WASHINGTON STATE
Academy of Sciences
Science in the Service of Washington State

The Science of Salmon Hatcheries

Summary of a Workshop organized by the
Washington State Academy of Sciences for the
Washington Department of Fish and Wildlife

Seattle, WA

Workshop Date: May 23, 2019

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Preface

The Washington State Academy of Sciences (WSAS) was established in April 2005 by Senate Bill 5381 as requested by then Governor Gregoire. Its purpose is to improve public policies and programs through the integration of informed, independent scientific analysis and communication with policy makers, and its mission is "Science in Service of Washington State." In keeping with its mission, WSAS responds to requests from state agencies to advise on matters of science and technology.

The Washington State Department of Fish and Wildlife (WDFW) asked WSAS to assist with its update and review of the science that can inform hatchery reform as part of its Hatchery and Fishery Reform Policy (C-3619) Review Process. WSAS's involvement is but one part of the WDFW review and report development process. A number of other important components, including opportunity for public input, lie outside the purview of WSAS's involvement.

In response to WDFW's request, WSAS convened an expert committee, reviewed a preliminary manuscript prepared by WDFW's project team, and organized a workshop on May 23, 2019 to provide in-person comments about the manuscript to the agency's project team. WSAS invited several additional reviewers to participate in the workshop, as well as several observers who had expressed an interest in attending.

Bringing state-of-the-art science to management practices is not a trivial process. Thus, as scientists we not only consider state-of-the-art knowledge; we also acknowledge its limitations and suggest experiments to improve the state-of-the-art and its application. It is in this spirit of continual search for knowledge and its subsequent application in the public arena that we provided feedback to the WDFW project team.

This summary captures the many diverse scientific discussions that occurred at the workshop among the WDFW project team, WSAS's Committee Members, and invited supplemental reviewers. Our summary does not contain recommendations for WDFW. It contains questions posed by observers during the workshop and summaries of answers provided by the WSAS project team, committee members, or supplemental reviewers. The full list of workshop attendees can be found as Appendix I.

On behalf of the Committee, we thank the WDFW project team for their diligent and thoughtful work in preparing the preliminary manuscript and for their candid responses to questions and input during the workshop. We also thank the supplemental reviewers for their critical input, and the observers for their thoughtful questions. Clearly, the health and sustainability of migratory fish present many challenges at the forefront of scientific research and hatchery management. We hope that our review of the project team's early work assisted in addressing those challenges.

Larry Dalton, PhD
Chair
WSAS Committee on the Science of Salmon Hatcheries

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Introduction

Ron Warren, the Washington Department of Fish and Wildlife (WDFW) Assistant Director for the Fish Program, and Dr. Larry Dalton, Chair of the Washington State Academy of Sciences' (WSAS) Committee on the Science of Salmon Hatcheries presented the background and purpose of the workshop in their opening remarks.

In brief, the Washington Fish and Wildlife Commission (Commission) directed WDFW to a) conduct a review and evaluation of WDFW's Hatchery and Fishery Reform Policy (C-3619); b) review and update the science of fish hatcheries in Washington State; and c) engage in outreach and public engagement.

WSAS's role in this process is to provide scientific advice and feedback to the WDFW project team that is charged with reviewing and updating the science of fish hatcheries. Separate and apart from WSAS's scientific review, WDFW is carrying out parallel processes of policy review and evaluation and stakeholder engagement throughout 2019 and into 2020.

The purpose of the workshop in Seattle on May 23, 2019 was for the WSAS Committee and invited supplemental reviewers to provide direct feedback to the WDFW project team on its preliminary, incomplete manuscript. The workshop was designed to maximize discussion among Committee members, supplemental reviewers, and the authors of the preliminary manuscript. This summary does not reflect either the specific views of the Academy or the panel members; rather it is an effort to organize the diverse issues discussed at the workshop into a coherent framework.

The workshop was designed to focus discussion between WDFW'S project team, WSAS committee members, and invited supplemental reviewers on three main topics addressed in the preliminary manuscript: broodstock and escapement management, ecological risks and hatchery management strategies, and conservation benefits. The meeting also included a limited number of invited observers from various stakeholder groups who were allowed to submit questions in writing.

This summary captures the highlights of the scientific discussion during the workshop and includes the following appendices: Workshop Agenda (Appendix A); Introductory Slides by WDFW Assistant Director for the Fish Program (Appendix B); Introductory Remarks by Dr. Larry Dalton (Appendix C); Discussion Kickoff Slides by Dr. Michael Ford (Appendix D), Dr. Thomas Quinn (Appendix E) and Dr. Robin Waples (Appendix F); Brief biographies of members of the WSAS Committee on the Science of Salmon Hatcheries (Appendix G) and Supplemental Reviewers (Appendix H); List of Workshop Attendees (Appendix I); Questions from Observers (Appendix J); and Written Observer Comments (Appendix K).

Broodstock and Escapement Management

Dr. Michael Ford initiated the discussion on broodstock and escapement management by framing the discussion in the context of the Hatchery Scientific Review Group (HSRG) broodstock model guidelines (Appendix D).

Definitions – Terms used in this Discussion

pNOB is defined by the HSRG as the proportion of natural-origin broodstock and reflects the incorporation of wild fish into broodstock.

pHOS is the proportion of hatchery origin fish on the spawning grounds. pHOS is calculated by the HSRG in two ways: census pHOS and effective pHOS. Before understanding the two types of pHOS it is important to define the Relative Reproductive Success (RRS). RRS measures the reproductive success rate of the first-generation hatchery fish relative to the natural population, where the natural population is defined as having a value of 1. Low values for RRS indicate that first-generation hatchery fish reproduced less successfully than wild fish. In contrast, high values for RRS (i.e., near 1.0) indicate there was little difference in the reproductive success of first-generation hatchery fish and wild fish. Census pHOS is defined as the number of hatchery origin spawners divided by the total number of spawners, hatchery-origin and natural-origin combined. In contrast, effective pHOS considers whether or not the hatchery fish are able to reproduce effectively. It is calculated by taking the equation for the census pHOS and adjusting for the RRS of hatchery-origin fish. There is a debate about use of effective pHOS in that when used in modeling the genetic effects of hatcheries (see below), it may be "double-counting" the effects of selection, non-genetic factors that may influence hatchery fish reproductive success, such as spawning location or timing. As one example, if most hatchery fish spawn in population spawn in poor quality habitat and therefore have poor success, it would be reasonable to 'discount' these spawners when calculating the overall pHOS for the population.

Taken together, pNOB and both ways of calculating pHOS represent mechanisms of evaluating and potentially controlling gene flow between natural wild and hatchery populations.

The Proportionate Natural Influence (PNI) results from calculations using the proportion of natural origin broodstock (pNOB) and the proportion of hatchery origin spawning fish (pHOS). pNOB is divided by the sum of pNOB and pHOS. It is used as an approximation of the proportionate influence of the natural environment on the average phenotypic values of wild and hatchery populations.

$$PNI = \frac{pNOB}{pNOB + pHOS}$$

PNI reflects population fitness and is used in management of integrated hatchery programs to estimate the genetic risk of the hatchery program to the wild populations it interacts with. An entirely wild population would have a PNI of 1; a population composed entirely of hatchery fish would have a PNI of 0.

Discussion

The model of Ford (2002) is used in a heuristic sense to show the result of reducing pHOS (to reduce the genetic flow of hatchery fish into the wild fish population) and increasing pNOB ()to increase the genetic flow of wild fish into the hatchery population. The preliminary manuscript included WDFW's scenario modelling inferring that there is a higher fitness benefit provided by decreasing the flow of hatchery fish into the wild population than by increasing the proportion of wild broodstock in the hatchery. Few hatchery programs have a high PNI, although it was noted that some hatchery programs in Idaho and Washington using primarily or entirely natural-origin broodstock have a high PNI. Currently, managers are better able to control the incorporation of the wild population into the hatchery population, (pNOB), by adding wild fish into the broodstock. Controlling the escapement of hatchery fish into the wild population (pHOS), is more difficult. While mechanisms are employed to prevent straying fish, those mechanisms are imperfect. In addition, there may be objections to controlling hatchery-origin fish on the spawning grounds in depressed populations. When the wild population is severely impacted within a watershed, managers within that watershed may face difficulties increasing the flow of genes from the wild population into the hatchery population simply due to a shortage of natural-origin fish.

The HSRG developed scientifically based management tools and principles with the goal of hatcheries operating with the highest degree of effectiveness. It assessed compatibility of production with recovery, and supported sustainable fisheries. HSRG principles are based on a simple heuristic genetic model for stabilizing selection using the concepts described in the preceding paragraphs. The model assumes one phenotypic fitness-related trait to represent the domesticating effect of interbreeding with hatchery-origin fish although in reality domestication is determined by multiple traits. The simplified approach towards traits is used in the model. HSRG provided standards around pHOS and PNI for hatchery programs depending on hatchery design, population designation and recovery phase. HSRG guidelines spread the use of pNOS, pNOB and PNI.

The use of pHOS, pNOB, and PNI results in a genetic approach to broodstock management and protection of the wild population; however, ecological factors such as habitat capacity and ocean dynamics also need to be considered. The relative contributions of each are not fully understood. For example, in areas where habitat is critically impacted, conservation programs may not be able to recover the wild population.

The portfolio effect refers to the increase of metapopulation stability when the diversity of the metapopulation increases. Both ecological and genetic factors contribute to the diversity of the metapopulation. Asynchrony of the runs, for example, contributes to portfolio effects, but the genetic contributions to asynchrony are not well understood in comparison to other contributions. The scientific gaps in understanding of the genetics of hatchery and wild populations results in the current dependency on heuristic models, although these gaps are being filled by ongoing studies.

When assessing the gene flow between the wild and natural populations, in the absence of parentage analysis within a watershed, it becomes necessary to rely on the number of stray hatchery fish entering spawning grounds to approximate gene flow. That is, census pHOS is used. In certain situations it becomes important to know the effective pHOS, or the rate at which the stray hatchery fish are directly contributing to the wild population, with the potential result of shifting the fitness of the wild population. The challenge of effective pHOS versus census pHOS changes depending on the scenario used. A paper by Waples and Baskett emphasizes the importance of when selection occurs. In extreme cases where all hatchery spawners die prior to spawning, then an effective pHOS is needed. The scenario where selection of juveniles occurs after spawning, with greater risk of gene flow from hatchery to wild populations, is more difficult to assess because it is harder to determine whether effective or census pHOS is appropriate. Additionally, without knowing the reproductive success of the hatchery fish, establishing an accurate effective pHOS can be challenging. Depending on the fitness of the fish in these scenarios, the importance of effective pHOS cannot be discounted, because in both scenarios presented selection is still occurring.

In the preliminary manuscript, WDFW cited a report by Withler et al. that explored issues of hatchery reform. Withler et al. showed effective pHOS and census pHOS, but chose to use effective pHOS. In contrast, WDFW used census pHOS in models analyzing different scenarios for their preliminary manuscript. Selection is built into the WDFW model by giving hatchery fish lower effectiveness at reproducing in the environment. While some raised the possibility of WDFW using effective pHOS rather than census pHOS, that would require additional modifications to the model. As discussed, effective pHOS is a way to account for selection and the WDFW already contains an adjustment for selection. Using effective pHOS within the model would present issues because the results of the analysis would then account for selection twice.

It was noted that HSRG recommendations use the Relative Reproductive Success (RRS) to adjust pHOS. One solution presented was to accept ideas of effective pHOS as long as they do not have a genetic basis. Modelling suggests that within certain ranges the difference between effective and census pHOS is minimal, although there is a point at which the differences become large enough to become critical.

Questions emerged around how to approach different types of hatcheries with respect to pHOS, pNOB, and PNI. The majority of releases are from programs designed primarily to provide salmon for harvest rather than for conservation. HSRG provides a classification system to assist in goal setting and can be compared with a different system used in British Columbia. Many of the questions within this discussion revolved around whether and how to segregate hatcheries in terms of their goals, and how best to apply the models underlying various systems to policy recommendations.

As noted above, HSRG principles rely on a heuristic genetic model. Models exist, however, that capture the dynamics of freshwater and ocean habitats. Additional research is needed to more precisely model trophic cascades to come up with inferences of causation on ecological interactions from the bottom (primary production) up to the top (invertebrates).

The preliminary manuscript notes that "large-scale manipulative experiments that evaluate major changes in hatchery management are critical opportunities to advance hatchery reform science." A challenge for conducting scientific research is that experiments must run for multiple generations, which creates significant time-lags. In reality, management decisions must be made in the interim using conceptual models to inform those decisions in the absence of empirical data.

The central challenge of designing large-scale experiments (e.g., a cessation of releases from a hatchery to observe the dynamics of the population) to address a broader strategy is that implementing such experiments requires a control and such paired populations are seldom available, and each hatchery program has local constituents who might be expected to protest the cessation. In the absence of a control, other research approaches are needed. Given that hatchery production is essentially a landscape-level experiment, there are opportunities to generate data. One approach to understanding the data from within Washington state could be to compare them with data from the Sunshine Coast of British Columbia. Additionally, six to eight production hatcheries recently began experiments to broaden the time of the release window and test experimental release strategies leveraging partnerships across different stakeholder groups. Large-scale comparisons of hatchery and wild salmon using whole genome sequencing approaches may also be a rapid way of providing information on the empirical distribution of genetic differences between hatchery and wild fish.

Summary of questions raised during the discussion

- Other than the conceptual model, what other options exist?
- Are current models sufficient to set exact values for hatchery goals?
- How do we get from qualitative to quantitative models?
- In the context of broodstock and escapement management, which approach has more value, large-scale models or small-scale experimental approaches?
- How do we learn more about populations in order to move beyond current selection models?

- Is there a need for large-scale manipulative experiments? How can such experiments be designed given the length of time of the experiment and real-world constraints?

- The presence of hatcheries within the environment could be viewed as a landscape-scale experiment. In the absence of a control, is it possible to manipulate various parameters and have sufficient monitoring that would generate informative data over time? How can experiments currently underway be integrated into this process?

- How do we deal with scenarios where the difference between census pHOS and effective pHOS is critical? In other words, what is needed when there are significant numbers of stray hatchery fish on spawning grounds, and at the same time a relatively low proportion is spawning effectively?

- How do we approach different types of hatcheries when considering pNOB, pHOS, and PNI?

- To get an ESA permit to take wild fish into a hatchery, a net benefit to the wild population must demonstrated. For watershed basins with threatened or endangered wild populations should a pNOB greater than 0 be considered?

- Should pNOB be manipulated for non-conservation hatcheries?

- How can hatchery programs that have the goal of being integrated be eased to higher fitness when the fitness of the hatchery fish is low?

- Are there opportunities to simplify the current complexity of the HSRG broodstock and escapement principles? Does the complexity of the current HSRG broodstock and escapement principles provide benefit? Could the approach being used in British Columbia (define populations according to the criteria they meet, rather than define populations and assign criteria to them) provide value within Washington state?

- How do we set thresholds for hatcheries within the current heuristic model? Should habitat and ecosystem services be added to the current model to set harvest thresholds? What parameters are needed? Will a more complicated version of the heuristic model increase uncertainty?

- A synthesis of information across segmentations of hatcheries is needed. What is the alignment of different hatchery goals with their management practices and outcomes? Are the hatchery categories and phases used within HSRG grouping the actual management practices of pNOB, pHOS, and PNI or do the management practices cross the boundaries of the categories and phases? Could the approach being used in British Columbia provide value within Washington state?

- The importance of maintaining a certain number of fish within a habitat was raised. This issue is of critical importance to the southern resident orca population. Can we evaluate hatchery reform without considering the ecosystem services of fish? How do ecosystem services impact how we define conservation?

- Since comanagers in different regions have potentially different requirements from fish populations and hatchery programs, is there a need for different hatchery management in different regions?
- What scenarios are best served by segregated hatcheries vs. integrated hatcheries, and are incidental collateral impacts to wild populations desirable or not? When is it desirable to maximize versus minimize the divergence of the wild and salmon hatchery populations?
- What management actions are appropriate and needed when a critically important and threatened wild population coincides with harvest programs producing large numbers of hatchery fish within the same watershed basin?
- When a wild population is at a low level, where do wild fish provide the most utility? Given legal and environmental constraints, do wild fish provide more utility within the hatchery or by remaining in the wild? How do different scenarios within watershed basins change the utility of wild fish?
- What should be the goals of each hatchery program? Is the same conceptual model appropriate for all?
- How can realistic goals be set for different hatchery programs, such as production or conservation, consideration of location, the watershed basin, and the status of natural population where the goal is being set?
- When conservation goals are not being met by a specific hatchery program, is the goal unrealistic and in need of adjustment or is there a need to find new strategies for the hatchery to meet the original goal?
- When there are conflicting management goals, how are scenarios determined?
- Do the same paradigms apply in situations where the goal is to help the natural population, or where integrated hatchery programs become of increasing importance? Are the same paradigms applicable where the program provides other societal benefits?
- How should scientific discussions of broodstock and escapement management be nested within implementation or prior models such as the HSRG All-H Analyzer model (hatchery and natural production with habitat, hydro, and harvest goal)?
- How should issues at the boundaries of the scientific and the policy reviews be approached?

Suggestions for additions to the manuscript

- Expand the modelling in Figures 2 and 3 of to consider high PNI situations and not only low PNI situations. While the fourth panel of Figure 3 provides an example of 0.67, where the pNOB is 0.8, some tribal hatchery programs have pNOB of 1.0.
- Consider including ecosystem services of fish within the environment as part of the definition of conservation.
- Generate a table that summarizes the different risks and issues side-by-side with the scientific weight of evidence, and an assessment of the scientific weight of evidence.

Ecological Risks and Hatchery Management Strategies

Dr. Thomas Quinn initiated the discussion by providing background and posing questions about environmental risk and hatchery management strategies. For discussion purposes, the issues noted were sources of risk, the mechanism of risk, the response variables researchers can observe, and hatchery management practices that can influence risk (Appendix E).

The group discussed the risks of integrated hatchery programs and segregated programs. With integrated program, hatcheries managers aim to increase the fitness of hatchery fish to mimic the fitness of the wild population. Managers can increase the proportion of natural origin broodstock (pNOB) and adjust the manner in which the fish are raised so that it more closely parallels that of wild fish. In a segregated program, hatchery managers aim to decrease the fitness of the hatchery fish so that the fitness of the hatchery population is too low to pose significant risk to the wild population. In both instances a failure to accomplish the appropriate fitness level of the hatchery population may increase the risk to the wild population. The logistics of whether or not an integrated or segregated hatchery can accomplish its goals and the probability of failure are critical to assess risk to wild populations.

The preliminary manuscript includes a section on the risk of disease in the context of hatchery management and wild populations. Climate change has an impact on disease probability by increasing water temperature which can make the pathogens more virulent or the fish more susceptible in some cases. This interaction between climate change and pathogens will be an issue of increasing importance in the future but is already evident. In addition to the effects on the pathogens and fish resistance, warmer water is often associated with lower water levels. When water levels become low, thermal blocks within rivers can increase the density of wild fish. Disease is more readily transmitted in such situations and is worsened by an increase in temperature. In addition, fish populations are more vulnerable to disease when stressed, and increasing the density of fish within a hatchery increases the stress. In addition to these effects, chiefly pertinent to adult salmon, trailers where juveniles are held and marked at hatcheries can also increase the risk of disease transmission within a hatchery due to both increased stress and density of fish that occurs during the process.

Research on hatchery management strategies and their influence on predation is mixed, and so as a whole rather inconclusive. For example, it is unclear whether high concentrations of fish (e.g., released from a hatchery) decrease the likelihood that any single fish will be consumed by predators and thus buffer the wild fish against predation, or whether they concentrate predators and increase the per capita risk. The salmon smolts (e.g., coho salmon) released from a hatchery can be expected to prey on other, smaller salmonids such as pink and chum salmon fry, or wild conspecifics. There also is evidence of harbor seal predation on the salmonid population, although it is unclear how much impact they have relative to other predators. Predation is harder to measure within the Puget Sound than along the Columbia River, where marine mammals are commonly seen and documented preying on adult salmon.

Release strategy (i.e., the timing of release, volitional or forced, etc.) can affect the survival of the hatchery produced fish, and might also affect interactions with the wild population, and predation. At some hatcheries, the fish are forced to leave but other hatcheries use volitional release strategies, where fish are typically reared in acclimation ponds and emigrate when ready. The majority of hatcheries use on-site release rather than off-site but this varies, and release site can strongly affect the locations where the salmon return to spawn as adults.

Hatchery production releases have become increasingly synchronized (i.e., narrower window in time within years, and less variation among years) relative to the wild fish population. While survival rates of pulse releases are higher, and pulse releases are thought to reduce interactions with wild salmon, there is a lack of research on how this strategy impacts wild and hatchery fish interactions. Additionally, pulse releases decrease the variation of the life history of the hatchery fish and as a result decrease the population diversity. As a result, mean survival of hatchery fish increases, but the strategy may also create an increase in variance in survival rates. In other words, a narrow range of release may result in more “boom” and “bust” years. Also, there is uncertainty about the impact of pulse releases on the food web and on the wild population.

A gap exists in the scientific understanding of the relative contributions of different factors influencing fish survival. Since hatcheries produce juvenile rather than adult fish, and production does not guarantee return, hatcheries have limited capacity to increase fish production as measured by survival and return rates. Currently, hatchery managers may make adjustments to a program and may not achieve the ecosystem service or societal goals that were the basis for the change in the program strategy. In addition, at certain life stages there are environmental limitations on survival due to carrying capacity, disease and predation. There are a variety of reasons to have surplus fish related to harvest opportunities for fisheries since caps may be set on harvest in order to protect wild fish. Currently, surplus fish provide a food source for certain human and animal populations within Washington (see discussion in Appendix J, Comment 2). While there is an overabundance of fall chinook, the overall portfolio and diversity has decreased. Governance imposes constraints on what can be done related to pHOS and surplus fish.

When assessing population-scale abundance, productivity, and survival to hatchery metrics such as juvenile fish released or pHOS, it is difficult to disentangle marine and hatchery effects. Generating more precise estimates of release and return rates would provide value; however, analyses of these numbers rely on contrast. When assessing these metrics it must be acknowledged that many biological processes are being captured by a single metric.

Data on the release and return rates for hatchery fish populations and return rates for wild fish populations vary across states. Data are derived from different sources: in part from checking juvenile traps and in part by assessing the rate of hatchery markings on carcasses. The life histories of the fish also influence the effectiveness of the research methods used. Eastern Washington is currently employing more advanced technology, such as pit tags, and have generated good data over the last 5-10 years. Another approach, parental-based tagging where managers genotype the broodstock, has been used in the upper Columbia River Basin, but is not widely employed in Washington state.

Determining program size was noted as a critical element when managing risk from ecological factors, genetics, or broodstock management, but it is difficult to determine if a program is "oversized" or "undersized." There are risks to programs being too small to achieve ecosystem services or societal goals. If a program is too large, there may be negative effects to the wild fish. The risks can be genetic or ecological, with ecological factors being a critical and underdeveloped piece of hatchery management strategies.

Management strategies have focused on mitigating genetic risks and have been less focused on ecological risks. A common hatchery practice is to raise hatchery fish until they are at the smolt stage, based on the assumption that that strategy minimizes the smolts' interactions with the wild population. However, there is not sufficient evidence to fully understand what happens downstream after release, especially in the near-shore environment. There is also a potential for a large-magnitude impact on survival from ecological factors, and yet less is known about how ecological factors contribute. Environmental conditions may also influence the degree that hatchery and wild fish compete for resources or predate one another. In addition, environmental problems and climate change are not separable from hatchery reform.

Fish occupy ecosystems that have carrying capacities, meaning that each habitat can support a certain number of fish. Carrying capacities vary across whether the habitat being considered is a river, a stream, an estuary, a lake or an ocean. Furthermore, there is evidence that carrying capacity can change over time. There is a need to better understand the carrying capacity of the different environments, including the mechanisms of nutrient flow from the bottom up, in order to determine the appropriate scale for hatchery releases. Two questions that should be considered in discussing carrying capacity: 1) what is the capacity of the environment to support fish? and 2) how do hatchery and wild salmon interact, given current practices?

While there is some understanding of the carrying capacity for small streams and freshwater for coho salmon, there is insufficient evidence for what occurs in estuaries and marine environments within Washington state. A comparison of Washington state and Alaska during the 1970s implies a significant role for marine factors to affect total returns of salmon. Research on density dependent effects and natural production of food in marine environments may be useful to examine. Large fish populations in the ocean originating from Asian hatcheries and to some extent from Alaska hatcheries likely impact carrying capacity within the ocean, though competition with Washington's coho and Chinook salmon is likely very small. NOAA Fisheries is conducting research on the carrying capacity of estuaries within the Puget Sound. Consistent and extensive monitoring of juvenile salmon in estuaries, the Puget Sound, and in the marine environment is needed.

