouncil.org/fw/isab/isab2015-1.

ISAB (Independent Scientific Advisory Board). 2016-1. Predation Metrics Report. Northwest Power and Conservation Council, Portland, Oregon. ISAB Report 2016-1. www.nwcouncil.org/fw/isab/isab2016-1.

ISAB (Independent Scientific Advisory Board). 2017-1. Review of NOAA Fisheries' Interior Columbia Basin Life-Cycle Modeling Draft Report. Northwest Power and Conservation Council, Portland, Oregon. ISAB Report 2017-1. www.nwcouncil.org/fw/isab/isab2017-1.

ISAB (Independent Scientific Advisory Board). 2017-2. Review of Comparative Survival Study Draft 2017 Annual Report. Northwest Power and Conservation Council, Portland, Oregon. ISAB Report 2017-2. www.nwcouncil.org/fw/isab/isab2017-2.

ISAB (Independent Scientific Advisory Board). 2018-1. Review of spring Chinook salmon in the Upper Columbia River. Northwest Power and Conservation Council, Portland, Oregon. ISAB Report 2018-1. 246 pp. www.nwcouncil.org/fw/isab/isab2018-1/

ISAB/ISRP (Independent Scientific Advisory Board/Independent Scientific Review Panel). 2016-1. Critical uncertainties for the Columbia River Basin Fish and Wildlife Program. Northwest Power and Conservation Council, Portland, Oregon. ISAB Report 2016-1. 162pp. www.nwcouncil.org/fw/isab/isabisrp2016-1.

ISRP (Independent Scientific Review Panel). 2008-4. Retrospective Report 2007: Adaptive Management in the Columbia River Basin. Northwest Power and Conservation Council, Portland, Oregon. ISRP 2008-4.

ISRP (Independent Scientific Review Panel). 2009-46. Review of the Bitterroot and Blackfoot Subbasin Plans. Northwest Power and Conservation Council, Portland, Oregon. ISRP 2009-46.

ISRP (Independent Scientific Review Panel). 2011-14. Review of the Lower Snake River Compensation Plan's Spring Chinook Program. Northwest Power and Conservation Council, Portland, Oregon. ISRP 2011-14.

ISRP (Independent Scientific Review Panel). 2013-11. Final Report for the Geographic Review. Northwest Power and Conservation Council, Portland, Oregon. ISRP 2013-11.

ISRP (Independent Scientific Review Panel). 2017-2. Review of Umbrella Habitat Restoration Projects. Northwest Power and Conservation Council, Portland, Oregon. ISRP 2017-2.

ISRP (Independent Scientific Review Panel). 2017-7. Final 2017 Wildlife Project Review. Northwest Power and Conservation Council, Portland, Oregon. ISRP 2017-7.

Jay DA, AB Borde, and HL Diefenderfer. 2016. Tidal-fluvial and estuarine processes in the lower Columbia River: II. Water level models, floodplain wetland inundation, and system zones. Estuaries and Coasts 39:1299–1324.

Kaplan RS and DP Norton. 2001. Transforming the balanced scorecard from performance measurement to strategic management: Part I. Accounting horizons 15.1 (2001): 87-104.

Kerzner H. 2010. Project management-best practices: achieving global excellence. Vol. 14. John Wiley & Sons.

Kerkvliet J and C Langpap. 2007. Learning from endangered and threatened species recovery programs: A case study using US Endangered Species Act recovery scores. Ecological Economics 63.2 (2007): 499-510.

Krueger KL, DL Bottom, WG Hood, GE Johnson, KK Jones, and RM Thom. 2017. An expert panel process to evaluate habitat restoration actions in the Columbia River estuary. Journal of Environmental Management 188 (2017) 337-350.

Langpap C and J Kerkvliet. 2010. Allocating conservation resources under the Endangered Species Act. American Journal of Agricultural Economics 92.1 (2010): 110-124.

Lee KN. 1994. Compass and gyroscope: integrating science and politics for the environment. Island Press.

