ON THE SCIENCE OF HATCHERIES:

An updated perspective on the role of hatcheries in salmon and steelhead management in the Pacific Northwest

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Hatchery Scientific Review Group
Pacific Salmon Hatchery Reform

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Acronyms and Abbreviations

Accord	Columbia Basin Fish Accords. On May 2, 2008, Bonneville Power Administration signed the Columbia Basin Fish Accords along with several other federal agencies, states and Tribes. The memorandum(s) of agreement between the sovereigns are designed to supplement biological opinions for listed salmon and steelhead and the Northwest Power and Conservation Council's Fish and Wildlife Program. They provide firm commitments to hydro, habitat and hatchery actions, greater clarity about biological benefits, and secure funding for 10 years.
AHA	All H Analyzer
"All H" Strategy	Jointly addresses habitat, hatcheries, harvest and hydropower impacts
BiOp	Biological Opinion
BPA	Bonneville Power Administration
CRITFC	Columbia River Intertribal Fish Commission
CWT	Coded-wire tag
EDT	Ecosystem Diagnosis and Treatment
EIS	Environmental Impact Statement
ESA	Endangered Species Act
ESU	Ecologically Significant Unit
FCRPS	Federal Columbia River Power System
FHMP	Fisheries and Hatchery Management Plan
FPS	Fish Passage Survival
FTC	Fisheries Technical Committee
FWP	Columbia River Fish Basin and Wildlife Program (Northwest Power and Conservation Council)
GSI	Genetic stock identification
HGMP	Hatchery and Genetics Management Plan
HOB	The number of hatchery-origin fish used as hatchery broodstock

HOR	Refers to a fish of hatchery origin. When used as a variable, it is the total number of Hatchery-Origin Recruits from a hatchery program (the sum of HOS, HOB, and hatchery-origin fish intercepted in fisheries).
HOS	The number of hatchery-origin fish spawning naturally
HSRG	Hatchery Scientific Review Group
HRT	Hatchery Review Team (USFWS)
IDFG	Idaho Department of Fish and Game
ISAB	Independent Scientific Advisory Board
ISRP	Independent Scientific Review Panel
LSRCP	Lower Snake River Compensation Plan
MDN	Marine-derived nutrients
M&E	Monitoring and evaluation
Natural-Origin	Synonymous with “wild.” Some studies also use the term “wild” to mean natural-origin.
NMFS	National Oceanic and Atmospheric Administration—National Marine Fisheries Service
NOR	Refers to a fish of Natural-Origin (a product of natural spawning). When used as variable, it is the total number of Natural-Origin Recruits from a population (harvest plus escapement).
NOS	The number of natural-origin fish spawning naturally
NOB	The number of natural-origin fish used as hatchery broodstock
NPCC	Northwest Power and Conservation Council
ODFW	Oregon Department of Fish and Wildlife
PBT	Parentage-based tagging
pHOS	Mean proportion of natural spawners in a watershed or stream composed of hatchery-origin adults each year.
PIT tag	Passive Integrated Transponder tag
PNI	Proportionate Natural Influence on a composite hatchery-/natural-origin population. Can also be thought of as the percentage of time the genes of a composite population spend in the natural environment. Calculated as pNOB/(pNOB + pHOS).

pNOB	Mean proportion of a hatchery broodstock composed of natural-origin adults each year.
RIST	Recovery Implementation Science Team
R/S	Recruits per Spawner
SAFE	Select Area Fishery Evaluation
SAR	Smolt-to-adult return. Survival rate is measured from the point where a juvenile fish is released to eventual capture at some point in the future.
SNP	Single nucleotide polymorphisms
USFWS	United States Fish and Wildlife Service
VSP	Viable Salmonid Population
WDFW	Washington Department of Fish and Wildlife

Executive Summary

Hatcheries have long played a necessary role in meeting harvest and conservation goals for Pacific Northwest salmon and steelhead. However, a need to reform the hatchery system has been identified by scientists and policymakers based on growing concerns about the potential effects of artificial propagation on the viability of salmon and steelhead in their natural habitats. The US Congress established the Hatchery Reform Project in 2000 as part of a comprehensive effort to conserve indigenous salmonid populations, assist with the recovery of naturally spawning populations, provide sustainable fisheries, and improve the quality and cost-effectiveness of hatchery programs. The Hatchery Scientific Review Group (HSRG) was charged with reviewing all state, tribal, and federal hatchery programs in Puget Sound and Coastal Washington. The review used an ecosystem-based approach founded on two central premises: that harvest goals are sustainable only if they are compatible with conservation goals, and that artificially propagated fish affect the fitness and productivity of natural populations with which they interact. The intent of the project is for science to direct the process of reform. Reforms should ensure that the hatchery system matches current circumstances and management goals.

Since 2000, the HSRG–an independent scientific review panel–has carried out its mission of incorporating the most up-to-date science into hatchery management, with financial support from state and federal sources.

The purposes of this report are to:

- Provide an updated perspective on the role of hatcheries in salmon and steelhead management in the Pacific Northwest.
- Evaluate the impact of the HSRG's work on hatchery management in the Pacific Northwest.
- Review new information and consider whether the HSRG's principles, broad recommendations, and analytical framework are still consistent with the best available science.

Hundreds of hatchery facilities in the Pacific Northwest are operated by federal, state, tribal, and local governments. Some of these hatcheries have been operating for more than 100 years. Most were built to produce fish for harvest when wild populations declined from habitat loss, overfishing, and the construction of hydroelectric dams. Hatcheries have generally been successful at producing fish for harvest. However, the traditional mitigation policy of replacing wild populations with hatchery fish is not consistent with today's conservation goals, environmental values, and scientific theories. Hatcheries cannot replace lost habitat and the natural populations that rely on it. It is now clear that the widespread use of traditional hatchery programs has actually contributed to the overall decline of wild populations. The historical use of artificial propagation for harvest mitigation has frustrated the successful integration of management directives and created regional economic inefficiencies.

Today, it is clear that hatchery programs must be seen as just one tool to be used as part of a broader, balanced strategy for meeting watershed or regional resource goals. Such a strategy also incorporates actions affecting habitat, harvest rates, water allocation, and other important components of the human environment.

Pursuant to the Hatchery Reform Project, comprehensive reviews of over 200 propagation programs at more than 100 hatcheries across western Washington were completed in 2004. Based on those reviews, analytical tools were developed in 2005 to support application of the HSRG's principles (HSRG 2009, Paquet et al. 2011). Also in 2005, Congress directed the National Oceanic and Atmospheric Administration–National Marine Fisheries Service to replicate the project in the Lower Columbia River Basin. Ultimately, that scope was expanded to include the entire Columbia River Basin, and the results of this hatchery assessment were reported soon thereafter (HSRG 2009). Three principles (listed below) emerged early in the HSRG's review and served as guidance for the development of recommendations for hatchery reform. The principles provide a method of incorporating the best available science into policy decisions about the design and operation of hatcheries.

Principle 1: Develop clear, specific, quantifiable harvest and conservation goals for natural and hatchery populations within an "All H" context. Habitat, hatcheries, harvest and hydropower (dams) constitute the "All H." Hatcheries should be used as part of a comprehensive strategy where habitat, hatchery management, hydropower operations, and harvest are coordinated to best meet resource management goals that are defined for each fish population in the watershed.

Principle 2: Design and operate hatchery programs in a scientifically defensible manner. The scientific rationale for a hatchery program in terms of benefits and risks must be formulated to explain how the program expects to achieve its goals. The strategy chosen must be consistent with current scientific knowledge.

Principle 3: Monitor, evaluate and adaptively manage hatchery programs. Ecosystems affected by hatchery programs are dynamic and complex; therefore, uncertainty is unavoidable. New data will change our understanding of the ecological and genetic impacts of hatchery programs, and this should lead directly to changes in hatchery operations.

Important HSRG Conclusions

The HSRG (2009) provided many specific and regional recommendations for each hatchery program evaluated. Important conclusions emerged that need to be addressed through policy, management, and research and monitoring as part of the hatchery reform implementation process.

- **Identify the purpose of the hatchery program in the context of an "All H strategy" to meet resource goals over time**. Hatchery programs may contribute to harvest, conservation, or both. To be successful, hatchery programs should be managed in concert with harvest and within an integrated long-term plan that also incorporates present and future habitat and hydropower scenarios. A hatchery should be the strategy of choice only to the extent that it is better in a benefit-risk sense than other alternatives to meet similar goals.

- **For hatchery programs with a harvest purpose, manage broodstocks to achieve proper genetic integration with, or segregation from, natural populations.** In an ideal integrated program, natural-origin and hatchery-origin fish represent two components of a single gene pool that is locally adapted to the natural habitat. A population that supports an integrated program would make a greater contribution to harvest than the existing natural habitat can sustain on its own. The intent of a segregated hatchery program for harvest mitigation is to maintain a genetically distinct hatchery population. The segregated approach uses only hatchery-origin fish for broodstock and results in a population that is adapted to the hatchery environment and can maximize the efficiency of hatchery propagation. The management of hatchery programs for harvest augmentation is a matter of balancing harvest benefits versus risks to affected naturally spawning populations.

- **The role of a hatchery program in the conservation of naturally spawning populations should be determined by the status of the population.** The use of hatcheries in population recovery should be informed by the science and principles of conservation biology. The management of conservation programs is a matter of balancing short-term demographic benefits versus long-term fitness goals. Conservation programs should be temporary and associated with biologically defined triggers to modify or terminate the hatchery programs.

- **Promote local adaptation of natural and hatchery populations.** Local adaptation is important because it maximizes the viability and productivity of the population, maintains biological diversity within and between populations, and enables populations to adjust to changing environmental conditions (e.g., through climate change). Many hatchery programs have disrupted the natural selection of population characteristics that are tailored to local conditions. Proper integration or segregation of hatchery programs is the HSRG's recommended means for minimizing the adverse effects of hatcheries on local adaptation of naturally spawning populations. Local adaptation of hatchery populations is achieved by using local broodstock and avoiding transfer of hatchery fish among watersheds.

- **Minimize adverse ecological interactions between hatchery- and natural-origin fish.** Ecological interactions include competition for food and space, predation of hatchery fish upon natural-origin fish, and the potential transfer of disease from hatchery- to natural-origin fish. One way to minimize these interactions is for hatchery programs to be operated so that reared and released fish are as similar biologically to their natural counterparts as possible. Alternatively, hatchery programs can be operated so that hatchery fish are segregated from their natural counterparts in time and space. In this context, it is also important that the rearing facilities meet all applicable environmental compliance requirements (e.g., water withdrawal, discharge, and screening, etc.).

- **Maximize survival of hatchery fish, consistent with conservation goals.** For hatchery programs to effectively contribute to harvest and/or conservation, the survival and reproductive success of hatchery releases must be high relative to those of naturally spawning populations. The primary performance measure for hatchery programs should be the total number of adults produced (those caught in fisheries plus those that escape to the hatchery or natural environment) per adult spawned at the hatchery. This measurement should be greater than that achieved in the wild. This is particularly important for integrated programs to avoid broodstock "mining" from the natural population. It also ensures that the fewest number of hatchery fish will be released to accomplish the desired goal.

- **Hatchery reforms increase the value of habitat improvements.** Measures that restore the fitness (and therefore productivity) of naturally spawning salmon and steelhead populations are necessary to realize the benefits from investments in habitat improvements. Conversely, when habitat improvements are made without hatchery and harvest reforms, the resulting benefits will not be fully realized. Productivity benefits are also likely to be realized on a shorter time scale from hatchery reform than improvements in habitat. Given these factors, there is no apparent biological reason to wait for future habitat improvements to take full effect before implementing hatchery and harvest reforms.

- **The role of science is to inform policy decisions.** Science should provide a working hypothesis for how management actions will affect resource outcomes. The HSRG has proposed its recommendations as one solution to increase the benefits and reduce the risks associated with operating hatcheries. The HSRG's framework provides an alternative to the century-old paradigm that guided hatchery policy in the past, in which hatcheries were the simple and ubiquitous solution to mitigate for habitat loss and over-harvest. The HSRG framework is more consistent with currently available science than the old paradigm. As new information becomes available, the HSRG framework should continue to be challenged and revised. Science thus informs policy decisions by evaluating potential biological benefits and risks associated with alternative management actions. Research that addresses specific questions related to hatchery reform can lead to more efficient policy adaptation.

- **Harvest reforms can complement hatchery reforms to improve harvest and better achieve conservation objectives.** The HSRG found that harvest reforms, in combination with hatchery reforms, can both increase harvest and help achieve conservation objectives. For example, mark-selective sport and commercial fisheries allow greater catches of hatchery-origin fish while reducing mortality to natural-origin fish needed for escapement and broodstocks. Mark-selective fisheries have the potential to improve the ability of managers to meet management targets for natural production, reduce straying, and decrease the number of hatchery-origin fish on the spawning grounds. Without increases in selective fisheries, solutions to meet conservation goals will require reduced hatchery production and catch. Similarly, opportunities were noted where more hatchery fish could be acclimated and released from specific locales (e.g., bays and tributaries). This would allow more intensive fisheries on the returning hatchery-origin adults near the point of release with fewer impacts on natural-origin fish than currently occur in more mixed-stock waters.

Detailed reports on all of the HSRG's reviews, analytical tools, and framework are available online at http://www.hatcheryreform.us. The HSRG understood that the scientific framework it proposed in 2009, along with its specific recommendations for hatchery reform, would require constant review and revision. The HSRG's framework recognized that there are significant uncertainties in assessing the effects and roles of hatcheries, including the future condition of habitat, climate change, and the ecological and genetic effects of hatchery fish on the viability of naturally spawning populations. Since the last HSRG publication in 2009, research and monitoring of hatchery programs has brought forward new information and insights on hatchery science. These advancements are the focus of the HSRG's 2014 report.

Implementation and Status of Hatchery Reform

The HSRG's hatchery reform recommendations have become a pervasive set of standards for developing new hatchery programs and making existing programs consistent with resource goals and 21st century science in the Columbia Basin, Puget Sound, and along the Washington Coast. The hatchery management principles developed by the HSRG are being institutionalized in several agency policies (e.g., Washington Department of Fish and Wildlife's Hatchery and Fishery Reform Policy adopted in 2009) and many hatchery management plans, and are widely cited in scientific reviews (e.g., Northwest Power and Conservation Council's Independent Science Review Panel's 2011 programmatic reviews). The HSRG has increased understanding of the potential conservation benefits of hatchery reform by emphasizing the importance of using models and the best available science. In addition, combining the HSRG hatchery reform framework with thoughtful designations of populations based on biological importance can lead to realignment of propagation programs to provide more sustainable harvest in the future.

Hatchery reform has been implemented across the region in a wide range of programs including treaty, state, federal, harvest, and conservation programs. The most frequently implemented program changes include installing weirs (allows better management of hatchery broodstocks and natural spawning populations), developing locally adapted broodstocks (improves survival and productivity of hatchery and wild populations), marking all hatchery releases (promotes effective broodstock management, wild stock assessment, and selective fisheries), and establishing new and more intensive selective fisheries (increases catch of hatchery-origin fish and survival of natural-origin fish). Some programs have developed comprehensive monitoring and evaluation plans that incorporate an adaptive management process.

However, more work is needed to align hatchery programs as part of an "All H" strategy coordinating the management of habitat, hatcheries, harvest, and hydropower to meet population goals. Many hatchery management plans do not contain quantitative harvest or conservation goals that are linked to population recovery goals. Also, many hatchery plans still do not state explicit assumptions about population status and biological importance (population designations) or biological metrics that are critical to effectively achieve harvest and conservation goals. Long-existing institutional divisions of responsibilities have been cited as impediments to collaboration and coordination among habitat, hatchery, harvest, and hydropower managers. In addition, managers often face logistical, stakeholder, regulatory, and fiscal challenges in meeting population management objectives.

The following are some key conclusions, findings, and scientific advances from this report that address habitat, hatchery, harvest, and hydropower management:

- Managing hatchery effects on the viability of naturally spawning populations is critical. Maximizing fitness and local adaptation is especially important to the viability of salmon and steelhead in the face of changing environmental conditions due to climate change.

- Managing hatchery effects on population fitness and local adaptation is necessary to realize the production potential of existing habitats and to realize benefits from investments in habitat improvements.

- Cultural and economic benefits of harvest are still important, and hatcheries are a necessary tool for the foreseeable future. Solutions exist that meet harvest goals while protecting the long-term viability of naturally spawning populations. However, this can only be achieved through scientifically informed decision-making and accountability for trade-offs between near-term benefits and long-term costs in population viability.

- The HSRG recommendations and working hypothesis have been criticized, but better, scientifically supported alternatives have not been proposed. The HSRG standards should be challenged with better alternatives, but not discarded because of imperfections or uncertainty. The existing paradigm has always contained imperfections and uncertainties. While findings of recent scientific studies are consistent with the HSRG framework and assumptions, results will help refine parameter values in the future.

- The biological principle behind the broodstock standards for both integrated and segregated populations is to promote local adaptation and restore productivity and viability. A major concern with many current hatchery programs is that they have been operated in a manner that disrupts natural selection for population characteristics that are tailored to local environmental conditions. Proper integration or segregation of harvest augmentation programs is the recommended means to minimize the adverse effects of hatcheries on local adaptation of natural populations. Recent studies and analyses suggest that segregated hatchery programs should be used with even greater caution than originally suggested by the HSRG, because of their potential to harm viability of natural-origin fish.

- Research priorities for harvest augmentation programs should include studies on the relative reproductive success of hatchery fish spawning in the wild and the long-term fitness effects on naturally spawning populations caused as a result.

- Avoiding negative ecological interactions between hatchery- and natural-origin fish should be a primary concern for recovery efforts and fisheries management. However, the HSRG has to date found no new information that might provide useful standards to estimate the size or scope of the effects of ecological interactions. The type, direction, and extent of ecological interactions should be assessed on a case-by-case basis.

The scientific literature indicates that artificial enhancement can be of great benefit in raising the level of nutrients in freshwater systems. The methods endorsed by the HSRG are distribution of adult carcasses (where disease issues are not a concern) or carcass analogs. Nutrification projects require careful planning and evaluation to ensure that resources are used wisely and risks are understood.

- The HSRG recommends that monitoring plans be implemented as part of a structured annual adaptive management decision process for hatcheries. This process should specify roles and responsibilities, schedules, and data and information sharing and coordination.

- The need for regional consistency and coordination is well recognized but remains elusive. Improvements in this area would result in better use of resources and more reliable information. Standards for estimating population viability would help decision-making at local and regional levels.

- Research programs, which tend to have global value, should be regionally designed, cost-effective, and coordinated to avoid misinterpretation and misapplication of results.

1.0 Background and Purpose

Hundreds of hatchery facilities in the Pacific Northwest are operated by federal, state, tribal, and local governments. Some of these hatcheries have been operating for more than 100 years. Most were built to produce fish for harvest when wild populations declined because of habitat loss, overfishing, and the construction of hydroelectric dams. Hatcheries have generally been successful at producing fish for harvest. However, the traditional mitigation policy of replacing wild populations with hatchery fish is not consistent with today's conservation goals, environmental values and scientific theories. Hatcheries cannot replace lost habitat and the natural populations that rely on it. It is now clear that the widespread use of traditional hatchery programs has actually contributed to the overall decline of wild populations. The historical use of artificial propagation for harvest mitigation has frustrated the successful integration of management directives and created regional economic inefficiencies.

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- Evaluate the impact of the HSRG's work on hatchery management in the Pacific Northwest.
- Review new information and consider whether the HSRG's principles, broad recommendations, and analytical framework are still consistent with the best available science.

2.0 Implementation of HSRG Recommendations

This chapter considers the HSRG's influence on the policies, management plans and operation of hatchery programs in the Pacific Northwest and gives examples of changes that have been implemented. It also indicates where further improvements are needed. The HSRG's hatchery reform principles have been widely adopted in agency policies, scientific reviews of hatchery programs, and hatchery management plans. However, implementing these principles as part of an "All H" strategy, where management of habitat, hatcheries, harvest and hydropower are coordinated to meet population goals, continues to be a challenge across the region. For example, adaptive management is an important component of successful hatchery programs because the benefits and risks of a program are continually changing, but it has not been widely or effectively implemented. Monitoring and evaluation (M&E) programs are hampered by insufficient data coordination, analysis and a lack of clear understanding of what data are critical to decision makers. Practical challenges with implementing the recommendations remain. Installing weirs and implementing broodstock management plans can be costly (both in terms of biological and social costs) and may not be logistically feasible in some cases. Constraints such as insufficient numbers of natural-origin fish and low productivity may continue to challenge implementation of needed hatchery reforms. In general, the implementation of HSRG recommendations has been consistent with the underlying principles, but, in the spirit of adaptive management and in consideration of on-the-ground realities faced by managers, the application of specific recommendations may need to be re-examined or prioritized.

In this chapter, we review recent progress on the status of hatchery reforms reflected in policies and plans (2.1), adoption of an "All H" approach (2.2), and actual implementation of reforms (2.3).

2.1 Adoption of HSRG Recommendations and Scientific Principles into Policies, Plans, and Program Reviews

Since 2009, HSRG recommendations have been incorporated into some agency policies and many hatchery program management plans. HSRG principles are often cited in the literature and referenced in scientific reviews of hatchery programs (Appendix 1).

2.1.1 Hatchery and Harvest Reform Policies in the Pacific Northwest

Washington State

Hatcheries

The Washington Department of Fish and Wildlife (WDFW) adopted the HSRG principles in its Hatchery and Fishery Reform Policy (WDFW Commission Policy C-3619), which was approved in November 2009.

The policy states that WDFW will *"use the principles, standards, and recommendations of the Hatchery Scientific Review Group (HSRG) to guide the management of hatcheries operated by the Department….and promote the achievement of hatchery goals through adaptive management based on a structured monitoring, evaluation, and research program."*

The policy includes priorities for implementing hatchery reform, which include improving broodstock management, developing an integrated "All H" strategy for each program, marking all hatchery releases, and developing complementary selective fisheries. Substantial progress has been made in adopting hatchery reform at WDFW hatcheries; see examples in Section 2.2.2.

The Confederated Tribes of the Colville Reservation designed and is managing its new Chief Joseph Hatchery pursuant to the HSRG criteria, recommendations and framework.

Harvest

To aid in developing selective fisheries, the WDFW Commission adopted a policy entitled *Columbia River Basin Salmon Management (POL-C3620)* (January 2013). The policy states (in part):

"The Department will promote the conservation and recovery of wild salmon and steelhead and provide fishery-related benefits by maintaining orderly fisheries and by increasingly focusing on the harvest of abundant hatchery fish. The Department will seek to implement mark-selective salmon and steelhead fisheries, or other management approaches that are at least as effective, in achieving spawner and broodstock management objectives."