Research conducted on the Great Lakes and Chesapeake Bay begins at nutrient cycles and the growth of planktonic stages through to vertebrate harvesting. Research on nutrient cycles and carrying capacity seems to be largely missing within Washington state. Nutrient impacts likely influence hatchery return rates. Better understanding of the trophic system within Puget Sound is needed in order to, in turn, better understand the carrying capacity for fish and other animals. Many studies on carrying capacity focus only on a single species rather than taking a holistic approach. While there is a study that took a holistic approach within one river, including all the food-web inputs, overall, freshwater research in this area has been limited.

The group discussed a need for an ecosystems indicator program. Some zooplankton monitoring in Puget Sound began about 5 years ago. The National Marine Fisheries Service is interested in research that would provide a better understanding of the consumers that interact within the ecosystem as well as competition. Consistent monitoring on a yearly basis of plankton, fish, and water conditions in the ocean, the basins, Puget Sound and Strait of Juan de Fuca is also needed. If data were collected over time, it may become possible to identify the indicators for survival for both hatchery and wild populations.

Scientific research conducted to assess the impact of hatchery fish populations on wild fish populations is a mix of lab experiments and field studies. Lab research has greater ability to set controls than field studies. The different approaches to scientific research and scale of experiments present challenges when integrating information in order to assess risk. The uncertainty of existing research when the scale reaches the level of a basin or region leads to hesitation to make large-scale changes to management practices.

Understanding ecological considerations to inform hatchery management calls for large-scale experiments across Puget Sound that would require a long period of time to conduct. In the absence of data needed to fully inform management decisions, the aim should be to mitigate impacts while continually attempting to learn more. Multiple approaches to large-scale experiments were discussed, each with strengths and weaknesses.

Currently, the majority of landscape-level experiments are opportunistic. Without a formal control the opportunistic experiments do not always provide data sets with significant differences from one another. The lack of contrast between data sets makes it difficult to reach conclusions that could inform management strategies and policy recommendations. While not necessarily the subject of peer-reviewed published studies, there are additional examples of experiments may provide insight, while not excluding other experimental approaches.

More aggressive experiments, such as simultaneous research on paired rivers, might be considered, and could generate higher-contrast results in a shorter time period. Shutting down fish production for a river for all species would result in high contrast data to inform hatchery management decisions. Given the length of time needed for these types of experiments, they are unlikely to occur due to societal and cultural constraints. Moreover, decisions about hatchery production cannot be separated from treaty rights and other legal considerations. Specifically, hatchery production at WDFW facilities is regulated and required by the Puget Sound Salmon Management Plan, which is supervised by the U.S. Department of Justice under the U.S. v. Washington litigation. The state cannot change production without consensus from tribal comanagers. In addition, there are requirements under ESA to contribute to killer whale forage.

It was mentioned that perhaps some stakeholders may be willing to serve as the experimental control. That is, certain hatcheries would increase production while other hatcheries would decrease production in a way that provides the contrast needed to understand the risks and mechanisms that could inform management decisions. It was also noted that designing experiments with dichotomous on-or-off outcomes may not present useful information for managers. Alternatively, there may be value in designing experiments that allow for data collection on outcomes when production is increased or decreased by set percentages. In any such a scenario, consensus with treaty holders would be required.

Another proposed approach was to conduct research in exclusionary zones where the habitat is good and there is no hatchery production, such as areas set up as gene banks for steelhead. The challenge of this approach is that there is generally a hatchery nearby for a different species. Another possibility is to monitor habitats within the existing exclusionary zones, and identify an exclusionary zone with a poor habitat as a control.

Large-scale supplementation research occurred in Idaho. That work suggests that if population bottlenecks are not addressed, increasing the number of hatchery fish is unlikely to result in significantly different outcomes. In these scenarios, replacing wild fish with hatchery fish is considered to be risky unless the underlying bottleneck issues are addressed. In addition, different species seem to have different bottlenecks. Additionally, there are some rivers where the hatchery production results in hatchery fish that show good returns and wild fish that show poor returns (i.e., pHOS is significantly higher than pNOB).

Risks related to hatchery management are not difficult to identify, However, assessing the likelihood that a risk will occur, its probable magnitude or impact when it does occur, and its uncertainty remains challenging. Research is needed to determine how to organize the uncertainty of risk. Some decisions have less potential risk than others, but in the absence of data, it is hard to assess whether a situation is a high or a low risk. The probability of a harmful outcome from a given risk could prioritize scientific research. Research on the mechanisms that produce risk and studying their probability would help identify the risk in order to stop or mitigate it.

Summary of questions raised during the discussion

- How can the goals of a given hatchery be achieved with minimal negative ecological or genetic impacts? How can the goal of maximizing hatchery fish survival be balanced with potential ecological risk?
- With respect to integrated and segregated hatcheries, what goals can be accomplished logistically? What are the consequences of failure?
- How do the various risks scale with the size of hatchery programs?
- Does increasing hatchery production hinder wild production relative to other stresses on the wild fish population?
- What are the risks of keeping hatchery releases narrow as compared to the risks of broadening the window of release so that fish leave the hatchery at different times? How about the benefits?
- How do hatchery and wild populations interact given current practices and the carrying capacity of the environment?
- How can carrying capacity be assessed relative to hatchery releases? Where in the life cycle does assessment need to take place? How can WDFW make carrying capacity a programmatic component in decision making around program size and ecological risk?
- What is the capacity of the environment to support fish?
- What are the environmental drivers that prevent the recovery of a fish population?
- Given that the risks are known and are also known to have an effect from research conducted in other regions and with other species, in the absence of empirical data is the way to minimize impact is to assume the risk will occur?
- How can a methodology be defined for data gathering that decreases the uncertainty of risk?
- What's the uncertainty around the impact and magnitude of risk?

- What are the top three most important science question as related to the risk of hatcheries? What type of study(ies) would provide an answer(s) to these questions?

- To what extent do the mechanisms underlying different risks need to be understood in to inform policy decisions?

- Are there scenarios in which the survival of wild salmon becomes so critical that the potential impacts of a more aggressive, larger-scale experiment could be justified? In these scenarios, would it be possible to compensate regions where production would be shut down?

Suggestions for additions to the manuscript

- Consider noting that the higher-release years in prior decades included large numbers of fry within the Figure 4 of the preliminary manuscript, and that the release of large numbers of fry was an ineffective management practice that was changed.

- Consider that the science update report may also serve as an educational tool for the public to better understand the issues surrounding hatchery fish production. For example, it may be useful to explain known factors that impact fish return, such as carrying capacity.

Conservation Benefits

Prior to the discussion Representative Debra Lekanoff shared her gratitude for the work being carried out by different stakeholders on hatchery reform and noted the importance of salmon within tribal cultures. For tribal cultures who identify as the salmon people, the health and existence of the salmon populations is deeply tied to identity. Prior to current practices around hatchery management, certain tribes had their own techniques to support the salmon populations through challenging environmental conditions. When considering scientific evidence around conservation benefits, remembering the cultural importance of salmon provides a critical portion of the broader picture of societal benefits that science can serve.

Dr. Robin Waples initiated the discussion of conservation benefits (Appendix F). A major question that emerged from the discussion was, “What should be considered as a benefit?” This question is critical when considering that there are broadly two types of hatcheries: conservation hatcheries with the goal of conserving or improving the status of wild fish populations, and general enhancement hatcheries with broader goals with societal benefits.

Benefits of hatcheries could include benefits to fish populations, ecosystem services, jobs, fisheries, education, or other societal goals. Hatchery programs serve tribal rights and fulfill legal requirements. These are broad benefits and services that are often nonmonetary, and thus are not always easily quantified or valued in the same currency as other risks and costs.

WDFW manages over 30 conservation hatchery programs with the goal of providing benefits to wild fish populations. Understanding the empirical evidence about what is effective and ineffective in achieving conservation benefits is critical. Three major benefits of hatchery programs were discussed with respect to wild fish populations. Empirical evidence shows that with proper management practices, conservation hatchery strategies can reduce short-term extinction risk and reseed vacant habitat. As discussed earlier, if issues that caused habitat decline have not been mitigated or if the wild fish population has been compromised genetically, the goals of the conservation hatchery may not be met. Many risks to fish are man-made, such as development to meet a growing human population, hydroelectric dams, and agriculture. Small stable populations in areas of degraded habitat may be achieved. However, public perceptions of recovery are often tied to use and societal benefit of recovered fish, and persistent but small populations may lead to public perceptions of failure. Furthermore, from a scientific standpoint, since a limited number of conservation hatchery programs have terminated, it is complicated to assess whether or not hatchery programs with conservation goals are creating self-sustaining populations that no longer require the presence of the hatchery program.

For use in the workshop, one conceptual approach to understanding conservation related costs and benefits was represented by plotting risk and benefit on a graph (see Appendix F, slide #4-6). The intersection of a curve representing hatchery benefits to the wild population and of a curve representing hatchery risks to the wild population would represent a tipping point that would help to determine whether or not to employ a hatchery program. It was proposed the tipping point could be viewed as a point within the phases of recovery under HSRG -- the preservation, re-colonization, local adaptation, and the conservation and harvest phases. Genetic requirements are not in place until the population reaches the local adaptation phase. These early phase programs often have high pHOS numbers. There was discussion about whether balancing the benefit to the demographic population risk to the genetic fitness of the population could be accomplished using cost-benefit analysis to identify tipping points. It was also suggested that when defining stages of recovery, more attention could be given to the relationship between the habitat and the population status.

Using this paradigm, when wild populations become low and unstable, the benefits of a hatchery outweigh the risk to wild population. The higher the risk of extinction, the higher the chance a hatchery could prevent an irreversible loss of a component of the species. When a population is doing well, a hatchery may have a higher chance of negative impacts with lower potential benefits to the wild population. The shapes of benefit and risk to the curves of the hatchery population to the wild population would change depending on the history of the wild population, the region, and the type of program that could be created to assist a wild population. It was noted that the best period to begin a conservation hatchery is when there are sufficient wild animals, before a wild population becomes too small or less productive, and thus more susceptible to a number of risks. On the other hand, starting a conservation hatchery program too early, when the natural population is still robust, creates risk with little prospect of a net benefit. Finding the right balance with respect to hatchery intervention is a very challenging problem.

Meta-analysis is an approach that could provide a mechanism to deal with uncertainty in the absence of information when deciding whether or not a given program is more likely to help or harm the natural population. Meta-analysis was employed when devising recovery strategies for the listed evolutionarily significant unit of Puget Sound Chinook (which is a listed population under the Endangered Species Act). Recovery planning teams created a variety of options for the potential contributions from populations from different tributaries and river systems and determined the levels of viability that were needed within the different systems to create overall population robustness. This analysis developed a sense of what was needed to be achieved overall for the Puget Sound Chinook to be de-listed, and how the different ecosystems could be leveraged to create an overarching long-term recovery plan with some variation allowed in certain areas. This example provides the potential power of analyzing hatchery programs and ecosystems within a broader context.

When the broader benefits of fish hatcheries are considered, economics can be employed in certain situations, while recognizing the limitations of economic approaches. Economic research can provide some insights about weighting non-use values and benefits of wild fish, including and going beyond conservation. However, economics cannot easily provide solutions for certain benefits, such as the deep cultural value of wild fish to tribal populations.

There is a research gap on benefit-cost analysis of fish production within Washington state. For example, the lack of economic research in Washington state on how the public views wild versus hatchery fish makes calculating the value of wild fish challenging. Within Alaska, the Salmon Project conducted a large-scale market survey of the value of wild fish and hatchery fish. In Alaska, while the public places an extremely high value on salmon, the public did not seem to value hatchery salmon differently from wild salmon. If public support for wild salmon is critical for conservation, then there may be a need for public education on the value of wild fish in regions where they are not valued differently from hatchery fish.

Many harvest programs that support fisheries are paid for by the government to meet obligations and thus the public funds the fisheries through tax-payer dollars. There is little information about the cost per fish produced within hatchery programs, especially when the broader indirect costs of supporting hatchery managers are considered. Due to the social and cultural goals of hatchery programs, benefit-costs analysis is rare and profitability is generally not a standard used when assessing a general enhancement hatchery program. A complicating factor is that certain communities and local economies are more dependent than others on fisheries and recreational fishing of salmon. It was noted that in certain cases, economic analyses of benefits and costs of hatchery programs may reveal that they are not a cost-effective strategy for supporting local economies. However, this type of analysis does not capture nonmonetary cultural value of critical importance to comanagers.

Beyond the cultural importance to tribes of wild salmon populations, it was noted that they are also a cultural and iconic species within Washington state. Within the Puget Sound, hatcheries provide salmon for 460,000 angler trips per year, which is valued at roughly $100 million annually to Washington state. (Washington state has an annual GDP of approximately $0.5 trillion, for comparison.) Different analyses produce different ranges of values of the benefit-cost of salmon per year of Puget Sound salmon. If such values are treated as earnings of a capital amount, then different values of salmon benefits to the population are produced.

Decisions about whether or not to close hatcheries are legally regulated by the Puget Sound Management Plan; those decisions provide insight into the complexity of assessing hatchery benefits. Hatcheries have closed over the past three decades largely due to budget constraints. Regulations for net-pens, and responding to the Endangered Species Act have also played a role in decisions to close hatcheries. Conservation hatcheries are set aside from the decision-making process and are not considered for closure.

Making decisions about which hatcheries to close includes factors beyond benefit-cost analyses based on monetary values. Societal and cultural benefits are also important. As budgets have been cut throughout watersheds, tribes are contributing to pay for and assisting hatchery management to maintain hatchery production. Tribes also operate their own facilities. Furthermore, different hatcheries are functionally dependent on one another for fish production. When considering the factors used to decide whether or not to close a hatchery, one also sees that the same ones are used when considering how to manage hatcheries.

Benefit-cost analyses can inform whether or not there is economic value in continuing to do what is being done; that is, if the benefit of a hatchery exceeds the cost of a hatchery. However, economics is not able to provide the scientific or causal relationships of a system. Economists rely on scientists for the information required to do their work, as well as the uncertainty of the data. If there is uncertainty in the answer to that question, then benefit-cost analysis is a useful tool. It may be, however, that for an issue such as fish hatchery co-management for which many other considerations come into play, benefit-cost analysis is not the appropriate tool.

However, economics may be able to assist hatchery managers and decision makers with other tools. For example, if a hatchery's goal is to produce a certain number of healthy juvenile fish and a certain yield of returning fish, then cost-effectiveness analyses can be used to maximize efficiency. In addition, given the current goals of various hatchery programs, economics may provide tools to provide the cheapest mechanisms to achieve those goals. An example would be a comparison of the cost of running a hatchery to the cost of removing a dam, increasing the level of water upstream, or habitat restoration. Cost-effectiveness analyses might illuminate complementary strategies to support fish populations within Washington state.

Summary of questions raised during the discussion

- What are hatchery program goals? Can a program achieve multiple goals effectively? What are strategies for multiple goals to be optimized?
- Do the four stages of recovery for HSRG adequately capture nuanced conservation goals for a given hatchery program? What other strategies could be incorporated?
- Is it possible to separate societal goals from conservation goals?
- How likely is it that conservation benefits will be realized?
- Is there sufficient evidence to assess the net long-term benefits to wild fish populations of hatchery programs?
- How do we account for the fact that when assessing program benefits, we are not facing a blank slate, but must account for a long history of hatchery management?
- How can conservation benefits and scientific research be integrated into the broader picture?
- Do fishery management practices give certain segments of the public a more positive view of hatchery fish (i.e. these are the fish one can catch)?
- Can a program be effectively modified or terminated once it is started? If it cannot, how should that factor into the decision about whether to start a hatchery program in the first place?
- What should be considered as a benefit of hatchery programs?
- What is the non-use value in the land that was ceded to tribes via treaties?
- Under what conditions can particular risks legitimately be ignored?
- How do we determine the risk-benefit tipping point of hatchery programs?
- How do we make decisions when assessing hatchery benefits and risks, e.g., structured or *ad hoc*?
- When the benefits and risks of hatcheries are of a different nature how do we weigh the benefits and risks within management decisions?
- How can the status of a habitat be factored into the determination of benefits and risks of a hatchery?

- When is it appropriate or inappropriate to use economic tools when assessing the benefits of salmon to society? To their ecosystems?

- Are there ways to do benefit-cost analyses of hatchery programs through the current review process, recognizing that such analysis is not purely a scientific one and would need to find ways to incorporate many different perspectives? Should harvest programs undergo benefit-cost analysis? Where would cost-effectiveness analysis around hatchery management and other conservation efforts be useful?

- How do we accurately measure the cost to the public of hatchery programs and the economic benefits to Washington state economy?

- How do we integrate managers, co-managers and researchers are currently doing around benefit-cost analysis and decision making?

- When developing economic tools to evaluate the benefits of a hatchery program, how can environmental factors, such as the ocean or habitat degradation, be adequately factored in to whether or not a hatchery program is successful? How do we establish the baseline for success?

Suggestions for additions to the manuscript

- Include examples of success from the scientific literature of reduction of short-term extinction risk, reseeding of vacant habitat, and increased recovery speed of depressed populations.

- Review a study on assessing the public value of fish by Layton, Brown and Plummer (1999), which is used by the WA Department of Ecology.

Hatchery Management–Balancing Risks and Benefits

Ron Warren led the discussion on balancing the risks and benefits of hatchery management, which are at the boundary of science and policy. Points raised in other discussions re-emerged during the final discussion. Surveys of Washington residents' support of salmon conservation indicate that support remains high. The extinction of salmon is not considered to be an option. Risks to wild fish populations are beyond hatchery management.

Habitat degradation within Washington state presents a challenge to the health of fish populations. Sources of degradation include population growth, development of or near natural habitat, pavement over streams, hydroelectric dams, agriculture, and forestry practices. While hatchery programs with conservation goals can attempt to counter the impact of habitat degradation, long-term stability of fish populations may depend on resolving issues that exist within the ecosystem.

It is unclear whether the trade-offs of development are being adequately considered by the public and by decision-makers. The estimate of population growth in Washington state is that by 2040 the population will grow by 4.9 million people. Decision-makers cannot assume constant human populations when assessing risks and benefits of hatchery management practices. There is a need for adequate planning around water and infrastructure, and preparation for how population growth will impact critical habitats. It is challenging to separate hatchery reform from other factors impacting salmon and human ecosystems.

There is a technical gap within the existing scientific literature between various hatchery management practices and the broader issues of risk to fish populations. One suggestion was that it may be worth considering strategies for assessing the risks from hatchery management practices, whether they are genetic or ecological, and risks from other sources, such as human development. There may be opportunities to integrate research on different risks within the context of Washington state. For instance, degrading habitat is linked to a reduction in carrying capacity. The relative risk of a hatchery program will change depending on the location of the hatchery program and the risks present to fish populations within that region. Understanding the interaction of various risks is critical, and in some cases, the risks to wild populations may become additive. It was noted that one strategy could be to increase habitat artificially, and that options to mitigate are not limited to the current habitats. Some areas of the state have additional habitat protections, such as the Olympic Peninsula, and may serve as a backstop.

Scientific research cannot answer cultural or political questions of hatchery management. And scientific uncertainty exists within each of the variables that contribute to the benefits and risks of hatchery programs. However, scientific research can inform a dynamic management plan that is capable of adapting to change over time. Ongoing research can provide guidance over time as factors evolve, such as the impacts of climate change, increases in population, challenges of hydroelectric power, growth in agriculture growth and other emerging issues within the state. And research can help inform adaptive management structures. Due to the history of hatchery programs within the region, it is difficult to establish a baseline or a control when assessing risk to natural population. However, as research gaps are identified and filled, and where sufficient data exist, monitoring must be established and continued.

Summary of questions during the discussion

- How much risk to the natural population is acceptable when supporting goals of fisheries and hatchery programs? What harvest sacrifices are we willing to make to assist natural populations?
- Is the potential risk to the natural population of continuing the status quo sufficient to convince stakeholder participation in efforts to establish a control for large-scale scientific research?

- In cases where the risk of hatchery programs is not well quantified, what actions should be taken or not taken?
- What level of scientific evidence is required prior to making changes to hatchery management policy?
- Where is the burden of proof? Should an enhancement project be allowed to go forward unless adverse effects can be proven beyond a reasonable doubt? Should an enhancement project be allowed to go forward unless adverse effects can be proven beyond a reasonable doubt?
- Do hatchery managers have the skills to assess operations from an ecosystems perspective? How can these skills be developed?
- What would be the elements of a balanced approach when considering different factors such as hatcheries, harvest management and habitat restoration?
- How can the breadth of scientific review be appropriately tailored to account for factors that impact hatchery reform science, such as habitat management, and constructive engagement of stakeholders?
- How do decision makers adequately address the impact of population growth on habitat?
- What additional strategies can be employed to assess the scientific literature about potential hatchery management strategies in order to understand which strategies are effective and ineffective? How does one ascertain the degree to which risk can be quantified, mitigated, and minimized? How can the risk of different hatchery management practices, such as those surrounding broodstock management, rearing strategies or release strategies, be quantified?
- How can technical input be integrated within broader strategies of policy development?

APPENDIX A

Agenda for "The Science of Salmon Hatcheries" Workshop

The Science of Salmon Hatcheries

A Workshop Convened by the Washington State Academy of Sciences for the Washington Department of Fish and Wildlife

Thursday, May 23, 2019 | 8 AM – 5:30 PM
901 5th Avenue, 5th Floor Conference Room
Seattle, WA 98164

Purpose of the workshop: *To provide an opportunity for WSAS committee members to discuss with the WDFW project team its preliminary manuscript/synthesis report, with a focus on issues or topics that would benefit from or can be strengthened by further face-to-face scientific discussion.*

AM

8:00	Continental breakfast; coffee/tea service
8:15	Purpose for DFW's request to WSAS*, Ron Warren, WDFW*
8:30	Welcome, About WSAS, Purpose of the Workshop, *Larry Dalton, WSAS Committee Chair*
8:45	Broodstock and Escapement Management
	Discussion kickoff lead: Mike Ford
10:15	Break
10:30	Ecological Risks and Hatchery Management Strategies to Minimize Those Risks
	Discussion kickoff lead: Tom Quinn

PM

Noon	Questions from Observers to WSAS Committee
12:20	Lunch
1:15	Conservation Benefits
	Discussion kickoff lead: Robin Waples
2:45	Break
3:00	Hatchery Management – Balancing Risks and Benefits
	Discussion kickoff lead: Ron Warren
4:45	Questions from Observers to WSAS Committee
5:00	Wrap up; other issues
5:15	Closing Comments – WSAS and WDFW, *Larry Dalton and Ron Warren*
5:30	Adjourn

APPENDIX B

PowerPoint Presentation-Purpose of the Workshop

Washington Department of FISH and WILDLIFE

Hatchery and Fishery Reform Policy Review

WSAS Workshop

May 23, 2019
Seattle, Washington

2009 WDFW Adopted its Hatchery and Fishery Reform Policy (C-3619)

The policy defined hatchery reform as:

"the scientific and systematic redesign of hatchery programs to help recover wild salmon and steelhead and support sustainable fisheries"

The intent of the policy is:

"to improve hatchery effectiveness, ensure compatibility between hatchery production and salmon recovery plans and rebuilding programs, and support sustainable fisheries"

The policy also includes a General Policy Statement and then the 11 Policy Guidelines that guide the management of our hatcheries and fisheries.

June 2018 Fish and Wildlife Commission Decision to Review the Policy

"…review of all sections and aspects of the Policy…the review should include examining performance results since the policy was adopted, updating appropriate policy language and scientific elements, changing language tone about the positive value of hatchery programs, and providing alternatives for policy revisions including at least

- Adding a categorical designation for mitigation hatcheries
- Accommodations of Southern Resident Killer Whale prey initiatives, and
- Different levels of hatchery-wild interactions that take into account the evolving science on risks to the salmon genetic resources of the State.

2. "While the review is underway and until the Commission adopts any revisions or refinements to the Policy, the Policy shall remain in effect except that policy guidelines 1, 2, and 3 for salmon species other than steelhead."

