UNITED STATES DEPARTMENT OF COMMERCE
National Oceanic and Atmospheric Administration
NATIONAL MARINE FISHERIES SERVICE
West Coast Region
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March 15, 2016

Henry Lorenzen, Chairman
Northwest Power and Conservation Council
851 SW 6th Avenue
Portland, OR 97204-1348

Dear Chair Lorenzen: Henry

Thank you for the opportunity to review the January 29, 2016, Independent Scientific Advisory Board (ISAB) and Independent Scientific Review Panel's (ISRP) *Critical Uncertainties for the Columbia River Basin Fish and Wildlife Program* report and to comment on possible revisions to the Council's 2006 Research Plan. The ISAB/ISRP did an excellent job of reviewing and organizing a massive amount of material related to past research and critical uncertainties. The science panels deserve a great deal of credit for their effort.

This letter provides our comments on the research areas we believe are the most important to pursue in the upcoming years. These comments were developed by both NOAA Fisheries' Interior Columbia Basin Office and the Northwest Fisheries Science Center. The list of projects is not comprehensive but describes specific research areas most important to assist regional decision making. Additionally, we believe that research priorities can be even better identified once the Program has adopted long-term quantitative fish and wildlife goals. We look forward to working with the Council as we undertake a regional collaboration to establish long-term goals for conservation and harvest of salmon and steelhead through the Columbia Basin Partnership. We hope that these long-term goals will also help focus the region's research and recovery efforts.

Sincerely,

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Need for Regional Salmon and Steelhead Goals

Research priorities should be based on management goals and how they support the decisions necessary for achieving those goals. In their report the ISAB/ISRP describe the difficulty in prioritizing uncertainties:

> Decision makers want to know from scientists what additional information is "critical," but what is critical depends on the decisions they (the decision makers) are considering making. On the other hand, scientists are asked to prioritize uncertainties, but this depends on which information would be most useful to the Council or other decision makers, i.e., what would help them make better decisions.[1]

Clear management goals are important for research projects because they help identify areas where research results could fill important knowledge gaps. From a practical standpoint there should be a commitment to target research dollars and efforts to those areas where there will be the greatest impact and where there is a gap in needed research.

Currently regional goals for Columbia Basin salmon and steelhead are not consistent or aligned among various management entities. The Council recently initiated a process to gather and refine fish and wildlife program goals and quantitative objectives. Council staff have compiled salmon and steelhead objectives from a variety of agency and tribal management plans, federal recovery plans, sub-basin plans, and other relevant documents and reports. In doing so, staff found there is a wide divergence of quantitative and qualitative goals and objectives for different species at varying geographic scales and locations. These differing regional goals and objectives have contributed to the wide array of research activities.

NOAA Fisheries is undertaking the Columbia Basin Partnership to address the need for regionally accepted, consistent goals for conservation and harvest of Columbia Basin salmon and steelhead. We believe that establishing quantifiable goals for conservation and harvest will promote the development of strategies to focus management actions and identify research needs. In this way, Endangered Species Act (ESA) recovery and Council Program actions can be better coordinated over the long term. Your support for the Partnership will be important as we move forward with this significant and ambitious task.

General Comments

We recommend that the Council articulate its research program within a strategic framework that clearly identifies priority research questions and their relationship to the Fish and Wildlife Program objectives, and that establishes clear feedback loops to ensure that research informs management actions as appropriate. This framework should distinguish research questions from monitoring and evaluation (while noting the integral conceptual and programmatic connections

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[1] Independent Scientific Advisory Board/Independent Scientific Review Panel (SAB/ISRP). 2016. Critical Uncertainties for the Columbia River Basin Fish and Wildlife Program. ISAB/ISRP 2016-1. January 29.

between these three types of exploration). In addition, the framework should describe the anticipated mix of types of research (e.g., descriptive vs. analytical, applied vs. fundamental, quantitative vs. qualitative, conceptual vs. empirical, etc.) as well as temporal and spatial scales at which research will be conducted. Transparency on these issues would help to set realistic expectations and provide context to the Council's partners and the public about how and when specific research programs will inform the questions to which they are directed.