Some key provisions in the policy include:

1. *<u>Gill Net License Buyback Program</u>. Initiate in 2013 the development (with Oregon) of a program to buyback non-tribal gill net permits for the Columbia River and implement that program as soon as the appropriate authority and financing is secured. Efforts should be made to also develop, evaluate, and implement other tools (e.g., minimum landing requirements) to reduce the number of gill net permits.*
2. *<u>Development and Implementation of Alternative Selective Gear in Transition Period</u>. The Department will investigate and promote the development and implementation of alternative selective gear during the transition period (2013-2016). If alternative selective gear is not available and practical, based on administrative, biological or economic factors, the use of gill nets in these fisheries will be allowed during the transition period. The development and implementation of alternative selective gear such as purse seines and beach seines should provide area-specific opportunity to target fishery harvests on abundant hatchery stocks, reduce the number of hatchery-origin fish in natural spawning areas, limit mortalities of non-target species and stocks, and provide commercial fishing opportunities. To facilitate the timely development of and transition to alternative selective gear and techniques, Washington should work with Oregon to develop incentives for those commercial fishers who agree to use these gear and techniques.*
3. *<u>Off-Channel Commercial Fishing Sites</u>. Seek funding (with Oregon) to evaluate the feasibility of establishing new off-channel sites. Seek funding to invest in the infra-structure and fish rearing and acclimation operations necessary to establish new off-channel sites in Washington, as identified by evaluations completed during the transition period.*
4. *<u>Barbless Hooks</u>. Implement in 2013 the use of barbless hooks in all mainstem Columbia River and tributary fisheries for salmon and steelhead.*

On February 8, 2014, the Washington Fish and Wildlife Commission approved a new policy for the Grays Harbor Region of the Washington coast entitled *Grays Harbor Salmon Management Plan*. The policy is designed to conserve wild salmon runs and clarify catch guidelines for sport and commercial fisheries in the bay.

Several Native American tribes are also using or experimenting with selective fishery techniques. The Confederated Tribes of the Colville Reservation, the Nisqually Indian Tribe, the Squaxin Island Tribe and the Nooksack Indian Tribe are using or have recently used selective gear in an attempt to increase the harvest of hatchery fish.

Oregon

The Oregon Department of Fish and Wildlife (ODFW) adopted its *Oregon Fish Hatchery Management Policy* in December 2010 (ODFW 2010a). This policy, which has similar objectives as the HSRG framework, does not reference the HSRG quantified criteria, recommendations or management framework.

Idaho

The guiding policy for the Idaho Department of Fish and Game (IDFG) is its *Fisheries Management Plan 2013-2018*. This plan does not contain a specific hatchery management policy nor does it reference HSRG criteria, recommendations, or management framework. However, many of the management strategies for anadromous fish identified in the plan are consistent with HSRG principles. Perhaps unique in the region, Idaho (where habitat is largely intact) has also designated a substantial number of drainages for wild salmon and steelhead management.

NOAA

The National Marine Fisheries Service is developing a policy direction for Columbia River Basin hatcheries in the Mitchell Act Environmental Impact Statement (EIS) (NMFS 2010[1]). The policy will guide budget and program reviews under the Endangered Species Act (ESA). The draft EIS evaluates hatchery program performance using HSRG performance metrics and the All H-Analyzer (AHA) model. Methods to achieve these metrics (installing weirs, reducing hatchery production, segregating hatchery programs, and selective fisheries) are discussed extensively. The HSRG recommendation on selective fisheries is directly cited in the EIS: *"without increases in selective fisheries, solutions to meet conservation goals will require reduced hatchery production and catch (HSRG 2009)."* In addition, NMFS used the best management practices developed by the HSRG as the basis for its hatchery program evaluations.

Independent Science Review Panel (ISRP) (Northwest Power Planning Council)

The ISRP noted in its programmatic reviews (ISRP 2011, 2013a) that program management plans should include an explicit summary of the HSRG and USFWS Hatchery Review Team (HRT) (see section 2.1.2 below) recommendations, discuss whether or not the program has been revised to align with these recommendations, and provide a justification for these choices. Several *new* salmon and steelhead

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[1] The Draft EIS was published in 2010. The final (supplemental) EIS is scheduled for release in 2013.

hatchery programs, all of which incorporate HSRG and HRT concepts, have recently been approved by the Northwest Power and Conservation Council after scientific review by the ISRP (Table 2-1).

Table 2-1. Examples of new hatchery programs approved by the Northwest Power and Conservation Council.

Hatchery Program	Sponsor/Operator	Status
Klickitat River Anadromous Fisheries (Step 1 Master Plan)	Yakama Nation	Approved 2008
Hood River Production Program (Step 1 Master Plan)	Confederated Tribes of the Warm Springs Reservation	Approved 2008
Okanogan Spring and Summer Chinook Program (Chief Joseph Hatchery Program) (Step 1-3)	Confederated Tribes of the Colville Reservation	Approved 2010
Crystal Springs Chinook and Yellowstone Cutthroat Trout Program (Step 1 Master Plan)	Shoshone-Bannock Tribes	Approved 2012
Snake River Sockeye Program (Step 1-3)	Idaho Department of Fish and Game	Approved 2012
Yakima Subbasin Summer/Fall Chinook and Coho Programs (Step 1 Master Plan)	Yakama Nation	Approved 2013
Walla Walla Spring Chinook Program (Step 1 Master Plan)	Confederated Tribes of the Umatilla Indian Reservation	Approved 2013

2.1.2 Other Scientific Hatchery Reviews

The US Fish and Wildlife Service HRT conducted a review of 24 salmon and steelhead hatcheries that it owns or operates (USFWS 2013). The reviews were modeled after the HSRG process and adopted the HSRG's scientific framework, principles and analytical tools. The HRT noted that it "*evaluated hatchery programs primarily from a scientific perspective, particularly with respect to the three principles adapted from the Hatchery Scientific Review Group (HSRG).*" Overall conclusions were that program and population goals should put less emphasis on mitigation goals and place more emphasis on the benefits of the programs in meeting population recovery objectives (HSRG Principle 1). The scientific defensibility of programs also needs to be more explicitly described (HSRG Principle 2).

In 2010 funds were appropriated by Congress to conduct a scientific review of hatchery programs in California. The California Hatchery Scientific Review Group (CA HSRG) completed its review in 2012. Regarding the potential for detrimental effects of hatchery programs on natural populations, the CA HSRG concluded (CA HSRG 2012, p. 19):

"Substantial research has shown that fish produced in hatcheries can have detrimental genetic and ecological effects on natural salmonid populations (Araki et al. 2008, Kostow 2009). Indeed, Standards and Guidelines put forth in this document (CA HSRG 2012) are intended to limit the potential for these types of effects. Fishery harvests that are sustained at high levels by targeting abundant hatchery-origin

fish may over-exploit naturally reproducing salmonids and may also induce selection on maturation schedules and other traits.“

2.1.3 Related Reviews and Comments

Recent applications of science to hatchery reform were evaluated by the Recovery Implementation Science Team, an independent scientific review team formed by NMFS (RIST 2009). The review focused specifically on 1) the use of the HSRG's AHA model as a planning tool for hatchery reform and 2) the use of weirs to reduce the demographic impact of hatchery-origin fish on wild populations. The AHA model uses the Ford (2002) fitness function, which is one possible hypothesis describing the impact of hatchery-origin fish on natural populations. The AHA model is sensitive to the input parameters in the fitness function, and as such, the RIST recommended that the model outputs be regarded as guidelines, not quantitative predictions. This recommendation is consistent with how the HSRG has used AHA model outputs, for example, in its 2009 review of more than 350 salmonid populations in the Columbia River Basin (HSRG 2009). The Recovery Implementation Science Team (RIST) also suggested that the AHA model incorporate information on potential ecological interactions between hatchery and natural-origin salmonids. Such interactions may occur at release sites, downstream, and in the ocean.

The HSRG suggests weirs as one possible approach to limiting the number of hatchery-origin fish on the spawning grounds and collecting natural-origin broodstock. The RIST reviewers noted that there are both biological and social costs associated with installing and maintaining weirs, and that it is often difficult to meet management objectives for reducing the number of hatchery fish on the spawning grounds. The reviewers suggested alternatives to weirs—reducing hatchery production, selective fisheries, and segregating hatchery production from wild populations—all of which are consistent with the HSRG's recommendations.

> Comments by the Recovery Implementation Science Team (RIST) (2009) regarding the work of the HSRG and application of the AHA are illustrative:
>
> *“The AHA user needs to be aware that: 1) the Ford model is only one of several possible ways to model domestication and almost certainly is incomplete in its approach, 2) it is a single-trait model attempting to simulate a multi-trait phenomenon, and 3) available data are inadequate for confident parameterization. We believe the model is useful for exploring scenarios, but would be concerned if the model were used to fine tune management actions based on small changes in the model's input parameters. Based on our review of the HSRG's recommendations for hatchery reform in the Lower Columbia River (see last section of the report), we are concerned that the level of uncertainty associated with the AHA output may not always be adequately characterized."*
>
> *“In interpreting the output from the AHA model, it is important to realize that population fitness is averaged over many generations. The fitness values are therefore close to what they would be at long-term equilibrium, and could be quite different from what the model would predict fitness to be in the near term.”*

Most hatchery programs proposed in the Columbia River Basin are subject to an extensive review process by the Northwest Power Planning Council's ISRP. The Lower Snake River Spring Chinook (ISRP

2011) and steelhead (ISRP 2013a) programs have also been reviewed. The reviews noted that although the programs addressed several key HSRG recommendations, they did not include sufficient detail on how new management practices are being implemented and how they will be used to meet specific management targets. The ISRP review also noted that some HSRG recommendations have been misinterpreted. For example, some programs are using sliding-scale broodstock management, where adjustments are made to the proportion of hatchery-origin adults used for broodstock based on the number of natural-origin returns. This approach is consistent with HSRG recommendations so long as broodstock standards (i.e., target percent hatchery fish on spawning grounds and target percent natural-origin fish in the hatchery brood) are maintained on average over time. This requires hatchery managers to incorporate higher numbers of natural-origin fish (above targeted values) in years when they are available in order to compensate for years when natural-origin fish returns are too low to achieve targeted values in the hatchery broodstock. Finally, the ISRP reviews noted that management plans should incorporate information on the status of natural populations and habitat, and should explicitly include an adaptive management framework (e.g., plans to reduce hatchery program sizes over time if goals are met). Both of these latter comments are consistent with HSRG recommendations.

The Columbia River Intertribal Fish Commission

The Columbia River Intertribal Fish Commission (CRITFC) and its member tribes have expressed concerns about incorporating the HSRG recommendations in the Northwest Power and Conservation Council's Columbia River Fish and Wildlife Program (FWP). These concerns are articulated in the following excerpts from their comments on proposals to incorporate HSRG framework into the FWP:

> *"Despite the intention of the Hatchery Scientific Review Group (HSRG) that its recommendations be offered to fisheries managers as guidance only, some recommendations seek adoption of the HSRG recommendations as Program measures. The Action Agencies and the Tribes recognize that hatcheries are providing important benefits to ESA-listed species and to the Tribes in support of their treaty fishing rights. Hatcheries are therefore an important part of the package of federal and tribal actions addressed in the FCRPS BiOp and the Accord. Further, the Yakama Nation concludes that it is inappropriate for NPCC to seek to establish standards or criteria for operating hatcheries that are legally required to provide mitigation for FCRPS operations. The management of such hatchery programs is properly the jurisdiction of resource agencies and tribes identified as the relevant co-managers by applicable state statute, federal Treaty rights case law, and the ESA. In practice, the appropriate resource co-managers are jointly developing hatchery management policies and plans that may incorporate HSRG guidance on a case-by-case basis. Adopting HSRG recommendations into the Program as a "one size fits all" measure would be inappropriate, needlessly contentious, and inefficient of resources." (Phil Rigdon, Yakama Nation, November 20, 2013)*
>
> *"The United States and the Pacific Northwest states have treaty duties. Like our sister Columbia River Treaty Tribes, the CTUIR possesses rights reserved by treaty to take fish destined to pass their usual and accustomed fishing places. See e.g., U S. v. Oregon (Sohappy v. Smith), 302 F. Supp. 899 (D. Or. 1969). These fish include those artificially propagated for rebuilding, mitigation and enhancement purposes. See United States v. Washington, 759 F.2d 1353 (9th. 1985) (holding that hatchery fish are "fish" within meaning of treaty fishing clause and subject to allocation thereunder). The work of the HSRG did not take these duties into account." (Kathryn Brigham, CTUIR, November 20, 2013)*

Additionally:

> *"We, like the other anadromous fish managers, support basin-specific, flexible approaches for the use of artificial propagation. Further, under the US vs. Oregon process we have made a successful link to rebuilding Columbia River salmon stocks by making a production/harvest connection. A review of pertinent scientific literature underscores the point that there are many different localized strategies employing artificial propagation in rebuilding salmon and steelhead and that different strategies are producing different results. See, Bosch & Galbreath, 2013. Much of this science is based on information that was not available from 2006-2008 when the work of the HSRG was carried out in the Columbia River Basin, and is the most current on the subject.*
>
> *The work of the HSRG and its AHA modeling exercising was a useful learning exercise for hatchery program managers. Many of the program specific recommendations contained in the voluminous appendices of the HSRG report have been implemented. However even at the time this work was carried out, it was intended to "be a tool not a rule.""*
>
> *"We do not believe that science or policy warrants support for the Native Fish Society and Wild Steelhead Coalition, Trout Unlimited, and the Bonneville Customer group's recommendations calling for the incorporation and implementation of the HSRG recommendations in Program and basin hatcheries."*
>
> *"The Basin has moved beyond the processes of the HSRG into a new round of ESA compliance for hatchery programs in the Basin. More than 100 detailed Hatchery Genetic Management Plans (HGMPs) have been developed for the propagation programs in the Basin, and many of [them] include recommendations of the HSRG where appropriate. NMFS is preparing biological opinions on the basis of these plans. This is an extensive body of work ongoing that is taking into account the best available scientific information, including site-specific and other biological information that was not available in 2006-2008."*

The HSRG understands that uncertainty is inevitable in natural resource management. As stated in their 2009 report, the HSRG also acknowledges that their framework is but one of several that are consistent with the current state of the science. However, the HSRG remains convinced that their proposed solutions are more likely to be successful in achieving harvest goals (including treaty responsibilities) consistent with conservation requirements (which are also a key treaty responsibility of the United States and PNW states), than the 20th century paradigm it recommends replacing. The central message of the HSRG is that the impacts of hatchery fish on naturally spawning populations must be carefully considered when planning and operating harvest augmentation and mitigation hatcheries and that the best available science should be used when informing decision makers about the tradeoffs involved.

2.2 All H Integration

Hatcheries are tools that can be used as part of a comprehensive "All H" strategy, where management of habitat, hatcheries, harvest, and hydropower are coordinated to meet population goals. In some cases, hatcheries are part of the long-term management strategy for a population; for example, scenarios where habitat or fish passage survival is not likely to improve in the foreseeable future. More work is needed to implement hatchery programs as part of an "All H" strategy. Agencies continue to struggle with coordinating fisheries management across departments, regions and disciplines.

2.2.1 The Importance of All H Integration

The importance of integrating fisheries conservation and management efforts across regions and disciplines has been addressed in numerous reviews (HSRG 2009, NPCC 2009, RIST 2009, NMFS 2012, ISAB 2013, and ISRP 2013b). Key recommendations from these documents can be found in Appendix 2. The recommendations are summarized here:

- The Northwest Power and Conservation Council's Independent Scientific Review Panel (ISRP) (2013b) reviewed Columbia Basin habitat restoration proposals and expressed concern that the proposed projects did not appear to be coordinated with basin-wide habitat monitoring initiatives (CHaMP and ISEMP) or provide specific information on quantitative benefits to fish populations (e.g., Viable Salmonid Parameters, or VSP).

- The Northwest Power and Conservation Council's Independent Scientific Advisory Board (ISAB) (2013) suggested developing a process, such as the Grande Ronde Model Watershed process, and then publicizing that process as an example of how fisheries management can be coordinated across disciplines within a large geographic area.

- The National Marine Fisheries Service (NMFS) (2012) is using regional consultations to address the effects of multiple fisheries-related restoration projects on regional scales. The purpose is to apply conservation principles consistently across the region. However, while these programmatic consultations bind together regions, they do not necessarily integrate across fisheries management disciplines.

- The Northwest Power and Conservation Council (NPCC) (2009) suggested improving coordination among the many fisheries programs in the Columbia Basin by establishing better data management and information sharing systems, improving communication among agencies, and holding focused workshops on specific issues to bring together participants from multiple agencies and disciplines.

- The Recovery Implementation Science Team (RIST) (2009) suggested several ways to improve understanding of hatchery-habitat interactions. Decision support models could be adapted to account for ecological interactions among hatchery and wild salmonids. The review also recommended developing better information about the cumulative effects of multiple hatchery releases, more flexibility in habitat inputs (productivity and capacity) to models, and greater consideration of non-hatchery factors limiting populations (e.g., habitat degradation).

- The Washington Department of Fish and Wildlife (WDFW) Management Framework for the 21st Century (2009) integrates management goals for wild fish populations, habitat, and hatcheries. The framework provides a set of specific, quantitative goals in each discipline and a timeline for reaching goals. See Appendix 2 for examples of program goals.

- The HSRG (2009) advocated that formal, structured adaptive management processes be designed for hatchery programs. There are considerable uncertainties about the costs and benefits of hatcheries, and new information on population status and habitat conditions should be evaluated on a regular basis by fisheries managers.

2.2.2 Progress in All H Integration

Hatcheries

The HSRG developed three key principles to guide the management of hatcheries: 1) explicit, well-defined goals, 2) scientific defensibility, and 3) informed decision making (adaptive management). **Principle 1** implies that goals for harvest (i.e., catch in various fisheries), and recovery and sustainability (usually described by VSP metrics) of natural production should be well-defined for all salmon and steelhead populations. **Principle 2** requires that the expected contributions (positive and negative) of a hatchery program toward the resource goals be explicitly stated. It also requires that the assumed present and future habitat conditions, harvest policies, and hydropower system operations affecting the outcome of the hatchery program be identified and supported by available information. This defines the expected “All H” context of the hatchery program. Finally, the scientific rationale (based on best available science) should be explicitly stated in the hatchery plan. This is perhaps best accomplished with a comprehensive model. The assumptions used in designing a hatchery program and the expected outcomes of the hatchery program (contribution to catch, impacts to natural populations) form a working hypothesis for the program that can then be tested and adjusted during implementation. **Principle 3** recognizes that uncertainty is inevitable and that new information will lead to revised assumptions and potentially different outcomes from the hatchery program. Thus, implementation of the adaptive management principle requires that information on all four Hs be brought forward and incorporated into an updated working hypothesis (model). This represents the science contribution to the adaptive decision making process. The interdependence of habitat, hatchery harvest, and hydropower actions is indisputable and thus the need for an “All H” integrated adaptive management process. We are aware of no disagreement over the need for an “All H” approach. The question is how to put it into practice. Below are several examples of how some aspects of an “All H” adaptive management process have been implemented. The hatchery program Master Plans recently approved by the NPCC (Table 2-1) each include a rigorous Annual Program Review (APR) process. This process provides a framework for pulling all of the most recently available data together, including monitoring and evaluation data, new research findings, and new data on fish passage, harvest and habitat. This new information is used to review program performance, update assumptions (for all Hs), evaluate progress toward stated resource goals for harvest and natural production, and thus inform the adaptive management process.

The annual review process described in the NPCC Master Plans has four steps: (1) review and update a scientifically defensible working hypothesis (key assumptions and expected outcomes) for the program; (2) report and review the most recent empirical data on key population metrics (status and trends); (3) establish biological targets and management triggers to ensure appropriate responses to annual variations in population abundance and other parameters (referred to as the Decision Rules); and (4) apply the Decision Rules to set management targets for hatchery broodstock, natural escapement, and terminal harvest, and refine M&E priorities for the coming season. The annual review process is formalized in a database and in a set of management tools that ensure consistency and accountability. The end product of this workshop is an Action Plan that contains the blueprint for program activities for the upcoming year.

The Chief Joseph Hatchery Program (CJHP), designed as a harvest and conservation program for Okanogan spring and summer/fall Chinook, has held an Annual Program Review for the past three years. The Cowlitz Hatchery programs for Chinook, coho, and steelhead are reviewed annually by the Fisheries Technical Committee (FTC), which includes representatives from federal and state agencies, Tacoma Power, and nongovernmental groups. The FTC's findings are also presented to the public to facilitate citizen participation. The Nisqually River Chinook population recovery process involves both co-managers and the Nisqually River Council, which gives local constituents in the watershed the opportunity to participate in decision making. The program's performance is reviewed annually, forecasts for the upcoming year are discussed, and adjustments to the management of weirs and broodstock collection are made accordingly. The Yakima/Klickitat Fisheries Project (YKFP) is a multi-species hatchery and habitat enhancement program for spring, summer and fall Chinook and coho salmon. Each species has a Monitoring Implementation Planning Team (MIPT) that designs and updates monitoring and evaluation programs on a yearly basis through an Internal Project Annual Review (IPAR).

In all of these examples, a formal process is in place that involves multiple agencies, fisheries management disciplines, and citizen participants in the annual review and management of these programs. The CJHP has a comprehensive monitoring and evaluation plan, a database to organize this information, and an analytical modeling tool (AHA) that can be updated as key assumptions change. The Cowlitz FTC has also been using the AHA model to guide annual program decisions and has begun implementing a comprehensive monitoring and evaluation plan. The Nisqually co-managers use the AHA model as part of a structured annual review of the program's biological targets and forecasts for the upcoming season, and to make adjustments to the decision rules that guide in-season management. The Yakima/Klickitat Fisheries Project (YKFP) have annual internal evaluations where the managers review, analyze and document the results from the previous year and make adaptive management revisions to each program based on these reviews. These revisions are captured in Policy Decisions signed by the policy representative of each of the management agencies that document the issues and any changes to the program. The YKFP also sponsors an annual two day Science and Management Conference where all project results are presented to researchers and the general public.

These processes will improve through adjustments over time. For example, monitoring and evaluation of the CJHP could be streamlined by setting priorities for data collection and analysis. Currently, most

Tribal resources are used for data collection, leaving insufficient resources for analyzing data and organizing results to prepare for the APR. The Tacoma FTC process is facing challenges from a vocal constituency concerned about harvest opportunities being in competition with conservation objectives. Broad agreement on strategies to achieve long-term sustainability of both natural production and harvest can only be reached by building trust between the management agencies and user groups, through accountability and meaningful public involvement. That precisely is the intent of the APR process and the rationale behind the three HSRG principles (clear goals, scientific accountability, and an informed decision-making process).

Habitat and Hydropower

Habitat monitoring and restoration have been a recent focus in the Pacific Northwest. In the Columbia Basin, three basin-wide programs have been developed to improve regional coordination of habitat monitoring and evaluation (ISEMP, CHaMP, and AEM; see Appendix 2). Extensive databases on habitat condition are being developed. These will provide data on habitat quality that may be used to update and improve estimates of population productivity and capacity using models such as Ecosystem Diagnosis and Treatment (EDT).

Improved information on fish passage survival is available due to advancements in fish marking and monitoring (e.g., Tuomikoski et al. 2012). This information is used, for example in the AHA model, to evaluate different hatchery management scenarios. Fish passage survival estimates in Tuomikoski et al. (2012) also include measures of uncertainty (i.e., confidence intervals) that could be incorporated into an “All H” working hypothesis.