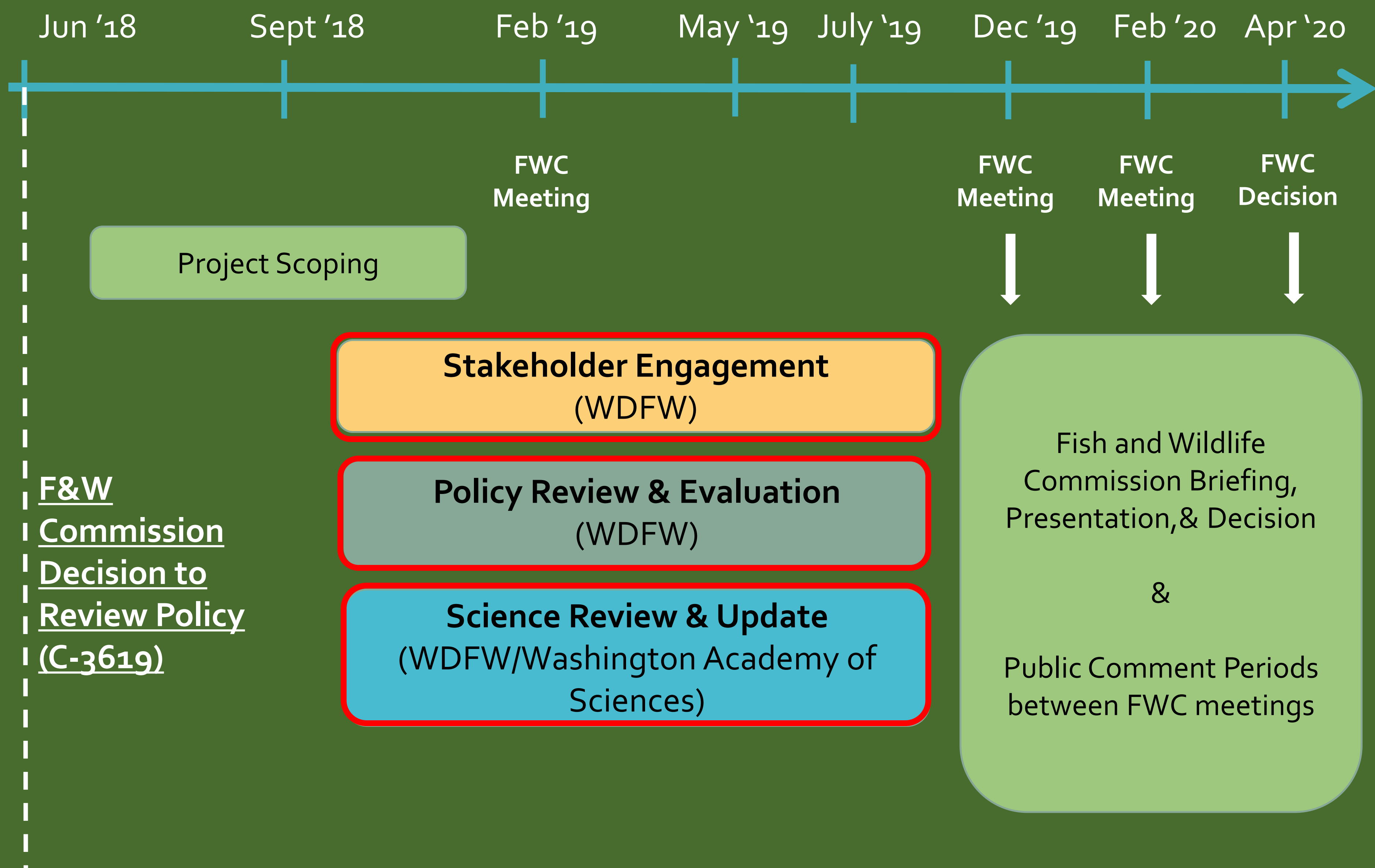
Policy Review Elements

- **Policy Review and Evaluation** – evaluating the implementation of the 11 Policy Guidelines
  - Led by WDFW
- **Science Review and Update** – a review of hatchery reform science in Washington State
  - Led by WDFW, guided by Washington State Academy of Sciences (WSAS)
- **Outreach and Public Engagement –** periodic informational meetings to **1.** inform stakeholders of the review process and status **2.** allow for comments and feedback.

Policy Review Elements Cont…

- **Executive Summary & Recommendations Report** – combining thoughts and opinions from policy and science reviews
  - Led by WDFW review team
- **Policy Revisions and Language Updates**
  - WDFW review team & FWC

Project Timeline



WSAS Involvement

- **Review of DFW's Science Paper Outline**
  - Completed 2/11/19
- **Science Workshop** – *in person scientific discussions around the challenges and information gaps in the preliminary draft.*
- **Peer Review of Final Draft**
  - **July – August 2019**

Questions?

APPENDIX C
Introductory Remarks by WSAS Committee Chair Dr. Larry Dalton

Introductory Remarks from Dr. Larry Dalton, Committee Chair

Let me add my welcome and express my thanks for your contribution of scientific expertise to this Workshop. As already noted by Ron Warren, the purpose of the request to WSAS and this Workshop is to contribute scientific information to the Hatchery and Fishery Reform Policy (C-3619) Review Process. Specifically, WDFW asked WSAS to assist with its update and review of the science that can inform hatchery reform. Our involvement is but one part of the WDFW review & report development process. There are a number of other important components, including opportunity for public input, which lie outside the purview of this Workshop and will not be addressed.

I want to acknowledge and thank the WDFW project team working on the hatchery reform science report for their diligent and thoughtful effort in developing the current preliminary manuscript. This work in progress is an excellent springboard for the topics to be addressed in this Workshop.

However, a consideration of this work in progress emphasizes that there are many topics that must be covered today and discussion on each topic will have to be limited. To committee members and supplemental reviewers, I ask your assistance with time management. Please keep your questions and comments concise and, of course, focused on science.

Washington State Academy of Science staff will prepare a summary of comments from this meeting, which will be sent to WDFW.

We welcome those of you who have traveled here today to observe our workshop discussion. Please note that our discussions will focus on the science of hatchery reform. We have built time into the agenda for your questions to be presented to our committee. So that we may make the most of our limited time, we ask that you write your questions on the cards provided and submit them to Donna Riordan no later than 11:30 AM for the question period before lunch, and 4 PM for afternoon question period. You are also invited to provide written input by Friday, May 31, which we will include as an addendum to our summary to WDFW.

Preparing manuscripts of this nature is a complex process, requiring many iterations. Given the preliminary nature of the manuscript and purpose of our committee to review it, it was not appropriate to make it available to others, other than invited reviewers, prior to the Workshop. However, I think you will find that our Discussion Leaders will define context and critical considerations with respect to topics covered. Given the extensive expertise in this room, I don't foresee a problem in plunging right into the topics that must be covered.

Bringing science to management practices is not a trivial process. The State-of-the-Art of Science is constantly evolving. Even our understanding of something as basic as the periodic table has changed over the course of my lifetime. Alkali metals were assumed to be able only to give up electrons and not accept electrons. Nobel gas elements were assumed to be completely unreactive. We now know that neither of these tenets is absolutely correct. Thus, as scientists we not only consider state-of-the-art knowledge but we acknowledge its limitations and suggest experiments to improve the state-of-the-art and its application.

Before we launch into our technical program, I would like to briefly introduce the Washington State Academy of Sciences to you. It was established in April 2005 by Senate Bill 5381 as requested by then Governor Gregoire. The purpose was to improve public policies and programs through the integration of informed, independent scientific analysis and communication with policy makers.

Our mission is "Science in Service of Washington State."

A perfect example of service to the State being carried out this month by Academy members includes this Committee's review of the science of hatchery reform.

APPENDIX D

PowerPoint Presentation- Broodstock and Escapement Management

Broodstock management discussion questions

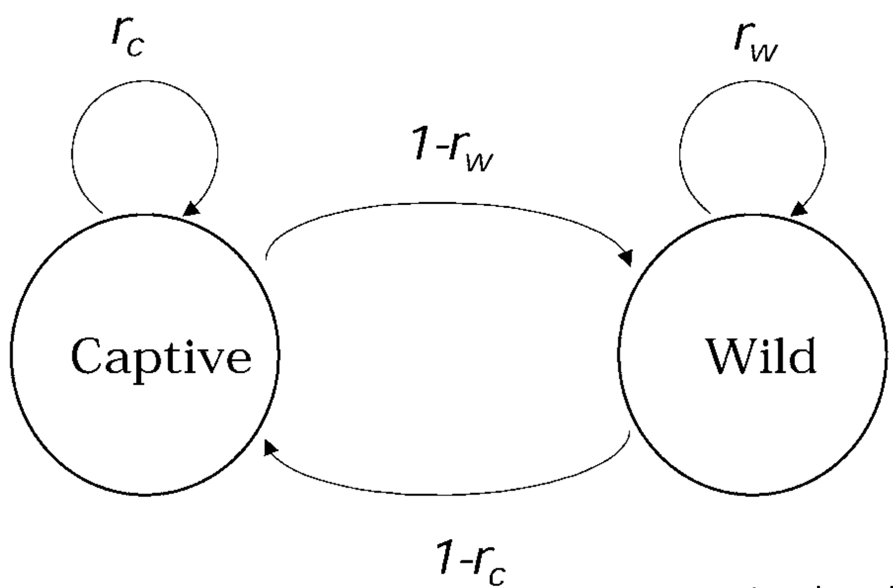
- Are conceptual model of genetic change in hatchery wild systems useful?
- What are good options for translating the results of conceptual models to real-world advice or guidelines?
- Varying assumptions about the strength of selection, heritability etc can have large effects on the overall projected fitness loss over 20 generations (Figure 3 in the report). What sort of monitoring or data would be required to understand where a population is on these lines?
- Are we in a “How to get there from here” scenario? Many populations may already suffer from widespread fitness loss in part from hatchery effects. How can it be reversed? Should guidelines and strategies be different depending on the population’s history (e.g. the HSRG’s stages of recovery approach)?

How gene flow influences domestication

- “Integrated programs” use gene flow (pHOS, pNOB) to attempt to limit domestication
- Can gene flow from W -> H limit domestication?

HSRG Model

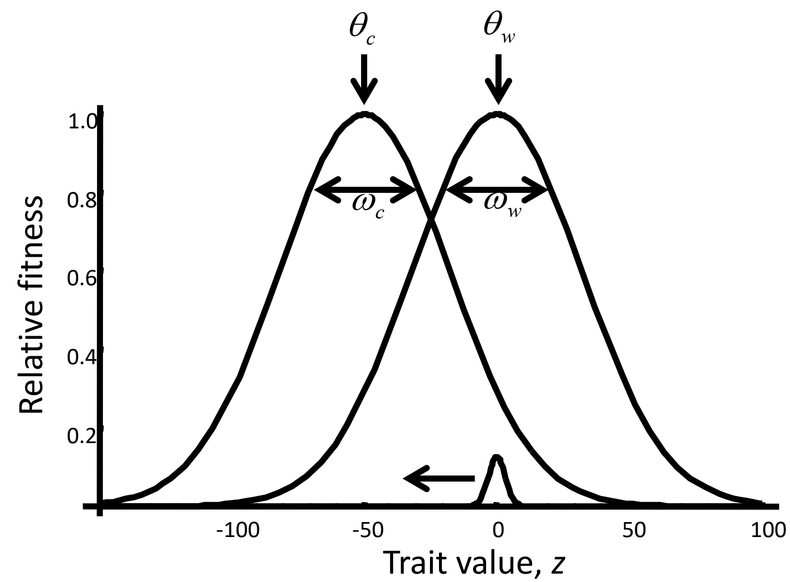
- Based on Ford (2002):



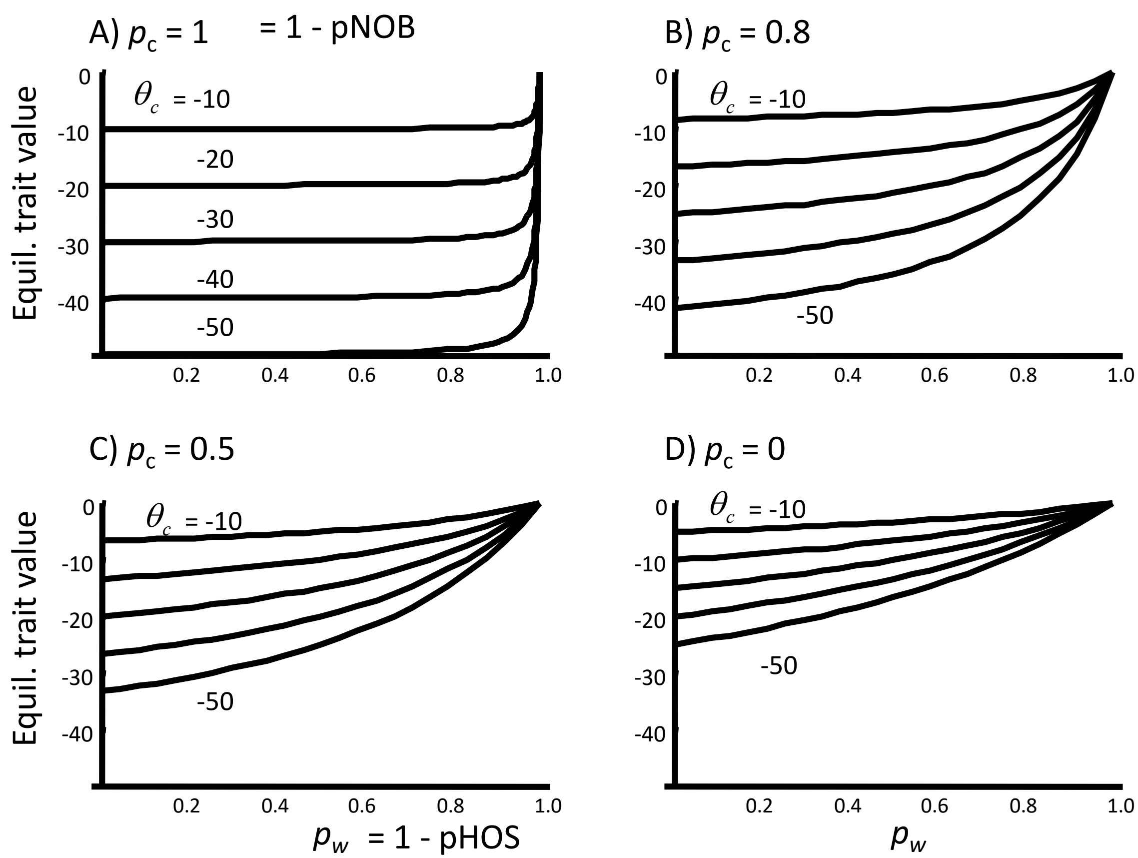
Lynch and O'Hely 2001

Model assumptions

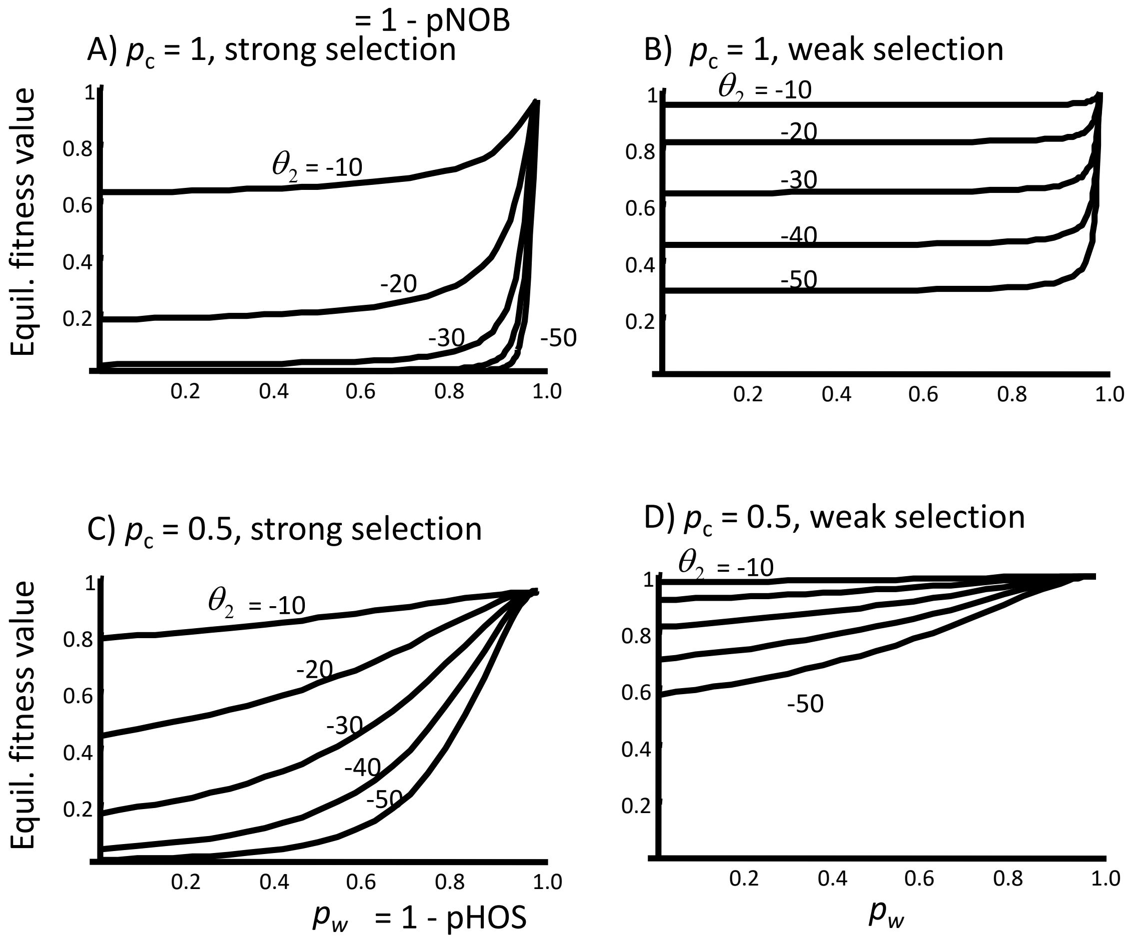
- Two environments
- One trait
- Many loci of small effect
- Constant genetic variance and heritability
- Gaussian selection
- Selection prior to reproduction
- Simple demographic model



Basic results – trait evolution



Basic results – fitness



Main conclusions

- Gene flow matters
  - Higher pNOB = less domestication
  - Higher pHOS = more change in wild population
  - Combination of low pNOB / high pHOS can have large fitness consequences
- Wild population most in need of supplementation also most vulnerable to negative effects

HSRG Extensions (PNI)

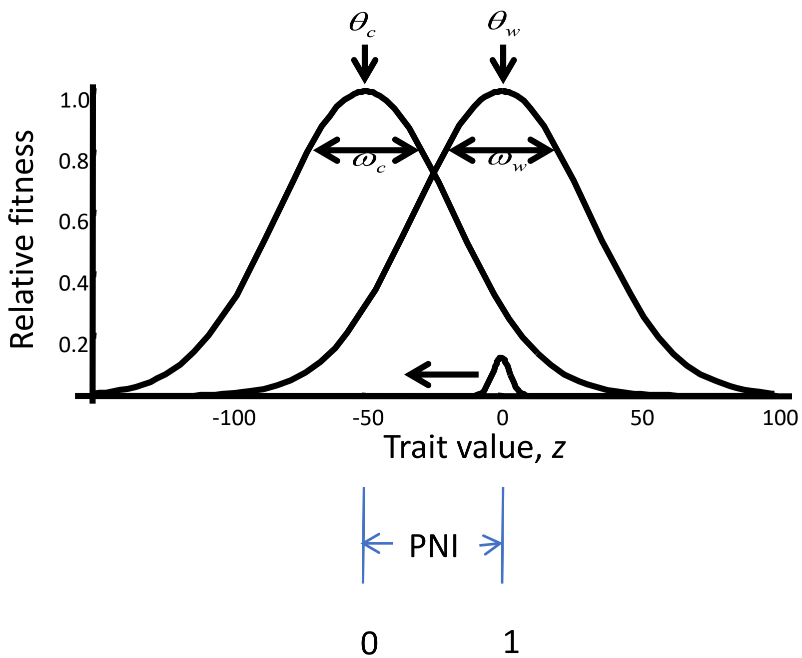
- Craig Busack and the HSRG further explored the model, and noted some additional interesting points
- Simplifying assumptions about values for selection, heritability..

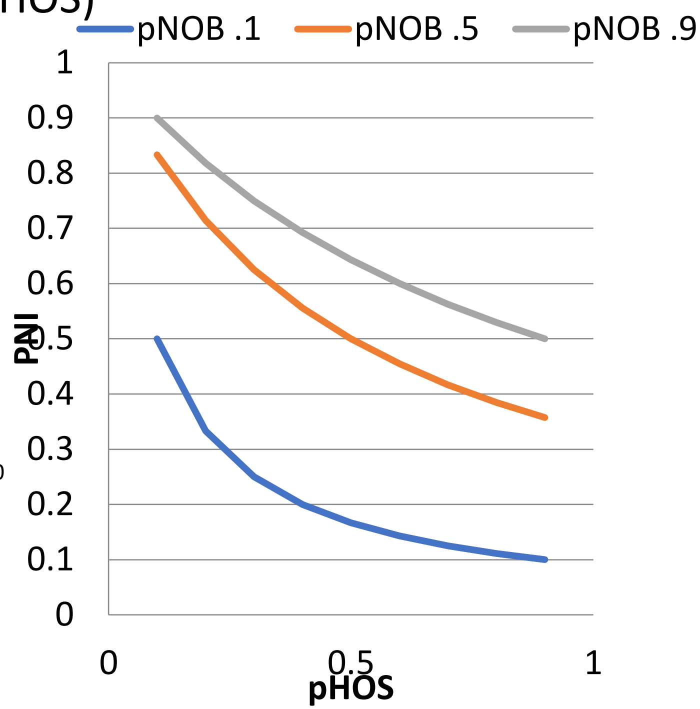
  then

- Equilibrium trait value depends on just:
  - pNOB, pHOS, heritability and selection strength
- AND can be interpreted as Proportionate Natural Influence = relative degree of adaptation to wild

PNI (or it's all about gene flow)

PNI = trait value relative to wild optima
= pNOB / (pNOB + pHOS)





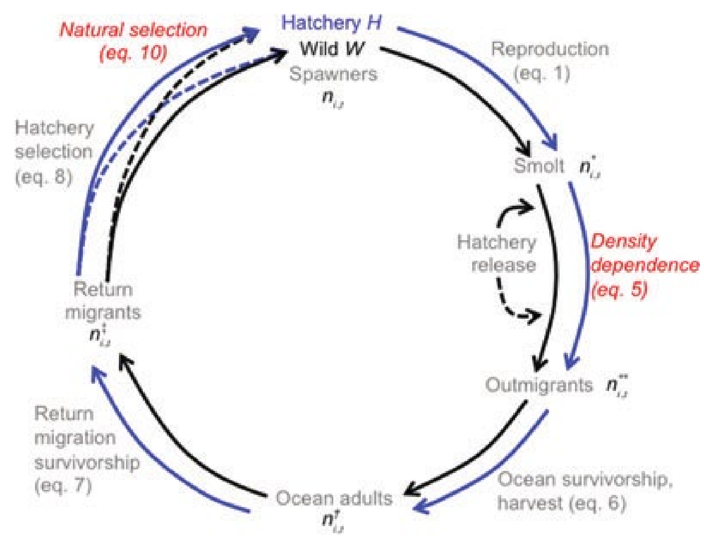
Caveats on PNI

- Only relates to trait optima
- Fitness effects could be large or small depending on selection strength, differences between wild and hatchery optima
- Basic equation is an approximation only
- Based on long-term equilibrium conditions

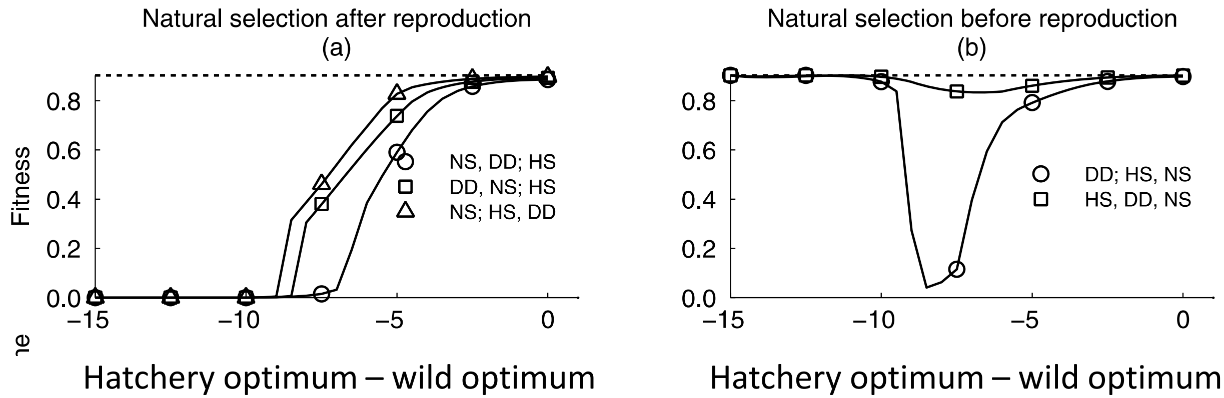
More recent models

- Baskett and Waples 2012, Baskett et al. 2013

- Further explored segregated versus integrated approach
- More sophisticated genetic model (few assumptions)
- Explored more complicated life cycle
  - Density dependence
  - Selection before or reproduction



Baskett model results



Management guidelines

- HSRG guidelines for “integrated” program
  - PNI > 0.67 (0.5 for some populations)
  - pHOS < 0.30
  - pNOB > 0.10
- Rationale: make sure evolution of combined hatchery/wild population is mostly driven by wild component

That’s the theory – any reality?