We agree with the ISAB's finding that, at least for some high priority research topics, "What is often needed . . . are studies lasting for a decade or more that involve multiple subbasins and are conducted by integrated teams of professionals representing a diverse array of disciplines."[2] The Council should carefully consider how to appropriately integrate longer-term research projects with research on uncertainties that consist of hypotheses with a higher likelihood of being answered in a shorter (5- to 10- year time horizon). We also recommend that the Council consider how to better evaluate and communicate interim progress on longer-term research questions. This will not only ensure adaptive management of the research programs themselves but also clarify expectations regarding how and when such research will inform management decisions. In addition, because very large-scale and long-term experiments present formidable logistical and practical challenges, the Council should explicitly consider the potential benefits to be gained from continuing to integrate salmon and steelhead life-cycle modeling into the Fish and Wildlife Program.

Comments by Theme

We have identified a number of research uncertainties and priorities organized around the 14 primary themes outlined in the ISAB/ISRP report. We do not have specific comments on the first two themes, **Public Engagement** or **Human Development**, but these are at times addressed in the remaining 12 themes. Again, we are not submitting specific edits or comments on the ISAB/ISRP report but rather recommend potential activities that could be incorporated into the Council's updated research plan with the aim of helping the region make better management decisions.

Theme 3. Tributary Habitat

The Council's 2006 Columbia River Basin Research Plan (p. 15) provides a concise and straightforward articulation of the critical uncertainties that continue to be high priorities for tributary habitat.[3] The Council should consider retaining numbers 1 and 2 (number 3 relates not to tributary but to mainstem habitat) while modifying number 4 to clarify that it encompasses investigation of how changing climate may affect tributary habitat. The Council should also consider adding a critical uncertainty related to the need (also identified in the 2006 Research Plan) to define a comprehensive life-cycle approach that addresses both natural variability in environmental conditions and human impacts on physical, chemical, and biological processes affecting fish and wildlife populations.

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[2] Ibid.

[3] Northwest Power and Conservation Council. 2006. Columbia River Basin Research Plan. February. Council document 2006-3

Extent to which tributary habitat restoration actions affect the survival, productivity, distribution, and abundance of native fish populations. Tributary habitat restoration is based on the broadly accepted and well-supported hypothesis that by carrying out actions to ameliorate factors limiting habitat capacity or productivity we can improve habitat function and thereby improve both freshwater and life-cycle survival. The region has made great strides in developing cutting edge programs designed to explore and refine these hypotheses, and we need to build on that progress and continue this line of inquiry within an effective adaptive management framework.

The Council's 2006 Columbia River Basin Research Plan also stated that "a comprehensive life-cycle approach that addresses both natural variability in environmental conditions and human impacts on physical, chemical, and biological processes affecting fish and wildlife populations must be defined." We also agree that understanding these larger-scale uncertainties regarding how the benefits of salmon habitat improvement in tributaries may be reduced by mainstem, estuary, or ocean survival or by predation, harvest, and effects of hatchery fish or of non-native species is critical. Aspects of this issue more specific to tributary habitat include how land use interactions with stream conditions influence fish populations (e.g., are juvenile fish emigrating from historically grazed watersheds less likely to survive the hydropower system than juveniles from a wilderness area?). In which populations is survival most affected by the hydropower system? In which populations is the potential for improving tributary habitat survival, and life-cycle survival as a result of tributary habitat improvement, greatest? Columbia Basin research efforts should continue work to develop life-cycle models and approaches to salmon and steelhead conservation and management.