Harvest

Harvest in ocean, mainstem, and terminal fisheries reduces the number of hatchery and natural-origin fish that return to spawn and thus impact the ability of hatchery managers to meet program goals. Since 1995, mark-selective fisheries have been used in some areas to link hatchery management practices to harvest. Mark-selective fisheries that remove hatchery fish have the potential to improve the ability of managers to meet management targets for natural production, reduce straying, and decrease the number of hatchery-origin fish on the spawning grounds. Similarly, directing and operating hatchery programs in locales such as Youngs Bay, Oregon, that allow for subsequent known-stock, terminal harvest is a means to allow managers to sustainably increase harvest in specific fisheries while reducing risks to natural populations.

The HSRG views mass marking and an increased emphasis on selective harvest of hatchery-origin fish as a necessary part of a strategy to meet harvest objectives while reducing impacts on natural-origin fish by reducing the contribution of hatchery fish on the spawning grounds.

The HSRG’s 2009 Report to Congress states in Recommendation 9:

> *“To both increase salmonid harvest and minimize adverse biological effects on natural populations, the HSRG recommends that most fisheries be managed as selective fisheries, where marked hatchery fish are retained and unmarked fish are released with minimal*

> *mortality. Selective commercial fishing gear needs to be developed and assessed for use in the Columbia River."*

In the Columbia River, the Oregon Department of Fish and Wildlife (ODFW) and WDFW Commissions have jointly developed a new management framework for commercial and recreational selective fisheries (WDFW Commission 2013). During the transition period (from 2013 through 2016), gill nets may be used in areas where hatchery fish are prevalent, but the departments are developing incentives to promote the use of selective gear such as purse and beach seines to reduce mortalities of natural-origin fish and non-target species.

The WDFW Commission's Columbia River Basin Salmon Management Policy states:

> *"The Department will investigate and promote the development and implementation of alternative selective gear during the transition period (2013-2016). If alternative selective gear is not available and practical, based on administrative, biological or economic factors, the use of gill nets in these fisheries will be allowed during the transition period. The development and implementation of alternative selective gear such as purse seines and beach seines should provide area-specific opportunity to target fishery harvests on abundant hatchery stocks, reduce the number of hatchery-origin fish in natural spawning areas, limit mortalities of non-target species and stocks, and provide commercial fishing opportunities. To facilitate the timely development of and transition to alternative selective gear and techniques, Washington should work with Oregon to develop incentives for those commercial fishers who agree to use these gear and techniques."*

The WDFW has also made most recreational fisheries in Puget Sound, Strait of Juan de Fuca, and freshwater tributaries into selective fisheries for hatchery Chinook and coho salmon. Both Oregon and Washington have made recreational Chinook and coho fisheries off the coasts into either partially or entirely selective fisheries. Recreational fisheries for steelhead have been mark selective throughout the Pacific Northwest for many years.

The Chief Joseph Hatchery Master Plan includes a 10-year program to develop and evaluate gear for selective harvest. Preliminary results of gear testing (2008-2010) found an immediate mortality rate of 0.1% for beach and purse seines and 20% for tangle nets. Additional tests are in progress for hoop nets, dip nets, hook-and-line, net traps, and weirs. The purpose of the program is to use selective harvest as a tool to reduce the proportion of hatchery-origin fish on the spawning grounds. The HSRG has not yet conducted a comprehensive analysis of the costs and benefits of selective fisheries. Selective harvest may have more benefits in terminal fisheries because they have a more direct impact on the target population. Future work by the HSRG should model the benefits and risks of selective fisheries under different scenarios.

High harvest rates on hatchery fish with minimal impact on natural-origin stocks can also be achieved by releasing hatchery juveniles, and harvesting returning adults, in areas where natural-origin fish are largely absent. Examples include the Tulalip Bay fishery in Puget Sound and the Select Area Fishery Evaluation (SAFE) fisheries in the Lower Columbia River.

2.3 Implementation of Hatchery Reform

The following sections provide background information on harvest and conservation hatchery programs and on the number and type of hatchery programs in the Columbia River Basin (Section 2.3.1). Detailed examples of harvest and conservation hatchery programs that have recently been revised in response to the suggestions of the review teams across the Pacific Northwest are provided (Sections 2.3.2 and 2.3.3) as well as conclusions about hatchery reform implementation (Section 2.4). In addition, a summary of recent changes to more than 50 hatchery programs in Washington, Oregon, and Idaho is provided in Appendix 3.

2.3.1 Overview of Harvest and Conservation Hatchery Programs

Hatchery programs have traditionally been designed to meet either harvest or conservation objectives, although some harvest programs also have conservation benefits. As mentioned above, the HSRG recommends that both harvest and conservation programs adhere to three key principles: they should have well-defined goals that are expressed in terms of resource values (i.e., meeting specific harvest levels or population recovery goals), must be scientifically defensible, and must include an adaptive management process.

Harvest programs should be designed to provide specific harvest benefits (i.e., catch) in specific fisheries without causing adverse impacts to naturally spawning populations. The tolerance of a given population to hatchery influence is a function of the population's biological significance (Primary, Contributing, or Stabilizing[2]) and population status (abundance, productivity, diversity, and spatial structure) (HSRG 2009). Some harvest programs also provide conservation benefits. For example, harvest programs that maintain the abundance of a local population in watersheds with limited capacity for natural production have the potential to provide a safety net to populations vulnerable to demographic extinction.

Conservation programs may be designed to preserve an existing population, recolonize available habitat, and/or provide a demographic safety net. The HSRG has defined four biologically-based phases for conservation programs: preservation, re-colonization, local adaptation, and full restoration. The transition from one phase to the next is based on quantitative biological triggers rather than an arbitrary timeline. Conservation programs may remain in one phase for a prolonged period, for example if habitat quality is not yet high enough to support the transition from the re-colonization to the local adaptation phase (see Section 3.6 for additional discussion).

The HSRG initially divided hatchery programs for harvest augmentation into two types, integrated and segregated, and proposed that using these strategies can limit reductions in the reproductive fitness of natural populations due to the genetic introgression of hatchery fish. In segregated programs, hatchery

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[2] Primary, Contributing, and Stabilizing designations reflect the relative contribution of a population to recovery goals and objective levels of viability consistent with recovery criteria. Primary is the most important population designation and Stabilizing is the least important designation (LCRSRP 2004).

populations are isolated from natural populations to the maximum extent possible, with limited gene flow between the populations due to straying. Integrated programs associate hatchery populations with specific natural populations. In an integrated program, gene flow between the populations is managed so there is greater gene flow from the natural population to the hatchery population than from the hatchery to the natural population.

In 2009 the HSRG proposed a third type of program, the "stepping-stone program", which is a combination of an integrated and a segregated strategy. When natural production is too low to support an integrated program (or to tolerate a segregated one) of sufficient size to meet harvest objectives, the HSRG suggests that managers consider a two stage or "stepping-stone program." Initially, a small integrated program is defined that accompanies a larger segregated program (see Section 3.2.1). The intent is to transition, over the long-term, into a fully integrated program once natural production is sufficient to provide the required number of natural-origin brood fish through improvements in the other "Hs."

To illustrate the potential impact hatchery programs could have on existing natural populations, the number of salmonid populations in the Columbia River Basin with integrated hatchery programs, segregated programs, or no hatchery program (natural population) is shown in Table 2-2. The table shows the status of populations in 2010, and also shows the program purpose (harvest, conservation, or both harvest and conservation). Just under half of all Chinook, coho and steelhead and all of the sockeye populations in the Columbia Basin have some type of hatchery program that could directly impact them. An inventory of populations in Puget Sound and the Washington Coast would likely show similar results. At the time of our reviews, most of these programs did not meet HSRG broodstock standards for the relative numbers of hatchery-origin fish that spawn naturally or the proportion of natural-origin fish used in the hatchery broodstock.

Table 2-2. Status of populations and hatchery programs in the Columbia River Basin (2010[3]).

Program Type	Purpose	Chinook	Coho	Steelhead	Sockeye	Chum
Integrated	**Harvest**	10	5	4	0	0
	Conservation	10	3	7	2	1
	Both	17	1	6	0	0
	Total	**37**	**9**	**17**	**2**	**1**
Segregated	**Harvest**	50	22	60	0	0
	Conservation	1	1	0	0	0
	Both	3	1	0	0	0
	Total	**54**	**24**	**60**	**0**	**0**
Natural Populations	**Total**	**106**	**34**	**85**	**2**	**18**

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[3] Based on HSRG (2009) and updated in 2010 for the Mitchell Act EIS.

In addition, a recent example of a large scale hatchery program that could have major impacts to important natural populations within the Columbia Basin is the planned John Day Mitigation Program (JDMP). This program anticipates an additional 8.5 million fall Chinook (approximately) to be reared and released into the Columbia River between Bonneville and Priest Rapids Dams. A review of the current Environmental Assessment reveals a concern with achieving production targets (old hatchery paradigm) and impacts to ESA listed populations. The population most likely impacted is the upriver bright fall Chinook population spawning in and around the Hanford Reach area of the Columbia River (below Priest Rapids Dam). This population, the largest naturally spawning fall Chinook population in the Columbia Basin, is not currently listed under the ESA; this is due in part to its high spawning abundance and productivity. It is unclear if the impacts to this population from a large increase in hatchery production, such as the number of strays into natural spawning areas or the anticipated increased harvest activity that will be implemented to catch these fish, have been adequately analyzed from an "All H" perspective.

2.3.2 Examples of New Harvest Programs Designed to Meet HSRG Standards and Principles

Cowlitz Chinook, Coho, and Steelhead (Washington)

The Cowlitz River hatchery programs were established to augment 11 populations of Chinook, coho salmon and steelhead. The primary goal of each program is to provide harvest opportunities (both pre-terminal and terminal) that are compatible with the long-term conservation of indigenous salmonid populations in the basin. These are integrated harvest programs, and the proportion of natural-origin broodstock (pNOB) and hatchery-origin spawners (pHOS) are managed based on the HSRG guidelines for an acceptable level of hatchery influence to the natural population, commensurate with the population designations (Primary, Contributing, or Stabilizing).

The Fisheries and Hatchery Management Plan (FHMP) (Tacoma Power 2012) for the Cowlitz programs was updated in 2012 to improve the adaptive management process and incorporate the most recent science. Biological targets and decision rules were developed for each of the 11 populations to guide the process. One novel aspect of the programs is the credit mechanism, which reduces hatchery production by the number of wild fish produced in the system above the hydropower projects. This is consistent with the HSRG recommendation that hatchery production may be adjusted downward as wild populations recover. Providing credits for naturally produced smolts is viewed as an incentive to increase the survival of out-migrants passing over Cowlitz Falls and Mayfield dams.

Lower Columbia Steelhead and Puget Sound Steelhead (Washington)

Guided in part by the AHA model, managers recently made several important changes to the WDFW Lower Columbia River and Puget Sound steelhead programs in response to region-wide programmatic recommendations by the HSRG. These are segregated harvest programs, in most cases using non-local broodstock, for which the large-scale movement of eggs and juveniles between watersheds has been the accepted practice. Recent program changes include:

- A regional system of wild steelhead management zones (basins) with no hatchery releases is being developed.
- In streams with hatchery programs:
    - 100% locally adapted hatchery broodstock will be used (i.e., each hatchery will only use eggs from fish returning to its facility, which reduces the need to transfer eggs/fish between watersheds).
    - Early spawn timing of the hatchery population will be maintained through selective broodstock collection to minimize interaction with later spawning wild runs. Cutoff dates for spawning of hatchery fish are being used to maintain earlier run timing.
    - Smolts will only be released at locations with adult collection capabilities to allow for the capture and removal of unharvested adults.
    - In some programs where the proportion of hatchery adults that spawn in the wild exceeds the recommended level, there have been cuts to the number of smolts released or the release location has been changed to try to control these excesses (see Appendix 3 for examples).

Okanogan Summer Chinook Salmon (Washington)

The Okanogan summer Chinook program consists of an integrated harvest and a conservation program. The conservation goals are to increase the abundance, productivity, and distribution of naturally spawning summer Chinook in the Okanogan basin. Harvest goals are to increase tribal and recreational fishing opportunities by increasing the number of returning hatchery-origin adults. The program is managed based on the HSRG's recommendations for a Primary population. Key components of the recovery program include developing a local broodstock, expanding broodstock collection to represent the entire historical run timing, propagating both yearlings and subyearlings to represent natural population diversity, improving the spatial distribution of spawning, and controlling the proportion of hatchery-origin fish spawning in the wild (pHOS).

During the planning process for the program, studies were conducted with the goal of developing appropriate broodstock collection methods. A radio telemetry study collected information on broodstock behavior, particularly the relationship between arrival timing and spawning location. A second study evaluated the efficacy of different broodstock capture methods and compared survival of Chinook captured using several methods (selective gear, beach seines, tangle nets, and traps). A comprehensive monitoring and evaluation plan was developed for this program that incorporates the "All H" process and is being used as a model for several other programs.

Snohomish Basin Chinook Salmon (Washington)

The Snohomish River Basin supports two distinct Chinook salmon populations in two separate tributaries: the Skykomish (summer Chinook) and Snoqualmie (fall Chinook) populations. The Tulalip Tribes and WDFW operate two Chinook salmon hatcheries in the basin for summer Chinook to provide tribal and recreational harvest opportunities and meet Pacific Salmon Treaty obligations with Canada. The program was converted to an integrated program in response to the HSRG recommendations. To protect the natural population while integrating this program, the number of natural-origin adults removed for broodstock is limited to less than 20% of the NOR escapement. The Snoqualmie fall Chinook salmon population is managed for natural production—there are no releases of hatchery-origin fall Chinook salmon into the drainage.

The Snohomish Basin Salmonid Recovery Technical Committee has worked to integrate the "All H" process into management of Snohomish Basin Chinook salmon using the AHA model (Kaje et al. 2008). The committee evaluated the Skykomish population for its ability to maintain estimated fitness by the use of mark-selective fisheries and trapping to remove surplus hatchery fish from the system. The modeling results were found to be highly sensitive to the effectiveness of each method at reducing the ratio of hatchery fish, particularly during periods of low productivity. The committee examined the sensitivity of the estimated abundance of the Snoqualmie natural spawning population to the abundance of hatchery strays. Hatchery-origin Chinook salmon from a variety of sources (both within and outside the basin) have been documented in the Snoqualmie watershed, averaging 25% of the spawning population in recent years. The report concluded that for the Snoqualmie population an important pattern emerged: when productivity is low (i.e., habitat is poor or only slightly improved), natural fish abundance is limited significantly by the spawning effectiveness of stray hatchery fish. In contrast, when productivity is high, abundance is limited by habitat capacity, as the effect of strays is diluted by the high ratio of natural-origin fish to hatchery fish.

The key outcome of these modeling exercises was to help prioritize monitoring efforts in the basin. Better information is needed on the abundance and source of hatchery strays in the Snoqualmie system, and the estimates of the effectiveness of selective fisheries and trapping at regulating hatchery-origin fish numbers in the Skykomish system.

Upper Salmon River Chinook Salmon (Idaho)

The Upper Salmon River summer Chinook salmon programs provide harvest that is compatible with long-term conservation goals for the populations. Three programs, Pahsimeroi River (Pahsimeroi Hatchery), South Fork Salmon River (McCall Hatchery), and Upper Salmon River (Sawtooth Hatchery), each annually release approximately one to 1.8 million spring/summer Chinook salmon smolts. Managers expect this smolt production to produce, on average, enough adults returning above Lower Granite Dam to meet harvest objectives. The programs are managed based on the HSRG's recommendations for a Primary population.

Managers have identified a strategy for managing Upper Salmon River summer Chinook salmon that protects and enhances the natural spawning populations while maintaining harvest via the current hatchery programs. The programs include both an integrated component (releasing approximately 200,000 smolts per program) and a segregated component (releasing approximately 800,000 to 1.6 million smolts per program). Integrated programs are managed to include more natural-origin adults in the broodstock than hatchery-origin adults in the habitat (PNI goal ≥ 0.67). Adult returns from the integrated component may be used as broodstock for the segregated programs if returns exceed the integrated programs' broodstock and natural spawning targets. This approach, referred to as a two-stage "stepping-stone program", was recommended by the HSRG during their independent review of the programs (HSRG 2009) (Section 3.2). Due to current natural production and harvest patterns, the integrated component of the program is not large enough to provide brood for the segregated component of the "stepping-stone program." Over time, the integrated component is expected to increase sufficiently to provide brood for the segregated component in most years.

East Fork Salmon River Steelhead (Idaho)

The program in the East Fork Salmon River represents the only integrated program for steelhead managed by the Idaho Department of Fish and Game. The effort was initiated in 2001 as an attempt to bolster abundance of natural-origin summer steelhead in the drainage. A permanent trapping facility exists in the East Fork Salmon River, but is approximately 18 miles upstream of the mouth and also upstream of much of the spawning and rearing habitat in the drainage. This constraint makes integrated population management challenging as the proportion of hatchery-origin fish spawning downstream of the trapping facility cannot be controlled.

Recent production objectives in the East Fork include releasing 170,000 integrated smolts immediately downstream of the trapping facility. The number of hatchery-origin adult returns in the past few years to the trapping facility from this level of production has greatly outnumbered the number of natural-origin returns. It is also presumed that a significant proportion of fish spawning downstream of the trap are hatchery-origin. The genetic influence of the hatchery population for the East Fork is higher than desired because the majority of fish spawning, both naturally and in the hatchery, are of hatchery-origin. To decrease potential impacts of hatchery-origin adults on the fitness of the natural population, beginning in brood year 2013, the number of hatchery-origin smolts will be reduced to 60,000. Additionally, an effort will be made to use 100% natural-origin adults as broodstock. This strategy will provide the best opportunity to maintain a minimum number of returning adults to the East Fork to meet broodstock needs at the hatchery and still meet escapement objectives for natural-origin adults.

Umatilla Coho Salmon (Oregon)

The Umatilla coho salmon program was established to reintroduce a natural coho salmon run and provide harvest. Until recently, this segregated program used out-of-basin broodstock and released more than 1.5 million smolts each year. The HSRG reviewed the Umatilla program in 2009 and made several recommendations, including developing a locally adapted broodstock, reducing the program size to achieve pHOS standards, marking all juvenile releases, and developing a monitoring program to assess spawning ground composition and reproductive success of natural spawners.

Recent program changes have included reducing the program size by 68% (from 1.53 million to 500,000 releases). Managers are developing a locally adapted broodstock by collecting adult coho that return to Three Mile Dam. The program now marks 80% of hatchery releases to facilitate a selective harvest program. Future plans include developing a comprehensive monitoring and evaluation plan (ODFW 2010b).

Sandy River Spring Chinook Salmon (Oregon)

The ODFW's Sandy River Spring Chinook hatchery program has recently undergone some important changes in response to the recommendations made by the HSRG. It is assumed that the changes to the program will assist with conservation efforts for the natural spring Chinook population in the Sandy River Basin (designated as a Primary population), while providing fish for recreational and commercial harvest. The changes include: 1) Reduce the number of fish released from 300,000 to 120,000 smolts, 2) Increase marking to 100% AD clip and CWT, 3) Acclimate and release smolts in the Bull Run River to congregate adults low in the basin, increase harvest in the area, and minimize their migration to the natural spawning ground in the upper Sandy River basin, 4) Integrate broodstock (currently with 20% natural-origin adults, or pNOB 0.20) and reduce the hatchery fraction on natural spawning grounds to less than 10% (pHOS 0.10) (the target is to maintain a population PNI > 0.67), and 5) Hatchery fractions are managed with seasonal weirs/traps installed at various locations in the upper Sandy River, Cedar Creek and lower Bull Run River, to capture and remove hatchery adults from the spawning population. The Sandy River Spring Chinook program is therefore designed to meet or exceed the HSRG proposed standards for a Primary population.

2.3.3 Examples of New Conservation Programs Designed to Meet HSRG Standards and Principles

Elwha Chinook Salmon (Washington)

The Elwha Chinook program was established to restore the naturally spawning Chinook population in the Elwha River basin. The HSRG initially reviewed the Elwha program in 2004 and recommended that the primary focus should be on improving the quality and diversity of smolts to achieve the required number of adult broodstock. The HSRG also suggested expanding hatchery facilities to reduce or eliminate the need to transport eggs and fry outside the watershed for incubation and rearing. These recommendations are being addressed by the program. A new hatchery has been built that will allow tribal fisheries managers to expand and enhance hatchery operations with the removal of the Elwha Dam. In addition, the HGMP for the Elwha program was updated and the NMFS consultation is complete. The HSRG conducted a comprehensive review of the program in 2012 at the request of the Elwha Tribe and WDFW. Based on that review and subsequent HSRG recommendations, the program has adopted the four biological phases of restoration (preservation, re-colonization, local adaptation, and full restoration, see Section 3.6). In addition, the co-managers have designated the Elwha Chinook population to be a Primary population and adopted the HSRG broodstock standards for operating the hatchery program commensurate with that designation, developed quantitative biological triggers for the transitions between phases based on VSP criteria, and developed a clear set of decision rules for each program phase. Co-managers have also established a target for the proportion of hatchery-origin fish that spawn naturally and a plan to achieve it (e.g., installing a weir or using selective fisheries), and plan to visibly mark all releases.

Redfish Lake Sockeye (Idaho)

The Idaho Department of Fish and Game (IDFG) and NOAA Fisheries initiated a captive broodstock program for the endangered Snake River sockeye salmon population in 1991 with the goal of preventing species extinction, slowing the loss of population genetic diversity, and increasing the population size. The program is using a three-tiered approach to: 1) increase number of adult sockeye returns, 2) incorporate more natural-origin returns in hatchery spawning designs and increase natural spawning escapement, and 3) develop an integrated program that meets criteria established by the HSRG to ensure sufficient influence of the naturally spawning portion of the population on the composite population.

The hatchery program's purpose is to preserve genetic resources, provide a demographic safety net and over time contribute toward the draft delisting goal of 2,500 sockeye adults returning to Sawtooth Basin lakes. The program is managed based on the HSRG's recommendations for a Primary population. The program uses several different "spread the risk" reintroduction strategies to ensure that a failure of one strategy does not risk the whole population, and conducts ongoing research to determine the most successful release options (including adult plants, eyed egg/fry plants and smolt plants within the basin). To guard against catastrophic loss at any one brood facility, the captive broodstock components of the program are duplicated at facilities in Idaho and Washington. Emphasis is placed on the annual development of genetically diverse broodstocks. Fish culture variables (e.g., broodstock mating designs, in hatchery survival, maturation success, fecundity, egg survival to eye, and fish health) are monitored and evaluated to ensure maximum program success.

A new IDFG smolt production hatchery (Springfield Hatchery) was completed in 2013. Smolt production will ramp up from approximately 180,000 to one million over a three-year period. Managers will follow a phased approach to implementation beginning with a re-colonization phase (intended to jump start natural production) followed by a local adaptation phase where the composite population will be managed consistent with HSRG recommendations. The phased approach will facilitate adaptive management as returns increase.

Yakima Coho Salmon (Washington)

In 1996, the Yakima River Coho Supplementation Project was one of the high priority re-colonization projects approved by the Northwest Power Planning Council (now the Northwest Power and Conservation Council, NPCC) for the purpose of re-establishing a naturally spawning population and moving release sites higher in the watershed. The project was expected to progress through four experimental design phases: 1) select and introduce an appropriate donor stock, 2) test and initiate re-colonization of natural habitat, 3) continue colonization and transition to local broodstock, and 4) a local adaptation phase. Phases 1 and 2 have been accomplished (Bosch et al. 2007) and the NPCC has approved a Master Plan to implement the third and fourth phases. The purpose of the proposed actions is to increase harvest levels, natural spawning abundance, and spatial/temporal distribution of coho in the Yakima River Basin.