- We know there is more to it that this
  - Multiple traits
  - G x E interactions
  - Epigenetic effects?
- We haven’t yet measured all of the relevant parameters (at least in the same population)
  - Heritability (H and W)
  - Selection strength (H and W)

Data consistent with basic ideas

- Estimates heritability
- Measuring selection in W and H
- Differences in reproductive success related to pNOB

APPENDIX E

PowerPoint Presentation-Ecological Risks and Hatchery Management Strategies to Minimize Risk

A review of hatchery reform science in Washington State

Anderson et al. (2019 – Preliminary manuscript)

Ecological Considerations

Thomas P. Quinn
School of Aquatic and Fishery Sciences
University of Washington

Ecological Risks: What risks? What are we worried about?

- 1. Harm to the wild population's abundance, distribution, productivity? *"First, do no harm."*

- 2. Lack of proportionate increase in the total population with hatchery additions? *"Diminishing returns."*

- 3. Harm to other salmonids, fishes, or organisms?

- 4. Other concerns?

Response Variables

- Survival (juveniles)
- Growth (juveniles)
- Behavior (juveniles)
- Reproductive success (adults)
- Abundance (population)
- Productivity (population)

Mechanisms

- Competition: food and space (feeding and breeding)
  - Numerical (too many fish) vs. Differential (H – W inequality)
  - Limiting habitats: stream, lake, estuary, ocean
  - Intra-specific vs. inter-specific
- Predation
  - Hatchery fish eat conspecifics or other salmonids (bad)
  - Hatchery fish saturate predators (good)
  - Hatchery fish attract predators (bad)
- Genetic interactions
  - Straying from or into the hatchery
  - Residualism (maturation without migration)
- Disease

Drivers

- Program size
  - Total number released or relative to natural production?
  - Why are fewer released than in the past?
  - How are hatchery effects integrated with other drivers?
  - Are habitat changes and ocean conditions considered?
- What determines production goals?
  - Salmon ecology?
  - Hatchery capacity?
  - Fishing demand?
  - Killer whales?

Drivers cont'd

- Release strategies
  - On-site or off-site
    - What is the goal? Juvenile distribution or adult homing
  - Volitional or forced
    - What is the goal? Hatchery operations or ecology?
  - Timing of release
    - Consequences: Pied Piper effect? Predation?

Drivers cont'd

- Mass marking:
  - How prevalent is it and what are the benefits and drawbacks?

Conclusions of the report

- 1. HSRG goals are somewhat arbitrary but well-founded
- 2. Removing Proportionate Natural Influence and pHOS etc. goals is unwise
- 3. HSRG principles are complicated and can result in working at cross-purposes
- 4. Segregated programs will rarely be better than integrated ones
- 5. Hatchery reform is more difficult the larger the hatchery program, on an absolute basis, and relative to the natural population.
- Overall, the hatchery reform has been dominated by genetic concerns and ecological ones have been less emphasized.

WDFW Hatchery and Fishery Reform Policy

Purpose

“The purpose of this Washington Department of Fish and Wildlife policy is to advance the conservation and recovery of wild salmon and steelhead by promoting and guiding the implementation of hatchery reform.”

WDFW Hatchery and Fishery Reform Policy

Purpose

"The purpose of this Washington Department of Fish and Wildlife policy is to advance the conservation and recovery of wild salmon and steelhead by promoting and guiding the implementation of hatchery reform."

What are the real issues here?

<u>Desire for:</u>

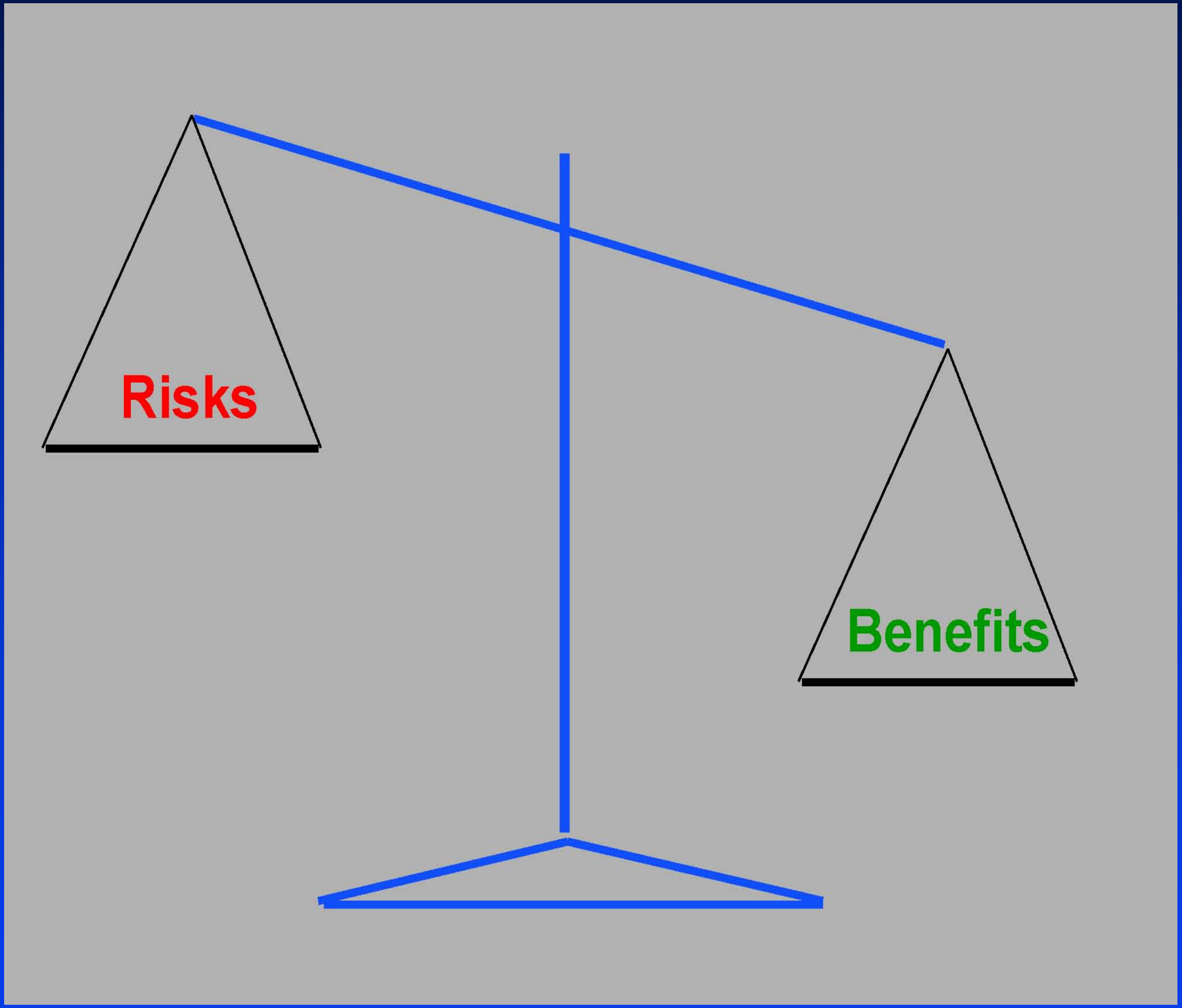
1. More salmon for fishermen?
2. More salmon for killer whales?
3. More flexibility in operations?

- Are increased adult salmon returns a realistic goal?
- How would they be divided between humans, killer whales, harbor seals, and other components of the ecosystem?
- Would this hinder recovery of healthy wild salmon runs?

APPENDIX F

PowerPoint Presentation-Conservation Benefits

Risk-benefit considerations for salmon hatcheries



Types of benefits to be considered

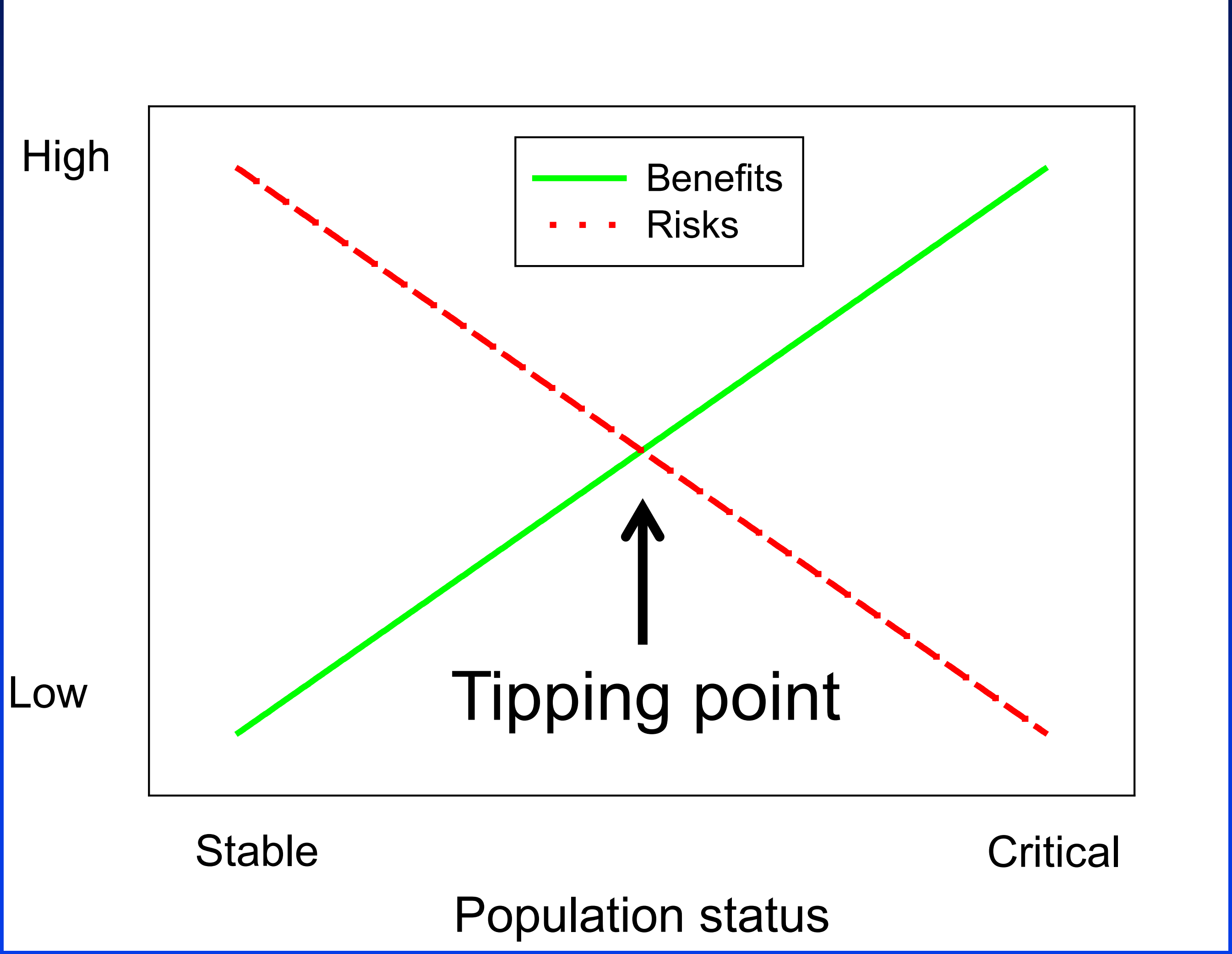
Conservation	General
• Natural populations	• Natural populations
	• Harvest
	• Mitigation
	• Treaty obligations
	• Public education
	• Jobs

Potential benefits of propagation for natural populations

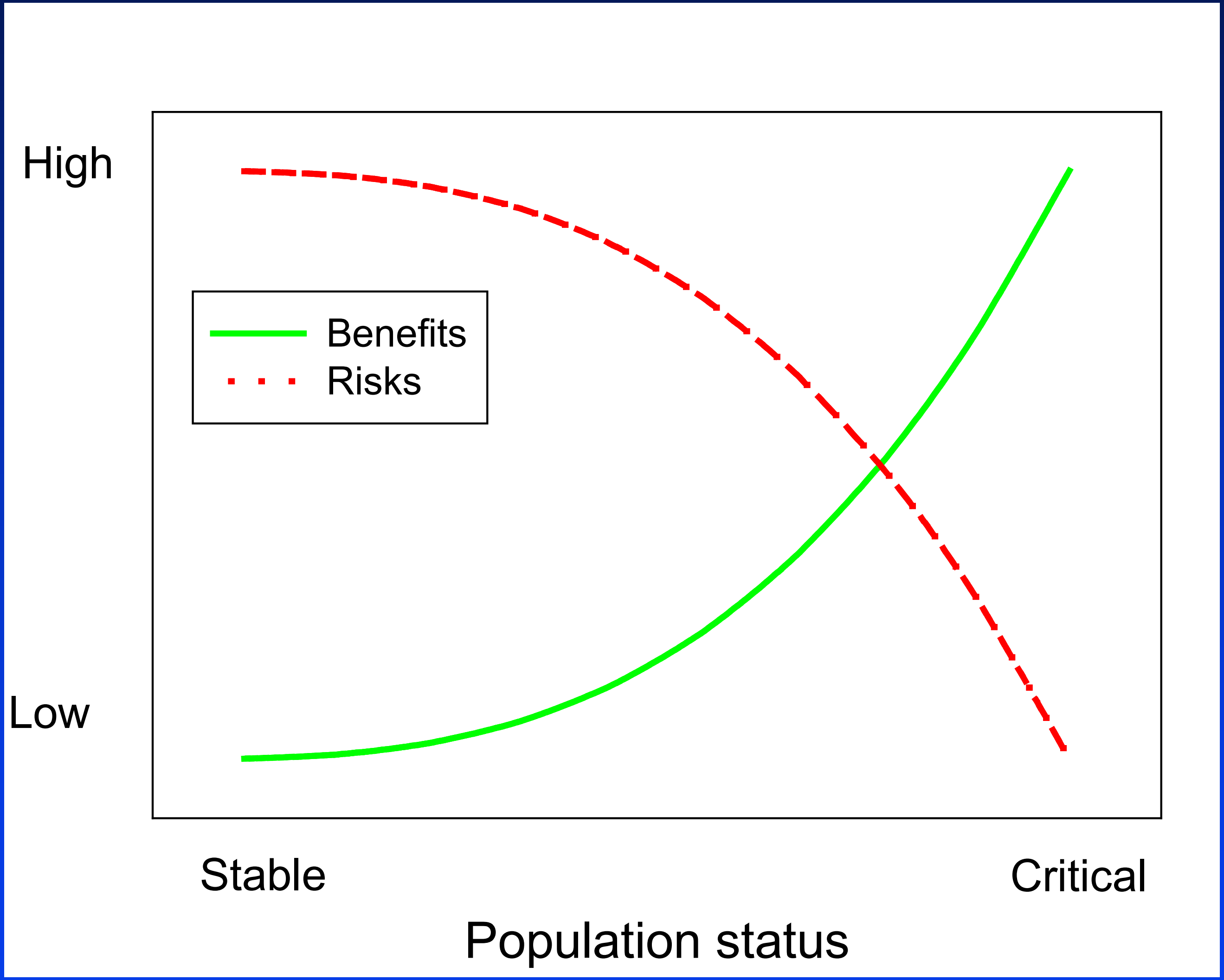
1. Reduce short-term extinction risk*
2. Reseed vacant habitat*
3. Speed recovery(*)

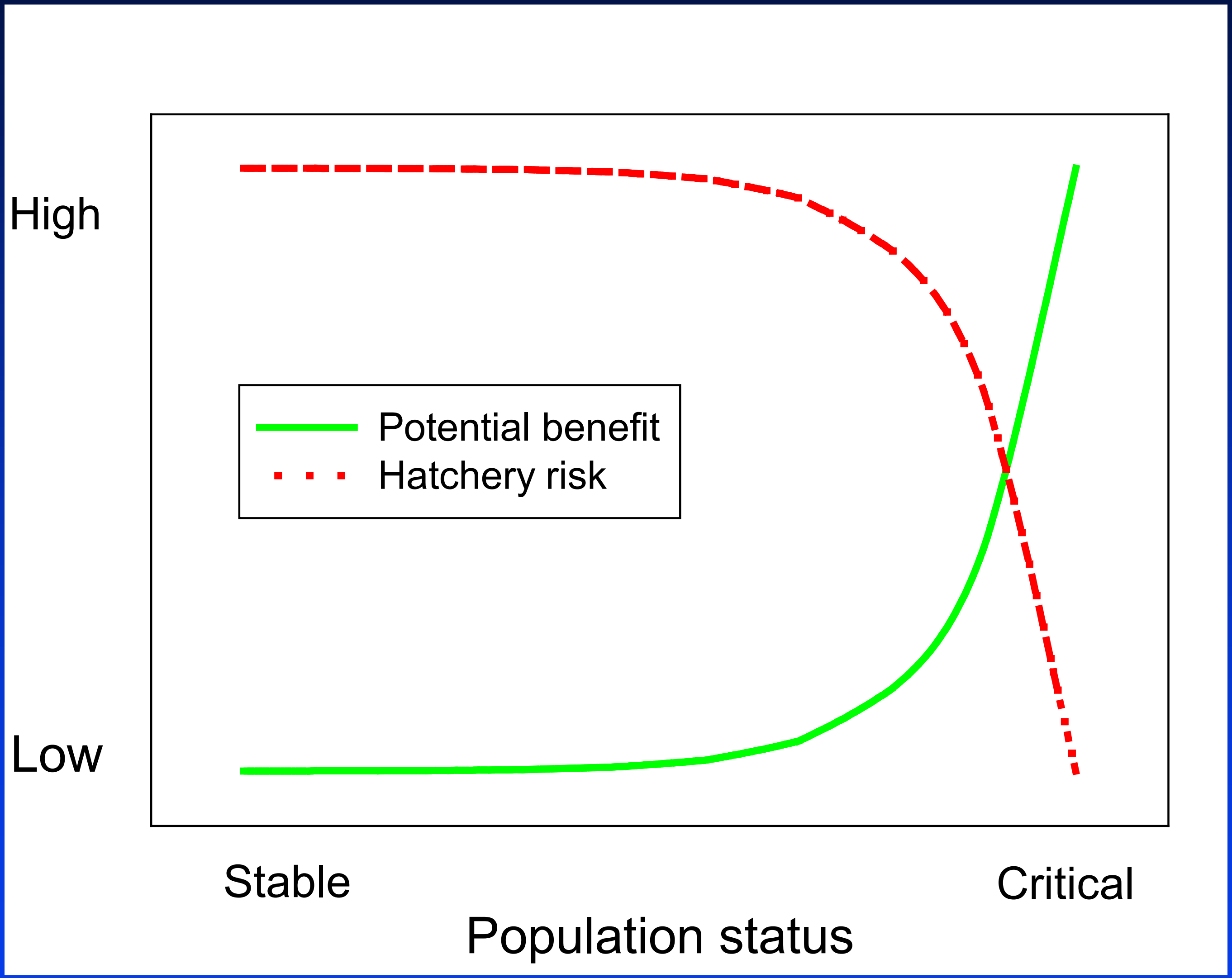
* Empirical evidence exists

Risks and potential conservation benefits of supplementation



What shapes do risk and benefit curves take?




High
Low
Potential benefit
Hatchery risk
Stable
Critical
Population status

Risk tradeoffs

- Release strategies
- Broodstock collection
- Program scale
- Population mixing
- Marking

Questions for discussion

What are program goals?

Can a program effectively achieve multiple goals?

How likely is it that conservation benefits will be realized?

Under what conditions can particular risks legitimately be ignored?

Where is the risk-benefit tipping point?

Have all sources of uncertainty been accounted for?

Can a program be effectively modified or terminated once it is started?

A meta Question

Is it better to do a meta-risk/benefit analysis that jointly considers multiple programs?

Question for (later) discussion

Burden of proof:

Should an enhancement project be allowed to go forward unless adverse effects can be proven beyond a reasonable doubt?

or

Should a project *not* be allowed to go forward unless it can be demonstrated that no adverse effects will occur?

And who decides?

APPENDIX G
WSAS Committee Members

Washington State Academy of Sciences
Committee Members, the Science of Salmon Hatcheries

Larry Dalton, Committee Chair

B. Seymour Rabinovitch Endowed Chair in Chemistry and
George B. Kauffman Professor Emeritus | University of Washington

Larry Dalton has served on the faculties of Vanderbilt, SUNY, USC, and the University of Washington. At UW, he served as the founding Director of the National Science Foundation Science & Technology Center on Information Technology Research. His awards at UW include the 2003 American Chemical Society Award in the Chemistry of Materials, the 2011 Linus Pauling Medal of the American Chemical Society, the 2006 Institute of Electrical and Electronics Engineers William Streifer Scientific Achievement Award, the QEM (Quality Education for Minorities) /MSE (Mathematics, Science, and Engineering) Network 2005 Giants in Science Award, and a Helmholtz International Award (2015). He is a Fellow of the American Chemical Society, the Materials Research Society, the Optical Society of America, the International Society for Optics and Photonics, and the American Association for the Advancement of Science. Dr. Dalton is a Senior Member of the Institute of Electrical and Electronics Engineers. He obtained a B.S. in 1965 and a M.S. from 1966 from the Honors College of Michigan State University. He then obtained a Ph.D. from Harvard University in 1971 with Professor Alvin Kwiram.

Barry Barejikian*

Program Manager & Manchester Station Chief | Northwest Fisheries Science Center (NOAA)

Barry Berejikian leads the Behavioral Ecology Team at the Northwest Fisheries Science Center. He joined the Northwest Fisheries Science Center in 1995 and began work on several projects aimed at quantifying the effects of artificial propagation of salmon and steelhead on natural populations. In 2004, the Behavioral Ecology Team initiated the first studies on the benefits and risks of stock enhancement for marine species in Puget Sound. In 2010, the team began applying behavioral studies of larval sablefish to improve the efficiency and success of marine aquaculture. Dr. Berejikian served on the Northwest Fisheries Science Centers Research Council from 2007 to 2012. He received a B.S. degree in Environmental and Systematic Biology from California Polytechnic State University, San Luis Obispo in 1990, and his M.S. degree (1992) and Ph.D. degree (1995) in Fisheries from the University of Washington.

Joe Cook

Associate Professor of Economic Sciences | Washington State University

Joe Cook's research focus is primarily on water and sanitation policy in low-income countries, water resources economics and policy, and nonmarket valuation. His research has appeared in publications such as the *Journal of the Association of Environmental and Resource Economists*, *Environmental and Resource Economics*, *Water Resources Research*, the *Journal of Policy Analysis and Management*, and *World Development*. He has conducted 13 household surveys in six countries and is an active member of the SIDA-funded capacity-building Environment for Development network. Consulting assignments have included work for the U.S. Millennium Challenge Corporation, the Asian Development Bank, the Hopi Tribe, and the Washington State legislature. He has a M.S. and Ph.D. from the University of North Carolina and a B.S. from Cornell University.

Mike Ford

Director of the Conservation Biology Division | Northwest Fisheries Science Center (NOAA)

Mike Ford joined Northwest Fisheries Science Center in 1995 and has been Director of the Conservation Biology Division since 2003. At the Northwest Fisheries Science Center, he focused initially on using molecular methods to study local adaptation in salmon, before focusing for many years on research to study interactions between hatchery and wild salmon. Dr. Ford has led and participated on multiple Endangered Species Act status review teams for salmon and whales; he has been involved with various aspects of recovery planning for salmon and southern resident killer whales. He received his B.S. from Stanford University and his Ph.D. in population genetics from Cornell University.