Accuracy of procedures being used to identify limiting habitat factors. Likewise, the region has made significant progress in ensuring that habitat actions are directed toward priority limiting factors, and we should continue to refine and enhance our ability to assess and understand those limiting factors. An important aspect of this is having, at least for targeted sub-basins, specific analyses based on best available science that identify which tributary habitat improvements are most critical for each population. A related need is to continue to improve our understanding of the interactions among restoration actions. For example, restoring habitat complexity by adding large wood may have little impact on improving fish production if the system is nutrient-limited. Limiting factors should be treated as hypotheses and the resultant management strategies to address them as experiments, so that the actions taken to address the limiting factors can be assessed for both relevance and impact.

Ensuring long-term viability of fish and wildlife populations in the face of natural environmental variation as well as likely future human impacts on habitat (including climate change). Regarding climate change, the Council should consider combining and broadening critical uncertainties 2.4 and 3.1 as identified in the ISAB/ISRP 2016 document under the Tributary Habitat "theme" to be more broadly reflective of the topic of climate change adaptation and resiliency in tributary habitat. A great deal of information has become available in the past 10 years about predicted impacts of climate change on watershed discharge, fish and habitat distribution, vulnerable species and habitats, frequency and distribution of catastrophic events, and changing weather patterns. The Council could establish a broad set of prioritized sub-uncertainties that integrates this kind of information with commensurate hydropower

system operation projections (under changing climate predictions) within a theme of Tributary Habitat Adaptation and Resiliency Research.

In a process with co-managers, partners, and climate change experts, the Council should tease out the highest priority *applied research* hypotheses where a great deal of uncertainty still persists about the fundamental science behind crafting viable strategies for evaluating alternatives that would ensure that salmon and salmon habitat has a high likelihood of survival over the next 50 years.

The Council also should clarify the intersection of Tributary Habitat uncertainties 2.4 and 3.1 with the two critical uncertainties identified under Theme 8, Climate Change (how will climate change affect fish and wildlife? what actions could ameliorate climate change effects are important ones?). It might be helpful to mention that there is an existing general protocol for addressing these questions in salmon habitat restoration planning (Beechie et al. 2013, Restoring salmon habitat for a changing climate, River Research and Applications, 29:939-960). This protocol has been successfully implemented in the Pacific Northwest, and could be more broadly implemented in Columbia River sub-basins through focused workshops. There is also a high degree of uncertainty regarding how climate change will indirectly affect fish populations by altering disturbance regimes (e.g., fire, pests, and landslides).

Public engagement as a cross-cutting theme. Several of the themes identified by the ISAB/ISRP would benefit from further exploring how they might cross-cut with the tributary habitat theme. For example, public engagement is highly developed in certain subbasins in terms of diverse stakeholder engagement and coordination of habitat assessment information with prioritization and implementation of improvement actions. However, there are also gaps. For example, watershed assessment information is better developed and better understood by diverse stakeholders in some areas than in others. Further, as a region, we have engaged more productively with some affected sectors than with others. There also is a need at least in some locations for there to be "ambassadors" to ensure cross-education and feedback between local practitioners and those implementing larger-scale, longer-term research and monitoring. Overall, the Council should clarify what greater public engagement would actually look like, along with a stronger vision for the end products.

Reservoir Habitat. Finally, the productivity of reservoir habitat in blocked areas is a critical uncertainty in predicting the increase in carrying capacity from transporting salmon around barriers. Subyearling Chinook salmon have been observed to use lentic habitat as their primary freshwater rearing habitat in numerous systems, and are able to achieve relatively high growth rates in many such situations. In areas slated for reintroduction of anadromous salmonids, factors such as predation, food availability, and competition with resident species need to be investigated. Furthermore, the relative survival rates, carrying capacities, and contributions to adult returns from smolts reared within reservoirs versus lotic habitats above and below them are uncertain. A better understanding of these factors will help predict the cost-effectiveness of transporting fish around barriers as a restoration and conservation tool.