The Master Plan includes both integrated and segregated hatchery programs and was designed to meet or exceed HSRG standards. The segregated program component will be at Prosser Hatchery on the lower Yakima River and the integrated program will be at Holmes Ranch Hatchery on the upper Yakima River. The segregated program will release 500,000 smolts downstream of Prosser Dam using broodstock collected at the dam. The integrated program will rear and release 500,000 parr and 200,000 smolts in the upper Yakima and Naches rivers using broodstock collected at Roza and Sunnyside. Fish will be 100% coded wire-tagged, but not adipose fin-clipped so that release locations can be distinguished, but the fish would not be harvested in selective fisheries.

The integrated program (Phase 1) will transition to an increasing percentage of locally adapted broodstock as runs of natural-origin adults increase (Phase 2). No more than 20% of the natural run will be taken for broodstock in any given year. When the number of natural-origin coho returns exceeds hatchery-origin returns, the focus of the integrated program will shift to one that equally emphasizes harvest and conservation (Phase 3). The long-term goal is to have an average run of 10,000 natural-origin fish. Phase 4 will begin when the number of natural-origin coho exceeds hatchery-origin coho at Prosser Dam for three consecutive brood years. The three year period was selected as the criterion because it corresponds to the three year life cycle of coho.

2.4 Summary and Conclusions for Section 2

The HSRG's hatchery reform recommendations have become a pervasive set of standards for developing new hatchery programs and making existing programs consistent with resource goals and 21st century science in the Columbia Basin, Puget Sound, and Washington Coast. The hatchery management principles developed by the HSRG are being institutionalized in several agency policies and many hatchery management plans, and are widely cited in scientific reviews. The HSRG has increased understanding of the potential conservation benefits of hatchery reform by emphasizing the importance of using models and the best available science. In addition, combining the HSRG hatchery reform framework with thoughtful designations of populations based on biological importance can lead to realignment of propagation programs that provide more sustainable harvest in the future.

Hatchery reform has been implemented across the region in a wide range of programs. In addition to the examples described above, a brief overview of more than 50 hatchery programs in Washington, Oregon, and Idaho that have recently been revised to incorporate HSRG recommendations is provided in Appendix 3. Table A-3-1 compares the status of 11 Puget Sound programs before and after the 2004 HSRG program reviews. The comparisons focus on whether programs include the following elements 1) population designation, 2) specific, quantifiable harvest or conservation goals, 3) targets for Proportion of Natural Influence (PNI), proportion of fish spawning naturally that are of hatchery-origin (pHOS), and proportion of hatchery broodstock composed of natural fish (pNOB), 4) appropriate broodstock management methods, and 5) methods to manage pHOS (e.g., weirs, selective fisheries). Table A-3-2 briefly describes recent changes to Columbia River Basin hatchery programs made after the HSRG (2009) recommendations were released. These recommendations focused on broodstock management and managing spawning ground composition (pHOS).

The most frequently implemented program changes include installing weirs, developing locally adapted broodstock, marking all releases, and establishing new and more intensive selective fisheries. Some programs have developed comprehensive Monitoring and Evaluation Plans that incorporate an adaptive management process. However, many of the hatchery management plans developed to date still do not state explicit assumptions about population status and biological significance (e.g., population designations), identify pHOS and PNI targets based on the population designation, or contain quantitative harvest or conservation goals that are linked to population recovery goals.

More work is needed to implement hatchery programs as part of an "All H" strategy, where management of habitat, hatcheries, harvest, and hydropower are coordinated to meet population goals. Long existing institutional divisions of responsibilities have been cited as impediments to collaboration and coordination among habitat, harvest, and hatchery managers. In addition, managers often face logistical, stakeholder, regulatory and fiscal challenges in meeting population management targets for pHOS, pNOB and PNI.

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3.0 The Status of Hatchery Science

Uncertainty is inevitable in natural resource management. To reduce uncertainty over time we must challenge existing assumptions and hypotheses with new data and better models. The assumptions (or model), upon which the HSRG conclusions and recommendations are based should be challenged, not to see if they are perfect—they are not—but to see if another set of assumptions (another model) exists that is more broadly supported by available scientific data and information.

This chapter is a review of relevant peer-reviewed literature related to hatchery reform, particularly those studies that have been published since the completion of the 2009 HSRG report. The intent is, in part, to draw attention to new information, in part to clarify and expand on issues not fully addressed in the 2009 report, and if appropriate to adapt previous HSRG assumptions. In this chapter, we discuss:

- The HSRG working hypothesis (theoretical foundation) for evaluating the hatchery effects on the viability of natural populations, and a review of recent literature on the topic (Section 3.1),
- Hatchery broodstock management as a key part of the solution to balance conservation risks versus harvest benefits from harvest augmentation programs (Section 3.2),
- Ecological interactions related to hatchery operations (Section 3.3),
- Fish health issues (Section 3.4),
- Nutrient enhancement (Section 3.5),
- The role of hatcheries for conservation and recovery (Section 3.6), and
- RM&E and adaptive management requirements for hatchery programs (Section 3.7).

3.1 Hatchery Effects on Viability of Natural Populations

Fitness and local adaptation are critically important to the viability of salmon and steelhead today, particularly in the face of a changing environment due to climate change and human population growth. These characteristics are essential if we are to realize benefits from investments in habitat improvements.

There is growing recognition that population diversity within exploited species contributes to their long-term sustainability and should be incorporated into management and conservation schemes (Hilborn et al. 2003, Schindler et al. 2010). Populations with high diversity are more resilient during periods of environmental change such as climate fluctuations or in response to anthropogenic habitat alterations, both positive (e.g., habitat restoration) and negative (e.g., logging or urbanization). However, large-scale releases of salmon and other species into the wild can reduce population diversity and have unintentional negative effects on the recipient populations (Laikre et al. 2010). These negative effects include loss of genetic variation, impaired ability to adapt to habitat conditions, and changes in population structure resulting in reduced viability of naturally spawning populations.

The viability of salmon populations is described in terms of four interrelated parameters: productivity, abundance, diversity and spatial structure (McElhany et al. 2000). At the core of hatchery reform is the question of how to reduce the loss of productivity due to hatcheries, while retaining the abundance benefits provided by hatcheries. The HSRG recognizes that cultural and economic benefits of harvest are important and that hatcheries are a necessary tool in the foreseeable future—solutions exist where harvest goals can be met while protecting the long-term viability of naturally spawning populations. However, this can only be achieved through scientifically informed decision making and accountability for trade-offs between near-term benefits versus long-term costs in viability.

3.1.1 The HSRG Hypothesis

The 2009 HSRG conclusions and recommendations are based on a set of assumptions that should be challenged and refined as new scientific data and information become available. The HSRG standards should be challenged with better alternatives, and not discarded because of imperfections. At the core of these assumptions are working hypotheses about fitness and productivity.

The HSRG defines population productivity as the product of habitat potential and genetic fitness (Box 1). Optimum productivity within a given habitat is achieved when a population is fully adapted to that habitat. When this occurs, a fitness factor of 1 is assigned in the AHA model.

Box 1. POPULATION FITNESS AND PRODUCTIVITY

In the HSRG framework, population fitness is defined as the inherent productivity of a population relative to its optimum productivity in the available habitat. In this sense, fitness is a measure of the ability of a population to fully utilize the available habitat, and population productivity is the product of habitat potential and population fitness. Fitness varies over time based on the genetic legacies of the natural-origin and hatchery-origin spawners. If the composition of hatchery and natural-origin fish on the spawning grounds and in the hatchery remain constant over time, fitness reaches equilibrium (“long-term fitness”), which is the fitness value reported in an AHA analysis.

The HSRG modeled long-term fitness using a quantitative genetic model based on Ford (2002) and implemented in AHA. Ford (2002) modeled fitness of a wild and captive population using a phenotypic model where a suite of fitness correlated traits (such as time of spawning, length, etc.) are modeled as a single quantitative trait under selection with different optimum trait values in the captive and wild environments. The model includes assumptions about the heritability of the trait, the strength of selection, and the optimal phenotypic trait value and variance in the two environments.

AHA uses a set of global parameters (the same values were used for all populations). The global parameters used in AHA assume high heritability and strong selection. These parameter values are part of the HSRG working hypothesis and have been subjected to sensitivity analyses (HSRG 2004).

The Ford fitness model parameters are thoroughly detailed in HSRG (2009). Briefly, the parameters are:

θ = Phenotypic optimum or expected mean of the phenotypic probability distribution for the hatchery or natural population
σ^2 = Phenotypic variance for the trait in question in natural or hatchery environment
h^2 = Heritability of the trait in the natural or hatchery population
ω = Strength of selection, or selection intensity

In applying the Ford approach in AHA to model long-term genetic effects, the HSRG assumed high heritability, strong selection, equal phenotypic variance, and differing phenotypic optima for the natural and hatchery population as follows:

$\sigma^2_{Nat} = \sigma^2_{Hatch} = 10$
$\theta_{Hatch} = 80$
$\theta_{Nat} = 100$
$h^2_{Nat} = h^2_{Hatch} = 0.5$ (high heritability)
$\omega^2_{Nat} = \omega^2_{Hat}$ 100 (or 10x σ^2) (strong selection)

3.1.2 Proportionate Natural Influence

The HSRG and WDFW used the Ford model to develop the concept of Proportionate Natural Influence (PNI), which can be interpreted as a measure of how well the population is adapting to the natural environment (HSRG 2009, Appendix A1, White Paper No. 1). PNI is defined as:

$$PNI = \frac{pNOB}{(pNOB + pHOS_{Eff})}$$

where pNOB is the proportion of natural-origin fish in the hatchery broodstock and $pHOS_{eff}$ is the effective proportion of hatchery-origin fish in the naturally spawning population.

The HSRG recognized that hatchery-origin fish spawning in the wild may on average produce fewer adult progeny than natural-origin spawners. To account for this, the HSRG defined the quantity $pHOS_{Eff}$ (effective pHOS) such that

$$pHOS_{Eff} = (\text{RRS} * HOS_{census})/(NOS + \text{RRS} * HOS_{census})$$

where HOS_{census}[4] is the number of hatchery-origin adults in the spawning population and RRS is the reproductive success of first generation hatchery-origin adults relative to natural-origin adults. NOS is the number of natural origin spawners.

The relative reproductive success (RRS) of first generation hatchery-origin adults in the wild is affected by both genetic and environmental factors. For example, domestication selection and choice of hatchery broodstock may affect spawn timing, growth and maturation of hatchery fish, while release location and size/age at release may affect the choice of spawning location. In the 2009 HSRG analyses, a set of default RRS values were used. The RRS values for coho and Chinook were typically set at 0.8[5]. The values used for steelhead varied depending on the donor (hatchery) population and the recipient (natural) population (Table 3-1). Depending on circumstances and available information, these values were adjusted for some hatchery programs.

Table 3-1. Steelhead RRS (partly based on Kalama River studies) (Leider et al. 1984)

	Affected Natural Populations		
Hatchery population	**Late Winter Steelhead**	**Summer Steelhead**	**Summer A-run and B-run**
Early Winter Steelhead (Chambers)	0.11	0.11	-
Summer Steelhead (Skamania)	0.17	0.18	-
Late Winter Steelhead (Native)	0.8	0.8	-
Summer Steelhead (Native)	0.8	0.8	-
Summer A and B-Run (Segregated hatchery)	-	-	0.25
Summer A and B-Run (Native)	-	-	0.8

The HSRG working hypothesis applied the Ford (2002) fitness model in AHA to calculate long-term fitness as a function of pHOS and pNOB over time. In other words, pNOB and pHOS are the "management variables" for which target values are set for each population. The HSRG recommended a set of standards (see Chapter 3.2) for managing fitness loss due to hatchery influence in terms of the management variables pHOS and PNI[6] based on the effects on fitness predicted by the model, as applied

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[4] Throughout the document, pHOS refers to $pHOS_{Eff.}$

[5] The HSRG chose the default RRS value of 0.8 to represent a modest loss of reproductive success due primarily to suboptimal use of spawning and rearing habitat caused by being released from a hatchery and a tendency to return close to the release point. RRS is likely to vary from case to case, and further empirical studies should be encouraged to refine RRS estimates.

[6] Note that PNI is an indicator of fitness calculated from pHOS and pNOB, which are the operational or management variables, i.e., those that the managers control.

in AHA. As indicated in Chapter 2 of this report, there is general acceptance of pHOS and PNI as useful and suitable indicators to formulate biological management targets for fitness. However, uncertainty still remains regarding the relationships between pHOS, PNI and fitness in specific circumstances. For example:

- Are the HSRG pHOS and PNI standards equivalent as indicators of fitness?
    - Is the 5% pHOS standard sufficient for limiting the influence of segregated hatchery programs on Primary populations (see Table 3-2)?
- How is PNI estimated for “stepping-stone programs”?
    - What are the cumulative effects of multiple programs (from a segregated program “on top of” an integrated population)?
- When is PNI an appropriate indicator of fitness?
    - PNI is not well defined when pNOB is zero and pHOS is small
    - The PNI standard is currently only applied to integrated programs

Much of the implementation of HSRG recommendations since 2009 has focused on achieving the HSRG standards for pHOS and PNI (Chapter 3.2). The pHOS standards to limit the impact of segregated hatchery programs on natural populations are 5% for primary populations and 10% for contributing populations; the corresponding PNI standards for integrated hatchery programs are 0.67 and 0.5. Table 3-2 compares the relative fitness effects of pHOS and PNI standards on naturally spawning populations as predicted by the Ford model and applied in the AHA model.

Table 3-2. Predicted long-term effect on fitness as a function of PHOS and PNI for segregated and integrated hatchery programs. Shading indicates HSRG standards for Primary (green) and Contributing (blue) populations.

Segregated		Integrated		
			Fitness Factor	
pHOS	Fitness Factor	PNI	pHOS=10%	pHOS=30%
2%	0.85	0.77	0.92	0.91
3%	0.76	0.75	0.91	0.9
4%	0.68	0.71	0.89	0.87
5%	0.62	0.67	0.86	0.83
6%	0.57	0.60	0.81	0.77
10%	0.20	0.50	0.74	0.67

In the example shown in Table 3-2, note that the standard for a segregated population (pHOS < 5%) results in a significantly lower relative fitness (0.62) than the corresponding fitness values (0.83 - 0.86) for an integrated population with a PNI > 0.67. This suggests that the HSRG standard for segregated populations may be insufficient to safeguard the long-term viability of the affected naturally spawning Primary and Contributing populations. Both segregated and integrated broodstock strategies have a role in hatchery management. However, recent studies and further AHA analyses suggest that segregated hatchery programs should be used with greater caution and require more intensive monitoring.

The CA HSRG went a step further in their assessment of segregated hatchery programs. Using the definitions of integrated and segregated programs from the HSRG 2009 report, they noted (CA HSRG 2012, p. 17):

"We emphasize that for a program to be truly segregated, the proportion of hatchery-origin spawners on a natural spawning ground, pHOS, must be equal to zero."

And also:

"We note that numerous Columbia River hatchery programs have been designated as segregated, but have not achieved the criterion of pHOS equal to zero. In addition, when hatchery-origin fish from highly segregated programs breed in natural populations, the potential reduction in fitness of the natural population is greater than that from hatchery-origin fish from an integrated program. Therefore, the California HSRG asserts that a truly segregated anadromous fish hatchery program is not possible in California, and we are therefore generally unsupportive of the concept."

3.1.3 Recent Literature

Fitness Models

As described above, the HSRG currently predicts the long-term fitness consequences of hatchery programs on natural populations in AHA using the Ford (2002) model. Recently, Baskett and Waples (2013) extended the work of Ford (2002) by incorporating the timing of natural selection into the model. They developed a phenotypic model to contrast two management strategies: a "keep them similar" (integrated) and a "make them different" (segregated) strategy, and quantitatively evaluated these two strategies with a coupled demographic-genetic model.

Model outcomes differed depending on the relative timing of: 1) natural selection, 2) density dependence, and 3) release of propagated individuals. If natural selection only occurs between reproduction and release, the integrated strategy performs better. However, if natural selection occurs after release and before reproduction, the segregated and integrated strategies perform similarly because in both scenarios, maladaptive traits may be purged from the population. The authors also note that the fitness effects of hatchery releases are much greater if the releases occur before any density-dependent interactions. Finally, they conclude that setting appropriate management goals, and evaluating the consequences of failing to achieve the desired targets, are as important as selecting a management strategy.

Both the HSRG (2009) and Baskett and Waples (2013) conclude that both the integrated and segregated strategies are viable alternatives. Selecting a strategy depends on both the management goals and feasibility of achieving those goals. Baskett and Waples (2013) found that intermediate strategies result in the greatest adverse fitness and demographic consequences. This finding is also consistent with the HSRG's working hypothesis about productivity and fitness.

Incorporating the findings of Baskett and Waples (2013) into AHA would require better information on the timing of natural selection, which may occur at varying magnitudes across all life history strategies.

3.1.4 Empirical RRS Studies

The HSRG hypothesis is that reproductive success of hatchery fish spawning in the wild was assumed (by the HSRG) to be reduced due to both genetic and phenotypic characteristics acquired from life in the hatchery. Hatchery fish spawning in the wild are assumed to produce fewer adult offspring than natural-origin fish due to both domestication selection and environmentally induced characteristics (e.g., choice of spawning location). The HSRG recognizes that not all hatchery-origin adults on the spawning ground ($pHOS_{census}$) successfully produced progeny. To account for this, the HSRG derived the quantity $pHOS_{Eff}$ (effective pHOS) such that:

$$pHOS_{Eff} = \text{RRS} * pHOS_{census}$$

Management goals for populations are expressed in terms of $pHOS_{Eff}$ and this quantity is used to calculate PNI. Thus, results from short-term RRS studies can be incorporated into the AHA model. The 2009 HSRG Columbia Basin analyses assumed that RRS is species/race specific and that the effect is measurable over just a few generations.

Recent studies have combined the tools of traditional marking and parentage analysis with analysis of a variety of life history traits to determine reproductive success and survival of hatchery fish. Studies have focused on specific factors associated with reproductive success including sex, age at return, hatchery effects, and release location. Often multiple factors are associated with reduced reproductive success. The majority of recent studies address short-term (i.e., one or several generations) fitness, although many are designed to continue to monitor future generations. Many studies have reported reduced RRS consistent with HSRG assumptions (Table 3-1).

The number of offspring produced by hatchery broodstock may be a poor indicator of fitness. Ford et al. (2012) investigated the relationship between the reproductive success of hatchery broodstock and the reproductive success of their progeny in the wild using multigenerational pedigrees of supplemented populations of spring Chinook on the Wenatchee River. Both sex and age at return were identified as factors that explain why broodstock fish with the greatest reproductive success in captivity tended to produce offspring with poor reproductive success in the wild. Broodstock that produced the largest number of male offspring also tended to produce younger, smaller offspring, which had relatively low reproductive success, suggesting that offspring number may be a poor indicator of fitness. The authors conclude that the number of grand offspring produced may be a better indicator of long-term fitness.

Hatchery-origin returns may be younger and less productive than those from natural-origin spawners. Williamson et al. (2010) found that hatchery-origin Chinook tended to be younger and to return to lower areas of the watershed than natural-origin Chinook. However, the hatchery fish were released lower in the Wenatchee River than where the natural fish were spawning. Other than differences in age structure, carcass recovery location was the only measured trait that differed notably between hatchery- and natural-origin fish. Carcass recovery location also had a significant effect on fitness, such that fish that were recovered higher in the watershed had higher average fitness than those that were recovered lower in the watersheds. When spawning location was included as a predictor, the model coefficients associated with hatchery-origin became less negative for both females and males and were not significant for females in one of the two models. Hess et al. (2012) found that younger hatchery-origin male Chinook were less likely to successfully spawn than older males. However, reproductive success (in terms of number of offspring produced) of the natural- and hatchery-origin fish that successfully spawned was similar. The authors concluded that Chinook reared in the hatchery for a single generation had no negative fitness effects on natural-origin fish. Anderson et al. (2013) studied the re-colonization of Chinook salmon in the Cedar River above a barrier dam over a seven year period and found that hatchery-origin male spawners were consistently less productive than natural-origin males. They concluded that allowing hatchery-origin males to spawn in the wild increases the genetic risk to the population with little demographic benefit.

Several recent studies have found that larger male body size is associated with higher reproductive success. Anderson et al. (2013) found this association in Chinook salmon. Berejikian et al. (2009) found that larger male body size in chum salmon is associated with increased reproductive success and access to nesting females. Berntson et al. (2011) studied steelhead in the Imnaha Basin, Oregon, and concluded that the most important indicators of reproductive success are origin (hatchery vs. natural), length, return date, and number of same-sex competitors. Natural-origin parents were less negatively affected by same-sex competitors than hatchery-origin parents. These studies contrast with results from Chilcote et al. (2011) who found negative fitness interactions in both sexes in steelhead; the differences may be attributed to differences in life history strategies between species (Ford et al. 2012).

Specific questions about relative reproductive success were addressed in several studies conducted under controlled conditions in an artificial spawning channel (Knudsen et al. 2008, Schroder et al. 2008, and Schroder et al. 2010). The studies compared breeding success of natural-origin spring Chinook to first generation hatchery-origin adults. Knudsen et al. (2008) found that natural-origin spring Chinook females had greater total gamete mass, individual egg mass, fecundity, and reproductive effort (measured by the gonadosomatic index, or GSI) than hatchery-origin females, after accounting for body length. Hatchery-origin females were smaller than natural-origin females, and there was probably some fitness loss in first generation hatchery-origin spawners due to the effects of body size. Knudsen et al. (2008) found that while egg-fry survival rates varied among years, no consistent difference between hatchery- and natural-origin fry was found. However, Schroder et al. (2008) reported that eggs deposited by natural-origin females survived to the fry stage at a 5.6% higher rate than those spawned by hatchery females. Subtle differences between hatchery- and natural-origin females in redd abandonment, egg burial, and redd location choice may have been responsible for the difference observed.

Schroder et al. (2010) found that natural-origin males exhibited higher attack rates and greater social dominance than hatchery males, which may have been due to differences in body size. Natural-origin males were 9% heavier than hatchery males. Natural- and hatchery-origin males did not differ in the frequency of courting behaviors or in the number of mates, and pedigree analyses showed that natural- and hatchery-origin males had comparable breeding success values.

3.1.5 Mechanisms Causing Loss of Fitness

Mechanisms leading to rapid loss of reproductive fitness in naturally spawning hatchery salmon after as little as a single generation of hatchery reproduction and rearing have been the subject of several recent studies (e.g., Araki et al. 2008, Chilcote et al. 2011, Christie et al. 2012a, Ford et al. 2012, and Thériault et al. 2011). As discussed by Ford et al. (2012), several mechanisms could explain rapid loss of reproductive success including domestication selection and inbreeding depression due to small numbers of hatchery breeders.