Shawn Narum

Lead Geneticist | Columbia River Inter-Tribal Fish Commission

Shawn Narum leads a research group focused on population and ecological genomics of salmonids and other native fish species of the Pacific Northwest. His research includes studies on genetic effects of hatchery practices, genetic tagging and monitoring of fisheries, and genetic adaptation to local environments. Much of his research is facilitated by recent advances in molecular technology including SNP genotyping and next-generation sequencing equipment in the Hagerman Genetics Laboratory at the Columbia River Inter-Tribal Fish Commission. He obtained a B.S. in Fishery Biology from Colorado State University, a M.S. in Marine Science from the University of San Diego, and a Ph.D. in Natural Resources from the University of Idaho.

Thomas Quinn

Professor of Aquatic Fisheries and Sciences | University of Washington

Thomas Quinn is a leading authority on the behavior, ecology, evolution, and conservation of salmon and trout. For decades, he has served as one of the principal researchers for the UW Alaska Salmon Program, where his research has helped to reveal many of the patterns and processes in the behavior and ecology of salmonids. He has used a wide variety of laboratory, field, and analytical approaches to study salmon migration, homing, reproduction, and other themes, including work on all species, and in stream, lake, and marine habitats. In Washington, he has studied the re-colonization of rivers by salmon after dam removal or modification, interactions between wild and hatchery-produced fish, and the movements of salmon and trout in Puget Sound.

Robin Waples

Senior Scientist | Northwest Fisheries Science Center (NOAA)

Robin Waples' early research involved taxonomy and population genetics of tropical and temperate marine fishes, but after joining the Northwest Fisheries Science Center he has worked primarily with salmon. Before assuming the role of senior scientist at the end of 2000, Robin led the Conservation Biology Division and its precursors for a decade. During this time the Conservation Biology Division staff conducted a series of comprehensive reviews of the status of Pacific salmonids under the federal Endangered Species Act. From 1999-2003 he was the Center's scientific lead for salmon recovery planning, and during 2003 and 2004 he was a visiting scientist at university laboratories in France and the U.S. Dr. Waples has a B.A. in American Studies from Yale University and a Ph.D. in Marine Biology from Scripps Institution of Oceanography.

Peter Westley

Assistant Professor of Fisheries Conservation and Fisheries Ecology | University of Alaska Fairbanks

Peter Westley's research seeks to understand how fishes respond and adapt to abrupt environmental change across levels of biological organization. Work in his lab addresses this overarching question through the combination of field, laboratory, meta-analysis, and modeling approaches. He obtained a B.S. in Fisheries from the University of Washington in 2004 and a Ph.D. from the Memorial University of Newfoundland in Canada in 2012.

James Winton

Senior Scientist Emeritus, Fish Health | Western Fisheries Research Center (USGS)

Jim Winton works with scientists, technicians, post-doctoral researchers, graduate students and visiting scientists working to improve methods for the detection of fish pathogens, determine factors affecting the epidemiology of fish diseases, and develop novel control strategies for reducing losses among both hatchery-reared and wild fish. He obtained his B.A from the University of Colorado, Boulder and his Ph.D. Oregon State University in 1981.

**Note*: An asterisk notes a committee memberwho was not able to attend the May 23rd Meeting in person.

APPENDIX H
Supplemental Reviewers

Supplemental Reviewers

Ernie Brannon

Professor Emeritus of Fishery Resources and Animal Science | University of Idaho

Ernie Brannon has served as Professor at both the University of Washington and the University of Idaho. He is a member of the Aquacultural Research Institute at the University of Washington. His research interests include salmon migration, salmon spatial distributions, and the effects of oil spills on salmon.

Craig Busack

Senior Scientist | National Marine Fisheries Service, West Coast Regional Office (NOAA)

Craig Busack serves as a Senior Scientist of at the Anadromous Production and Inland Fisheries Branch of the West Coast Regional the National Marine Fisheries Serve. His responsibilities include keeping the people in his branch informed of scientific developments in the hatchery world, advising consultation biologists on technical issues, developing and maintaining modelling and analytical tools used in hatchery consultations. He also serves as a subject matter expert in litigation. Although he has worked on several other aquatic species, the bulk of his experience is in working on issues dealing with risks and benefits (primarily genetic) of salmon and steelhead hatcheries. Prior to his current position, he worked for 22 years in the Fish Program of the Washington Department of Fish and Wildlife and its predecessor agency, the Washington Department of Fisheries, as a biologist, research scientist, unit leader, and eventually as chief fish scientist. Craig Busack obtained his Ph.D. in Genetics from UC Davis.

Mike Crewson

Salmonid Enhancement Scientist | Tulalip Tribes

Michael Crewson has 35 years of experience designing and managing salmonid enhancement projects and associated monitoring programs. For the past 15 years, Mr. Crewson has served as a Salmonid Enhancement Scientist for the Tulalip Tribes evaluating regional hatchery enhancement programs. His has experience conducting and overseeing fishery management, hatchery supplementation and enhancement programs as a Fishery and Hatchery Manager, Research Biologist, and Fish Health Specialist for tribal, federal, state and private fishery management agencies and entities. His particular interests include designing enhancement programs to monitor and assess ecological and genetic interactions among juvenile and adult, natural-and hatchery-origin salmonids, evaluating program performance and applying adaptive management to ensure hatchery programs are operated with best available science, integrated to be consistent with concurrent habitat and harvest management programs. He holds a M.S. degree in Fisheries from the University of Washington School of Aquatic and Fishery Sciences with major emphasis in aquaculture and fish health.

Kathryn Kostow*

Analyst |Coffee Creek Bioscience

Kathryn Kostow is affiliated with the Coffee Creek Bioscience in Oregon. She mixes volunteer work and short-term contracts. She worked with Oregon Department of Fish and Wildlife for 25 years as a Senior Scientist of Fish Biology and additionally spent five years within the utility industry. She has expertise in ecology, endangered species, fisheries, natural history, wildlife, fish, and fish taxonomy. She additionally has served on the Hatchery Science Review Group. She studied biology at the College of Idaho and then attended graduate school at the University of Minnesota, where she specialized in ecology.

Timothy Linley

Ecology Group | Pacific Northwest National Laboratory

Tim Linley came to the PNNL in 2010 and joined the Ecology group the same year. He has conducted research on fish geochemistry, osmoregulation, reproduction and behavior, and acoustic telemetry. He has also managed facilities involved in various aspects of fish production, including rearing, adult harvest and brood stock management, stock enhancement, and restoration projects. Dr. Linley obtained a B.S. in Wildlife Ecology from the University of Wisconsin in 1979, his M.S. in Fisheries from University of Washington in 1988, and his Ph.D. in Fisheries from University of Washington 1993.

Lisa Seeb

Research Professor of Aquatic and Fisheries Sciences | University of Washington

Lisa Seeb is a geneticist who uses genomics approaches to unveil the ecological structure of Pacific salmon populations. She and her husband, Jim Seeb, lead the Ecological Genomics Laboratory, part of the Alaska Salmon Program of the School of Aquatic and Fisheries Sciences. The Laboratory conducts both basic and applied research, ranging from developing tools for stock identification to understanding the role of structural variation and gene duplications in salmonids. In addition, Dr. Seeb serves as a member of the Hatchery Scientific Review Group. Prior to joining the University of Washington in 2007, she served as a senior geneticist at the Alaska Department of Fish and Game for 17 years. She received an A.B. in Zoology from the University of California, Berkeley, an M.S. in Zoology from the University of Montana, and a Ph.D. in Fisheries from the University of Washington.

Adrian Spidle

Fisheries Geneticist | Northwest Indian Fisheries Commission

Adrian Spidle worked at the Leetown Science Center where he focused on population genetics, systematics, and broodstock management in endangered Atlantic salmon, before joining the Northwest Indian Fisheries Commission. He has now worked at the Northwest Indian Fisheries Commission for fifteen years, where he coordinates research among state and tribal comanagers of Pacific salmon. He provides consultation on broodstock management in salmon hatchery operations. He additionally works the on design of monitoring programs to assess hatchery performance contribution of hatchery fish to recovery of Endangered Species Act-listed salmon populations. He obtained a B.S in 1990 and a M.S in 1994 from Cornell University in Natural Resources. He continued his research at University of Washington where he focused on fisheries.

Bill Young

Hatchery Evaluations Coordinator of the Department of Natural Resources | Nez Perce Tribe

Bill Young coordinates the research, monitoring and evaluation of hatchery-reared spring Chinook salmon, fall Chinook salmon and coho salmon. Information is used to adaptively manage the hatchery populations to maximize adult returns, minimize negative impacts to wild populations and evaluate the success of hatchery supplementation to recover and enhance natural populations. He also supervises and oversees the Snake River Basin Germplasm Repository that contains one of the largest germplasm collections of fish in the world. The repository contains cryopreserved sperm from multiple populations of Endangered Species Act-listed Chinook salmon steelhead from the Snake River basin. He obtained his Ph.D. in Zoology in 1996 from Washington State University.

**Note* : An asterisk notes a supplemental reviewer who was not able to attend the May 23rd Meeting in person.

APPENDIX I
Attendance List

List of Workshop Attendees

WSAS Committee Members

Larry Dalton, University of Washington, Committee Chair
Joe Cook, Washington State University
Mike Ford, Northwest Fisheries Science Center (NOAA)
Shawn Narum, Columbia River Inter-Tribal Fish Commission
Tom Quinn, University of Washington
Robin Waples, Northwest Fisheries Science Center
(NOAA)
Peter Westley, University of Alaska Fairbanks
James Winton, Western Fisheries Research Center (USGS)

Supplemental Reviewers

Ernie Brannon, University of Idaho
Craig Busack, National Marine Fisheries Service (NOAA)
Mike Crewson, Tulalip Tribe
Timothy Linley, Pacific Northwest National Laboratory
Lisa Seeb, University of Washington
Adrian Spidle, Northwest Indian Fisheries Commission
Bill Young, Nez Perce Tribe

WDFW Staff

Joe Anderson, Research Scientist
Bethany Craig, Fisheries Biologist
Alf Haukenes, Director of Fish Health
Eric Kinne, Hatcheries Division Manager
Douglas Kramer, Budget and Operations Manager
Andrew Murdoch, E. WA Science Division Manager
Todd Seamons, Director of Molecular Genetics Laboratory
Ken Warheit, Chief Scientist
Ron Warren, Assistant Director

WSAS Staff

Donna Gerardi Riordan, Executive Director
Devon Emily Thorsell, Program Coordinator
Vivian Ericson, Project Consultant
Nick Montoni, Research Assistant

Observers

Rep. Debra Lekanoff, 40th Legislative District
Lee Blankenship, Hatchery Scientific Review Group
Tom Chance, Lummi Natural Resources Department
Leslie Connelly, WA Office of Financial Management
Dave Croonquist, Coastal Conservation Association
Peggen Frank, Salmon Defense
Ron Garner, Puget Sound Anglers
Michael Kern, Ruckelshaus Center
Yoshi Kumara, House Rural Development, Agriculture and Natural Resources Committee
Erik Neatherlin, Governor's Salmon Recovery Office
Michael Schmidt, Long Live the Kings
Butch Smith, Ilwaco Charter Association
Peter Soverel, The Conservation Angler
Frank Urabeck, Sport Fishing Advocate
Jacques White, Long Live the Kings

APPENDIX J
Questions from Observers

Observer Questions

The WSAS Science Review Committee Members and Supplemental Reviewers answered questions from Observers at the Workshop on Science of Salmon Hatcheries. Questions (edited slightly for clarity) and answers are included below.

1. Poor fitness is often described as an inherent HOS issue. However, studies have indicated that HOS often have high fitness when spawning in previously unoccupied habitat or underseeded habitat. Low HOS fitness can therefore be explained by habitat capacity & quantity spawning area selection of HOS (e.g., Hood River studies), and other environmentally induced effects. Do the panel members disagree with this general assessment? If so, why?

   Answer : When the density of fish is low within a given habitat, competition and other factors that constrain low HOS fitness populations may be masked or absent. There is strong genetic control over a number of attributes that affect behavior and survival. The genetics of the hatchery fish populations change over a couple generations. This selection may not be apparent when the fish are in optimal environmental conditions or face no competition. This has been seen in the Hood River, the re-colonization of the Cedar River, and some work in New Zealand and in South America.

2. In regards to reducing program size because surplus adults appear [to be] high, certain factors must be considered:

   - Production decreases are likely to result in a disproportionate reduction to harvest.
   - Larger hatchery programs have better genetic diversity and phenotypic expression. This is counter to hatchery reform concepts.
   - Surplus adults are extremely important for introducing marine derived nutrients.

   Discussion : Panel members discussed the current uses of surplus fish carcasses. Programs use different approaches to using surplus fish and some practices are not possible in all regions. Certain programs create and spread pellets from the carcasses to return nutrients to the environment. Depending on the quality of the surplus fish, carcasses may go to low-income families, tribes, or pet-food. In certain cases, fish carcasses are buried.

3. One of the primary reasons the WDFW Commission gave when they suspended the science-based recommendations under sections 1, 2 and 3 was there was new science that countered those recommendations. A WDFW report to the Governor said the HSRG was unable or unwilling to address the new science.

Are those scientific issues being addressed in the report?

Answer : The WDFW is conducting a scientific review of hatchery reform to address these issues within the report. The literature in the last ten years has not fundamentally changed the way hatchery-wild interactions are assessed. Review of the literature did add depth to the understanding of risks and WDFW was able to assess new knowledge around mechanisms.

4. We need to look at 120+ years of hatchery production that has released billions of salmonids in over 600 creeks, streams, rivers of the state, many of them probably spawned.
What is a wild fish?
Could properly designed in-basin integrated hatchery programs re-build the natural origin spawners while also supplying fish for anglers, tribes, and the SRKW?

Answer : Discussions during the workshop sessions touched on the two questions. Genetic research tools have rapidly evolved and it is now increasingly possible to analyze the genomes of fish populations. It is now possible to evaluate the differences between hatchery fish and ancestral populations or wild fish populations. An example of this technology is being deployed in the Yakima basin; there may be an opportunity for this research to be broadened to a greater number of regions, such as the Green River. In regions where there has been significant hatchery production and interaction between hatchery and natural fish it becomes important to consider the gene pool across a species. Ideally management would be aimed at finding the right gene combinations that work well in the environment and maintaining a diverse portfolio. It was noted that natural populations are reasonably able to resist gene flow from less fit hatchery fish, and that the long history of hatcheries does not preclude the idea of wild fish populations. There are examples in areas with a long history of high levels of hatchery production where natural populations with genetic characteristics are distinct from the hatchery population. There is significant research on fitness decline within hatcheries and to some degree certain hatchery populations are able to re-adapt to the environment in optimal conditions. Some research shows that a large portion of hatchery production is not diverse within Washington state when considering life history and type. Idaho has examples of greater diversity in hatchery production, although it does become harder to achieve diversity as the size of hatcheries increase.

5. When will policy effectiveness via performance monitoring data analysis be addressed? Part of this review or subsequent project?

Answer : The WDFW performance evaluation of the Fish and Wildlife Commission Policy will be presented to the Commission in late 2019. Modifications to the policy are expected through December 2019 to February 2020.

6. NOAA approval of FMEP, HSRG, HGMP leading to ESA coverage relied on WDFW hatchery policy – Commission approved.
How can NOAA continue ESA coverage when the Commission directs WDFW to suspend regulations 1, 2 & 3?

Answer : Hatchery and Genetic Management Plans (HGMP) continue to cover exactly what was in the policy and still meets the approval of NOAA fisheries for operation under ESA. Rather than cite the regulatory policy, the HGMPs tend to cite the requirements presented by NOAA.

7. Focus on genetic integrity tends to alter attention to life history diversity. Colonization in S.A/N.Z. has been rapid with highly diverse life history structure. (ex. Canadian Great Lakes)

   How [does one] protect wild life history diversity from hatchery fish by driving down pHOS[?]

   Answer: In one study done in New Zealand, Chinook salmon from the Sacramento River were used to generate both ocean juveniles and stream juveniles; the fish diverged within 20 generations. Some phenotypic diversity manifested rapidly when fish populations were exposed to cold and warm water, indicating some level of phenotypic plasticity. Some lack of diversity that can occur within hatchery population results from a narrow release window or other practices. Within Washington many efforts are focused on preserving the genetics of the wild population. The crux is to limit pHOS, and decrease interactions between wild and natural fish populations. In the scenario where the population of hatchery fish interacts with the wild population then there is a need to increase integration.

8. Can you cite a hatchery program that has benefitted wild populations? Allendorf says there aren't any.

   Answer : Examples where there was benefit to the wild population from a hatchery include Red Fish Lake, Johnson Creek and Hama Hama. In certain cases the goal of a hatchery program is to reduce fishing pressure on the natural population, such as the Interbay Atlantic Salmon.

9. [The] underlying premise of this exercise [is] continued, massive, widely distributed hatchery program. Is this a good idea given history?
   How about careful audit of one or more hatchery programs?

   - Biological (return rate; H.W.)
   - Ecological
   - Cost of fish to hand
   - Social
   - Opportunity cost

   Answer: This question was not able to be addressed directly; however, the ongoing work by WDFW to conduct a science review, an implementation review of 161 hatcheries, and a policy review is intended to assess a number of the concerns raised within this question.

10. Productivity of hatchery programs appear to decline over time. How have populations responded to cessation of hatchery programs:

   - Sol Duc
   - Wind
   - Skagit
   - Asotin Creek
   - Nisqually
   - Cowechin
   - Hood Canal
   - Green River (Toutle tributary)

   Comparison/recovery – White Salmon, Sandy, Elwha

   Answer: This question was not addressed directly, but different approaches to conducting research were discussed during the sessions.

APPENDIX K
Written Observer Comments

Written Observer Comments have not been edited for content, clarity, or length. They are presented as they were received by WSAS.

May 30, 2019

Donna Riordan
Executive Director
Washington State Academy of Sciences

Dear Ms. Riordan

The Conservation Angler appreciates the invitation to observe the science team technical review of hatchery issues. I found the discussion difficult to follow and lacking in coherence without access to the foundational document. Please send copies of the draft policy review to:

The Conservation Angler	The Conservation Angler
Attn: Peter Soverel	Attn: David Moskowitz
16430 72nd Ave W	3241 NE 73rd Ave
Edmonds, WA 98026	Portland, OR 97213-5821

We take particular issue with the Washington Fish & Wildlife Commission directive to improve "the tone" regarding the benefits of hatcheries. This directive has the effect of short-circuiting a base-line review of whether the hatchery-based management paradigm which Washington State has pursued for at least 100 years should be continued. The evidence, based upon that 100+ years of experience, is clear: this approach has not protected wild stocks from drastic declines. Almost all DPS units for every species are ESA listed or already extinct. In our view, WDFW and NOAA have pursued a positively harmful set of management policies predicated on massive releases of hatchery fish for many decades rather than husbanding and recovering wild stocks. In many cases throughout this history, reliance on hatchery production to "mitigate" for salmon habitat destruction and dam construction has provided "scientific" coverage for those very same destructive activities. Faced with the plain reality, I was extremely disappointed that none of the presenters even raised the possibility of that radical changes to hatchery-based management paradigms are long over-due.

Wild salmonid stocks have been in sharp and continuing decline for many decades. The hundreds of hatchery programs operated in Washington have failed to slow, much less, reverse this trend. Indeed, the inescapable conclusion is that these hatchery programs are either ineffective and a poor investment of state and federal public funds or the hatchery programs are part of the problem which also means they are a waste of money. Indeed, there is considerable scientific evidence that

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hatchery programs have and continue to harm wild salmon and steelhead populations through genetic and ecological interactions. This evidence includes many work products of the Hatchery Science Review Group (HSRG) itself. Indeed, it is the HSRG's increasingly strong recommendation that pHOS, the proportion of hatchery-origin spawners present on the spawning grounds of wild salmon and steelhead, generally be kept to no greater than 5% or less. The Columbia River and Northwest Indian Treaty Tribes in particular have, in general, steadfastly opposed such recommendations because they know that compliance with such minimal conservation recommendations require reduction in current hatchery programs, not increases. Governor Inslee's scientifically questionable initiative to recover Southern Resident Killer Whales (SRKW) by increasing the production of hatchery Chinook salmon from numerous programs in Puget Sound, the Washington Coast, and the Columbia River basin has provided both the political cover and excuse for this initiative to weaken, if not abandon, these and other recommendations of the HSRG. This political context must be kept foremost in mind in conducting any scientifically credible and independent review of the HSRG. I have attached a lengthy, representative bibliography covering some of the hundreds of peer reviewed studies/analyses documenting the myriad of harmful impacts that hatchery programs visit on wild stocks.

Stated plainly, the massive fiscal investment in hatchery mitigation has not worked. However, the presenters did not describe how continuing with this failed paradigm will be modified to work in the future and ignore decades of evidence to the contrary. Further, the participants did not explore the many known harmful impacts of hatcheries on wild stocks or how future hatchery operations would avoid or lessen these many known impacts. Nor was there any discussion of the opportunity costs associated such as diverting hatchery costs to say, for example, an expanded/accelerated culvert replacement program. Neither was there any consideration (or even mention) of needed revisions and/or reduction to ocean mixed-stock Chinook fisheries and rapid transitioning to terminal area and in-river fisheries and the use of selective (especially passive, fixed-location) fishing gears, that can be more easily managed for stock-specific spawner escapement goals, and that would largely occur after returning mature adult Chinook had passed marine areas in which SRKW forage.

TCA was especially disappointed that this review process will not undertake and actual analysis of the efficacy of the hatchery-based model or even the Commission directed comparison of WDFW implementation of the policy guidelines, implementation and outcomes. We are left to wonder how the Department or Commission can formulate a coherent set of policies without an evaluation of the policies and outcomes that have produced the present results.

Asserting that what has failed in the past will be successful in the future without describing in

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detail the changes, doesn't make it so. The first step is a careful, independent performance audit (biological, financial – cost benefit, ecological, social) of the existing hatchery policies and programs. This has never been done for goodness sake!

Following that audit, TCA encourages WDFW, NOAA, WSAS to undertake careful comparative analysis of the several areas suggested below with the objective that such analyses would guide policy development to help recover wild stocks and understand the influence of hatcheries in this process.

COLONIZATION/RECOVERY

I. Recovery following Dam Removal.

More or less contemporaneously, dams were removed from the Sandy, White Salmon, Rogue and Elwha rivers. Recovery strategies are different in each of the systems. It would be useful and informative to compare salmon/steelhead responses to the different recovery strategies

1. White Salmon: natural colonization
2. Sandy: mixed strategy – mostly natural colonization with minimal hatchery releases
3. Elwha: mixed strategy – winter steelhead/Chinook hatchery based; other species and summer-run steelhead natural colonization

Interestingly, in the case of the Elwha, natural origin winter steelhead and Chinook have occupied the newly opened habitat and have not increased in abundance. Summer steelhead, 100% natural recovery, on the other hand have responded dramatically with hundreds of wild summer steelhead returning to the upper watershed. In any case, a comparative analysis of how wild fish have responded to different hatchery strategies in the different watersheds would help us develop management practices that promote healthy abundant wild fish populations.

II. Colonization

Steelhead and Chinook have been introduced to several areas beyond their natural range where they have established thriving natural origin populations, including many watersheds into which they had not been purposely introduced– Chile/Argentina, Canadian Great Lakes v. US Great Lakes, New Zealand, US-Canadian-Russian Arctic. Except for US Great Lakes tributaries, wild populations quickly displayed a wide-range of life history variations adapted to local conditions and developed diverse, abundant natural populations. These situations share a number of similarities:

1. Relatively low level of initial stocking which were discontinued
2. Locally developing wild populations not exposed to continuing interactions with hatchery fish

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3. Self-colonization of unoccupied habitat (spread of introduced species to unoccupied habitat –Chile, Argentina, New Zealand, Tasmania, Canadian Great Lakes, US-Russian-Canadian Arctic)
4. Wide diversity of life-history expression and migration behavior in response to local environmental conditions.

The response of US Great Lakes tributary populations is the notable exception. Introduced Chinook, Coho and steelhead have not generally produced locally adapted, natural origin populations in the face of continued, annual, massive hatchery introductions which appear to suppress local adaptive mechanisms.