Theme 4. Hydrosystem and Passage Operations

Trophic dynamics in the reservoirs. For juvenile spring migrants where mainstem passage exists, approximately half of the mortality occurs in the reservoirs, and the rest occurs at the dams (based on comprehensive passage (COMPASS) modeling). In addition, individuals can grow up to 10 mm during downstream migration (Muir et al. 2006). We have very little understanding of the food web dynamics in reservoirs and how it affects survival and growth. What is the role of the competitors, predators, and prey in shaping these dynamics?

PIT-tag effects on returning adults. Prioritize research on whether Passive Integrated Transponder (PIT) tagged juveniles return at lower rates than non-PIT tagged fish. The ISAB/ISRP report does not appear to consider the potential effects of PIT tagging on adult returns. Returns of adult fish PIT tagged as juveniles has become an important tool for assessing the potential effects of management actions throughout the basin (including that of the hydro-system). Some information suggests that PIT tagged fish are returning at substantially lower rates than untagged fish (biasing survival estimates low). While this is likely a minor issue when assessing relative return rates of alternative actions (i.e., transport vs inriver returns), it is potentially an important factor if used as an absolute value (i.e., use of smolt to adult return rates (SARs) as a performance goal).

Relationship between temperature and survival. Prioritize research on the effect of temperature on juvenile survival. The ISAB/ISRP report states that there is limited information on the relationship between survival of juvenile migrants through the hydrosystem and water temperature. The COMPASS model (reviewed several times by the ISAB) has established survival versus temperature relationships based on many years of PIT-tag data (Zabel et al. 2008). Based on sensitivity analyses, it is likely the strongest factor related to in-river survival.

Potential impacts of elevated levels of dissolved gas. The report states that we have a strong understanding of the impacts of dissolved gas on salmon populations, and that impacts are minimal because we operate the system to prevent dissolved gas from going above 120% supersaturation. However, proposals exist to raise this threshold to 125%. We do not know how increased levels of gas would impact juveniles, adults, and resident fish populations. We also don't know of the potential for synergistic effects with higher water temperatures that would be encountered under climate change.

Competing juvenile bypass system hypotheses. Conduct research to determine whether juveniles entering bypass systems are inherently less fit or does entering bypass systems cause them to be less fit. Though the ISAB/ISRP report acknowledges that there are competing hypotheses surrounding juvenile bypass systems, the report does not appear to call for studies to determine which of these competing hypotheses is correct. The operation and maintenance of bypass systems is an important component of fish passage strategies at most mainstem hydroelectric projects. Determining between these two hypotheses would address a critical uncertainty that underlies many regional disputes about fish passage operations, etc.

Theme 5. Mainstem Habitat

Thermal Refuges. Availability of thermal refuges is critical for the long-term persistence of salmon populations. It is important to both (1) understand the spatial availability of thermal refuges and (2) explore ways to provide these refuges in the future. Water temperature is a key factor influencing Pacific salmon and other aquatic organisms. Yet until recently, data describing spatial and temporal patterns in freshwater thermal regimes have been scarce. Recent advances in sampling technologies and modeling techniques have yielded large and novel datasets that can provide insights about how salmon respond to thermal regimes, and how these thermal regimes may be affected by climate change.

Theme 6. Estuary, Plume, and Ocean

Estuary habitat action effectiveness research. Action effectiveness research is critical to ensuring that habitat restoration in the floodplain below Bonneville Dam helps recover the estuarine processes and functions that support the growth and survival of a diverse set of salmonid species and the full range of their life history strategies.

One of the Council's sub-strategies for the Fish and Wildlife Program is to "restore estuarine function to protect and enhance critical habitat and spawning and rearing grounds in the estuary and lower Columbia River." Over 70% of the tidally-influenced floodplain of the Columbia River estuary has been lost due both to dike and levee construction and river management (lower flows have disconnected some areas of the floodplain). For salmonids, habitat restoration means looking for opportunities to reconnect large areas to the mainstem. A major gap in our knowledge with respect to estuarine restoration is how different salmonid stocks respond to these floodplain reconnections. The floodplain can provide habitat for juvenile rearing, but also exports ecosystem services (e.g., prey and other organic material) where it supports the survival of fish that are actively moving downstream. We need to understand how recovering tidally-influenced floodplain affects the growth, body condition, residence time, age at maturity, and survival of focal fish species and the degree to which historical estuarine processes are restored by projects that breach dikes and levees.