Rapid adaptation to captivity and reduced reproductive success in the wild was observed by Christie et al. (2012a). They investigated the fitness of first generation hatchery steelhead spawned in captivity compared to wild steelhead from Hood River, Oregon, and found that hatchery fish had double the lifetime reproductive success when spawned in captivity compared with natural-origin fish spawning in the wild. The authors suggested that this was evidence of adaptation to captivity in a single generation. The authors also found a low effective number of breeders (N_b) and high variance in reproductive success among hatchery fish spawning in the wild. They concluded that the Ryman Laikre effect (Ryman and Laikre 1991) was most severe when >10% of fish on the spawning ground were of hatchery-origin and when hatchery fish had high RRS in the wild (Christie et al. 2012b). Rapid loss of reproductive success in hatchery fish was also investigated by Thériault et al. (2011) in coho salmon from the Umpqua system. The authors identified the lack of natural mate selection in the hatchery as a causal mechanism for reduced reproductive success of first generation offspring in the wild.

A long-term study of Forks Creek, Washington, steelhead, a well-characterized system in which steelhead that stray from the hatchery interbreed with natural-origin fish (Seamons et al. 2012), provides information on the fitness consequences of the hatchery program. Researchers followed four generations of hatchery releases and monitored effective population size (N_e) and inbreeding (Δf) (Naish et al. 2013). Even though the hatchery maintained a relatively constant effective size, it had an increasing census size (N) resulting in a decreasing N_e/N ratio. This was attributed to a small broodstock population and high variance in reproductive success, particularly in males, which resulted in inbreeding in the wild. Naish et al. (2013) showed that body length and weight of returning adults decreased significantly with increasing inbreeding (Δf). The authors concluded that small changes in the inbreeding coefficient can affect fitness-related traits in propagated populations. The study provides a framework for tracking hatchery practices that lead to inbreeding and reduced effective population size, which in turn reduce long-term fitness.

3.1.6 Summary of Recent Research

Recent parentage studies are providing new information on RRS in relation to age and size at reproduction, release and return timing and location, and mating preferences. These studies are also providing estimates of inbreeding, effective population size, heritability of traits, strength of selection, and potentially timing of natural selection within the life cycle. When comparing studies of RRS (see Appendix 4), it is critical to carefully consider the assumptions and study design. The power to detect differences in RRS is relatively small in most studies (less than 10-15%; Araki et al. 2008). It is therefore important to expand the size of these studies so that smaller differences in RRS can be detected, because a small difference in RRS can have strong effects on fitness over many generations (Crow 1989).

3.1.7 Summary and Conclusions for Section 3.1

- Maximizing fitness and local adaptation are critically important to the viability of salmon and steelhead in the face of changing environment due to climate change and human population growth. These characteristics are essential if we are to realize benefits from investments in habitat improvements.

- The HSRG recognizes that the cultural and economic benefits of harvest are important and that hatcheries are a necessary tool in the foreseeable future—solutions exist where harvest goals can be met while protecting long-term viability of naturally spawning populations. However, this can only be achieved through scientifically informed decision making and accountability for trade-offs between near term-benefits versus long-term cost in viability.

- The assumptions upon which the 2009 HSRG conclusions and recommendations were based should be challenged and refined as new scientific data and information becomes available. The HSRG standards should be challenged with better alternatives, and not discarded because of imperfections. The recent studies cited above are consistent with the HSRG framework.

    - Recent research results can be used to better inform the RRS estimates used in the AHA model in a species- and stock-specific manner (e.g., see Table 3-1 above). These studies did not address the long-term impact of hatchery introgression on the fitness of the naturally spawning population, which forms the basis for the HSRG pHOS and PNI standards. While the HSRG recommendations and working hypothesis have been criticized, no better, scientifically supported alternatives have been proposed.

    - Further theoretical and empirical studies are needed to test and refine management standards to control fitness loss due to hatchery programs under a range of different circumstances.

- Both segregated and integrated broodstock strategies have a role in hatchery management; however, recent studies and further AHA analyses suggest that segregated hatchery programs should be used with greater caution.

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3.2 Hatchery Broodstock Management

A major conclusion in the HSRG 2009 Report to Congress was that hatchery broodstocks for harvest augmentation programs should be managed to achieve proper genetic integration with, or segregation from, natural populations. This limits the risk of fitness loss in natural populations due to straying. The HSRG developed quantitative standards for the proportion of natural-origin spawners consisting of hatchery-origin fish (pHOS), the proportion of hatchery broodstock derived from natural-origin fish (pNOB), and the proportionate natural influence (PNI) on an integrated population, calculated as a function of pHOS and pNOB (see Section 3.1).

The designation of a population as Primary, Contributing or Stabilizing is a science-informed policy decision. Standards recommended by the HSRG for broodstock management are as follows:

HSRG criteria for hatchery influence on Primary populations:

- The proportion of effective hatchery-origin spawners (pHOS) should be less than 5% of the naturally spawning population, unless the hatchery population is integrated with the natural population.

- For integrated populations, the proportion of natural-origin adults in the broodstock (pNOB) should exceed pHOS by at least a factor of two, corresponding to a PNI (proportionate natural influence) value of 0.67 or greater and pHOS less than 30%.

HSRG criteria for hatchery influence on Contributing populations:

- The proportion of effective hatchery-origin spawners (pHOS) should be less than 10% of the naturally spawning population, unless the hatchery population is integrated with the natural population.

- For integrated populations, the proportion of natural-origin adults in the broodstock (pNOB) should exceed pHOS, corresponding to a PNI value of 0.50 or greater and pHOS less than 30%.

HSRG criteria for hatchery influence on Stabilizing populations:

- The current operating conditions were considered adequate to meet conservation goals. However, this implies that existing conditions should be maintained.

In order to meet these standards, the number of hatchery fish on the spawning grounds must be monitored and controlled. This can be accomplished by selectively removing hatchery fish (e.g., via harvest or weirs) or by reducing or totally eliminating hatchery production.

HSRG (2009) modeling results showed that in most cases, both conservation goals and harvest goals can be met with an appropriate combination of reduced/relocated hatchery production, selective harvest of hatchery fish, and/or selective removal of hatchery adults with tributary traps or weirs. Marking or tagging all hatchery fish so that they are easily distinguished (in real time) from natural-origin fish is a basic requirement for selective harvest, as well as for monitoring escapement and achieving desired levels of pHOS, pNOB and PNI.

3.2.1 Integrated Versus Segregated Programs

The HSRG (2009) identified two ways to reduce hatchery influence on fitness in harvest augmentation programs: 1) decrease the fraction of natural spawners that are of hatchery-origin (segregated approach), and 2) make hatchery fish less different from the locally adapted naturally spawning population (integrated approach). The HSRG generally suggested no preference for one approach over the other, leaving open the question of the relative benefits of each. However, the HSRG did consider whether the approach was consistent with the population designation (Primary, Contributing, or Stabilizing).

The HSRG defined an integrated hatchery program as one where 1) the naturally spawning and hatchery produced fish are considered components of a single population, and 2) the adaptation of the combined population is driven more by the conditions of the natural environment than the hatchery. In an integrated harvest augmentation program there is no implied intent to allow hatchery fish to spawn naturally.

Based on modeling results, the HSRG hypothesized that a PNI significantly greater than 0.5 (see Table 3-2) would be required before any substantial improvement in fitness would be expected for a previously hatchery dominated naturally spawning population. It likely would take several generations of high PNI before fitness benefits would be realized. In fact, analyses suggest that population abundance might decrease in the short-term as the number of hatchery-origin spawners is reduced, before abundance again increases due to fitness improvements. In other words, it may require a short-term cost to achieve a long-term benefit.

Different definitions of integrated hatchery programs have been used by others, leading to different conclusions, not because of differences in the underlying biological assumptions, but because of differences in the definition of an integrated program. Chilcote et al. (2011), for example, used a more liberal definition of integration and arrived at the conclusion that integrated programs were less effective. Those conclusions are not applicable to integrated programs as defined by the HSRG.

Segregated programs have been studied in several systems. Seamons et al. (2012) evaluated a segregated steelhead program at Forks Creek, Washington, where the Chambers (via Bogachiel Hatchery) stock was introduced. Segregation relied on divergent life history strategies based on spawn timing. They found that spawn timing failed to prevent interbreeding when physical isolation was ineffective. Up to 80% of the naturally produced steelhead in any given year consisted of hatchery/wild hybrids.

Smith and Engle (2011) studied the interaction between upriver brights (URBs) and tule fall Chinook salmon that have been spawning in the White Salmon River for approximately 22 years. The two lineages migrate together through portions of the lower Columbia River. Historically, they spawned allopatrically (separately), but following hatchery releases of URBs and tules, they now spawn sympatrically (there is now overlap in spawning). Genetic parental assignment tests revealed that juveniles leaving the White Salmon River from March to early May resembled tules, while those leaving from late May to June resembled URBs. Hybrid detection revealed that between 4.3% and 15.0% of the juveniles in each year were tule x URB hybrids. However, unlike the Seamons et al. (2012) study, they found no evidence that hybrids survive to return as adults or successfully cross back into the parental populations. Separation of the two Chinook lineages appears to be maintained by intrinsic and extrinsic factors but with a potential loss of long-term fitness to both segregated (hatchery and natural) populations. These studies suggest that segregated programs that rely on divergence in spawn timing need to be carefully monitored, and can pose significant risks to the wild populations when physical barriers are absent, breached, or otherwise ineffective.

In some situations, it is not feasible to meet harvest objectives using either integrated or segregated hatchery programs. This occurs when pHOS cannot be reduced sufficiently to meet the standards of a segregated program or when natural production (abundance) is insufficient to support an integrated program large enough to meet harvest objectives. If revising harvest objectives and reducing hatchery production is not an option, a compromise approach is a “stepping-stone program.” A “stepping-stone program” consists of an integrated program that produces broodstock for a segregated program (Figure 3.1). This maintains genetic continuity between the hatchery population and natural-origin fish returning to the system. Adults produced by the integrated program need to be distinguishable from adults produced by the segregated (“stepping-stone program”, i.e., coded wire tag only/adipose fin clip only, respectively). If sufficient numbers of adults return from the integrated program to meet escapement needs, integrated broodstock needs, and the second stage “stepping-stone” broodstock needs, the smolts may be adipose fin clipped as well to allow for additional harvest. Managers should monitor this closely and revert to coded wire tags only if insufficient adults return to meet all needs. Unharvested “harvest component” fish (segregated program) would not be used for broodstock, nor released upstream of the weir, nor returned to a population downstream of the weir. Unharvested adults could be used for stream nutrification as appropriate.

“Stepping-stone programs” may be used as a transition to an integrated program while natural habitat conditions improve.

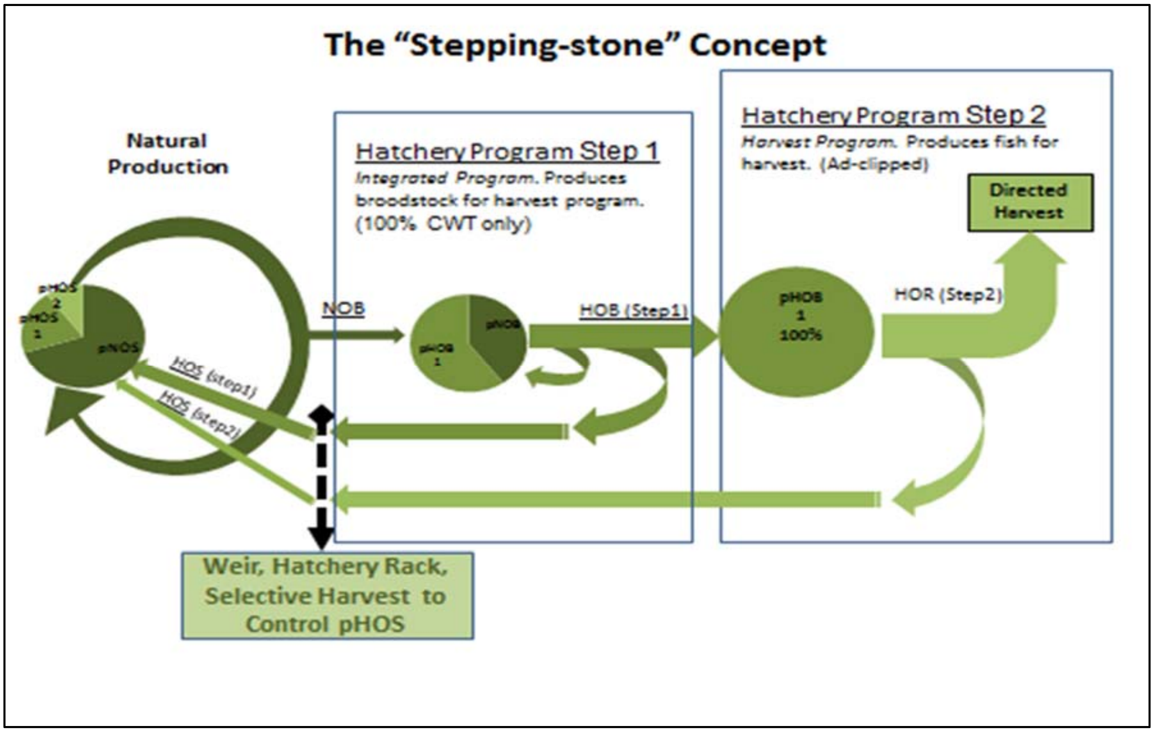

Figure 3-1. A "stepping-stone program" consists of two interdependent hatchery programs: an integrated broodstock generator and a segregated harvest program. As with a simple integrated program, the intent is for the combined hatchery and natural population to adapt to the conditions in the natural environment.

3.2.2 Spawning and Mating Protocols and Counter Selection

The HSRG, as outlined in HSRG (2004), Campton (2004), and Mobrand et al. (2005), recommended selecting adults randomly throughout the natural period of adult return to achieve two principal objectives: 1) maximizing the genetic effective number of breeders, and 2) ensuring that every selected adult has an equal opportunity to produce progeny (i.e., avoid selective breeding and artificial selection in the hatchery environment). Specific recommendations in HSRG (2004) include collecting and spawning adults randomly with respect to time of return, time of spawning, age, size and other characteristics related to fitness. The HSRG (2004) stated this is particularly critical in conservation programs, where populations are small or have experienced significant declines. Specific recommendations to achieve these objectives include mating male and female hatchery fish following pairwise (one male to one female), nested (e.g., one male to three females), or factorial (e.g., three-by-three spawning matrix) designs and avoiding mixed milt spawning (e.g., where eggs are fertilized by the simultaneous or sequential addition of sperm from multiple males, which results in unequal genetic contributions among male spawners and subsequent reductions in effective population size (N_e)).

Additional considerations have been published largely relating to the purpose and goals of the hatchery. Quinn (2005) commented on the Campton (2004) article. He first reviewed the literature indicating that pooling of milt does not necessary result in equal proportions of eggs fertilized (e.g., Gharrett and Shirley 1985, Withler and Beacham 1994, and Naish et al. 2013). Some form of sperm competition exists resulting in variation in reproductive success. Quinn (2005) further stated that random mating is not "benign" and that breeding schemes outlined in Campton (2004) may maintain genetic diversity, but do not remotely resemble natural systems. Quinn (2005) concluded that hatchery breeding will inevitably relax selection on certain traits and enhance reproductive success of competitively inferior individuals. In response, Campton (pers. comm.) agreed with the fundamental statements of Quinn (2005) that no hatchery can reproduce the patterns of breeding and selection that would occur in the wild, but given that fact, hatcheries should strive for selective neutrality by maximizing the genetically effective population size through equal contributions of spawners. Campton (2004) also pointed out how differences in hatchery strategies (i.e., integrated and segregated) and goals might influence the choice of mating protocols.

More recently, Hankin et al. (2009) modeled the long-term consequences of three mating regimes in Chinook salmon: 1) completely random, 2) random excluding jacks, and 3) selective on length with male length ≥ female length. They stated that regimes 1 and 2 are common in hatcheries while regime 3 emulates the outcome of natural spawning behavior that favors larger males. Results were evaluated based on resulting age and sex structure; they found that regimes 1 and 2 can result in substantial selection for younger age at maturity. Hankin et al. (2009) recommended that large-scale hatcheries replace completely random mating regimes with mating protocols that emulate the outcomes of natural spawning.

Reconciling these different views will require evaluation of breeding plans on a case-by-case basis while considering the hatchery strategy, goals, and history and current status of the program.

3.2.3 Captive Rearing and Breeding[7]

In the 2009 Report to Congress, the HSRG indicated that broodstock rearing and breeding protocols for Primary populations should be managed to maximize biological significance. This is especially important in the breeding and rearing of fish for gene rescue (i.e., conservation hatchery intervention actions). A major objective of captive breeding for conservation programs is to maintain the genetic characteristics of the population in order to maximize success when reintroduction into the wild becomes feasible (Trushenski et al. 2010). As much as possible, captive breeding programs should employ strategies to maintain a large effective population size and to reduce inbreeding depression and domestication selection.

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[7] Captive rearing and breeding is a specific, very intensive type of hatchery production, in which fish are kept in captivity throughout all life stages (egg/fry/adult and spawning), unlike the more common type of hatchery production in which adults are captured and spawned, the eggs hatched and juveniles released into the wild after some period of rearing.

The gene rescue program for ESA-listed endangered Redfish Lake sockeye salmon is among the best examples of the uses of these conservation and genetics principles to improve outcomes in a captive rearing and breeding program. The Redfish Lake sockeye program is one of the longest running captive broodstock programs (almost 24 years) in the Pacific Northwest (Kline and Flagg, in review). Kozfkay et al. (2008), describe modified factorial mating schemes based on genetic distance used to guide mate selection on spawning days for the Redfish program. These take into account band sharing proportions (e.g., kinship coefficients) among all possible mate combinations and different population attributes including: 1) relative founder contribution, 2) the genetic importance of individuals, 3) genetic diversity and heterozygosity within and among individuals, and 4) relative relatedness among individuals. Representative numbers of eggs from each subfamily are then incubated in isolation to facilitate the development of successive year captive broodstocks (Maynard and Flagg 2012). Use of these guidelines and procedures has allowed the Redfish program to retain approximately 95% of the original founding genetic variability of the population, a value almost 10% higher than other programs surveyed (Kalinowski et al. 2012).

3.2.4 Collecting and Rearing Wild Eggs from Redds

In the 2009 Report to Congress, the HSRG indicated a concern that hatchery programs may be operated in a manner that disrupts natural selection for population characteristics that are tailored to local conditions in the natural environment. In some cases, only a limited number of eggs and progeny are desired to initiate a gene rescue action. For these types of conservation hatchery intervention actions, it may be possible to collect viable eyed eggs from the wild as a source of juveniles for these programs.

As described by Berejikian at al. (2011), the collection of eyed eggs from naturally produced redds represents one approach to balance production and genetic factors involved with the sourcing of gametes for hatchery production. Hydraulic methods are normally used to collect eggs from redds. For this procedure, water is injected (pumped) under high pressure through a wand inserted into a previously identified redd, forcing the embryos to the surface, where they can be collected in the net. These eggs are then reared in a hatchery. These hydraulic egg-sourcing techniques are normally associated with conservation actions for depleted stocks. In laboratory and field studies, Berejikian et al. (2011) showed that a high percentage of hydraulically extracted eggs were viable (~94%), were infrequently damaged (~1-4%), and the fry derived from the eggs survived well to first feeding (~95%).

Hydraulic redd sampling does not require barrier weirs, handling of adults, or removal of a female's entire fecundity from natural production. Importantly, hydraulic redd sampling has potential advantages in that it can occur after sexual selection and frequency-dependent selection have occurred naturally on the spawning grounds and, therefore, has the potential to reduce artificial selection pressures caused by artificial spawning.

Given these results, the HSRG recommends managers consider hydraulic mining of redds as an option for future population rescue or re-colonization efforts.

3.2.5 Survival of Hatchery Fish

The HSRG has recommended that survival of hatchery fish be maximized, consistent with conservation goals: *"In order for hatchery programs to effectively contribute to harvest and/or conservation, the reproductive success and survival of hatchery releases must be high relative to those of naturally spawning populations. The primary performance measurement for hatchery programs should be the total adults produced (harvest plus escapement) per adult spawned at the hatchery. All too often in the past, hatcheries have been evaluated based on the number of smolts released, [rather than adults produced]"* (HSRG 2004, 2009). Maximizing the survival of hatchery fish also allows goals to be achieved with the minimum amount of production, thereby reducing take of natural-origin fish for broodstock (integrated programs), the potential for adverse ecological interactions (e.g., competition) with natural-origin juvenile fish, and possibly fiscal costs.

A number of studies have focused on survival of hatchery fish and the effects of the rearing environment on homing and age at return. Some of the new studies present results from the first generation of a multi-generational study. Various studies have been designed to evaluate growth in relation to both origin (hatchery vs. wild) and hatchery environment. Optimum growth regimes to avoid residualism in Hood Canal steelhead were investigated in three hatchery populations by Berejikian et al. (2012). Two of their hatchery populations had mean smolt size and size variability at age-2 within the range of wild smolts while a third population exhibited high growth and high male maturation rates, providing additional evidence that the rearing environment plays a significant role in residualism.

The topics of early male (precocious) maturation and residualism in Chinook salmon were also addressed by several authors. Pearsons et al. (2009) studied precocious spring Chinook salmon males from hatchery production in the Yakima River and concluded that they do not contribute favorably to harvest and may pose ecological risks to other taxa; most have relatively low reproductive success with a loss of fitness to the population (see also Larsen et al. 2010).

Rearing environment as well as origin (hatchery vs. wild) was studied in coho salmon by Chittenden et al. (2010). Rearing environment was a significant factor while the population origin (hatchery vs. wild) was not. In the study, Chittenden et al. (2010) created three treatments, H x H, H x W, and W x W, to evaluate rearing environment. Few phenotypic differences were noted among genetic groups in the same habitat, but rearing environment played a significant role in smolt size, survival, endurance, and predator avoidance. Because these studies vary in design, species and objectives, replicated experiments are warranted as well as longer-term studies across generations incorporating relative reproductive success (section 3.1).

Homing and imprinting was evaluated by Dittman et al. (2010) in spring Chinook in the Yakima River that were released from satellite acclimation facilities after common initial rearing at a central facility. While homing was evident, hatchery fish were recovered away from the release sites often in spawning areas used by wild fish. They suggest that genetics, environmental and social factors, or requirements for specific spawning habitat may ultimately override the instinct to home to the site of rearing or release.

3.2.6 Summary and Conclusions for Section 3.2

The biological principle behind the broodstock standards for both integrated and segregated populations is to promote local adaptation and increased productivity and viability. A major concern with many current hatchery programs is that they have been operated in a manner that disrupts natural selection for population characteristics that are tailored to local environmental conditions. Proper integration or segregation of harvest augmentation programs is the recommended means to minimize the adverse effects of hatcheries on local adaptation of natural populations. Local adaptation of hatchery populations is achieved by using local broodstock (of natural-origin, in the case of integrated programs; of local hatchery-origin in the case of segregated programs) and avoiding transfer of hatchery fish among watersheds. It is important to promote local adaptation because it maximizes the viability and productivity of the population over time and maintains biological diversity within and between populations.

Local adaption is also critical to enable populations to adjust to changing environmental conditions, for example through climate change.

The most critical needs for hatchery programs with a harvest augmentation purpose are to:

- Manage hatchery broodstocks to achieve genetic integration with, or segregation from, natural populations. Implement pHOS and PNI standards to reduce hatchery influence and increase local adaptation of natural populations. These standards should be continually reviewed as new literature becomes available and adjusted accordingly when appropriate.