RESPONSE TO DISCONTINUATION/REDUCTION OF HATCHERY OPERATIONS

Washington has established several wild steelhead management zones (rivers) along with numerous rivers which are no longer planted with hatchery steelhead and/or adult, hatchery steelhead are not passed upstream. Wild steelhead have responded differently in different watersheds:

1. <u>Rapid, significant increase in wild steelhead populations</u>: Skagit, Nisqually, Wind, Solduc, SF Toutle, Asotin Creek. Interesting angler catch rates in the Solduc are 4-5 five times greater than catch rates in the Bogachiel hatchery-based fishery;
2. <u>No significant wild steelhead response</u>: Hood Canal tributaries; North coast Olympic Peninsula tributaries (East/West Twin, Lyre, etc.), Hoh;
3. <u>Undermined response</u>: Coweeman, Clearwater, Puyallup, Rogue, Nooksak;
4. <u>John Day River</u>: This river hosts the largest run of wild steelhead in entire Columbia/Snake basin. It has never been stocked with hatchery steelhead.
5. <u>Okanogan Sockeye</u>: Okanagan Sockeye: Comparison of hatchery and wild productivity at Osoyoos Lake (wild) and Skaha Lake (hatchery) is very illuminating. After focusing on improving flows/passage through over 100 irrigation dams in the Okanagan basin to benefit Osoyoos Lake productivity, remaining spawning habitat, and passage to Skaha Lake, natural production increased dramatically with recent smolt production ~10-40 times greater from Osoyoos Lake (wild smolts) than from Skaha Lake (smolts from hatchery fry releases) and with 150-450K adult returns (past 9 Columbia dams) of which Osoyoos wild adult returns are ~10 times greater than the hatchery origin adult returns to Skaha Lake.

WILD STEELHEAD RECOVERY FOLLOWING DISCONTINUATION OF HARVEST

Wild steelhead have demonstrated a remarkable ability to rapidly increase abundance based solely on the elimination or drastic reduction of harvest:

1. Puget Sound. By citizen's initiative (1933), Washington eliminated commercial harvest of steelhead. Wild steelhead populations had been severely depressed by commercial harvest (winter steelhead wholesale prices were higher than Chinook or sockeye). Between 1933 and 1950, as a result of the combination of elimination of commercial harvest and restrained recreational harvest (depression, WWII), wild Puget Sound wild steelhead populations expanded rapidly in spite of increasing human population, continuing habitat degradation and dam construction;
2. Situk River (Alaska). From at least 1934 to 1939 canneries paid a bounty for wild steelhead, rainbow, and Dolly Varden on the astonishing assumption that elimination of these nuisance fish would boost sockeye populations. In 1934 alone, 143,000 of the combined targeted fish, including smolts, were killed. In 1940 the cannery quit funding the bounty and closed operations due to lack of sockeye. The efforts to eradicate steelhead included dynamite which, of course, also killed sockeye. This was followed by 10,000 military personnel during WW II stationed nearby resulting in further harvest of what remained. In 1948, another apparent attempt to kill steelhead and Dolly Varden occurred at the counting weir. Nevertheless, with the departure of soldiers and discontinuation of eradication efforts, the 1952 a weir count of steelhead enumerated 25,000-30,000. From the mid-1970s to 1994 steelhead sport harvest was gradually reduced to virtually zero. Steelhead increased in stages with high weir counts peaking at 12,000-15,000 steelhead in 2004-2007, a peak 10 times higher than from 1953-1981 after the Situk steelhead collapse, and likely even more dire levels of depletion during the period of attempted eradication in the 1930s and 1940s. This is from a river basin of only 77 sq. mi., similar to the Hoko, Tolt, or Dickey rivers of Washington.
3. Utkholok/Kvachina/Snotalvayam rivers (Kamchatka Russia). The Conservation Angler and Moscow State University along with scientific partners (Russian Academy of Sciences, Flathead Lake Biological Station, Washington State University, University of California – Davis, Washington Department of Fish & Wildlife, Oregon Department of Fish & Wildlife, NOAA, Wild Salmon Center) have conducted long-term study of native steelhead in these small watersheds 1994-present. These populations were listed as threatened as a result of commercial fishing. These steelhead populations had never been exposed to hatchery influences/interactions. As a result of our presence with accompanying fisheries enforcement officers, harvest was eliminated. On arrival in

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1994, each river supported runs of about 2,000 wild steelhead. Within 15 years those runs had expanded dramatically (25,000; 9,000; 7,000 respectively). Not only had the populations increased by 7-12 fold, all previously documented life-history variations were again represented in each river's population structure. Again, elimination of harvest was the only action taken to restore vibrant wild steelhead populations. These are small rivers with flow regimes comparable to perhaps the Tolt (Utkholok) or Pilchuck (Kvachina & Snotalvayam).

STEELHEAD-SEARUN CUTTHROAT COMPARISON

Throughout Puget Sound with the notable exceptions of Skagit and Nisqually, wild steelhead populations are in dire conditions. Many biologists attribute these declines to poor marine survival estuary-Port Angeles. In contrast to most steelhead populations, many, perhaps most, searun cutthroat populations appear to be stable and fairly robust. Both species spend similar periods of fresh and marine waters. There are no cutthroat hatchery releases and harvest is restricted to freshwater with a slot limit to protect maiden fish. What factors contribute to differential survival rates?

Each of the broad areas described above should help illuminate the consequences of different management paradigms and hatchery regimes for steelhead that may also be useful regarding other species. It is worth noting the Lake Washington sockeye peaked at about 750,000 adults, all natural origin. The projected Lake Washington sockeye return for 2019 is 15,000+/- in spite of massive sockeye hatchery program – hardly an endorsement of hatchery benefits.

MITIGATION STRATEGIES

Mitigation funding as compensation for dams blocking access has been allocated almost exclusively to hatchery programs of one sort or another such as trap and truck. In fact, this reliance on hatchery production as the dominant (often the only) "mitigation" strategy historically facilitated and encouraged dam building on the mainstem Columbia and Snake Rivers and elsewhere throughout the Pacific Northwest. Almost no consideration of alternative strategies or use of funds have been considered such as:

1. fish friendly flow/ramping regimes;
2. Ensuring that dams comply with fish passage laws and design standards;
3. ensuring dam operations comply with water permit standards (temperature, dissolved oxygen/nitrogen;

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4. trap and haul operations are extremely expensive, require facility modifications to facilitate juvenile migration ($300-$500 Million per facility), etc. Return rates for natural origin adults from these programs are hard to statistically distinguish from zero. Might not those huge financial expenditures associated with trap and haul programs re-introducing salmon/steelhead above dams be more beneficially used to fix culverts blocking access to high quality habitat; design, implementation, monitoring of different hatchery strategies; and so on?

Clearly, given the state of Washington's wild salmonid populations, continuing to operate massive hatchery release programs, mining wild brood stock to prop up hatchery programs, tinkering with trap and truck re-introduction above dams/barriers and continuing to authorize unsustainable sport and tribal and non-tribal commercial fisheries, undermine wild salmon and steelhead productivity and continue to threaten their recovery and long-term survival. These management operations have failed for the past 100+ years and none of the WSAS presenters provided any evidence that these or similar operations will now be effective.

It is past time for WDFW to take on a leadership role in developing a radically different management paradigm to promote recovery of healthy, abundant wild stocks. We suggest five important elements to address:

1. The failure of the hatchery production program for salmon and steelhead,
2. The need to work to eliminate the passage barriers (i.e. culverts) and create predation traps (physical structurers);
3. Re-think mitigation strategies beyond continuation of massive hatchery programs;
4. The need to change how the federal funding commitments are allocated to more appropriately to address what wild salmon, steelhead and trout need to be successful, and;
5. The need to re-configure the current heavy subsidy to the commercial and sport fishing industries to allow a transition to a wild fish future.

Thank you for your attention and consideration,

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Jack Stanford, Ph.D., professor emeritus and retired director, University of Montana Flathead Lake Biological Station;
James Lichatowich, retired AD, Oregon Department of Fish & Wildlife; author;
Rick Williams, Ph.D., independent consultant; author
Nick Gayeski, Ph.D., fisheries biologist, director conservation biology, Wild Fish Conservancy
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HATCHERY SALMON ARE DIFFERENT FROM AND HAVE IMPACTS ON WILD SALMON: OUOTES FROM THE SCIENTIFIC LITERATURE

Collected by Bill M. Bakke
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Allendorf et al. 1994: "We are not aware of a single empirical example in which (hatchery) supplementation has been successfully used as a temporary strategy to permanently increase abundance of naturally spawning populations of Pacific salmon."

Altukhov et al 1991: "Artificial reproduction, commercial fisheries, and transfers result in the impairment of gene diversity in salmon populations, and so cause their biological degradation."

Araki et al. 2007: "We show that genetic effects of domestication reduce subsequent reproductive capabilities by ~40% per captive-reared generation when fish are moved to natural environments. These results suggest that even a few generations of domestication may have negative effects on natural reproduction in the wild and that the repeated use of captive-reared parents to supplement wild populations should be carefully reconsidered."

Araki et al. 2008: "Captive breeding is used to supplement populations of many species that are declining in the wild. The suitability of and long-term species survival from such programs remain largely untested, however. We measured lifetime reproductive success of the first two generations of steelhead trout that were reared in captivity and bred in the wild after they were released. By reconstructing a three-generation pedigree with microsatellite markers, we show that genetic effects of domestication reduce subsequent reproductive capabilities by ~40% per captive-reared generation when fish are moved to natural environments. These results suggest that even a few generations of domestication may have negative effects on natural reproduction in the wild and that the repeated use of captive-reared parents to supplement wild populations should be carefully reconsidered."

"Our review indicates that salmonids appear to be very susceptible to fitness loss while in captivity. The degree of fitness loss appears to be mitigated to some extent by using local, wild fish for broodstock, but we found little evidence to suggest that it can be avoided altogether. The general finding of low relative fitness of hatchery fish combined with studies that have found broad scale negative associations between the presence of hatchery fish and wild population performance, should give fisheries managers pause as they consider whether to include hatchery production in their conservation toolbox."

"Accumulating data indicate that hatchery fish have lower fitness in natural environments than wild fish. This fitness decline can occur very quickly, sometimes following only one or two generations of captive rearing."

Araki, Hitoshi, Becky Cooper, and Michael S. Blouin. 2009. Carry-over effect of captive breeding reduces reproductive fitness of wild-born descendants in the wild. Biological Letters 5: (5) 621-624.

"Supplementation of wild populations with captive-bred organisms is a common practice for conservation of threatened wild populations. Yet it is largely unknown whether such programmes actually help population size recovery. While a negative genetic effect of captive breeding that decreases fitness of *captive-bred* organisms has been detected, there is no direct evidence for a carry-over effect of captive breeding in their *wild-born* descendants, which would drag down the fitness of the wild population in subsequent generations. In this study, we use genetic parentage assignments to reconstruct a pedigree and estimate reproductive fitness of the wild-born descendants of captive-bred parents in a supplemented population of steelhead trout (*Oncorhynchus mykiss*).

"The estimated fitness varied among years, but overall relative reproductive fitness was only 37 per cent in wild-born fish from two captive-bred parents and 87 per cent in those from one captive-bred and one wild parent (relative to those from two wild parents). Our results suggest a significant carry-over effect of captive breeding, which has negative influence on the size of the wild population in the generation after supplementation. In this population, the population fitness could have been 8 per cent higher if there was no carry-over effect during the study period.
"The F2 individuals compared in the study were all born in the same river, presumably experienced the same environment, and spawned in the river in the same year. Thus, genetic differentiation during captive breeding in the previous generation is most likely responsible for the reduced fitness of wild-born fish from hatchery parents. A strong genetic effect of captive breeding is consistent with the results of previous studies (Araki et al. 2007, 2008). However, this study also suggests a carry-over effect of the captive breeding, which reduces the reproductive fitness of wild-born descendants in the wild and the population fitness of subsequent generations."

<u>Araki and Schmid</u> 2010: "We summarized 266 peer-reviewed papers that were published in the last 50 years, which describe empirical case studies on ecology and genetics of hatchery stocks and their effects on stock enhancement. Specifically, we asked whether hatchery stock and wild stock differed in fitness and the level of genetic variation, and whether stocking affected population abundance. Seventy studies contained comparisons between hatchery and wild stocks, out of which 23 studies showed significantly negative effects of hatchery rearing on the fitness of stocked fish, and 28 studies showed reduced genetic variation in hatchery populations. None of these studies suggested a positive genetic effect on the fitness of hatchery-reared individuals after release.

"The answer to the question whether hatchery stocking is helpful or harmful to wild stock depends on the goal of the hatcheries, species and the cases. A major limitation in our knowledge is the link between the performance of hatchery fish in the wild and their influence on the stocked populations. Parentage analyses based on genetic methods seem useful to investigate this link. Until we find a way to mitigate the negative genetic impacts on wild stock, however, hatchery stocking should not be assumed as an effective remedy for stock enhancement."

<u>Bachman 1984:</u> "Hatchery brown trout fed less, moved more, and expended more energy than wild brown trout in streams."

Bacon, et al. 2015 Atlantic Salmon conservation stocking at the Girnock Burn was designed to reduce the overwinter mortality associated with poor in-redd survival (Malcolm et al. 2004, 2005) and the within-cohort competition associated with patchy spawning habitat (Webb et al. 2001b; Einum et al. 2008). The procedures were implemented under low stock sizes when spawner numbers were thought to be inadequate to maximize freshwater production. Under these conditions, the beneficial effects of stocking were expected to be large. However, this study found no beneficial effect of artificial incubation and stocking over and above natural processes.

Bams 1970: "Hatchery pink salmon migrated to the ocean one to two weeks earlier than wild pinks."

Berejikian and Ford 2004: "All of the studies we found for Scenarios 1 (nonlocal, domesticated hatchery stocks) and 4 (captive and farmed stocks) found evidence of highly reduced relative fitness for nonlocal, domesticated hatchery stocks, captive broodstocks, and farmed populations. We therefore conclude that it is reasonable to assume that steelhead, coho, and Atlantic salmon stocks in these categories will have low (<30%) lifetime relative fitness in the wild compared to native, natural populations."

Berntson et al. 2011. "Hatchery supplementation programs are designed to enhance natural production and maintain the fitness of the target population, however, the relative reproductive success (RRS) of hatchery-origin fish was 30–60% that of their natural-origin counterparts. There is acute interest in evaluating the reproductive performance of hatchery fish that are allowed to spawn in the wild.

"Despite the higher reproductive success for natural individuals, hatchery fish outnumbered natural ones by more than five to one, yielding an overall hatchery contribution to our offspring sample that was nearly twice that of natural fish… yet it is equally clear that hatchery-reared fish left fewer offspring per individual than their natural counterparts."

Bingham et al 2014: "We examined whether a supplementation program for steelhead *Oncorhynchus mykiss* in southwestern Washington could produce hatchery fish that contained genetic characteristics of the endemic population from which it was derived and simultaneously meet a production goal. Hatchery fish were produced for three consecutive years by using broodstock comprised of endemic juveniles that were caught in the wild and raised to maturity, and then the program transitioned to an integrated broodstock comprised of wild and hatchery adults that returned to spawn.

"Importantly, some auxiliary conservation-based husbandry protocols were attempted (i.e., pairwise mating between males and females) but not always completed due to insufficient broodstock and conflict between production and conservation goals.

"The hatchery met production goals in 6 of 9 years, but wild-type genetic integrity of hatchery fish was degraded every year.

"Specifically, we analyzed 10 microsatellites and observed a 60% reduction in the effective number of breeders in the hatchery.

Hatchery fish consequently displayed reduced genetic diversity and large temporal genetic divergence compared with wild counterparts. To ensure the benefit of conservation-based husbandry, spawning protocols should be based on scientific theory and be practical within the physical and biological constraints of the system. Finally, if conservation issues are considered to be the most important issue for hatchery propagation, then production goals may need to be forfeited.

"The goal of this study was to evaluate whether broodstock management at the AFTC hatchery maintained wild-type genetic characteristics in hatchery fish used to supplement the steelhead population in Abernathy Creek.

Blouin 2003: "Non-local domesticated hatchery summer-run steelhead achieved 17-54% the lifetime fitness of natural native fish."

Blouin 2009: "If anyone ever had any doubts about the genetic differences between hatchery and wild fish, the data are now pretty clear. The effect is so strong that it carries over into the first wild-born generation. Even if fish are born in the wild and survive to reproduce, those adults that had hatchery parents still produce substantially fewer surviving offspring than those with wild parents. That's pretty remarkable."

Blouin 2009: "The implication is that hatchery salmonids – many of which do survive to reproduce in the wild– could be gradually reducing the fitness of the wild populations with which they interbreed. Those hatchery fish provide one more hurdle to overcome in the goal of sustaining wild runs, along with problems caused by dams, loss or degradation of habitat, pollution, overfishing and other causes. Aside from weakening the wild gene pool, the release of captive-bred fish also raises the risk of introducing diseases and increasing competition for limited resources."

Blouin 2009: "There is about a 40% loss in reproductive fitness for each generation spent in a hatchery."

Blouin 2012: Rapid Adaptation to Captivity in Steelhead. We previously demonstrated that first- and second-generation hatchery steelhead from the Hood River have lower fitness in the wild than do wild fish, and that the difference between first- and second-generation fish is genetically based. Furthermore, wild-born fish have lower fitness if their parents were first-generation hatchery fish. The mechanism for these fitness declines has remained elusive, but hypotheses include: environmental effects of captive rearing, inbreeding among close relatives, relaxed natural selection, and unintentional domestication selection (adaptation to captivity). We used a multigenerational pedigree analysis to demonstrate that domestication selection can explain the precipitous decline in fitness observed in hatchery steelhead released into the Hood River, Oregon. After returning from the ocean, wild-born and first-generation hatchery fish were used as broodstock in the hatchery. First-generation hatchery fish had higher reproductive success (measured as the number of returning adult offspring) when spawned in captivity than did wild fish spawned under identical conditions, which is a clear demonstration of adaptation to captivity. We also documented a tradeoff among the wild-born broodstock: those with the greatest fitness in a captive environment produced offspring that performed the worst in the wild. These results demonstrate that a single generation in captivity can result in a substantial response to selection on traits that are beneficial in captivity but maladaptive in the wild. Circumstantial evidence points to crowding in the hatchery as a potential selective mechanism.

Bowles 2008: “Hatchery programs are not a substitute for, or an alternative to, achieving a viable wild population according to NOAA Fisheries' Hatchery Policy. Instead, any hatchery programs have to support natural production.”

“The threats to wild populations caused by stray hatchery fish are well documented in the scientific literature. Among the impacts are substantial genetic risks that affect the fitness, productivity and genetic diversity of wild populations. Genetic risks increase substantially when the proportion of the adult population that is hatchery fish increases over 5% (Lynch and O'Hely 2001, Ford 2002).”

“Hatchery programs also pose ecological risks to wild populations that can further decrease abundance and productivity (reviewed by Kostow 2008). The level of risk is related to both the proportion of the fish in a basin that are hatchery fish and to the source of the hatchery fish. Ecological risks due to the presence of hatchery adults (including adults of a different species) have been demonstrated when the proportion that is hatchery fish is over 10% (Kostow and Zhou 2006).

“In comparison to these risk levels, the proportion of adults in the Deschutes that are out-of-basin hatchery steelhead has been as high as 73%, while the proportion in the lower John Day has been as high as 30% (note that additional out-of-basin stray hatchery Chinook are also present in these basins and also may contribute to the ecological risks). Threats to productivity and genetic diversity are particularly critical when the hatchery fish originate from a substantial distance away from the natal basin of the wild population (Reisenbichler 1988, Waples 1995). This increased threat applies to the Deschutes and John Day populations since the stray hatchery fish are from a different DPS, primarily the Snake River DPS.”

“The recovery plan for Oregon populations in the Mid-Columbia Steelhead DPS found that out-of-basin hatchery strays are a primary threat to Deschutes River and John Day River steelhead populations (Carmichael et al. 2008). According to the recovery plan, the Mid-Columbia Expert Panel found, regarding these strays, that ‘The principal concern relates to a continuing detrimental impact of stray hatchery fish in natural spawning areas on the genetic traits and productivity of naturally produced steelhead’(Carmichael et al. 2007, section 8.1.2).”

“Origin of broodstock will not alleviate ecological hatchery risks (Kostow and Zhou 2006), and by itself it may not be enough to substantially reduce genetic risks.”

“While it is reasonable to expect that a substantial decrease in hatchery fraction would contribute to recovery, the proposed hatchery actions for most of the populations are just a change in broodstock. A population that is supported by a hatchery program is not "trending toward recovery" until the hatchery influence can be removed and the wild population is demonstrated to be self-sustaining without it.”

Brannon et al. 1999: (Independent Scientific Advisory Board) : “The three recent independent reviews of fish and wildlife recovery efforts in the Columbia River Basin addressed hatcheries. There was consensus among the three panels (National Fish Hatchery Review Panel, National Research Council, Independent Science Group), which underscores the importance of their contributions in revising the scientific foundation for hatchery policy. The ten general conclusions made by the panels are listed below.

1. Hatcheries generally have failed to meet their objectives
2. Hatcheries have imparted adverse effects on natural populations
3. Managers have failed to evaluate hatchery programs
4. Rationale justifying hatchery production was based on untested assumptions.
5. Hatchery supplementation should be linked with habitat improvements
6. Genetic considerations must be included in hatchery programs.
7. More research and experimental approaches are required.
8. Stock transfers and introductions of non-native species should be discontinued.
9. Artificial production should have a new role in fisheries management.
10. Hatcheries should be used as temporary refuges rather than for long-term production.

Braun et al. 2015: “While we found that genetic differences among populations and life history diversity are correlated with asynchrony and response diversity, human impacts on salmon populations, including dams (McClure et al. 2008a), hatcheries and fishing (McClure et al. 2008b), continue to erode biological diversity in salmon populations (Waples et al. 2009). For example, the dynamics of populations impacted by dams and hatcheries are becoming increasingly synchronous (Moore et al. 2010, Carlson and Satterthwaite 2011).”

Braun, Douglas C., Jonathan W. Moore, John Candy and Richard E. Bailey. 2015. Population diversity in salmon: linkages among response, genetic and life history diversity. Ecography 38: 001–012, 2015

Brauner 1994: “In freshwater swimming velocity tests, wild coho salmon smolts swam faster than hatchery fish. In seawater hatchery fish performance compared to wild fish was poor. Hatchery fish had more difficulty osmoregulating.”

Briggs 1953: ““It was possible to obtain some indications of the efficiency of artificial propagation through information supplied by state and federal agencies engaged in fish cultural operations in the three Pacific coast states and in New Zealand. For the portion of the life cycle up to the free-swimming fry stage, the survival of individuals was computed, beginning with the eggs which were brought upstream by the mature females. Utilizing the small amount of information available, a crude percentage survival was calculated as follows: Silver salmon, 58.5; king salmon, 65.1, and steelhead trout, 47.8 percent. These percentages may be compared to the survival data for the same three species under natural conditions in Prairie Creek: Silver salmon, 74.3; king salmon, 86.0, and steelhead trout, 64.9 percent. Therefore, there is no doubt that, during the period of study, substantially more young fish were introduced as fry into Prairie Creek via natural propagation than could be supplied through standard hatchery methods utilizing the entire run in the creek.

Buhle et al. 2009: "Our analyses highlight four critical factors influencing the productivity of these populations: (1) negative density-dependent effects of hatchery-origin spawners were ~5 times greater than those of wild spawners; (2) the productivity of wild salmon decreased as releases of hatchery juveniles increased; (3) salmon production was positively related to an index of freshwater habitat quality; and (4) ocean conditions strongly affect productivity at large spatial scales, potentially masking more localized drivers. These results suggest that hatchery programs' unintended negative effects on wild salmon populations, and their role in salmon recovery, should be considered in the context of other ecological drivers."

"We found that wild populations of Oregon coast coho salmon responded to changing hatchery practices during the 1990s. Productivity, expressed as the per capita growth rate in the absence of harvest, improved with reductions in the density of hatchery origin fish spawning in the wild and the numbers of hatchery smolts released into rivers. The strongest negative effects of hatcheries were associated with hatchery-reared adults breeding in the wild, precisely the pathway that might be expected to contribute most to population rebuilding."

Byrne et al. 1992: "Building more hatcheries should cause alarm to biologists concerned with the preservation of native stocks until it is demonstrated that supplementation can be done in a way that does not reduce fitness of the native stock."

"It is unlikely that hatchery propagation, no matter how enlightened, can optimize traits necessary for the long-term survival of steelhead in a natural stream."