The Council's Fish and Wildlife Program is currently supporting some of this action effectiveness research in the estuary, although large portions are funded by the Corps of Engineers under its Anadromous Fish Evaluation Program. Long-term monitoring with at least some support from the Fish and Wildlife Program will be needed to ensure that habitat restoration projects are effective and that the fish populations affected by the hydropower system respond to these mitigation projects with improved growth and survival.

Mechanisms influencing salmonid ocean survival. It is critical that we continue to work on developing a mechanistic understanding of the relationships between environmental conditions in the ocean and the likelihood of adult returns to Bonneville Dam in order to model the future status of Columbia basin salmon and steelhead under different mitigation and climate scenarios.

Although multiple correlations between ocean indicators and salmon survival exist, we are currently trying to develop a mechanistic understanding of these relationships. Just relying on

statistical correlations has resulted in poor prediction efficiencies for even well fitted models such as those that compare the Pacific Decadal Oscillation Index to adult returns. Once we have a better understanding of the mechanisms underlying the ocean ecology of juvenile salmon ("bottom up" feeding ecology, "top down" predation pressure, warm temperatures, etc.), we can produce testable hypotheses regarding the effects of different hatchery mitigation scenarios or harvest management plans. We will also have better models of the relationships between water storage and release operations, the size and shape of the plume, and survival during the first weeks of ocean life. And we need to improve our understanding of the effects on the future status of salmon and steelhead of variable ocean conditions including those we have seen in the past (natural variation) and those we are likely to see in the future (anthropogenic climate change).

Theme 7. Contaminants

Spatial distribution of contaminant and potential effects on salmonids. A more comprehensive evaluation of the spatial distribution (past and present) of contaminants is needed to inform where risks to fish and wildlife are highest. Researchers are currently starting a pilot project to evaluate contaminant loads in juvenile salmonids to assess sub-lethal impacts (e.g., condition, growth, survival, and migration behavior). Integration of this information into existing life-cycle models will provide insights into potential population level impacts of contaminant loads.

Theme 8. Climate Change

Climate change risk assessment. Climate change is an important critical uncertainty addressed in the ISAB/ISRP report. A critical question is how to manage climate-related uncertainty, and how to incorporate the element of uncertainty in future ecosystems functions and associated risk to species and habitat in decisions about hydropower operations. Is there an adaptive management structure that can be developed to lower the risk to species and their habitats? What are the fundamental elements of a decision analysis to reach a recommendation that addresses climate-related impacts and uncertainties?

Maintaining life history diversity and ecosystem resilience. How best to maintain life history diversity and ecosystem resilience to climate stressors is a critical uncertainty. Will additional stress related to increased temperature and poor flows favor some salmonid populations over others? The importance of tributary habitat to maintain fish populations into the future needs to be studied. An understanding of how or if the hydrosystem can be operated to ameliorate the physical effects of climate change, particularly at times when vulnerable life stages will be present is also needed. How can we increase survival while the physical environment is changing, and how important will genetic diversity be in the face of those physical changes? Is there anything we can do now to support genetic diversity?

Develop better decision support tools. Advanced life cycle models that can incorporate temperature and flow changes, or specific decision support tools that guide restoration actions are needed to address climate change risk.