- Use proper spawning protocols in the hatchery including: collecting and spawning adults randomly with respect to time of return, time of spawning, age, size and other characteristics related to fitness. Further studies on random vs. non-random spawning method are needed.

- Maximize the survival of hatchery fish consistent with conservation goals. This will ensure that the fewest possible hatchery fish are released to achieve the desired goals, thus minimizing ecological and genetic impacts.

- Evaluate hatchery programs based on the number of returning adults they produce, rather than on the number of juveniles they release.

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3.3 The Role of Hatcheries for Conservation and Recovery

Efforts to recover Pacific salmon are occurring across a broad landscape where habitat conditions range from the highly urbanized to the nearly pristine. Conservation hatcheries – hatcheries operated to maintain or recover natural populations and their genetic resources – are an important tool in these efforts (HSRG 2004, 2009). Consequently, the current and changing conditions of salmon habitats and ecosystems as they respond to salmon recovery efforts as well as to other drivers of change, such as climate change and increasing human populations, lead to different opportunities and challenges for using conservation hatcheries.

A key principle of the HSRG's approach to hatchery reform is that hatcheries need to consider the ecosystem context and habitat conditions in which they operate to be successful (HSRG 2004). The HSRG, for example, incorporated this kind of information in their reviews of individual hatchery programs (HSRG 2009). Only recently, however, has the HSRG considered an explicit framework that recognizes different ecosystem conditions in which conservation hatchery programs may operate in. In their review of the Elwha River Fish Restoration Plan, the HSRG defined four stages of recovery associated with the expected changing habitat conditions in the river and the role of conservation hatcheries during these stages. These stages were: 1) preservation, 2) re-colonization, 3) local adaptation, and 4) full restoration (HSRG 2012).

This framework is applicable to many situations in the Columbia Basin and throughout the Pacific Northwest region. In constructing and implementing this framework, objectives should be primarily biological, but importantly also need to include cultural components in returning salmon and steelhead to Native American and First Nation salmon cultures.

In this section, we build on this approach to develop a more detailed framework for conservation hatcheries associated with phases of recovery. We describe the different phases. We outline the objectives of conservation hatcheries during these phases. We consider the requirements for success. Finally, we propose considerations for decision-making triggers for when to transition from one kind of conservation hatchery program to another.

3.3.1 Classification of Conservation Programs

Across the spectrum of ecological conditions in which salmon recovery occurs, we recognize four phases of restoration and rebuilding, ranging from preventing extinction to full restoration (Table 3-3). Transition between phases is determined by changes in habitat and ecosystem conditions that lead in turn to changes in population status and the biological objectives necessary to continue to full restoration. Some amount of overlap of objectives may occur in different phases. In many cases, the change from one phase to another will not mean that previous objectives are no longer important but rather that the need for these objectives has lessened and new objectives are a greater priority. For example, as major threats of population extinction are removed, the objective of reintroducing fish to newly accessible or restored habitat may become the primary objective of the conservation hatchery program. However, the shift to a different phase does not mean the hatchery program should no longer provide any buffer against extinction. To avoid potential confusion, transparent identification of priority objectives is essential.

3.3.2 Conservation Programs for Preservation

The primary objective of preservation programs is to secure the genetic identity and diversity of the natural population when it is threatened by extinction until habitat can support survival at all life stages. In practice, this occurs by providing demographic protection of the population that minimizes the loss of genetic diversity through genetic drift (Berejikian et al. 2004). Some rare alleles and adaptive variation in the wild may be lost or altered during this phase (Fraser 2008) but in preservation programs, this is acceptable because the alternative is loss of the entire population.

Requirements for Success

The key requirement of success is that benefits of the program outweigh potential risks. Increasing evidence indicates that preservation programs are successful in the short-term in buffering the demographic risk of extinction. Likewise, evidence indicates these programs can maintain significant neutral and quantitative genetic diversity over multiple generations (Fraser 2008). The ecological uniqueness and complexity of these programs and the different management tolerances for demographic, ecological, and genetic risk and associated trade-offs, however, make it difficult to provide specific guidelines for success that can be applied everywhere (Berejikian et al. 2004). This variation and associated uncertainty means that overall success will depend on careful, case-by-case application of key principles advocated by the HSRG:

- Clear identification of the conservation goals for the population and program
- Design and operation of the program to be scientifically defensible, and
- Ensuring that programs are capable of learning from their results and using new information to improve (Mobrand et al. 2005).

More detailed explanation of how these principles may be implemented is available in HSRG (2009).

Considerations for identifying triggers

One of the most important questions is “When do you start a conservation hatchery program?” The decision to start such a program depends on a multifaceted assessment of potential threats, logistical considerations, and biological variables. Biological variables include the biological significance of the population (Allendorf et al. 1997), trends in abundance (Boyce 1992), and potential losses of genetic diversity. The HSRG (2005) provided simple, first-step guidelines based on maintaining a genetic effective size (N_e) in the population of 500 or greater.

Table 3-3. Biological phases of restoration and objectives for different ecosystem conditions.

Biological Phases	Ecosystem Conditions	Objectives
Preservation	Low population abundance; habitat unable to support self-sustaining population; ecosystem changes pose immediate threat of extinction	Prevent extinction; retain genetic diversity and identity of existing population
Re-colonization	Underutilized habitat available through restoration and improved access	Re-populate suitable habitat from pre-spawning to smolt outmigration (all life stages)
Local Adaptation	Habitat capable of supporting abundances that minimize risk of extinction as well as tribal harvest needs; prevent loss of genetic diversity; and promote life history diversity	Meet and exceed minimum viable spawner abundance for natural-origin spawners; increase fitness, reproductive success and life history diversity through local adaptation
Full Restoration	Habitat restored and protected to allow full expression of abundance, productivity, life-history diversity, and spatial distribution	Maintain viable population based on all viable salmonid population (VSP) attributes using long-term adaptive management

3.3.3 Conservation Programs for Re-colonization

The primary purpose of conservation hatchery programs during a re-colonization phase is to introduce salmon to areas with suitable habitat where the fish do not occur or are at unsustainably low densities. Reintroducing salmon to large areas of habitat that has been inaccessible because of large dams is only one opportunity for re-colonization. Many smaller barriers, such as water diversion structures and culverts, also prevent migratory salmon from accessing available habitat (Gibson et al. 2005). In some cases, pollution or habitat changes, such as aggraded stream channels resulting from hydrological manipulations or loss of riparian habitat, have blocked upstream migration of anadromous salmonids effectively eliminating them from upstream habitat (Platts 1972, Idaho Department of Environmental Quality 2001, Skokomish Indian Tribe and Washington Department of Fish and Wildlife 2010).

Reintroduction may focus on increasing any or all of the desired attributes of viable salmonid populations: spatial structure, abundance, productivity, and diversity. Defining clear objectives based on the existing opportunity and the conservation goals for the region is important (Tear et al. 2005) because in some cases, it may be necessary to accept a lesser amount of one attribute to achieve a greater amount of another. Likewise, some objectives are more achievable in the short-term while others may take many years.

Spatial Structure – The most obvious objective of reintroductions using conservation hatchery programs is an increase in spatial structure. Depending on the nature of the opportunity, this objective could be to establish a new population where one formerly existed, thereby expanding the number of populations across the landscape, or to increase the distribution of individuals within an existing population into newly accessible or different habitats. Successful increases in spatial structure are expected to buffer against the risk of extinction (Ruckelshaus et al. 2003, Good et al. 2007).

Abundance – Increasing abundance is another important objective. Newly accessible habitat is expected to increase capacity for population growth and increase abundance. Increasing abundance – an obvious objective of many recovery plans – may not always be the most important for reintroductions. How much and how rapidly abundance increases depends on the amount and quality of the newly accessible habitat. In some cases, the longer term benefits of increasing spatial structure and diversity (discussed below) by expanding distribution into new and different habitat, for example, may be greater than the shorter term benefits of increased abundance.

Productivity – Increasing productivity is a third potential objective of reintroductions. Because of a compensatory relationship with abundance, salmon often display their highest productivities at low densities in underutilized habitat (Ricker 1954). This is the idealized condition for reintroductions. However, the net productivity of reintroductions depends on the quality of the newly accessible habitat and the connectivity between reintroduced individuals and the rest of the population(s). In some areas, reintroductions may be "sinks" where despite the increase in spatial structure, for periods of time there is no significant increase or even a net demographic loss for individuals for that area. This alone does not necessarily mean that reintroduction cannot be successful. If the circumstances allow for connectivity between this area and highly productive individuals in other areas, the population may support the presence of sinks (Pulliam 1988) and allow reintroduction to achieve other objectives, such as increases in diversity.

Diversity – Increasing diversity is the fourth major objective of reintroductions. Where reintroductions are intended to establish new populations, the increase in diversity provides a long-term buffer against extinction of metapopulations (Ruckelshaus et al. 2003, Moore et al. 2010). Where reintroductions are intended to expand distribution of individuals within a population, access to new or different habitat can increase phenotypic and genetic life history diversity. This in turn is expected to increase the long-term productivity of the population by providing resilience to environmental change (Greene et al. 2010). Increases in life-history or genetic structure in new environments may initially reflect phenotypic plasticity in behavior or morphology (Hutchings 2011) and patterns of genetic drift and isolation. In contrast, evidence of adaptive changes in salmon in new environments suggests that it may take 50-100 years (Hendry et al. 2000, Quinn et al. 2001, Koskinen et al. 2002).

Requirements for success

A number of authors and groups have summarized the success and failures of hundreds of reintroductions (Soorae 2008, 2010, 2011) and have published guidelines (IUCN 1987, 1998, 2012, George et al. 2009, McClure et al. 2011). Although each set of guidelines focuses on particular refinements, general principles for reintroductions have not changed much in 25 years and we do not repeat those here. However, we highlight requirements for success that apply more specifically to using conservation hatcheries consistent with HSRG principles.

Develop clear, specific, measureable conservation goals for natural and hatchery populations.
Conservation goals are a key element for success in all hatchery programs and the purpose of the program needs to be consistent with those goals (HSRG 2004, 2009, 2012). Above, we briefly discussed the importance and potential trade-offs among four attributes of viability that conservation goals for reintroduction need to include. Because multiple factors affect the success of re-colonization (Pess et al. 2008, Pess 2009) and different viability attributes respond over different timeframes, a key requirement in appropriately identifying objectives is identifying realistic timeframes to achieve the objects (McClure et al. 2011).

Design and operation of the program needs to be scientifically defensible.
The key requirement for success is that the benefits of the program outweigh potential risks. McClure et al. (2011) reviewed the potential benefits and risks of using conservation hatcheries to reintroduce salmon to newly accessible habitat. Other important elements that contribute to being scientifically defensible follow.

The program is supported by other management actions that address the key, known limitations on productivity of reintroduced and recolonizing salmon.
Factors that affect successful re-colonization include 1) barriers to migration, 2) amount and quality of habitat available, including potential changes because of climate change, 3) life history adaptations of the reintroduced individuals, 4) a source of recolonizing individuals that is large enough to support the program objectives, 5) the scale of reintroduction (such as rate and distribution), and 6) interactions with existing fish or other aquatic species (Pess et al. 2008, Pess 2009). Appropriate management actions will need to consider the presence of these factors both within the basin where reintroduction is occurring and outside of the basin. Harvest, even if it does not directly target the reintroduced fish, may also affect success when the fish occur outside of the basin in a mixed-stock fishery. Likewise, ecological interactions that limit productivity (e.g., Sanderson et al. 2009) may be just as important outside of the area of introduction (Brenkman et al. 2008) as well as within the habitats to be recolonized. Because opening access to new habitat provides opportunities for reintroductions of multiple species, the interactions of multiple reintroduction programs is also a factor.

The program is based on conceptual, qualitative, or quantitative models that describe testable assumptions under which the program is expected to contribute to its goals.
In the last 25 years, reintroduction efforts have moved from being management exercises to incorporating experimental designs (Seddon 1999, Seddon et al. 2007). Because reintroduction success depends on multiple, interacting factors, designing and documenting these programs requires multidisciplinary teams of practitioners and scientists.

The broodstock chosen has life history and morphological characteristics that are suitable for the environmental characteristics of the area where the reintroduction will occur.
Where the reintroduction is to expand the range of an existing population, fish from the existing population with genetic background that minimizes exposure to hatchery environments are most likely

to succeed. Where reintroduction is intended to re-establish a distinct population, indigenous populations that are geographically close to the reintroduction area are initial candidates because they are likely to share the same genetic legacy as the population that occurred there originally and they may be adapted to similar environmental conditions.

The source population for reintroduced salmon can sustain removals.

It is necessary to balance the risk of removing fish from the donor population, which may also be at low abundances, with the risks associated with different reintroduction strategies and the scale of the program. Multiple translocations of natural-origin fish, for example, may be a significant demographic burden on the donor population although they minimize the challenge of using hatchery-origin fish that initially may not be as well adapted to the environmental conditions. In contrast, amplifying the abundance of fish chosen for reintroductions over a short time using hatcheries, establishing a new broodstock to support the program, or using an already established hatchery stock will minimize the demographic impact on the natural donor population and produce more fish for large-scale efforts, but they increase the likelihood that the fish may not be as well adapted to the local conditions.

The scale of the program is consistent with the goals for the population and the reintroduction objectives, the scientific assumptions under success is expected to occur, and the risks to the donor population.

Reviews of reintroduction programs indicate that they are more likely to be successful when larger numbers of individuals are released, but have gradually diminishing returns (Griffith et al. 1989, Wolf et al. 1996, Fischer and Lindenmayer 2000).

Ensure that programs are capable of learning from their results and using new information to improve.

Reintroductions, if they succeed, rarely succeed the way they were planned (Wolf et al. 1996, Godefroid et al. 2011). Monitoring is essential to learn what is not working and why (IUCN 1998, 2012, Seddon et al. 2007, Close et al. 2009). Monitoring also provides information to determine whether the conservation hatchery program should transition to a different phase of restoration (Section 3.2.1). Successful monitoring will focus on the objectives of the program (Tear et al. 2005) and factors that might be limiting success. Trends in abundance, life-stage specific survivals, and spatial distribution may provide the earliest indications of success or problems, whereas documenting adaptive changes in diversity and shifts in fitness may take much longer (McKay and Latta 2002).

Considerations for identifying triggers

A key transition for conservation hatchery programs focused on reintroduction is the change to promoting local adaptation of the natural population. Key considerations are that the reintroduced fish are self-sustaining, spatially distributed to avoid potential catastrophic losses, and have large enough effective population sizes to maintain genetic variation for natural selection to act on. Potential metrics and examples of thresholds are in Table 3-4. Program-specific triggers will vary based on the different characteristics of the species, habitat, and goals of the program.

Table 3-4. Example metrics and triggers for moving to local adaptation phase

Viability Attribute	Example Metrics	Example of Triggers
Abundance	Geometric mean spawner abundance	> Spawner abundance increasing; geometric mean abundance > 600
Productivity	Recruits/Spawner Lambda	> 2.5
Spatial Distribution	Redd density in spawning habitat	50% of spawning habitat is used
Diversity	Genetic effective population size (N_e)	> 500

The larger the trigger threshold, the longer local adaptation benefits (e.g., increased productivity) are deferred. One strategy to move toward local adaptation more quickly would be to test sustainability by adopting a lower set of triggers for reverting back to the re-colonization phase. Ultimately the decision of how rapidly to move toward sustainability is a policy decision. Remaining in a re-colonization phase may allow higher levels of hatchery production, perhaps for harvest purposes, at the price of delays in achieving local adaptation.

3.3.4 Conservation Programs for Local Adaptation

The theory and application of guidelines of conservation programs to promote local adaptation are described in other HSRG publications (HSRG 2004, 2009). The reader may consult those for additional detail.

3.3.5 Conservation Programs and Harvest

The treaty and reserved rights of Native Americans and their cultural and spiritual connection to salmon require that tribal harvest be included when defining and achieving sustainability. A population cannot be considered fully recovered unless tribal harvest is accommodated. Hatchery programs can provide harvest opportunities even during the early biological recovery phases (preservation and re-colonization) so long as the programs are designed and operated to not conflict with the biological necessities of recovery. For example, during the century long preservation phase in the Elwha River, the hatchery was the genetic preserve for the native fish population, while also providing harvest. As this recovery program moves through the recovery phases after dam removal and as habitat improves, the hatchery program will serve to speed up re-colonization while also continuing to provide compatible harvest for indigenous peoples.

3.3.6 Summary and Conclusions for Section 3.3

Across the spectrum of ecological conditions in which salmon recovery occurs, we recognize four phases of restoration and rebuilding, ranging from preventing extinction to full restoration. Conservation hatchery programs have different roles in each of these phases. The primary objective of preservation programs is to secure the genetic identity and diversity of the natural population when it is threatened by extinction until habitat can support survival at all life stages. The primary purpose of conservation hatchery programs during the re-colonization phase is to introduce salmon to areas with suitable habitat where the fish do not occur or are at unsustainably low densities. The primary purpose of conservation programs during the local adaptation phase is to provide a demographic buffer for the population while promoting long-term local adaptation. Defining the purpose and objective of the conservation hatchery programs consistent with the overall goals for recovery is essential for success. Transition between phases is determined by changes in population status and in response to habitat and ecosystem conditions that lead in turn to implementing the different biological objectives of hatchery programs that are necessary to continue to full restoration. Success also depends on designing and operating the program based on transparent, testable scientific assumptions. Finally, monitoring and evaluation programs that provide information to refine programs and trigger the transition between phases are essential for success.

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3.4 Ecological Interactions

Ecological impacts of hatchery programs can vary greatly depending on the species, husbandry protocols, and environmental conditions in the receiving habitat. In 2012, the International Conference on Ecological Interactions between Wild and Hatchery Salmon organized sessions for the Pacific Northwest focused on managing interactions. Their findings and recommendations are published in Rand et al. (2012) and indicate that avoiding negative effects of competition from released hatchery salmonids on wild (natural-origin) fish should be a primary concern for recovery efforts and fisheries management. Several factors affect competition among juvenile salmonids, including whether competition is intra- or interspecific, duration of freshwater cohabitation of hatchery- and natural-origin fish, relative body size, prior residence, environmentally induced developmental differences, and fish density.

Intraspecific competition is expected to be greater than interspecific competition because of greater niche overlap between conspecific hatchery- and natural-origin fish (Rand et al. 2012). Competition is expected to increase with prolonged freshwater cohabitation. Hatchery-origin smolts are often larger than natural-origin smolts, and larger fish are usually superior competitors. Temporal and spatial opportunities for interaction at various life stages include incubation and juvenile rearing in freshwater; rearing and migration of smolts in rivers, estuaries, and near-shore river flumes; rearing of adults in ocean migration routes; and adult interactions on return migration and on the spawning grounds. Competition among adults is thought to occur in two ways, one mediated through spawn timing and the other primarily via competition for mates.

A body of evidence supports the existence of competition in the ocean when large numbers of salmonids are present (Daly et al. 2011, Kaeriyama et al. 2012, Ruggerone et al. 2012). Studies suggest that in years of relatively poor ocean conditions (low upwelling), competition may cause decreased survival and growth in the presence of large numbers of hatchery releases (Daly et al. 2011, Grant 2012). These ocean competition scenarios potentially have the greatest effect when prey abundance is lowest and these conditions could be exacerbated by climate change. The Northwest Power and Conservation Council adopted the Ocean and Plume Science and Management Forum Charter in 2013 to:

- Identify information gaps in ocean and plume science
- Connect critical uncertainties in the ocean and plume with management questions outlined in the Fish and Wildlife Program
- Explore management applications that would be responsive to emerging ocean and plume science, and
- Provide opportunities for information sharing between ocean and plume researchers and estuary and freshwater managers.

The potential for impacts associated with categories of interactions vary widely among species of salmon based on variables including size at release, numbers released, method of release, length of time in the hatchery, and length of time that natural-origin fish are in proximity to one another. The quantification of the ecological effects of hatchery fish on naturally spawning populations remains an unresolved issue. The effects on fish health are an exception (Section 3.5). Recent models have been shown useful in predicting ecological interaction outcomes (RIST 2009). Virtually any population model can be adapted to incorporate ecological impacts. The PCD (Predation-Competition-Disease) Risk Model (Pearsons and Busack 2012) is currently being used in the Pacific Northwest to estimate ecological effects. The PCD Risk Model incorporates a number of ecological factors including predation by hatchery fish, hatchery versus wild fish competition for resources, and disease infection as a result of encountering hatchery fish. By varying items of production goals, hatchery strategies, and management actions, the model provides ways to explore the effects to help determine whether alterations such as releasing different numbers at different sizes, locations, or times could potentially reduce negative ecological interactions.

Overall, the HSRG can provide little exact guidance regarding criteria for managing the effects of ecological interactions from hatchery programs. In some cases a maximum "census pHOS" of 10% can be used for steelhead based on Kostow (2012). The HSRG has recommended volitional release of smolts, in particular for steelhead to reduce interactions with natural-origin juveniles (see Snow et al. 2013). Kostow (2009, 2012) recommended several general principles to help reduce the probability of negative ecological interactions. These include:

- Operating hatchery programs within an integrated management context
- Reviewing hatchery programs to determine if there is still a benefit toward reaching management objectives and discontinuing programs that no longer serve a social or biological need
- Reducing the number of hatchery fish that are released and scaling hatchery programs to fit carrying capacity
- Providing on-going evaluation of management actions and allowing periodic readjustments

These recommendations (Kostow 2009, 2012) are a reinforcement of the principles established by the HSRG (2009) Report to Congress, in particular:

- Recommendation 3: Ensure goals for individual populations are coordinated and compatible with those for other populations in the Columbia River Basin
- Recommendation 4: Identify the purpose of the hatchery program (i.e., conservation, harvest or both)
- Recommendation 5: Explicitly state the scientific assumptions under which a program contributes to meeting the stated goals
- Recommendation 11: Coordinate hatchery programs within the Columbia River Basin ecosystem to account for the effects of all hatchery programs on each natural population and each hatchery program on all natural populations

- Recommendation 14: Regularly review goals and performance of hatchery programs in a transparent, regional, “All H” context
- Recommendation 16: Design and operate hatcheries and hatchery programs with the flexibility to respond to changing conditions
- Recommendation 17: Discontinue or modify programs if risks outweigh the benefits

One way to address these interactions is for hatchery programs to be operated so the released fish are segregated from their natural counterparts in time and space. Alternatively, hatchery fish can be reared and released to be as biologically similar to their natural counterparts as possible (integrated approach), although the latter approach does not always preclude the adverse effects of competition, and may in fact increase it. Size, time, age, location and method of release of hatchery fish affect the severity of competition. Predation by hatchery fish upon other salmonids is less well understood, but generally assumed to be less significant than competition. Hatchery fish can also pose a disease threat to natural-origin fish both before and after their release from the hatchery. To avoid this threat, hatcheries should adopt fish culture practices that minimize or avoid disease risks. Suggested practices include providing suitable water supplies, low rearing densities, appropriate feeds and feeding protocols, careful sanitary procedures, avoiding out-of-basin fish transfers and screening for, then limiting the use of broodstock with high levels of pathogens.