Lundin JI, LL Johnson, J Spromberg, C Laetz, D Baldwin, and NL Scholz. 2017. Toxics as an Obstacle to Salmon Recovery in the Columbia River Basin. Chapter 5 in Interior Columbia Basin Life-Cycle Modeling. Zabel et al. 2017. NOAA-Fisheries, Northwest Fisheries Science Center, Seattle, WA.

Lusardi RA and PB Moyle. 2017. Two-way trap and haul as a conservation strategy for anadromous salmonids. Fisheries. 42:478-487.

Manhard CV, JE Joyce, and AJ Gharrett. 2017. Evolution of phenology in a salmonid population: a potential adaptive response to climate change. Canadian Journal of Fisheries and Aquatic Sciences 74: 1519–1527.

Mantua NJ, and et al. 1997. A Pacific interdecadal climate oscillation with impacts on salmon production. Bulletin of the American Meteorological Society 78.6 (1997): 1069-1079.

McGarvey DJ**.** 2012. Differential saturation of Pacific Northwest and Southeast (U.S.A.) fish assemblages. Ecology of Freshwater Fish 21(4):617-626.

Naidoo R, A Balmford, P Ferraro, S Polasky, T Ricketts, and M Rouget. 2006. Integrating economic costs into conservation planning. Trends in Ecology and Evolution 21(12): 681-87.

Naidoo R and T Iwamura. 2007. Global-scale mapping of economic benefits from agricultural lands: implications for conservation priorities. Biological Conservation 140 (1–2): 40–49.

Naiman RJ. 2013. Socio-ecological complexity and the restoration of river ecosystems. Inland Waters 3.4: 391-410.

National Marine Fisheries Service. 2017. Recovery Plan for the Southern Distinct Population Segment of Eulachon (*Thaleichthys pacificus*). National Marine Fisheries Service, West Coast Region, Protected Resources Division, Portland, OR, 97232.

National Research Council. 2005. Valuing ecosystem services: toward better environmental decision-making. National Academies Press.

Newbold SC and J Siikamäki. 2009. Prioritizing conservation activities using reserve site selection methods and population viability analysis. Ecological Applications 19.7 (2009): 1774-1790.

Newig J and O Fritsch. 2008. Environmental governance: participatory, multi-level-and effective? No. 15/2008. UFZ Diskussionspapiere.

NMFS (National Marine Fisheries Service). 2016a. 5-Year Review: Summary & Evaluation of Snake River Sockeye Snake River Spring-Summer Chinook Snake River Fall-Run Chinook Snake River Basin Steelhead. National Marine Fisheries Service, West Coast Region, Portland, OR

NMFS (National Marine Fisheries Service). 2016b. 5-Year Review: Summary & Evaluation of Upper Columbia River Steelhead Upper Columbia River Spring-run Chinook Salmon. National Marine Fisheries Service, West Coast Region Portland OR.

NPCC staff (Northwest Power and Conservation Council). 2017. *Draft* 2014 Columbia River Basin Fish and Wildlife Program Implementation Assessment Report. Available online: link

NOAA Module for the Ocean Environment. 2014. Prepared for the NOAA Fisheries, Northwest Regional Office. Prepared by the Northwest Fisheries Science Center, July 2014. www.westcoast.fisheries.noaa.gov/publications/recovery_planning/salmon_steelhead/domains/interior_columbia/snake/ocean_module.pdf

Null SE, ST Ligare, and JH Vierse. 2013. A method to consider whether dams mitigate climate change effects on stream temperatures. Journal of the American Water Resources Association 49(6):1456-1472.

Ostrom E. 1990. Governing the Commons: The Evolution of Institutions for Collective Action. Cambridge University Press, New York.

Ostrom E. 2009. Beyond Markets and States: Polycentric Governance of Complex Economic Systems [Nobel Prize lecture]. Stockholm, Sweden: Nobel Media.

Ostrom E. 2014. Collective action and the evolution of social norms. Journal of Natural Resources Policy Research 6.4:235-252.

Petrosky CE and HA Schaller. 2010. Influence of river conditions during seaward migration and ocean conditions on survival rates of Snake River Chinook salmon and steelhead. Ecology of Freshwater Fish 19.4: 520-536.