Theme 9. Non-Native Species

Support research to guide management of non-native species. We emphasize the importance of the ISAB/ISRP report recommendation that states "Support research to guide management of non-native species." First, we need basic science to answer questions about the abundance, distribution, and behavior of recreational game fishes in Columbia and Snake River mainstem and tributary habitats. This also means taking proactive steps to invest in monitoring programs and technology (i.e., electrophoretic-DNA) to identify distribution and spread of non-natives. Managers can then be poised for rapid interventions when necessary. Basic information about non-natives is also necessary to examine complex questions about the costs vs. benefits of non-native recreational game fishes – to answer these types of questions will require interdisciplinary approaches that bring together economists, natural scientists, and social scientists. There are also tremendous opportunities for "Public Engagement" with recreational anglers, outdoor enthusiasts, and other groups surrounding these questions.

Theme 10. Predation

Determine the extent of pinniped predation in the Columbia River. Scientists have been making a concerted effort to evaluate the extent of pinniped predation on adult Chinook salmon as they migrate through the lower Columbia River from the estuary to Bonneville Dam since 2010. This work has focused on survival of spring/summer Chinook salmon because their migration timing through the lower Columbia River most closely matches that of the transient but growing sea lion population. Survival estimates from this study indicate that natural mortality within the first 145 miles of freshwater (e.g. the reach between the mouth of the Columbia River and Bonneville Dam) is significant. After accounting for harvest and impacts from sampling gear, weighted mean annual survival has ranged from 59%-90%. Importantly, survival has been consistently higher for salmon arriving late in the run compared to those returning early or on peak. Given similar timing for observations of pinnipeds in the lower river, these results imply predation is a likely source of mortality. They also imply some fish populations may be at higher risk than others based on their behavior. Importantly, annual mortality has increased in recent years while significantly more sea lions have been observed at haul out sites near Astoria, Oregon.

It is imperative that we continue to study the relationship between fish and pinnipeds. Although circumstantial evidence for predation is compelling, we need more explicit information about pinniped diets in order to make a direct connection between fish mortality and predation. For example, it is likely that Stellar sea lions, California sea lions, and harbor seals will all have varying proportions and numbers of salmonids, sturgeon, and/or bait fish in their diet. This is also likely true for each of the pinniped age classes represented within the river. The knowledge gained from these studies will not only enable us to measure how salmon survival is affected by the growing Columbia River predator population, it will enable us to take the necessary steps towards managing this interaction in an intelligent and responsible way.

Injury and delayed mortality caused by predators. There is a heightened awareness of predators and their potential impacts on fish and wildlife. The ISAB/ISRP report identified our need to know the extent to which the viability or abundance of native fish and wildlife populations is

jeopardized by predation. They specifically note the need to know the number of individuals killed by predators. We want to extend this need to also examine the injury rate and subsequent delayed mortality. To date, the implications of marine mammal injury for adult salmon survival have only been evaluated in the mainstem Columbia and Lower Snake rivers, yet there are indications that injured individuals traveling far upstream may not successfully reach spawning sites. Scientists have been monitoring injuries, and preliminary analyses indicate that roughly 30% of adults arriving at Lower Granite Dam exhibit signs of pinniped injury. Currently, there is no estimate of marine mammal caused delayed mortality above Lower Granite Dam. Yet, there are multiple reasons why Chinook injured by marine mammals may exhibit significantly reduced spawning success above Lower Granite Dam, including extended travel times and energetic costs to reach spawning grounds and thermal stress, both of which could exacerbate effects of injury.

Theme 11. Fish Propagation

Critical review of HSRG gene flow guidelines. A critical review of Hatchery Scientific Review Group (HSRG) gene flow guidelines is needed. These guidelines have not been evaluated in peer-reviewed literature. Recent work has shown that modelling based on HSRG guidelines can have very different outcomes depending on assumptions. If the region moves to adopt the HSRG guidelines, they need to be better supported scientifically.

Translating relative reproductive success information to population effects. The ability to translate relative reproductive success (RRS) information to population effects is important. Data on genetic effects of hatcheries is largely based on relative reproductive success studies, yet exactly how this translates to population productivity and abundance is unknown, and is critical information.