The type, direction, and extent of ecological interactions should be evaluated on a case-by-case basis (Flagg et al. 2000). The potential for impacts associated with categories of interactions vary widely among species of salmon based on variables including size at release, numbers released, method of release, length of time in the hatchery, and length of time that natural-origin fish are in proximity to one another. Potential opportunities for research in all aspects described above exist, but are rarely pursued due to difficulties in performing studies in the wild, lack of funding, and higher priorities for other research projects.

3.4.1 Summary and Conclusions for Section 3.4

Avoiding negative ecological interactions between hatchery salmonids and natural-origin fish should be a primary concern for recovery efforts and fisheries management. These include considerations of intra- or interspecific competition, duration of freshwater cohabitation, body size, prior residence, or environmentally induced developmental differences. Intraspecific competition should be expected to be greater than interspecific competition because of greater niche overlap between conspecific hatchery and natural-origin fish. Competition is expected to increase with prolonged freshwater cohabitation. Hatchery-origin smolts are often larger than natural-origin smolts, and larger fish are usually superior competitors. Temporal and spatial opportunities for interaction at various life stages include incubation and juvenile rearing in freshwater; rearing and migration of smolts in rivers, estuaries, and near-shore river flumes; rearing of adults in ocean migration routes; and adult interactions on return migration and on the spawning grounds. Other interactions, both positive and negative, can also occur between salmonids and other non-target taxa in the watershed.

Nonetheless, the HSRG has found no “new” information that might provide useful standards to estimate the size or scope of effects of ecological interactions. The potential for impacts associated with categories of interactions varies widely among species and groups of salmon based on variables including size at release, numbers released, method of release, and length of time hatchery and natural fish are in proximity to one another. Therefore, the type, direction, and extent of ecological interactions should be assessed on a case-by-case basis.

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3.5 Fish Health

During the HSRG's visits to hatcheries in Washington State, Oregon, and Idaho, hatchery staff invariably appeared satisfied with the services provided by the fish pathologists responsible for disease control for their particular hatcheries. Notwithstanding this, disease control in hatcheries raising Pacific salmon and steelhead (*Oncorhynchus mykiss*) still relies on avoidance techniques and the use of anti-microbial compounds. Unfortunately, in their fight against fish diseases, fish pathologists responsible for fish health in these hatcheries are still handicapped by the lack of suitable vaccines. When efficacious vaccines are available, vaccination offers a number of advantages over that of using anti-microbial drugs for controlling infectious diseases. The protection provided by vaccination is usually long-term, the risk of developing drug-resistant strains of fish pathogens is removed, and the need for delaying the release of drug-treated hatchery fish until drug residues are at acceptably low levels is obviated. In addition, vaccines afford protection not only against bacteria but also viruses, and the possible adverse effects of drugs to humans and the environment are removed.

During the HSRG's hatchery visits, three diseases were identified as the most frequent problems by hatchery staff: bacterial kidney disease (BKD) caused by the bacterium *Renibacterium salmoninarum* (Rs), bacterial coldwater disease (BCWD) caused by the bacterium *Flavobacterium psychrophilum* (Fp), and infectious hematopoietic necrosis (IHN) caused by a rhabdovirus (IHNV).

Considerable effort has been expended over the years in attempting to develop a satisfactory vaccine for BKD, and while an efficacious anti-Rs vaccine (Renogen) is commercially available for Atlantic salmon (*Salmo salar*), none exists for Pacific salmon. Rs is a facultative intracellular pathogen, and devising effective treatments for such pathogens has always proved difficult. It is generally agreed, however, that stimulating cell-mediated immunity rather than humoral (antibody-mediated) immunity is the only approach likely to result in an effective anti-BKD vaccine. DNA vaccines in mammals stimulate both types of immunity and they very likely also do so in fish (Kurath 2008). A DNA vaccine against another facultative intracellular fish pathogen, *Mycobacterium marinum*, has been described (Pasnik and Smith 2005) that resulted in short-term protection (up to 90 days) against heavy challenges with the pathogen. This suggests that a similar type of vaccine for controlling BKD might be possible. One such trial with a DNA vaccine against Rs using the gene for the p57 virulence factor produced by Rs failed to yield protection against BKD (Kurath 2008) but the search for other Rs virulence factors should be continued so that anti-BKD DNA vaccines based on the corresponding virulence genes can be evaluated for their efficacy. The Rs genome has been delineated, so studies using the DNA vaccine approach with Rs should be possible.

A number of studies have been conducted in an attempt to develop a vaccine against Fp (Cipriano and Holt 2005, Starliper 2011). These studies have yielded promising results, particularly when the vaccines were injected. Levels of protection were much more modest when the vaccines were administered by immersion or by feeding. Most of the studies were conducted using rainbow trout (*Oncorhynchus mykiss*) but promising results were also obtained with coho (*O. kisutch*) and ayu (*Plecoglossus altivelis*). Following injection, protection has been obtained using various cell fractions as well as heat- and formalin-inactivated Fp cells. In addition, live attenuated Fp cells have yielded protection by both injection and immersion methods. Vaccine studies should be pursued with a view to developing a commercially available one that is effective in those species of Pacific salmon that are particularly prone to BCWD.

Studies to develop effective vaccines against IHNV have shown great promise, particularly with DNA vaccines (see review by Kurath 2008). Trials with such vaccines in rainbow trout (Anderson et al 1996), Atlantic salmon (Traxler et al. 1999) and in Chinook (*Oncorhynchus tshawytscha*) and sockeye (*Oncorhynchus nerka*) salmon (Garver et al. 2005) have yielded significant protection. Most of the studies have involved rainbow trout in which immunity could be elicited in very small fish (0.8-1.0 gm) using very small doses of vaccine (as low as 0.001 ug per fish), and the resulting immunity was durable (up to 25 months in one study). The main problem with DNA vaccines is that they usually have to be injected. This presents a problem because the fish need protection while still very small, and injecting large numbers of very small fish is still not practical. Research to develop a machine for accomplishing mass injections of very small fish is needed and is to be encouraged. Machines exist for nose-tagging very young salmonids and it might be feasible to modify machines like this for accomplishing the task. For example, could nose tags be coated with the vaccine? Would injection via the nose yield protection akin to that resulting from intra-muscular injection? These are questions that warrant investigation.

Although suitable vaccines for use against the above diseases in salmonid hatcheries in the Pacific Northwest are presently lacking, it should be possible to protect freshly hatched salmon and steelhead against two of these diseases (BCWD and IHN) by injecting brood females shortly before spawning with high-titer antisera raised in mammals against virulent strains of these pathogens. These two diseases cause their greatest losses in very young salmonids. It is well established that vertical transfer of maternal immunity in fish (including salmonids) occurs (Swain and Nayak 2009). Indeed, Brown et al. (1997) showed that by injecting pre-spawning coho females with anti-*Vibrio anguillarum* antibodies generated in rabbits it was possible to load their eggs with antibodies in quantities sufficient to passively protect juvenile coho salmon, injected with the egg contents, against the disease vibriosis, caused by this bacterium. It was concluded, therefore, that the neonate fry containing the antibodies in their yolk sacs would also have been protected against vibriosis. Such protection is liable to be short-lived (any protection conferred by the antibodies in the yolk sac would likely have ended once the yolk sac was fully absorbed) but it would have provided protection against these diseases while the juvenile fish were developing full immuno-competence. Sera containing antibodies against the pathogens causing BCWD and IHN have been shown to be protective against these pathogens when fish were passively immunized with such sera (LaFrentz et al. 2003, Traxler et al. 1999). The pre-spawning injection of brood females with high-titer sera raised against these two pathogens would therefore very likely provide their juvenile progeny with short-term protection against these pathogens. Unfortunately, it is uncertain whether this approach would work to protect juvenile salmon against BKD because immunization trials with fish containing sera with antibodies generated against the Rs pathogen have shown, at best, unsatisfactory or no protection (Kaattari and Piganelli 1997, Turgut et al. 2010). It is clear, however, that the efficacy of injecting pre-spawning brood females with antisera containing mammalian antibodies against problem fish pathogens should be investigated further and that the procedure, if effective, should be adopted as a means of protecting very young salmonids from pathogens that might affect them at the neonate stage.

Further research leading to the availability of vaccines effective against the three diseases mentioned above is highly recommended. The current lack of these vaccines means that effluents and fish released from hatcheries affected with these diseases will continue to pose a risk to fish (including native fish) downstream of these hatcheries. In addition, without the disease control provided by these vaccines, hatchery program sizes will have to be increased to allow for the losses that can be expected due to these diseases.

3.5.1 Climate Change and Fish Health

Most scientists now regard climate change as a virtual certainty, the evidence for it (increased global temperatures, melting sea ice, and rising seawater levels), being compelling (online see *2012 American Meteorological Society (AMS) Information Statement on Climate Change*; and see *US NRC (2012) Climate Change: Evidence, Impacts, and Choices*). The HSRG has considered the impact that increased global temperatures will likely have on salmonids and their habitat in the Pacific Northwest and has published an article on the topic in its System-wide Report on Columbia River Basin Hatchery Reform, Appendix A-3 “Effects of Climate Change”, accessible from the HSRG website (www.hatcheryreform.us). The only significant uncertainty is the rapidity with which the warming will occur. If it develops slowly over decades, salmonids may have an opportunity to adapt to the new conditions, thus increasing the chances of their survival in a warmer world. If, however, it occurs rapidly, areas of the world capable of supporting salmonid populations may be reduced in size. For example, in Pacific North America, the southern limit for salmonids may move northwards.

It is anticipated that increased temperatures will have an overall negative effect on human health (online see *NRDC Global Warming Effects and Threats on Human Health*), and doubtless the same will be true for salmonid fishes. Most salmonids function best in a very narrow temperature range (approximately 13 to 18^{0}C) and temperature increases beyond this range are likely to negatively impact the optimum functioning of many of their physiological processes including that of the immune system. The result will be increased susceptibility to microbial infections and parasites. Many of the salmonid pathogens already enzootic in Pacific Northwest have optimum temperatures for growth higher than that for salmonids (for example, the bacteria causing vibriosis, furunculosis, and yersiniosis, the organism causing Ichthyphoniasis, and the parasite responsible for Ceratomyxosis). Higher water temperatures accompanying climate change are therefore likely to trigger more frequent and acute disease outbreaks due to these pathogens. Indeed, outbreaks of Ichthyphoniasis in Chinook salmon returning to the Yukon River have been attributed to increasing water temperatures in that river, and laboratory studies of the Yukon isolate have documented that the disease progresses more rapidly as water temperatures increase (Kokan et al. 2009).

It is more difficult to predict how increased temperatures will affect the incidence and severity of BCWD, BKD, and IHN, all of which currently cause serious losses in hatchery salmonids in the Pacific Northwest. BCWD usually occurs in spring when water temperatures are 4-10^{0}C. The optimum temperature for growth of the causative bacterium is 15^0C. It is unlikely that the disease will disappear but the cool water period favoring the disease may become shorter. With BKD, the causative bacterium grows best at 15-18^0 C, and the disease that it causes is usually very slow to develop. However, time-to-death following exposure to the pathogen is accelerated with increases in water temperature. Observations in salmonid hatcheries found that mortalities in infected fish occurred after 60-90 days at temperatures of 7.2-10^0C but above 11^0C they showed up after only 30-35 days. With warmer water temperatures, BKD mortalities are therefore likely to occur earlier during the rearing period. With IHN, outbreaks usually occur with water temperatures between 8^0C and 15^0C. However, outbreaks above 15^0C have been occasionally observed. This disease is thus likely to persist as a problem with increased temperatures.

The warming trend is likely to cause some species of tropical and subtropical fish to migrate away from the equatorial waters that they normally inhabit to take advantage of cooler waters north or south of their usual rearing locations. These fish may bring with them disease agents never before experienced by salmonids. Anadromous salmonids encountering these agents at sea are therefore very likely to spread the infection to other salmonids following their return to freshwater to spawn. Affected populations can be expected to suffer large losses as a result. Certainly, this has been the case when salmonids have been exposed to fish pathogens new to them. For example, naturally-spawning populations of rainbow trout suffered serious losses when the parasite causing whirling disease was inadvertently introduced to the Rocky Mountain West region. Similarly, when the virus causing viral hemorrhagic septicemia was introduced into the Great Lakes region, spectacular losses occurred in a large number of fish species, including salmonids and the forage fish they feed on. It is anticipated that fish will not be the only vectors of diseases new to salmonids. Birds, especially migrating piscivorous birds, could serve as disease vectors either by external contamination with warm-water fish pathogens or because of survival in the birds of pathogens present in warm-water fish they have eaten. Some salmonid pathogens have been shown to survive ingestion by birds (for example, the virus responsible for infectious pancreatic necrosis and the bacterium responsible for yersiniosis). It is probable therefore that some disease agents found in warm-water fish could be transmitted by birds to salmonids. Finally, human activities may also result in such disease transfers. These activities are thought to account for the introduction of whirling disease to North America (from Europe) and are very likely responsible for the appearance of this disease in the Rocky Mountain West region. Human activity is also a possible explanation for the appearance of viral hemorrhagic septicemia in the Great Lakes region, perhaps via ballast water released from ocean-going ships or by bait fish brought in from outside the region.

3.5.2 Summary and Conclusions for Section 3.5

Fish pathologists responsible for disease control in salmonid hatcheries in Washington State, Oregon, and Idaho perform an admirable service with the tools available to them. However, to enhance their effectiveness there is a need for mass-administrable vaccines for controlling three of the more persistent diseases that currently occur in some of the hatcheries (BKD, BCWD, and IHN). Research is therefore required to ensure that these vaccines become available. Anticipated benefits of vaccine use are that fish and effluents from the hatcheries would present a reduced disease risk to fish (including natural-origin salmonids) downstream of them; that increased survival resulting from vaccine use should permit the use of smaller hatchery programs for meeting production goals; and that smaller programs will help to offset the costs incurred in using vaccines and, more importantly, reduce the impact that hatchery fish might have on natural-origin populations.

Climate change, characterized by increasing global temperatures, is likely to have a negative impact on salmonids. If the change is rapid enough, it is likely to result in a global reduction of areas capable of supporting salmonid populations. Salmonids have a very narrow temperature range for best performance, and if global temperatures rise too rapidly to permit adaptation, salmonids are likely to be put at risk because of impaired immune function. In addition, many of the fish pathogens already present among salmonid populations have optimum temperatures for growth above those of salmonids. Rising global temperatures are therefore not likely to make these pathogens disappear. Rather, increased temperatures are likely to result in more frequent and acute disease outbreaks. In addition, new disease agents such as those known to cause diseases in warm water fish are likely to be introduced as a result of global warming, and contact with new pathogens is known to result in serious losses among salmonids. In the Pacific Northwest, vectors responsible for new disease introductions will likely include species of marine fish migrating from warming southern waters to take advantage of cooler waters to the north.

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3.6 Nutrient Enhancement

Since the publication of HSRG White Paper No. 6 (HSRG 2009, Appendix A6), researchers have continued to study the implementation and effectiveness of nutrient enhancement for increasing the production of Pacific salmon. There has been considerable effort in measuring how ecosystems respond to the addition of nutrients and how nutrients are incorporated. Comparisons between the different sources of nutrients have continued, revealing the role of live salmon as ecosystem engineers in incorporating nutrients (ISAB 2011).

The effectiveness of nutrient enhancement efforts in increasing Pacific salmon populations depends on whether the lack of nutrients is limiting the populations and how well the nutrients are delivered into the system. While significant effort is spent placing carcasses in rivers in Washington and Oregon, an overall evaluation of the effectiveness of this program is lacking.

New research is summarized below, grouped by general question.

What are the physical mechanisms by which marine-derived nutrients (MDN) are incorporated into the ecosystem?

Along with bringing nutrients, live salmon affect the way these nutrients are incorporated into the ecosystem by the physical changes they make to the stream as they disturb the sediments (Tiegs et al. 2009, Rex and Petticrew 2010, Holtgrieve and Schindler 2011, Albers and Petticrew 2012). Incorporation of nutrients into flocculants during spawning is one mechanism for retaining nutrients in the stream (Rex and Petticrew 2010, Albers and Petticrew 2012, Albers and Petticrew 2013) and therefore, management efforts to restore salmon ecosystems should consider how salmon disturbance affects the incorporation of MDN into food webs, and not focus solely on the addition of nutrients.

What are the ecosystem effects of MDN?

Ecosystems respond to the addition of carcasses on a broad, but highly variable scale (Levi et al. 2011). Janetski et al. (2009) used meta-analysis to provide the first quantitative identification of environmental and methodological variables that influence stream ecosystem responses to salmon:

“Results obtained from 37 publications that included 79 streams revealed positive, but highly inconsistent, overall effects of salmon on dissolved nutrients, sediment biofilm, macroinvertebrates, resident fish, and isotopic enrichment. Variation in these response variables was commonly influenced by salmon biomass, stream discharge, sediment size, and whether studies used artificial carcass treatments or observed a natural spawning run. Dissolved nutrients were positively related to salmon biomass per unit discharge, and the slope of the relationship for natural runs was five to ten times higher than for carcass additions. Mean effects on ammonium and phosphorus were also greater for natural runs than carcass additions, an effect attributable to excretion by live salmon. In contrast, we observed larger positive effects on benthic macroinvertebrates for carcass additions than for natural runs, likely because disturbance by live salmon was absent. Furthermore, benthic macroinvertebrates and biofilm associated with small sediments (<32 mm) displayed a negative response to salmon while those associated with large sediments (>32 mm) showed a positive response.”

3.6.1 Primary production

The ecosystem response to the addition of MDN has been examined throughout the range of Pacific salmon through experiments that manipulate carcass loading. Cram et al. (2011) added carcasses to experimental channels along the Cedar River, Washington and found little evidence that carcasses influenced primary producer biomass or fish growth; however, nutrients and some primary consumer populations increased with loading rate. These effects varied through time. They hypothesized that the variable effects of carcasses were a result of ambient abiotic conditions, such as light, temperature and disturbance that constrained trophic response.

Whole stream metabolism measures indicate that live salmon runs increase ecosystem respiration but not necessarily gross primary production (Levi et al. 2013). Salmon-derived nutrients stimulate plankton communities (Chen et al. 2011). On the other hand, the biofilm (Holtgrieve et al. 2010, Holtgrieve and Schindler 2011, Albers and Petticrew 2012) and macroinvertebrates (Monaghan and Milner 2009) tend to be negatively affected by dense spawning and redd construction, but these populations recover once the disturbance ends (Honea and Gara 2009). In nutrient-poor streams, salmon spawners can alleviate biofilm nutrient limitation and subsequent community respiration (Rüegg et al. 2011). Salmon carcasses can affect decomposition rates of leaf litter in streams, likely by providing an alternate food source for macroinvertebrates (Bretherton et al. 2011).

3.6.2 Aquatic insects

Aquatic insects directly consume carcasses (Heintz et al. 2010). Some, but not all species of aquatic insects, which are important prey for juvenile salmon, respond with increased growth rates (Minakawa et al. 2002) and density (Claeson et al. 2006, Lessard and Merritt 2006, Kiernan et al. 2010) when they are able to feed on carcasses.

3.6.3 Resident fish

Resident fish can benefit from direct consumption of fry and eggs, as well as macroinvertebrates that had fed on salmon carcasses. The benefits include increased growth rates (Wipfli et al. 2003, Scheuerell et al. 2007, Denton et al. 2009, Kiernan et al. 2010, Rinella et al. 2011). Again, the results are variable. In small streams in northern California, Wilzbach et al. (2005) studied the combined effects of riparian canopy opening and the addition of salmon carcasses on the biomass, density and growth rates of resident cutthroat trout and rainbow trout, and found them to be most affected by canopy removal.

3.6.4 Juvenile Salmonids

One of the main benefits of salmon carcasses is thought to be an increase in the production or condition of juvenile salmonids. Uchiyama et al. (2008) found that the characteristics of sockeye nursery lakes and watersheds, particularly the magnitude of adult escapement and their fresh-water residence time significantly affected the availability of MDN to juvenile sockeye. Perhaps because of such differences in watersheds, studies measuring the response of juvenile salmonids have been variable. Kohler et al. (2012) observed that both growth rates and stomach fullness in salmonids increased following the addition of carcass analogs. Harvey and Wilzbach (2010) saw no change in juvenile salmonid biomass, growth or nutrient retention in relation to changes in carcass distribution in six northwestern California streams.

In an experiment with juvenile coho salmon, Giannico and Hinch (2007) found that smaller fish at high density showed increased growth rates and presmolt size in response to the addition of salmon carcasses while the growth of larger fish at low densities was unaffected. Conversely, the addition of carcasses conferred no overwinter survival benefit to the smaller fish, but the larger fish were positively affected. In natural and experimental Alaskan streams, juvenile coho salmon exhibited increased growth rate and energy density in response to salmon carcasses (Wipfli et al. 2003, Rinella et al. 2011).

3.6.5 Riparian plants

Salmon carcasses can affect the growth of vascular and non-vascular riparian plants, both natural (Helfield and Naiman 2001, Wilkinson et al. 2005, Drake et al. 2006, Nagasaka et al. 2006, Hocking and Reynolds 2012) and agricultural (Merz and Moyle 2006).

What is the role of juvenile salmonids in the transport of MDN?

The role of juvenile salmonids in contributing and distributing MDN when they die (or are preyed upon) before outmigration and in exporting MDN during outmigration is being investigated. Warren and McClure (2012) analyzed the import and export of nutrients via hatchery activities in the Snake River watershed and found that in years with high smolt mortality, there can be a significant net input of nutrients while in years of low smolt mortality, hatchery activities collectively yielded a net loss of nutrients. Scheuerell et al. (2005) found a nonlinear relationship between nutrient import by adult Chinook salmon in the Snake River Basin and subsequent export by smolts, such that smolts exported proportionally more phosphorus as spawner abundance decreased. Moore et al. (2011) describe a similar relationship in coastal California watersheds and attribute it to smolts being larger and disproportionately more abundant at lower spawner densities than at higher spawner densities. At low abundance, they found that salmon can drive a net export of phosphorus from streams.

What are the differences between the sources of MDN: live salmon, artificially placed carcasses, and carcass analogs?

The timing and location of carcass deposition seems to be maximized by live salmon, compared with the addition of carcasses (Tiegs et al. 2011). Shaff and Compton (2009) examined the uptake of nitrogen derived from salmon carcasses in juvenile coho salmon. They found that unlike natural spawners, artificially placed carcasses did not appear to increase the use of marine derived nutrients. On the other hand, salmon carcasses appear to be superior to inorganic nutrient amendments for sustaining and restoring stream productivity (Wipfli et al. 2010). The use of salmon carcass analogs can provide a convenient, disease free-method of nutrient enhancement and do increase periphyton and macroinvertebrate biomass, but not stream water nutrient concentrations (Kohler et al. 2008, Kohler and Taki 2010, Kohler et al. 2012).

What limits the effectiveness of nutrient enhancement for restoring salmonid populations?

Placement of carcasses in rivers has become routine in Washington and Oregon. However, the effectiveness of these programs can be highly dependent on several factors.