"In most scenarios, supplementation of native stocks with hatchery fish caused replacement, not enhancement, of native fish.

The present-day approach to real or perceived deficits of steelhead abundance—building more hatcheries—should cause alarm to biologists concerned with the preservation of native stocks until it is demonstrated that supplementation can be done in a way that does not reduce the fitness of the native stock.

Campton et al. (1991) challenged the computational methods of Chilcote et al. (1986) for determining reproductive success. When Campton et al. reanalyzed the data, they found that hatchery adults produced only 15% as many smolts per female as did wild fish. This finding still supported the conclusion of Chilcote et al. (1986), which stated that hatchery steelhead had lower reproductive success than did wild fish.

Byrne and Copeland 2012: "Given the SAR (smolt to adult survival) rates measured during the study period and plausible over-winter survival rates in the study streams, we predicted that the observed juvenile production would produce few adults and would not result in a self-sustaining population. This conclusion was corroborated by adult return data. We found no evidence that adult outplanting increased wild population levels, i.e., there was no demographic boost in adult spawners. Further, the differences between the two study streams showed that supplementation programs should carefully assess each target stream.

"Even the most well-planned supplementation programs may have unpredictable consequences and should be carefully monitored to avoid negative effects (Naish et al. 2008). Unfortunately, evaluations of *ad hoc* adult outplant programs are seldom done. Decisions to introduce hatchery reared adults for spawning in the wild should be based on the needs of the target population and the ability of the habitat to support additional reproduction and rearing (ISAB 2002)."

<u>Caroffino, David C. et al. 2008:</u> "Through genetic monitoring of two-year classes, we determined that hatchery adults produced 1.3-6.2 times as many age-2 juveniles per female than naturally spawning fish. Survival of stocked fry of parents born in a hatchery relative to those of parents born in the wild was 70% in paired-stocking comparisons. These results suggest that stocking local-origin fry can increase the short-term abundance of depleted populations and that fish with no hatchery history are a better source for supplemental stocking. Additionally, sampling small numbers of adults for broodstock created genetically distinct groups, which could potentially cause long-term genetic change to the population. Genetic monitoring of adults will be essential to determining whether differences observed persist through the life cycle of the stocked fish."

<u>Chilcote et al. 1986:</u> "The success of hatchery fish in producing smolt offspring was only 28% of that for wild fish. We also found that 62% of the naturally produced summer-run smolts were offspring of hatchery spawners. Their dominance occurred because hatchery spawners within the watershed we examined effectively outnumbered wild spawners by at least 4 .5 to 1. We suggest that, under such conditions, the genetic integrity of wild populations may be threatened."

<u>Chilcote 2002</u>: Based upon a multiple regression analysis, recruitment and productivity in 12 naturally reproducing populations of Oregon steelhead were found to be significantly influenced by four variables, one of which was the level of hatchery fish in the spawning population. It appeared that the presence of hatchery fish depressed overall population productivity, reduced the number of recruits, and lowered the fitness of wild fish. This negative effect was insensitive to the type of hatchery fish. Although hatchery fish represented in five of the study populations were from hatchery broodstocks developed from local wild populations and managed in a manner to avoid domestication, the advantages of this strategy were not apparent. The negative effect of hatchery fish on natural production was not trivial. For example, in a mixed population where hatchery fish comprised 30% of the spawning population, the number of recruits produced was 1/3 less than in a population comprised entirely of wild fish. A variety of supplementation simulations, based upon these findings, demonstrated that the recruitment response of natural populations to the addition of naturally spawning hatchery fish was very weak and carried the additional penalty of reducing the genetic fitness of the wild fish. Various genetic and non-genetic explanations for these results were explored, including the consequences of reduced genetic diversity in hatchery populations as a result of having fewer families than would be found for a wild population of similar size. The management implications of these results are that hatchery steelhead, regardless of their broodstock type, are poor substitutes for wild fish in their natural environments. The addition of hatchery spawners to the natural environment does

not appear a useful tool for rebuilding depressed populations of wild steelhead. These results support the view that hatchery programs should be managed to minimize the number of hatchery fish that spawn and rear in natural habitats.

Chilcote 2002: "…there will be little benefit to bringing some of the wild fish into the hatchery environment if the resulting hatchery smolts will have ocean survival rates that are 1/10 of those for wild smolts….all indications are that hatchery fish, even from wild broodstocks, are not as successful as wild fish in producing viable offspring under natural conditions…."

Chilcote 2003: "Naturally spawning population comprised of equal numbers of hatchery and wild fish would produce 63% fewer recruits per spawner than one comprised entirely of wild fish. For natural populations, removal rather than addition of hatchery fish may be the most effective strategy to improve productivity and resilience."

Chilcote 2008**: "**At a recent meeting of lower Columbia River Salmon Recovery Stakeholders, the document, *Recovery Strategies to Close the Conservation Gap Methods and Assumptions,* hatchery fish impacts are discussed. It says, "…relative population survival rates (recruits produced per spawner) were found to decrease at a rate equal to or greater than the proportion of hatchery fish in the natural spawning population. In other words, a spawning population with 20% hatchery strays (regardless of the type of hatchery program and whether they are integrated or segregated) had the net survival rate (recruits per spawner) that was 20% less than a population comprised entirely of wild fish (0% hatchery strays). Likewise, a population with 40% hatchery strays had a population survival rate that was 40% lower than a population comprised entirely of wild fish."

Chilcote et al. 2011, 2013: "We found a negative relationship between the reproductive performance in natural populations of steelhead, coho, and Chinook salmon and the proportion of hatchery fish in the spawning population. We used intrinsic productivity as estimated from fitting a variety of recruitment models to abundance data for each population as our indicator of reproductive performance. The magnitude of this negative relationship is such that we predict the recruitment performance for a population comprised entirely of hatchery fish would be 0.128 of that for a population comprised entirely of wild fish. The effect of hatchery fish was the same among all three species. Further, the impact of hatchery fish from 'wild type' hatchery broodstocks was no less adverse than hatchery fish from traditional, domesticated broodstocks. We also found no support for the hypothesis that a population's productivity was affected by the length of exposure to hatchery fish. In most cases, measures that minimize the interactions between wild and hatchery fish will be the best long-term conservation strategy for wild populations."

Christie et al. 2011: "These results demonstrate that a single generation in captivity can result in a substantial response to selection on traits that are beneficial in captivity but severely maladaptive in the wild. We also documented a tradeoff among the wild-born broodstock: Those with the greatest fitness in a captive environment produced offspring that performed the worst in the wild."

Christie et al. 2014: Here, we review recent studies on the reproductive success of such 'early-generation' hatchery fish that spawn in the wild. Combining 51 estimates from six studies on four salmon species, we found that

(i) early-generation hatchery fish averaged only half the reproductive success of their wild-origin counterparts when spawning in the wild,

(ii) the reduction in reproductive success was more severe for males than for females, and

(iii) all species showed reduced fitness due to hatchery rearing. We review commonalities among studies that point to possible mechanisms (e.g., environmental versus genetic effects).

Furthermore, we illustrate that sample sizes typical of these studies result in low statistical power to detect fitness differences unless the differences are substantial. This review demonstrates that reduced fitness of early-generation hatchery fish may be a general phenomenon. Future research should focus on determining the causes of those fitness reductions and whether they lead to long-term reductions in the fitness of wild populations.

Christie et al. 2016: "…we measured differential gene expression in the offspring of wild and first-generation hatchery steelhead trout (Oncorhynchus mykiss) reared in a common environment. Remarkably, we find that there were 723 genes differentially expressed between the two groups of offspring.

We find that there are hundreds of genes that are differentially expressed (DE) between the offspring of wild fish (WxW) and of the offspring of hatchery fish (HxH) reared in a common environment. By using reciprocal crosses, we further show that these differences in gene expression cannot be explained as maternal effects, sampling noise, or false discovery. Thus, our data suggest that the very first stages of domestication are characterized by massive, heritable changes to gene expression. That the DE genes were dominated by pathways in wound repair, immunity and metabolism adds to growing evidence that adaptation to crowded conditions is an important early stage of domestication.
The large extent of divergence that occurs at the gene-expression level, but not at the genomic level, suggests that selection and not genetic drift is responsible for the large differences in expression detected between the offspring of wild and first-generation hatchery fish.

"Taken together, these results suggest that rearing density may play an important role in facilitating genetic adaptation to captivity, and that adjusting to large numbers of conspecifics may be an important first step towards domestication.

"O. mykiss are one of the few fish species considered to have been fully domesticated. Phenotypic responses to selection routinely occur in this species with less than ten generations of captive breeding. However, this is the first study to demonstrate that the earliest stages of domestication are characterized by large changes in heritable patterns of gene expression. As subsequent generations of domestication accrue, we speculate that the regulatory changes to expression become codified with gradual and more targeted shifts in allele frequencies (for example, selective sweeps). We hypothesize that adaptation to crowded conditions may drive much of this early domestication. Regardless of the mechanism, it is remarkable that a single generation of domestication can translate into heritable differences in expression at hundreds of genes.

de Eyto et al. 2016: "In Burrishoole, the most important determinant of freshwater survival of salmon was the deleterious effect of hatchery fish in the spawning cohort for salmon. While stocking is seen by many as a possible management action to conserve and bolster stocks, evidence continues to mount that where a wild population is present, and habitat is available, stocking is misguided."

Dickson 1982: "Juvenile hatchery fish show a behavioral shift in stream feeding position compared to wild fish. Hatchery fish feed nearer the surface. This may expose them to greater predation."

Ersbak et al. 1983: "Hatchery trout conditions declined after stocking. Hatchery fish were less flexible in switching to available food in the stream."

Fenderson, 1968: "Hatchery fish are more aggressive and dominate wild fish, and hatchery fish have a higher mortality."

Flagg and Nash, 1999: "The reviews conclude that artificial culture environments condition salmonids to respond to food, habitat, conspecifics and predators differently than fish reared in natural environments. It is now recognized that artificial rearing conditions can produce fish distinctly different from wild cohorts in behavior, morphology, and physiology."

Fleming and M.R. Gross 1993: "The divergence of hatchery fish in traits important for reproductive success has raised concerns. This study shows that hatchery coho salmon males are competitively inferior to wild fish and attained only 62% of the breeding success of wild males. Hatchery females had more difficulty in spawning than wild fish and hatchery fish had only 82% of the breeding success of wild fish. These results indicate hatchery fish may pose an ecological and genetic threat to wild fish."

Fleming et al. 1994: "Results of this study imply that hatchery fish have restricted abilities to rehabilitate wild populations and may pose ecological and genetic threats to the conservation of wild populations."

Fleming et al. 1997: "Reproductive success defined in the study as the ability to produce viable eyed embryos did not differ between hatchery and natural females. Hatchery males, however, achieved only 51% the estimated relative reproductive success of natural males under conditions of mutual competition. Hatchery males were less able to monopolize access to spawning females and suffered more severe wounding and greater mortality than natural males."

Fleming and Einum 1997: "Our results thus indicate that the farming of Atlantic salmon can generate rapid genetic change in fitness related traits as a result of domestication due to intentional and unintentional selection. As much of this change appears to be an adaptive response to the culture environment, it can be of value for programmes attempting to improve aquaculture production (e.g. Doyle *et al.*, 1991). This change, however, is a threat to wild populations when these fish escape and compete and breed with wild salmon. The invasion of escaped farmed salmon into rivers not only increases competition for resources, but also results in the infusion of different genetic traits into wild populations. Many of these traits are likely to be maladaptive for the local environment both because of the non-indigenous origins of the farmed salmon (Einum and Fleming, 1997) and because of the changes that have occurred due to culturing. While natural selection may be able to purge wild populations of such maladaptive traits, its actions are severely hindered by the year-after-year introgression of farmed salmon. The net result is almost certainly a decline in population fitness, as the influence of selection from the culture environment overrides that in the wild."

<u>Fleming et al. 2000:</u> "The farm fishes were competitively and reproductively inferior, achieving less than one–third the breeding success of the native fishes. However, evidence of resource competition and competitive displacement existed as the productivity of the native population was depressed by more than 30%. Ultimately, the lifetime reproductive success (adult to adult) of the farm fishes was 16% that of the native salmon. Our results indicate that such annual invasions have the potential for impacting on population productivity, disrupting local adaptations and reducing the genetic diversity of wild salmon populations."

<u>Flick, et al. 1964:</u> "Wild brook trout had higher summer and winter survival than hatchery fish."

<u>Ford, 2002</u>: "Substantial phenotypic changes and fitness reductions can occur even if a large fraction of the captive broodstock is brought in from the wild every generation. This suggests that regularly bringing wild-origin broodstock into captive populations cannot be relied upon to eliminate the effects of inadvertent domestication selection."

<u>Ford 2010</u>: "What is known from peer-reviewed scientific studies on the impact of hatchery salmonids on wild salmonids? Hatchery fish reproductive success is poor; there is a large scale negative correlation between the presence of hatchery fish and wild population performance; hatchery fish reproductive success is lower than for wild fish and this is true for both supplementation and production hatchery programs; there is evidence of both environmental and heritable effects; effects were detected for both release and proportion of hatchery spawners; negative correlations between hatchery influence and wild productivity are widespread; habitat or ocean conditions do not appear to explain the pattern; current science indicates that limiting natural spawning of hatchery fish is generally beneficial to wild populations; there is evidence that reducing hatchery production leads to increased wild production, and cumulative effects of hatchery could be a factor limiting recovery of some ESUs."

<u>Harnish, 2014</u>: 33 Summer Steelhead smolts residualized in the river making it 12.8% of the release group of 164. This represents 23,616 residual hatchery steelhead if applied to the number released. Hatchery summer steelhead dominated 16 of 19 (84%) of the interactions. 61.7% of all interactions observed were initiated by hatchery steelhead. Hatchery steelhead initiated more aggressive interactions than wild steelhead. We believe residualization is a problem in the South Santiam River due to the large numbers of residual hatchery summer steelhead observed.

<u>Hilborn 1992:</u> "Pacific salmon hatcheries have failed to deliver expected benefits and they pose the greatest single threat to the long-term maintenance of salmonids."

<u>Hjort and Schreck 1982</u>: "The results of this study also suggest a potential weakness in hatchery supplementation. Selection through hatchery environment and hatchery practices may be changing the overall phenotype of hatchery stocks, as well as the between-year variability of individual genotypes (as we found for transferrin). If these changes result in reduced performance of the donor stocks in other stream systems, practices designed to increase hatchery production must be weighed against the actual benefits to wild production."

<u>Hulett et al. 1994</u>: "Hatchery winter steelhead were about one-half as effective as wild winter-run steelhead in naturally producing smolt offspring. Hatchery winter steelhead were about one sixth as effective as wild winter steelhead in naturally produced adult offspring."

<u>Independent Economic Advisory Board (IEAB) 2002</u>: "Augmentation and mitigation hatcheries, which seek to enhance fish harvests, can be judged by the cost incurred per additional fish harvested. The costs per harvested hatchery fish ranged from $23 for Priest Rapids fall chinook, to $55 per Spring Creek fall chinook, to $453 for Irrigon hatchery summer steelhead, to $1,051 for McCall summer chinook, to $4,800 - $68,031 at the Leavenworth hatchery complex."

Hatchery	**Species Produced**	**Cost of a Salmon that is caught**
Leavenworth	spring chinook	$4,800
Entiat	spring chinook	$68,031 (Highest $891,000)
Winthrop	spring chinook	$23,068
Priest Rapids	fall chinook	$12.00 (Highest - $293)
Irrigon	summer steelhead	$453
Spring Cr.	fall chinook	$237 (range 14.53 - $460)
Clatsop	coho	$124
	Spring chinook	$233
	Fall chinook	$65
Nez Perce	fall and spring chinook	$3,700
McCall	spring chinook	$786 (range $522 to $1,051)

"The benefit of the fishery is $45 to $77 per fish for the commercial fishery and $60 per fish for the sport fishery"

ISAB 2002. "We believe that available empirical evidence demonstrates a potential for deleterious interactions, both demographic and genetic, from allowing hatchery-origin salmon to spawn in the wild. Because it is virtually impossible to 'undo' the genetic changes caused by allowing hatchery and wild salmon to interbreed, the ISAB advocates great care in permitting hatchery-origin adult salmon to spawn in the wild."

ISRP 2011: ". The BACI analysis found that productivity in the Imnaha River had decreased relative to all nine unsupplemented sites. The ISRP concludes that a conservation benefit in terms of NOR abundance is unlikely from supplementation. Based on the analysis of productivity loss in the Imnaha River, the ISRP concludes that costs to population fitness are likely.

"Hatchery-origin adults spawning in the stream produced parr at slightly higher rates than natural-origin fish (1.03:1), produced smolts at an equal rate (1:1), but produced adults at a lower rate (0.77:1)."

"The supplementation projects as they are currently conducted with high proportions of hatchery fish in the hatchery broodstock and on the natural spawning grounds are likely compromising the long-term viability of the populations."

"Over the long-term, however, hatchery-dominated programs that are implemented to reduce extinction risk will result in genetic changes owing to domestication selection and drift that are likely to offset any demographic benefit."

Johnson et al. 2013: "Our findings of genetic introgression suggest that temporospatial overlap can occur between naturally spawning summer and winter steelhead in upper Willamette River subbasins, and that assortative mating and current management have not entirely prevented hybridization between native and introduced *O. mykiss* stocks. Interbreeding with hatchery summer steelhead could lower the fitness of native UWR winter steelhead, as hatchery-reared Skamania stock summer steelhead have low fitness in the wild (Chilcote et al. 1986; Kostow et al. 2003; Leider et al. 1990)."

Jonsson et al. 1993: "Differences were evident for hatchery Atlantic salmon relative to wild salmon, with common genetic backgrounds, in breeding success after a single generation in the hatchery. Hatchery females averaged about 80% the breeding success of wild females. Hatchery males had significantly reduced breeding success, averaging about 65% of the success of wild males."

Jonsson and Jonsson 2002: "During the past 150 years, (hatchery) enhancement and supplementation have become essential parts of salmonid management. Interaction is likely to have a negative effect on the viability of wild populations."

Kliess 2004: "Salmonid management based largely on hatchery production, with no overt and large-scale ecosystem-level recovery program, is doomed to failure. Not only does it fail to address the real causes of salmonid decline, but it may actually exacerbate the problem and accelerate the extinction process."

Knudsen et al. 2006. "Perhaps the most important conclusion of our study is that even a hatchery program designed to minimize differences between hatchery and wild fish did not produce fish that were identical to wild fish."

Knudsen et al. 2008: "Consequently, in this project, on a per capita basis hatchery-origin female are a minimum of 6-7% less fit than wild fish owing to lower fecundity. This demonstrates that hatcheries do not produce fish that are identical to wild fish."

Kostow 2003: "Our data support a conclusion that hatchery summer steelhead adults and their offspring contribute to wild steelhead population declines through competition for spawning and rearing habitats. We conclude that even though naturally spawning hatchery steelhead may experience poor reproductive success, they and their juvenile progeny may be abundant enough to occupy substantial portions of spawning and rearing habitat to the detriment of wild fish populations. Therefore, the large numbers of introduced summer steelhead would have competed heavily with wild winter steelhead for habitat resources, and this may have contributed to their decline. In the Clackamas basin, smolt offspring of hatchery fish appear to have wasted the production from natural habitat because very few return as adults." (emphasis added)

Kostow 2004: "In conclusion, this study demonstrated large average phenotype and survival differences between hatchery-produced and naturally produced fish from the same parent gene pool. These results indicate that a different selection regime was affecting each of the groups. The processes indicated by these results can be expected to lead to eventual genetic divergence between the new hatchery stock and its wild source population, thus limiting the usefulness of the stock for conservation purposes to only the first few generations."

Kostow and Zhou 2006: "In the Clackamas River basin, the summer steelhead hatchery adults had poor reproductive success; fewer smolts were produced per parent than in the wild population, and almost no offspring of hatchery fish survived to adulthood (Kostow et al. 2003). The hatchery program was meant to provide a sport fishery, and the production of adult offspring was not intended. If successful hatchery reproduction had occurred, at least the offspring could have contributed to fisheries. Instead, the hatchery fish wasted basin capacity by occupying habitat and depressing wild production while producing nothing useful themselves. It is not unusual for hatchery adults to have poor reproductive success when they spawn naturally (other examples are provided by Reisenbichler and Rubin 1999, Kostow 2004, and McLean et al. 2004). The combined effect of poor hatchery fish fitness and depressed wild fish production due to competition with the hatchery fish poses a double jeopardy that could quickly erode natural production in any system."

Lapointe, Nicolas: "Consider stocking programs, many of which ignore regional genetic variation and local adaptation (Philipp et al. 1993; Hendry et al. 2011). The resultant mixing of previously isolated populations causes rapid homogenization of previously distinct gene pools and can lead to the loss of local adaptation (Campton 1987; Thornhill 1993). Hatcheries can be a major culprit here, as fishes evolve rapidly under hatchery selection, even when such selection is unintentional (Araki et al. 2008). Understanding the potential for genetic adaptation is increasingly important in the face of rapidly changing environments, as driven by climate change and other alterations to habitat (e.g., Somero 2010).

Leider, et. al., 1990: "The mean percentage of offspring from naturally spawning hatchery steelhead decreased at successive life history stages, compared to wild steelhead, from a potential of 85-87% at the egg stage to 42% at the adult stage. Reproductive success of naturally spawning hatchery steelhead compared to wild steelhead decreases from 75-78% at the subyearling stage to 10.8-12.9% at the adult stage."

Levings, et al., 1986: "Hatchery chinook used the estuary a shorter period of time than wild chinook. The greatest overlap between hatchery and wild chinook in the estuary is in the transition zone where greater competition could occur."

Lynch and O'Hely 2001: "Our results suggest that the apparent short-term demographic advantages of a supplementation program can be quite deceiving. Unless the selective pressures of the captive environment are closely managed to resemble those in the wild, long-term supplementation programs are expected to result in genetic transformation that can eventually lead to natural population no longer capable of sustaining themselves."

Marchetti and Nevitt. 2003: "Our work may suggest a mechanistic basis for the observed vulnerability of hatchery fish to predation and their general low survival upon release into the wild. The brains of hatchery raised rainbow trout are smaller in 7 out of 8 critical neuroanatomical measures than those of their wild reared counterparts. Our results are the first to highlight the effects of hatchery rearing on changes in brain development in fishes."

Mason, et al., 1997: "Hatchery x wild and wild x wild crosses had higher survival in the natural stream compared to hatchery x hatchery crosses."

McClure et al. 2008: "Continued interbreeding with hatchery-origin fish of lower fitness can lower the fitness of the wild population. Generally, large, long-term hatchery programs that dominate production of a population is a high-risk factor for certain viability criteria and can lead to increased risk for the population. The populations meeting 'high viability' criteria will necessarily be large and spatially complex. In order to meet these criteria (spatial structure and diversity) there should be little or no introgression between hatchery fish and the wild component of the population. Populations supported by hatchery supplementation for more than three generations do not in most cases meet ICTRT viability criteria at the population level."

"Artificial propagation does not contribute to increased natural productivity needed for viability, and appears in most cases, to erode productivity of wild populations."

McLean et al. 2004: "Hatchery steelhead spawning in the wild had markedly lower reproductive success than native wild steelhead. Wild females that spawned in 1996 produced 9 times as many adult offspring per capita as did hatchery females that spawned in the wild. Wild females that spawned in 1997 produced 42 times as many adult offspring as hatchery females. The wild steelhead population more than met replacement requirements (approximately 3.7 – 6.7 adult offspring were produced per female), but the hatchery steelhead were far below replacement (<0.5 adults per female)."

McMichael et al. 1997: "Our results indicate that residual hatchery steelhead reduced the growth of wild resident rainbow trout during summer under controlled conditions. We infer that when hatchery steelhead become residuals, thus increasing local densities of salmonids for extended periods, the growth of sympatric wild rainbow trout growth is likely to decrease. A reduction in size, due to slower growth during the summer, could decrease overwinter survival (Hunt 1969; Toneys and Coble 1979, 1980; Oliver and
Holeton 1979), resulting in decreased population size (Cunjak et al. 1987).

McMichael et al. 1999: "Hatchery steelhead behaviorally dominated wild O. mykiss in most situations. Hatchery steelhead were generally larger and behaved more aggressively and violently than wild fish, which may have contributed to their dominant status.

"Our study confirmed that releases of conventionally reared hatchery steelhead can pose ecological risks to preexisting wild populations.