Recovery from genetic impacts. There is no information available on how rapidly deleterious effects of hatcheries will decrease under reduced hatchery influence. This is especially important to developing realistic expectations of results from changes in hatchery practices.

Hatchery operation uncertainties. (1) Potential effects of hatchery effluent on aquatic species should be studied. Hatchery effluent contains a wide variety of chemicals, but standards for chemical discharge to ensure that aquatic species will not be adversely affected do not exist. (2) The potential for disease amplification from hatchery programs should be studied. Pathogens can be amplified in natural systems via two pathways: from effluent and by released hatchery fish. Little is known about horizontal transmission of disease from hatchery releases.

Ecological interactions with hatchery fish. To get a better understanding of ecological interactions with hatchery fish several lines of investigation are needed: (1) Residence/ outmigration time of hatchery fish in freshwater (from natal stream to estuary). (2) The number/proportion and diet composition of fish from a hatchery program that residualize. At what age does substantial piscivory begin to occur? Are residuals a common component of the natural-origin fish life history? (3) The number of natural-origin salmon and steelhead for each population and their age structure. (4) Amount of overlap in time in space. This would be useful to know for both the freshwater and marine environments.

Theme 12. Harvest

Select area fishery sites. In appropriate locations, explore and test opportunities to develop more select area fisheries. Several terminal-fishing sites in the Lower Columbia River have been developed to allow harvest hatchery production while minimizing incidental harvest of weaker stocks. This strategy could be expanded to other locations in the Columbia Basin (including above Bonneville Dam) to allow greater harvest, minimize incidental harvest, and lessen over escapement of hatchery fish into tributaries.

Base harvest and escapement strategies on improved stock production functions. Harvest/escapement management strategies based on current biological assessments of habitat carrying capacity and the annual and cyclical variations in survival patterns is important. Evaluating the projected performance of harvest strategies using updated stock production functions would be more useful than specific numeric biological escapement goals. The research and monitoring efforts necessary to define these relationships would be similar to those for determining quantitative adult escapement goals.

Develop new harvest strategies using genetic markers. Using both old insights (e.g. coded-wire-tag based inferences) and new tools (genetic markers), develop and evaluate new harvest strategies that might improve contributions to recovery.

Theme 13. Population Structure and Diversity

Improve understanding of major life history strategies. Research should be conducted to get a better understanding of the major life history strategies currently in play and how those relate to the relative distribution of freshwater habitats and habitat conditions (including temperature). Information would be used in habitat restoration planning and implementation and should improve the potential for achieving improved natural production and better accounting for potential climate change related impacts.

Relationship between genetic diversity and ecological evolutionary performance. We concur with the ISAB/ISRP report that a critical uncertainty is the extent to which the loss of genetic diversity affects long-term fitness, survival, and resilience of the remaining populations. This uncertainty would benefit from a coordinated basin wide effort to synthesize and analyze relevant information designed to come up with recommendations for effectively integrating future projects. Other challenges include empirical validation of theoretical population structure, and demonstration of the mechanistic links that will be needed to understand how metapopulations will respond to environmental change and to management actions.

Theme 14. Monitoring and Evaluation

Develop and apply life cycle modeling tools. Life cycle models are a powerful analytical tool that can help in examining the relative importance of impacts and uncertainties. Life cycle modeling provides an opportunity to (1) compile the many data pieces, (2) develop scenarios that test assumptions and address uncertainties, and (3) look for potential bottlenecks and constraints of populations. These models can also identify data gaps important for understanding

population processes. Thus, life cycle models can be useful to help formulate research questions and how best to implement monitoring efforts.

Improvement of fish monitoring methodologies. Improve (1) the precision and accuracy of methods used for estimating fish survival; (2) methods for "fish-in and fish-out monitoring" to evaluate density dependence and the benefits of habitat restoration; and (3) approaches to measuring the cumulative effects of habitat restoration on fish populations at a large spatial scale.

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