Polasky S, JD Camm, and B Garber-Yonts. 2001. Selecting biological reserves cost-effectively: an application to terrestrial vertebrate conservation in Oregon. Land Economics 77.1: 68-78.

Rieman BE, C Smith, RJ Naiman, G Ruggerone, CC Wood, JR Alldredge, PA Bisson, K Fausch, N Huntly, C Levings, E Merrill, W Pearcy, D Scarnecchia, and P Smouse. 2015. A comprehensive approach for habitat restoration in the Columbia Basin. Fisheries 40:124-135.

Rounds SA, MC Doyle, PM Edwards, and ET Furlong. 2009. Reconnaissance of pharmaceutical chemicals in urban streams of the Tualatin River basin, Oregon, 2002: U.S. Geological Survey Scientific Investigations Report 2009-5119, 22 p. https://pubs.usgs.gov/sir/2009/5119/

Rowe G, T Horlick-Jones, J Walls, and N Pidgeon. 2005. Difficulties in evaluating public engagement initiatives: reflections on an evaluation of the UK GM Nation public debate about transgenic crops. Public Understanding of Science 14.4:331-352.

Sarker A, H Ross, and KK Shrestha. 2008. A common-pool resource approach for water quality management: An Australian case study. Ecological Economics 68.1:461-471.

Shultz M and M Johnson. 2015. Computer modeling shows that Lower Snake River dams caused dangerously hot water for salmon in 2015. Columbia Riverkeeper White Paper. 11 p.

Sorel MH, AM Wargo Rub, and RW Zabel. 2017. Population-specific migration timing affects en route survival of Chinook salmon through a variable lower-river corridor. Chapter 6.a, Interior Columbia

Basin Life Cycle Modeling, May 27, 2017 Draft Report, National Marine Fisheries Service, Northwest Fisheries Science Center, Seattle.

Underwood EC, KR Klausmeyer, SA Morrison, M Bode, and MR Shaw. 2009. Evaluating conservation spending for species return: A retrospective analysis in California. Conservation Letters 2 (3): 130–37.

U.S. Department of Interior and Commerce. 2013. Klamath Dam Removal Overview Report for the Secretary of the Interior: an assessment of science and technical information. (https://klamathrestoration.gov/sites/klamathrestoration.gov/files/Full%20SDOR%20accessible%20022216.pdf)

Walters CJ. 1986. Adaptive management of renewable resources. New York: McMillan Publishing.

Watanabe M, RM Adams, J Wu, JP Bolte, MM Cox, SL Johnson, and JL Ebersole. 2005. Toward efficient riparian restoration: integrating economic, physical, and biological models. Journal of Environmental Management, 75(2), 93-104.

Weber N, N Bouwes, MM Pollock, C Volk, JM Wheaton, G Wathen, J Wirtz, CE Jordan. 2017. Alteration of stream temperature by natural and artificial beaver dams. PLOS One 12(5): e0176313. https://doi.org/10.1371/journal.pone.0176313.

Wipfli MS and CV Baxter. (2010). Linking ecosystems, food webs, and fish production: subsidies in salmonid watersheds. Fisheries, 35(8), 373-387.

Withler FC. 1982. Transplanting pacific salmon. Canadian Technical Report of Fisheries and Aquatic Sciences No. 1079. 32 pp.

Wydoski RS and RR Whitney. 2003. Inland Fishes of Washington. 2nd edition. University of Washington Press, Seattle.

Wu J, RM Adams, and WG Boggess. 2000. Cumulative effects and optimal targeting of conservation efforts: Steelhead trout habitat enhancement in Oregon. American Journal of Agricultural Economics 82.2: 400-413.

Wu J, and et al. 2003. Pacific salmon restoration: trade-offs between economic efficiency and political acceptance. *Contemporary Economic Policy* 21.1 (2003): 78-89.

Zabel R, and et al. 2017. Interior Columbia Basin Life-Cycle Modeling. NOAA-Fisheries, Northwest Fisheries Science Center, Seattle, WA.