"Acknowledging that releases of hatchery salmonids may affect preexisting wild salmonid populations
is an important step toward protection and recovery of imperiled populations of wild anadromous salmonids. Thorough evaluation of current hatchery programs and implementation of rigorous monitoring programs should be required in watersheds where depressed stocks of wild salmonids occur, even though these precautions will not ensure that wild stocks are protected or restored (Waples 1999)."

Meffe 1992: "Countless salmon stocks have declined precipitously over the last century as a result of overfishing and widespread habitat destruction. A central feature of recovery efforts has been to build many hatcheries to produce large quantities of fish to restock streams. This approach addresses the symptoms but not the causes of the declines."

Miller, R. B. 1953: "Hatchery cutthroat trout had lower survival compared to wild fish due to absence of natural selection at early life stages."

Miller, W. H. et al. 1990: "Over 300 (hatchery) supplementation projects were reviewed and the authors found: 1) examples of success at rebuilding self-sustaining anadromous fish runs with hatchery fish are scarce (22 out of 316 projects reviewed), 2) success was primarily from providing fish for harvest, and 3) adverse impacts to wild stocks have been shown or postulated for every type of hatchery fish introduction to rebuild runs."

Miller L. M. 2004: "We have documented an early life survival advantage by naturalized populations of anadromous rainbow trout *Oncorhynchus mykiss* over a more recently introduced hatchery population and outbreeding depression resulting from interbreeding between the two strains. Averaging over years and streams, survival relative to naturalized offspring was 0.59 for hybrids with naturalized females, 0.37 for the reciprocal hybrids, and 0.21 for hatchery offspring. Our results indicate that naturalized rainbow trout are better adapted to the conditions of Minnesota's tributaries to Lake Superior so that they outperform the hatchery-propagated strain in the same manner that many native populations of salmonids outperform hatchery or transplanted fish. Continued stocking of the hatchery fish may conflict with a management goal of sustaining the naturalized populations.

Miller L. M. et al. 2014: "Reduced reproductive success of hatchery fish spawning in the natural environment will reduce the ability of stocking programs to enhance wild populations. The reproductive success of hatchery females was significantly lower than that of wild females (approximately 60%) in all three study years; however, the reproductive success of hatchery males was only significantly lower in one year. Continued reliance on hatchery supplementation may hinder achievement of the long-term goal of a fishery supported largely by naturally reproducing populations."

Mobrand et al. 2005: "We concluded that hatcheries must operate in new modes with increased scientific oversight and that they cannot meet their goals without healthy habitats and self-sustaining naturally-spawning populations."

Moore et al. 2010: For a group of spatially distinct populations, synchrony in population dynamics can increase risk of simultaneous and global extinction. In contrast asynchronous population dynamics decrease extinction risk and may increase sustainability of long-term production from groups of populations. Pacific salmon exhibit fine-scale population structure and local adaptation to their natal habitats which likely contributes to asynchrony in population dynamics… artificial propagation programs may increase dispersal among populations, eliminating locally adapted life history variation. We document increased demographic synchrony among Chinook salmon populations within the Snake River region over the last 40 years, concurrent with increased intensity of human impacts…synchronization of Snake River salmon has compromised its performance. Management of spatially structured species can benefit from explicit consideration of population diversity.

"There was not only an increase in synchronization, but there was also a decrease in population productivity, further reducing portfolio (number of locally adapted stocks) performance.

"Chinook salmon populations within the Snake River Evolutionarily Significant Unit have become more synchronized; over 75% of the populations increased in synchrony over the last four decades.

"…hatchery releases, which increased substantially during the study period are associated with increased straying and decreased population structure. In addition, dams homogenize habitats and flow regimes, leading to the loss of habitat variability that maintains salmonid population diversity.

"Regardless of the underlying mechanisms, the observed increase in population synchrony has major conservation implications. First, the theory predicts that increased synchrony will increase extinction risk for the entire meta-population, which has already been identified as having a substantial risk of extinction.

"Improve salmon and steelhead management by 1) "Include population diversity as a goal for recovery; 2) Preserve the diverse habitats and natural processes that maintain response diversity. Preserving variable landscapes and the physical processes that maintain habitat variation will help maintain the different environmental conditions supporting adaptation and response diversity of phenotypic traits such as timing of migration and spawning; 3) Adjust artificial propagation programs to manage for response diversity. Reducing artificially inflated straying rates, using locally derived brood stock, and ensuring that hatchery-origin spawners are not overly represented on spawning grounds; 4) Manage harvest…to avoid depleting low productivity populations; 5) Monitoring should not just focus on currently productive populations but also include lower productivity populations."

Moran and Waples 2007: "…we show some compelling differences in reproductive success of hatchery and wild fish. Naturally spawning hatchery fish are less than half as productive as wild fish."

Mullan, "Mean hatchery spring chinook smolt to adult survival ranged from 0.16 to 0.55%, 1976-1988 compared to wild spring chinook survival rate of from 1.6 to 8.1%. Naturally produced smolts were about 10 – 80 times as viable as hatchery smolts."

Naish et al. 2008: "If one concern has been identified, it is that many hatchery programmes continue to be operated with few objectives, and with a poor understanding of the magnitude and importance of the impacts of genetic effects of hatchery releases and the role of this information in informing remedial actions."

"A rapidly growing body of literature points towards detrimental behavioural interactions between hatchery and wild fish. More is known about these interactions in freshwater rearing habitats than in estuarine and marine environments. There is also, however, a paucity of information on whether risk avoidance measures are effective at reducing competition and predation and, as far as we know, little attention is directed towards carrying capacity when the size of release is considered."

Naylor et al. 2005: "Interbreeding between wild and farmed fish can result in mixing gene pools if the hybrids can reproduce, and eventually can lead to a wild population composed entirely of individuals descended from hatchery fish. In a Norwegian study (Fleming et al. 2000), 55% of hatchery salmon in the experimental spawning population contributed 19% of the genes to adult fish in one generation later. Continued one-way gene flow at this rate would halve the genetic difference between hatchery and wild salmon every 3.3 generations and lead to rapid genetic homogenization."

Naylor et al. 2005: "In McGinnity and colleagues' (2003) recent farm release study in Ireland, the lifetime success of hybrids was only 27% to 89% as high as that of their wild cousins, and 70% of the embryos in the second generation died. These results provide strong evidence of how interbreeding might drive vulnerable salmon populations to extinction."

Naylor et al. 2005: "Aggressive farm and hybrid fish can also result in shifts of wild counterparts to poorer habitats, increasing mortality. The productivity of the native juvenile salmon population was depressed by more than 30% in the presence of farm and hybrid juveniles."

Naylor et al. 2005: "An earlier review (Hindar et al. 1991) of the genetic effects following releases of nonnative salmonids reached two broad conclusions. First, the genetic effects of intentionally or accidentally released salmonids on natural populations are often unpredictable and may vary from no detectable effects to complete introgression or displacement. Second, when genetic effects on performance traits (e.g. survival in fresh water and seawater) have been detected, they appear always to be negative in comparison with the traits of unaffected native populations."

Nickelson 1986: "Hatchery Coho juveniles are more abundant after stocking in streams, but the result is fewer adult returns and fewer juvenile coho salmon in the next generation than in streams that were not stocked."

Nickelson 2003: "Hatchery programs designed for harvest augmentation should be removed from basins with habitat that has high potential to produce wild salmonids. To aid recovery of depressed wild salmon, the operation of hatcheries must be changed to reduce interactions of hatchery smolts with wild smolts. A program that reduces harvest, restores habitat, and reduces hatchery effects is necessary."

NMFS 2010: "Hatchery production has been reduced to a small fraction of the natural-origin production. Nickelson (2003) found that reduced hatchery production led directly to higher survival of naturally produced fish, and Buhle et al. (2009) found that the reduction in hatchery releases of Oregon coast coho salmon in the mid1990's resulted in increased natural coho salmon abundance."

ODFW 2010: "Chilcote and Goodson examined data sets on population abundance for 121 populations of coho, steelhead, and Chinook in Oregon, Washington, and Idaho. They found that population productivity was inversely related to the average proportion of hatchery fish in the naturally-spawning population, consistent with the findings of Buhle et al. (2009). The magnitude of this effect was substantial. For example, a population comprised entirely of hatchery fish would have one tenth the intrinsic productivity of one comprised entirely of wild fish. There was no indication that the significance or strength of this relationship was different among the three species examined (chinook, coho and steelhead). In addition, there was no indication that the type of broodstock (integrated with the local natural-origin population versus segregated) affected the significance or intensity of the response." (Section 2: Updating the Scientific Information in the 2008 FCRPS BiOp May 20, 2010, Page 118 and Lower Columbia River Salmon Recovery Plan 9-2010 ODFW)

ODFW 2010a: "For example, the reduction in productivity between a population comprised entirely of wild fish and one comprised of equal numbers of hatchery and wild fish is 66 percent for steelhead, 76 percent for coho, and 43 percent for Chinook."

ODFW 2010b: "Hatchery programs have the potential to benefit or harm salmonid population viability by affecting abundance, productivity, distribution, and/or diversity. Hatchery related risks to salmon population viability include genetic changes that reduce fitness of wild fish, increase risk of disease outbreaks, and/or alter life history traits, and ecological effects—such as increased competition for food and space or amplified predation—that reduce population productivity and abundance. Hatcheries can also impose environmental changes by creating migration barriers that reduce a population's spatial structure by limiting access to historical habitat."

ODFW 2011: The study was able to determine that the F1 generation of coho released as unfed fry or as smolts both had a run time of 51 days compared to 73 days for wild-born fish. Coho released as smolts exceeded natural recruitment with a return rate of 3.1 to 3.5 per female compared to 1.3 to 1.4 per female for natural recruitment. Unfed fry varied with a recruitment rate of 1.0 and 2.0 per female. With the F2 generation, reproductive success (RS) was analyzed. The study found that compared to wild coho, the average reproductive success of progeny from the unfed fry releases which produced returning F2 coho was 38% lower for males and 16% lower for females. F2 coho from the smolts had even lower average reproductive success being 47% and 25% lower respectively than wild coho. Hatchery jacks however had a RS more equal to wild coho. The mechanism for the difference is still unknown. However, since both unfed fry and smolts have reduced RS, artificial mating and early life-stages in the hatchery likely had some impact on later reproductive success.

Ó Maoiléidigh 2008**: "**We conclude that extensive stocking programmes undertaken in Ireland over the last thirteen years have made little real contribution to the productivity of Irish rivers or to the goals of restoring self-sustaining salmon runs. Furthermore, evidence from recent experiments suggesting that artificial introductions are likely to depress rather than enhance the productivity of natural populations, including feral or quasi-wild populations that have been established by successful hatchery programmes, suggests that more caution and planning is required before hatchery reared progeny are released into the wild .

Paquet et al. 2011: "Hatcheries are by their very nature a compromise – a balancing of benefits and risks to the target populations, other populations, and the natural and human environment they affect."

Parkinson 1984: "The pattern of genetic variation reported here reflects an underlying stock structure that has to be considered in the management of this species. The presence of differences between adjacent streams supports the conclusion of straying, and genetic studies in various anadromous salmonid species which indicate that little interchange of individuals takes place between adjacent streams. Adjacent populations should therefore be managed as separate stocks.

The geographic distance between two stocks cannot be a measure of their genetic similarity and is, therefore, not very useful in assessing either the suitability of stocks for transplantation or the risk of disrupting genetic structuring through transplantation.

Perry, et al. 1993: "Idaho has been trying to unravel the secrets of hatchery and wild salmon interactions in nature. Since hatchery salmon do not survive as well as wild salmon, it is important to fix this problem. It is possible that a hatchery supplementation program may inadvertently replace the target natural population with one having lower survival and reproductive potential."

Reisenbichler, et al. 1977: His research shows that hatchery x hatchery crosses of steelhead fry survival were lower than for wild x wild crosses and wild x hatchery crosses in streams. Likewise, he found that hatchery x hatchery crosses survived better in the hatchery environment. The hatchery fish were derived from local wild steelhead and had changed in performance in two generations of hatchery rearing. Conclusion: differences in survival suggested that the short-term effect of hatchery adults spawning in the wild is the production of fewer smolts and ultimately, fewer returning adults than are produced from the same number of wild steelhead spawners.

Reisenbichler 1986: "Most (hatchery fish) out planting programs have been unsuccessful. Rigorous planning, evaluation, and investigation are required to increase the likelihood of success and the ability to promptly discern failure."

Reisenbichler 1992: "Because anadromous salmonids home to their natal streams to spawn, managers can expect the fish in different streams to be from genetically distinct stocks. We recommend that steelhead from different coastal drainages be considered and managed as distinct stocks."

Reisenbichler 1994: "Gene flow from hatchery fish also is deleterious because hatchery populations genetically adapt to the unnatural conditions of the hatchery environment at the expense of adaptedness for living in natural streams. This domestication is significant even in the first generation of hatchery rearing."

Reisenbichler 1996: "Available data suggest progressively declining fitness for natural rearing with increasing generations in the hatchery. The reduction in survival from egg to adult may be about 25% after one generation in the hatchery and 85% after six generations. Reduction in survival from yearling to adult may be about 15% after one generation in the hatchery and 67% after many generations."

Reisenbichler and Rubin 1999: "When the published studies and three studies in progress are considered collectively… they provide strong evidence that the fitness for natural spawning and rearing can be rapidly and substantially reduced by artificial propagation. This issue takes on great importance in the Pacific Northwest where supplementation of wild salmon populations with hatchery fish has been identified as an important tool for restoring these populations. Recognition of negative aspects may lead to restricted use of supplementation, and better conservation, better evaluation, and greater benefits when supplementation is used.

"Apparently domestic selection is often intense. The fitness of stream type chinook (spring chinook) salmon was diminished after four generations of culture, despite continuous gene flow from the wild population (on average, wild fish comprised 38% of the hatchery broodstock). The fitness of steelhead was diminished after only two generations in the hatchery (Reisenbichler and McIntyre, 1977). Presumably substantial change occurs in the first generation."

"These conclusions imply that supplementation (wherein wild fish interbreed with hatchery fish of reduced fitness) will reduce the productivity of naturally spawning populations, and often may compromise conservation objectives."

"Relative survival of hatchery steelhead continued to decline with age of the cohort, at least until after emigration as smolts. This decline suggests that the fitness of the next generation would be low even before interbreeding with more hatchery fish, and that continuous supplementation should progressively diminish the productivity of the naturally spawning population."

"The typical population proposed for supplementation is presumably one of low productivity which is substantially below carrying capacity. Continued supplementation of such a population may reduce its productivity so that the population even becomes dependent on supplementation and cannot replace itself otherwise."

Reisenbichler et al. 2004: "Genetic theory and data suggest that sea ranching (hatchery production) of anadromous salmonids (*Onchorhynchus spp.* and *Salmo spp.*) results in domestication (increased fitness in the hatchery program) accompanied by a loss of fitness for natural production. We tested for genetic differences in growth, survival, and downstream migration of hatchery and wild steelhead (*O. mykiss*) reared together in a hatchery. We found little or no difference in survival during hatchery rearing but substantial differences in growth and subsequent downstream migration. Intense natural selection after release from the hatchery favored fish that had performed well (e.g. grew fast) in the hatchery. This selection in the natural environment genetically changes (domesticates) the population because at least some of the performance traits are heritable. Domestication should improve the economic efficiency for producing adult hatchery fish but compromise conservation of wild populations when hatchery fish interbreed with wild fish."

RIST 2009: "Most information available indicates that artificially-propagated fish do have ecological impacts on wild salmonid populations under most conditions (e.g. a 50% reduction in productivity for steelhead in an Oregon population). To the degree that the trait distributions seen in wild salmon populations are adaptations to their environments, selection imposed by the hatchery environment could result in reduced fitness of hatchery fish in the wild."

Scheuerell et al. 2015: Using 43 years of monitoring data, we asked whether 11–23 years of supplementation have increased the density of naturally produced adults (i.e., fish that were born in the wild, not reared in a hatchery) in 12 supplemented populations, and if so, by how much. We found that, on average, supplementation has increased adult density among the 12 supplemented populations by only 3.3%.

In the US Pacific Northwest, salmon hatcheries release about 400 million juveniles per year at a cost of roughly $40 million USD (Naish et al. 2008). Many of these fish are produced to meet tribal, commercial, or recreational harvest demands, or to mitigate for habitat loss.

Massive efforts are underway worldwide to conserve at risk species, and societies would like to know what they are getting for their investment.

Schenekar, Tamara and Steven Weiss 2017: Captive bred individuals are often released into natural environments to supplement resident populations. Captive bred salmonid fishes often exhibit lower survival rates than their wild brethren and stocking measures may have a negative influence on the overall fitness of natural populations. Stocked fish often stem from a different evolutionary lineage than the resident population and thus may be maladapted for life in the wild, but this phenomenon has also been linked to genetic changes that occur in captivity. In addition to overall loss of genetic diversity via captive breeding, adaptation to captivity has become a major concern. Altered selection pressure in captivity may favour alleles at adaptive loci like the Major Histocompatibility Complex (MHC) that are maladaptive in natural environments.

Our results support that stocking measures in autochthonous [native] populations should be avoided, especially with nonnative fish. If stocking measures are inevitable in natural habitats, ideally, locally established brood-stocks with local genetic material should be used. Adaptation to captivity should be minimized, e.g. by the continuous supplementation of new "natural" genetic material in order to keep the genetic composition of the captive population as close to its source population as possible. Nonetheless, genetic or epigenetic changes can begin in the first generation of captivity (Christie et al. 2016) and thus it appears to be extremely difficult or impossible to use hatchery operations in any capacity without risking deleterious effects to the wild population.

Schroder, et al. 2008: "Pedigree assignments based on microsatellite DNA, however, showed that the eggs deposited by wild females survived to the fry stage at a 5.6% higher rate than those spawned by hatchery females. Subtle differences between hatchery and wild females in redd abandonment, egg burial, and redd location choice may have been responsible for the difference observed. Other studies that have examined the effects of a single generation of hatchery culture on upper Yakima River chinook salmon have disclosed similar low-level effects on adult and juvenile traits. The cumulative effect of such differences will need to be considered when hatcheries are used to restore depressed populations of chinook salmon."

Seamons et al. 2012. "We tested the efficacy of the strategy of segregation by divergent life history in a steelhead trout, Oncorhynchus mykiss, system, where hatchery fish were selected to spawn months earlier than the indigenous wild population. The proportion of wild ancestry smolts and adults declined by 10–20% over the three generations since the hatchery program began. Up to 80% of the naturally produced steelhead in any given year were hatchery/wild hybrids.

"…proportions of hybrid smolts and adults were higher in years when the number of naturally spawning hatchery-produced adults was higher. Divergent life history failed to prevent interbreeding when physical isolation was ineffective, an inadequacy that is likely to prevail…"

"Controlling the behavior or breeding biology of captively reared animals released into the wild is one of the most significant issues for managers tasked with minimizing risks associated with captive rearing.

“Hatchery steelhead are intercepted and harvested downstream of the Forks Creek Hatchery, but harvest rates are clearly not sufficient to prevent large numbers of hatchery-produced fish from reaching spawning grounds. Indeed, the number of hatchery produced adults returning to the Forks Creek Hatchery equaled or exceeded the total number of wild fish estimated to be spawning in the entire Willapa River during the most recent three return years.

“Hatchery rearing may have negative fitness consequences even when the stocks are locally derived (Araki et al. 2007b, 2009). Nonlocal populations, like the hatchery broodstock used at Forks Creek, often have lower reproductive success than native wild populations because of a lack of local adaptation (Kostow et al. 2003; reviewed in Berejikian and Ford 2004; Araki et al. 2007a, 2008; Chilcote et al. 2011; Fraser et al. 2011). Interbreeding between hatchery and wild stocks could have long-term fitness consequences.

“One obvious solution is to reduce or cease production and release of steelhead from the hatchery; however, this option may be unpopular and difficult to implement. Physical segregation may be augmented by improving weirs. However, weirs or dams are costly, and they affect the habitat to some extent. Flooding and debris compromise most weirs, allowing fish to bypass them. Even if barriers were completely effective at preventing upstream migration, the hatchery-produced fish might spawn elsewhere in the basin.

“Segregation by life history was thought to complement physical segregation, but our study shows that it failed to prevent genetic interactions between hatchery and wild steelhead populations. Thus, managers should also consider other options for minimizing interactions between wild and cultured animals.”

Shrimpton, et al., 1994: “Juvenile hatchery Coho showed a reduced tolerance to saltwater compared to wild coho.”

Slaney, et al., 1993: “Hatchery adult steelhead strayed more than wild steelhead.”

Sosiak, et al., 1979: “As juveniles, hatchery fish had less stomach fullness and fed on fewer taxa than wild fish. This was determined after hatchery fish were in streams from one to three months.”

Steward et al. 1990: Authors reviewed 606 hatchery supplementation studies and found that few directly assessed the effects on natural stocks. Genetic and ecological effects and changes in productivity of the native stocks that can result remain largely unmeasured. However, the general failure of supplementation to achieve management objectives is evident from the continued decline of wild stocks.

Swain, et al. 1991: Hatchery coho salmon diverged from the wild fish in fin size and body dimensions. These were considered adaptations to the hatchery environment.

Taylor, 1986: “Hatchery Coho salmon diverged in body structure and variation from that of the wild coho.”

Vincent 1987: Hatchery stocking ended in a Montana stream and wild trout more than doubled (160%) and the wild trout biomass increased by 10 times.

Theriault et al. 2011: "Supplementation of wild salmonids with captive-bred fish is a common practice for both commercial and conservation purposes. However, evidence for lower fitness of captive reared fish relative to wild fish has accumulated in recent years, diminishing the apparent effectiveness of supplementation as a management tool. To date, the mechanism(s) responsible for these fitness declines remain unknown. In this study, we showed with molecular parentage analysis that hatchery coho salmon (Oncorhynchus kisutch) had lower reproductive success than wild fish once they reproduced in the wild. This effect was more pronounced in males than in same-aged females. Hatchery spawned fish that were released as unfed fry (age 0), as well as hatchery fish raised for one year in the hatchery (released as smolts, age 1), both experienced lower lifetime reproductive success (RS) than wild fish.

Waples and Do 1994: Genetic interactions between hatchery and wild salmonids will increase as hatchery supplementation becomes a more dominate form of hatchery management.

Waples 1994: Hatchery captive brood stocks may shift genetic structure in natural populations.

Webster 1931: "To those of us interested in fisheries work, artificial propagation is never and should never be considered as replacing natural reproduction."

Williamson et al. 2010: Wenatchee River hatchery and wild spring chinook – "Hatchery-origin fish produced about half the juvenile progeny per parent when spawning naturally then did natural-origin fish. Hatchery fish tended to be younger and return to lower areas of the watershed than wild fish, which explained some of their lower fitness.

Wohlfarth 1986: Stocking with hatchery stocks cannot replace wild productivity because hatchery fish are selected for adaptation to the hatchery environment and do not perform well in the natural environment.

Wood, et al., 1960: Hatchery coho salmon 14 months after release into a stream did not reach the body composition of the wild salmon in time for downstream migration and had lower ocean survival.

Young, K. A. 2013: The debate over Atlantic salmon, Salmo salar L., stocking in Britain centres on the trade-off between enhancing rod fisheries and harming wild populations. This article informs the debate by quantifying the relationship between stocking and angler catch statistics for 62 rivers over 15 years. After controlling for environmental factors affecting adult abundance, the 42 rivers with stocking had non-significantly lower mean catch statistics than the 20 rivers without stocking. This difference increased with the age of stocked fish. Among stocked rivers, weak relationships between mean stocking effort and catch statistics also became more negative with the age of stocked fish. For stocked rivers, there was no evidence for a generally positive relationship between annual stocking efforts and catch statistics. Those rivers for which stocking appeared to improve annual rod catches tended to have lower than expected mean rod catches. The results suggest the damage inflicted on wild salmon populations by stocking is not balanced by detectable benefits to rod fisheries.

Zaporozhets: 2011. We document evidence of life history trait divergence between wild and hatchery salmon in Kamchatka region of the Russian Federation. Specifically, we document cases where hatchery salmon return at younger ages and smaller sizes and exhibit lower life history diversity compared to their wild counterparts. We feel a broader, ecosystem level approach to managing salmon hatcheries is warranted, as proposed by Lichatowich (1999) and Williams et al. (2003), to help ensure that hatchery fish are raised in conditions that more closely match those in the natural environment and hatchery risks are contained by adopting precautionary management approaches to help conserve wild salmon populations. We stress the importance of preservation of wild salmon populations, and we encourage further studies to more fully understand the consequences of interactions between wild and hatchery salmon.

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