- Nutrients are not always the limiting factor. The contribution of nutrient enhancement in restoring ecosystems and salmon runs will depend on whether the lack of nutrients that are delivered to the ecosystem are limiting productivity. Sanderson et al. (2009) tested whether primary producers are nutrient-limited in central Idaho streams and found that the type of nutrient limitation varied between streams and over time. In northern California streams, neither gross primary productivity nor periphyton biomass responded to the addition of carcasses, suggesting that other factors limit these streams (Ambrose et al. 2004). Schindler et al. (2005) reconstructed 300 years of sockeye salmon runs in Bristol Bay and lake algal production. Lake algal production was reduced by about two-thirds with the advent of commercial fishing that removed MDN, but recent sockeye population sizes are similar to pre-commercial fishing levels, indicating that this population is limited by other factors.

- Carcasses and analogs may not be delivered to the right location, or at the right time, in which case the nutrients may not be incorporated in a way that enhances productivity, or that maximizes their incorporation.

- Carcasses may not be retained in streams which lack structure that entraps the carcasses. Monaghan and Milner (2008) placed carcasses in a degraded river and found that instream structure (large woody debris, pools, etc.) is essential for retaining the carcasses. Without it, the carcasses can be quickly washed out of fresh water and into the estuary. Martin et al. (2010) demonstrated that the combination of salmon carcass analog and woody debris bundle additions aids in the short-term development of aquatic communities in newly created off-channel habitats.

- Further affecting the efficacy of nutrient enhancement programs is the influence of environmental factors, such as water temperature and discharge (Chaloner et al. 2007), that may not be considered during carcass and analog distribution.

What are the negative effects of nutrient enhancement?

One negative consequence of salmon carcass deposition can be the introduction of contaminants from the marine environment. Krümmel et al. (2009) confirmed that sockeye salmon have provided an important route for PCBs to enter the nursery lakes. American Dippers are indicators of stream quality, and were used to confirm that migrating salmon enhance contaminants in river food webs (Morrissey et al. 2011).

Distribution of hatchery salmon carcasses into watersheds for purposes of nutrification can pose a fish health risk if not properly managed. It is well recognized that disease organisms present in salmon carcasses can be transmitted to other salmonids following the release of those organisms into the water or through their direct consumption. To reduce this risk the HSRG recommends the following:

- Certify that adult broodstock is free of viral pathogens before planting. The adult sampling level should be a minimum of 60 fish for carcass plantings within the same watershed and 150 fish for plantings in different watersheds within the same fish health management zone.
- Freeze carcasses before planting to reduce the infectious titers of pathogenic organisms in salmon carcasses.
- Plant carcasses only within the historic range of the species being used for nutrient enhancement.
- Do not plant adults or juveniles which may have died of infectious disease. This includes pre-spawning adult mortalities and juvenile mortalities from hatchery ponds.

What is being done outside the Pacific Northwest?
Studies are beginning to show the effects of MDN in the Northeastern Pacific. Koshino et al. (2013) and Yanai and Kochi (2005) evaluated the uptake of MDN into stream and terrestrial ecosystems in Japan. Using data on escapement of adult Pacific salmon to spawning areas in the Russian Far East, Murota (2012) estimated how much marine-derived nitrogen and phosphorus are annually uploaded onto terrestrial ecosystems from the Northern Pacific Ocean. Guyette et al. (2013) measured a positive increase in the condition and growth rate of Atlantic salmon young of the year in response to the addition of salmon carcass analogs.

3.6.6 Summary and Conclusions for Section 3.6

The literature indicates that artificial enhancement can be of great benefit in raising the level of nutrients in freshwater systems. The methods endorsed by the HSRG are distribution of adult carcasses or carcass analogs. Certain guidelines and protocols should be applied to all nutrient enhancement projects. Nutrification projects require careful planning and evaluation to ensure that the resources are used wisely and that the risks to the resource are understood. There is widespread agreement in the published literature that haphazard distribution of carcasses or analogs does not optimize this management tool and may, in some cases, be counter-productive. Opportunities to understand the effects of distribution programs will be missed without including evaluation as part of the project.

Comprehensive protocols and guidelines for nutrient enhancement have been developed by Ashley and Stockner (2003), Washington Department of Fish and Wildlife, and Fisheries and Oceans Canada. These protocols and guidelines can be adapted to local needs. Programs should be followed up with a thorough evaluation to ensure the intended goals are being met. The HSRG continues to support its recommendations from the 2009 report regarding nutrient enhancement.

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3.7 Research, Monitoring and Evaluation (RM&E) and Adaptive Management

In Chapter 1 the three fundamental principles required for a successful hatchery program were identified. Principle 2 calls for scientific defensibility. This implies that hatchery programs should be operated in accordance with an explicit scientific rationale, which in turn must be consistent with available data and knowledge. In other words, hatchery management should be based on an explicit working hypothesis. This does not imply certainty, but it does imply scientific accountability when it comes to predicting benefits and risks associated with the hatchery program. Deciding what risks are acceptable to meet expected benefits is a matter of policy, within the context of an adaptive management process.

There is always some uncertainty about outcomes of management actions, but if the working hypothesis is not explicitly stated, resolution or reduction of those uncertainties cannot be pursued in a scientifically defensible manner. Acceptability of risk is a subject of policy debate and resolution, but the prediction and estimation of benefits and risks should be addressed through scientific investigation. This translates into testing the validity of the working hypothesis.

It is helpful to organize RM&E activities into four categories:

1) Performance or implementation—monitoring hatchery program operations relative to plans and agreements, including in-hatchery survival, broodstock collection, pNOB, disease management, etc.

2) Status and trends—monitoring goals and objectives for natural production and harvest.

3) Effectiveness monitoring—evaluating the proximal outcomes of hatchery programs (e.g., survival, harvest contributions, pHOS, etc.)

4) Research—hypothesis testing and parameter estimation related to the working hypothesis for hatchery programs. Research programs tend to have global relevance and should therefore be subject to regional coordination and collaboration.

RM&E requirements and priorities also depend upon the purpose of the hatchery program. Harvest augmentation programs differ substantially from conservation programs in terms of expected benefits and risk tolerances. Their RM&E priorities are therefore different. Programs with dual harvest and conservation purposes need to meet requirements for both categories. Programs labeled mitigation would generally be included among harvest augmentation programs.

Performance and status and trend monitoring are similar for harvest and conservation programs. It must be a priority to ensure that hatchery programs are operated, in all culture phases, as intended (performance/implementation monitoring). It should also always be a priority to track changes in the status of VSP parameters for all populations potentially affected (positively or negatively) by hatchery programs. Where the two types of hatchery programs differ is in effectiveness monitoring and in research priorities. Section 3.7.1 discusses effectiveness monitoring and research priorities for harvest augmentation programs and Section 3.7.2 reviews priorities for conservation and recovery programs.

3.7.1 RM&E for Harvest (and Mitigation) Programs

Research priorities for harvest augmentation programs

Research activities should focus on establishing and testing assumptions of a working hypothesis.

The HSRG captured the working hypothesis in the form of a model, the All H Analyzer (AHA). The HSRG concluded that implications of hatchery management can only be understood in the context of all other factors affecting the subject populations (habitat, harvest, and hydropower management).

As discussed above (Section 3.1 and 3.2) key assumptions in this working hypothesis (AHA) pertain to:

1) The relative reproductive success (RRS) of hatchery fish spawning in the wild, and

2) The long-term fitness (LTF) effects on the naturally spawning population caused by hatchery fish spawning in the wild.

HSRG modeled RRS as a short-term (first generation) effect due to both phenotypic (e.g., poor choice of spawning location) and genetic (e.g., different spawn timing) handicap of the hatchery fish, relative to the naturally spawning population (Section 3.1) and LTF as a consequence of the genetic legacies of both hatchery and natural population components, citing Ford (2002). Refinement of these relationships should be pursued as a regionally coordinated research priority for harvest augmentation programs.

Effectiveness monitoring for harvest augmentation programs

Harvest augmentation programs, where producing adult fish for harvest is the primary purpose, have the potential to negatively impact naturally spawning populations and the ecosystem. The challenge for managers is to balance harvest benefits against genetic and ecological risks. As discussed above (Section 3.2), among the means available to achieve this is to manage broodstock composition and hatchery straying to within acceptable limits. This requires managing not only spawner abundance, but also the composition of fish spawning naturally (as indicated by pHOS) and the hatchery broodstock (as indicated by pNOB) to reduce genetic and ecological impacts. Monitoring and estimating pHOS and PNI effectively each year must be a priority for all hatchery programs, particularly those with a harvest augmentation purpose.

3.7.2 RM&E Requirements for Conservation and Recovery Programs

Section 3.3 describes the changing role of a conservation hatchery program as the target population transitions from one phase to the next. Establishing specific criteria for implementing these transitions in terms of biological significance and population status should be a research priority. The ultimate goal of a conservation program is to contribute (in concert with habitat, harvest and hydropower measures) to the establishment of a self-sustaining population. Implementing a conservation program involves tracking (i.e., monitoring) the population status and shepherding the population from one phase to the next over time.

Research priorities for conservation programs

Refinement of criteria and triggers for the transition of conservation programs from one phase to another should be a research priority. Research should focus on benefits and risks of remaining in the current phase versus moving to the next one. For example, the choice of a trigger may affect trade-offs between the rate of fitness recovery of a recolonized population versus near-term harvest benefits from a hatchery colonization program that is not constrained by pHOS. Viability analysis that takes into account random and systematic variability (e.g., Pacific Decadal Oscillation and climate change) should be undertaken to understand the implications of delayed recovery.

Effectiveness monitoring for conservation programs

Reproductive success of both hatchery and naturally spawning fish must be monitored to ensure that the hatchery actually provides the intended demographic benefit in each phase.

Status and trend monitoring for conservation programs

For conservation programs, status and trend monitoring becomes particularly important, since transition triggers may be defined in terms of observed indicators of population viability.

Implementation monitoring for conservation programs

Each time the hatchery program transitions from one phase to the next, the operational procedures and biocriteria (e.g., program size and broodstock management) may change significantly. Monitoring of in-hatchery variables is critical.

3.7.3 Genetics Based Tools and Technologies

Genetic marking and identification methods and the costs of using these methods have changed substantially since HSRG (2009) was published. These advances should increase the accuracy and reduce reliance on untested assumptions associated with pHOS and PNI standards and provide more fine-scale estimates of stock structure as it affects population definitions and demographic estimates.

Genetic stock identification

Genetic stock identification (GSI) techniques have advanced both in laboratory and analytical approaches. In some cases, these advances are substantially improving GSI techniques and the ability to define fine-scale population structure, identify individuals to population of origin, and detect hatchery/wild introgression (e.g., Hohenlohe et al. 2011, Larson et al. 2013, Larson et al. 2014). Not long ago, projects based on several thousand individuals were the norm. Automated techniques now facilitate projects assaying 10,000s to 100,000s of individuals from one or more panels of 96 SNPs (single nucleotide polymorphisms) or 10-20 microsatellites (Beacham et al. 2012, Habicht et al. 2012, Dann et al. 2013).

These analytical and laboratory advances have also fueled an increasing number of studies based on individual assignment to stock (IA). For example, the Pacific Fish Trax project in collaboration with the West Coast Salmon Genetic Stock Identification Collaboration is using IA techniques to identify Chinook salmon from Oregon and California fisheries in near real-time and provide users with the origin of their fish.

Parentage Based Tagging (PBT)

The methodology supporting parentage based tagging (PBT) or as initially termed, full-parental genotyping (FPT) was initially reviewed by the expert panels of the Pacific Salmon Commission (Hankin et al. 2005, PSC 2008) and Anderson and Garza (2006). PBT uses high-throughput SNP genotyping and parentage analysis to assign hatchery-produced salmon to their hatchery and brood year of origin. Assignment to rearing treatment, release strategy, or even incubation tray is all possible with appropriate record-keeping. In addition to providing the stock of origin for tagged fish, the data can be used to assess genetic diversity, reproductive success and/or the heritability of specific traits. Standardization of SNP panels is ongoing (Warheit et al. 2013), and databases are now being developed to support the methodology.

PBT is now common in both the Sacramento and Columbia rivers and is ubiquitous in the Snake River Basin, where all Chinook salmon and steelhead hatchery broodstock are monitored with PBT (Hess et al. 2012, Steele et al. 2012). It is likely that the majority of cultured salmon from the Sacramento River, Columbia River and potentially many other river systems will be tagged using PBT in the near future. Steele et al. (2013) recently provided a validation of parentage-based tagging of hatchery steelhead in the Snake River Basin along with a comparison to coded-wire tags (CWT) and suggest that PBT will provide an unprecedented ability to mark millions of smolts and an opportunity to conduct parentage-based research. PBT is also being combined with GSI techniques; if parents are not in the database, the stock-of-origin of the individual can be determined through IA (see above).

Genetic-mark-recapture

Genetic mark recapture (GMR) (Pearse et al. 2001) is an approach increasingly used as an alternative to traditional mark recapture studies to obtain abundance estimates. Individuals are “marked” by obtaining their genotype from a fin or similar tissue sample. Most applications are based on multi-generational analyses where adults (parents) are the marked sample and their genotypes are “recaptured” in their progeny. The fraction of marked parents in the recapture sample is then estimated. Studies currently underway include Chinook salmon on the Green River (Seamons et al. 2012b), Stillaguamish River (Small et al. 2012), and Coweeman River (WDFW). Seamons et al. (2012b) provide a detailed analysis of the methodology and evaluation of the assumptions necessary to estimate abundances from the genetics data.

PNI based on gene flow (PNIG)

Analogous to GMR, genetic approaches to calculations of PNI (hereafter referred to PNI_{G}) are being explored. As defined in HSRG (2009, Appendix A, White Paper 1), PNI is a measure of the amount and the direction of gene flow between the hatchery environment and naturally spawning populations. The commonly applied surrogate, $\text{PNI}_{\text{Approx}}$, calculations are currently based on demographic data, and estimates rely on accurate identification and counting of hatchery- and natural-origin spawners both in the hatchery environment and on the spawning grounds. Recently, researchers (Ken Warheit, WDFW, pers. comm.; Adrian Spidle, NWIFC, pers. comm.) have proposed applying genetic methods to the calculation of PNI (see Wallace Summer Chinook HGMP, WDFW 2012). Their approach, termed PNI_{G}, uses parentage analysis (PBT) to obtain a more direct measure of gene flow and reproductive success with the estimates of $pHOS_G$ based on HOS_G and NOS_G all based on genetic parentage analysis.

Genomics

Over the last several years, there have been tremendous advances in sequencing technologies and salmonid geneticists are now able to incorporate 1,000s to 10,000s of markers allowing inferences concerning both neutral and adaptive processes on a genome-wide basis (Allendorf et al. 2010). One of the most promising techniques is known as RAD sequencing (restriction site associated DNA (RAD) markers; see Hohenlohe et al. 2010, Miller et al. 2012, and Narum et al. 2013a).

These genome wide resources will likely permit progress on long-standing questions in salmonid biology and hatchery research such as predicting the viability of local populations, predicting the ability of populations to adapt to climate and other anthropogenic challenges, and understanding the genomic regions important in domestication (Allendorf et al. 2010). To date, applications are broad and include developing linkage maps to identify adaptively-important traits (Everett et al. 2012, Miller et al. 2012), identification of highly divergent markers (outliers) for stock identification and hatchery-wild studies (Hohenlohe et al. 2011, Russello et al. 2012), and understanding the genetic basis of thermal adaptation and acclimation (Narum et al. 2013b) and propensity to migrate (Hecht et al. 2013). Additionally, functional genomic studies are revealing physiological profiles predictive of successful migration and spawning (Miller et al. 2011).

Environmental DNA

Sampling DNA from the environment (eDNA) rather than directly from an organism has emerged as a promising and powerful new tool for management and conservation in aquatic ecosystems (Ficetola et al. 2008, Jerde et al. 2011, Lodge et al. 2012, Yu et al. 2012). DNA can be collected by filtering water, and only minute concentrations are needed. The eDNA is then screened for species-specific molecular "barcodes" generally from mitochondrial DNA to determine presence or absence.

Recent work by Thomsen et al. (2012) provides additional evidence demonstrating the feasibility of this approach using empirical and controlled experimental conditions. They showed that eDNA is an accurate indicator of the presence of a diverse set of six aquatic or amphibious taxa in a wide range of freshwater habitats. They also demonstrated that the abundance of eDNA, as measured by quantitative PCR (qPCR), correlates positively with population abundance estimated with traditional tools. In addition, Thomsen et al. (2012) demonstrate that next-generation sequencing of eDNA can quantify species richness suggesting that the eDNA approach may become a rapid and affordable tool for detection of species, estimates of relative abundance, and quantification of biodiversity.

Estimates of effective size (N_e)

One of the most important parameters affecting genetic diversity is effective population size (N_e) (see Section 3.2.1 and HSRG 2004). Effective population size can be defined as the number of individuals in an *idealized* population that has a value of any given population genetic quantity that is equal to the value of that quantity in the population of interest. However, this parameter is also one of the most difficult to estimate in natural populations as there are many factors influencing N_e including sex ratio, variation in family size, fluctuations in population size, and age structure of the effective number of breeders. In salmonid populations, typically both the effective number of breeders per year (N_b) and effective population size per generation (N_e) are calculated. N_e is a function of the harmonic mean of the N_b values for individual years times the generation length (Waples 2002).

Advances both in the estimation of N_e and its use have recently been published. Estimates of contemporary effective size (i.e., the period encompassed by the sampling period) have historically been based on two samples, following the temporal method (Palstra and Ruzzante 2008). This temporal method depends on random changes in allele frequency over time. Recent work by Waples and Do (2010) reexamined the use of single-sample rather than two-sample methods. These single-sample methods are based on linkage disequilibrium to estimate N_e. Waples and Do (2010) suggest that their single-sample method has widespread applicability to conservation where comprehensive time series may not be available. Additionally, estimates of N_e from nearly complete parentage and demographic data are now being presented (e.g., Araki et al. 2007, Christie et al. 2012). There has also been increasing use of the ratio of effective size to census size (N_e/N). N_e is typically much less than the census size leading to interest in predicting N_e/N ratios for conservation planning and assessment (Palstra and Ruzzante 2008, Naish et al. 2013).

3.7.4 RM&E Coordination

The HSRG recommends that monitoring and evaluation plans be implemented as part of a structured annual adaptive management decision process. This process should specify roles and responsibilities, schedules, and data and information sharing and coordination.

The need for regional consistency and coordination is well recognized, but remains elusive. Better use of resources and more reliable information would result if improvements in this area were achieved. Standards for estimating VSP parameters would help decision making at local and regional levels.

Research programs, which tend to have global value, should be regionally designed and coordinated to avoid misinterpretation and misapplication of results.

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Steele, C. A., E. C. Anderson, M. W. Ackerman, M. A. Hess, N. R. Campbell, S. R. Narum, and M. R. Campbell. 2013. A validation of parentage-based tagging using hatchery steelhead in the Snake River basin. Canadian Journal of Fisheries and Aquatic Sciences 70(7):1046-1054.

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Appendices

On the Science of Hatcheries: An updated perspective on the role of hatcheries in salmon and steelhead management in the Pacific Northwest

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Appendices

Appendix 1	Example Citations of HSRG Recommendations and Principles
Appendix 2	Example Citations of All H Integration
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Appendix 4	Recent studies reviewing relative reproductive success (RRS) in Pacific salmon and their relationship to HSRG (2009) recommendations

Appendix 1

Example Citations of HSRG Recommendations and Principles

EXAMPLE CITATIONS OF HSRG RECOMMENDATIONS AND PRINCIPLES

Washington Fish and Wildlife Commission. 2009. WDFW Hatchery and Fishery Reform Policy, No. C-3619. 3 pp. http://wdfw.wa.gov/commission/policies/c3619.pdf

Policy guidelines state that WDFW will *"use the principles, standards, and recommendations of the Hatchery Scientific Review Group (HSRG) to guide the management of hatcheries operated by the Department….and promote the achievement of hatchery goals through adaptive management based on a structured monitoring, evaluation, and research program."*

NOAA Fisheries, West Coast Region. 2010. Draft Environmental Impact Statement to inform Columbia Basin hatchery operations and the funding of Mitchell Act hatchery programs. 1132 pp. http://www.westcoast.fisheries.noaa.gov/publications/nepa/hatchery/cb-ma-deis.pdf

The analysis of alternative management scenarios is based on two HSRG performance metrics, PNI and pHOS. Hatchery performance goals are defined in terms of meeting these performance metrics. Estimates of the metrics were generated using the "All H Analyzer" (AHA) model.

"In this EIS, performance goals are identified within each alternative. These goals apply to hatchery programs. There are two performance goals: stronger and intermediate. Both performance goals would likely reduce negative effects of hatchery programs on salmon and steelhead populations compared to the baseline conditions. Performance metrics are identified for each performance goal so that an implementation scenario can be identified. Performance metrics include two measurements: PNI and pHOS.

The following performance metrics were applied for each hatchery performance goal: For the stronger performance goal, integrated populations that are affected by hatchery programs would have a PNI of 0.67 or higher, and segregated, natural origin populations would maintain pHOS less than or equal to 0.05. For the intermediate performance goal, integrated populations that are affected by hatchery programs would have a PNI of 0.50 or higher, and segregated, natural origin populations would maintain pHOS of less than or equal to 0.10." (p. 17)

Recovery Implementation Science Team (RIST). 2009. Hatchery reform science - a review of some applications of science to hatchery reform issues. 93 pp. http://www.nwfsc.noaa.gov/trt/puget_docs/hatchery_report_april92009.pdf

"We believe the general thrust of the HSRG recommendations are scientifically sound and will lead to an improved situation for wild salmon populations, but do not think that the AHA model can accurately predict the outcomes of specific hatchery or habitat actions in a quantitative way. As it has been applied, the AHA model has been used to model the expected long term (decades) consequences of alternative hatchery scenarios. This seems consistent with the HSRG's intent to provide general guidance on the direction for hatchery reform. It is another reason, however, that the AHA model results should be interpreted as guidelines rather than quantitative predictions." (p. 4)

"Despite concerns about the extensive use of weirs to management movement of hatchery fish, the RIST agrees with the HSRG that the risks of extensive straying by hatchery fish into natural spawning areas are real and need to be considered if the region is to achieve recovery of wild salmon." (p. 8)

Crawford, Bruce A., and S. M. Rumsey. 2011. Guidance for monitoring recovery of Pacific Northwest salmon & steelhead listed under the Federal Endangered Species Act. National Marine Fisheries Service, NW Region. 160 pp. http://www.westcoast.fisheries.noaa.gov/publications/recovery_planning/salmon_steelhead/domains/rme-guidance.pdf

"In the Pacific Northwest, over 300 HGMPs are in need of revision or development to comply with the new ESA recovery needs and HSRG recommendations. These include programs associated with the FCRPS, Mitchell Act, and the Puget Sound EIS." (p. 96)

Independent Scientific Review Panel. 2014. Summary review of the Lower Snake Compensation Plan 2011-2014. ISRP 2014-6. 32 pp. http://www.nwcouncil.org/media/7109146/ISRP2014-6.pdf

(1) Independent Scientific Review Panel. Review of the Lower Snake River Compensation Plan's Spring Chinook Program. 2011. ISRP 2011-14. 69 pp. http://www.nwcouncil.org/fw/isrp/isrp2011-14

"Recently, there has been a Hatchery Scientific Review Group (HSRG) review of the LSRCP hatchery programs. Although the LSRCP reports and presentations identified some HSRG recommendations, in general they did not elaborate sufficiently on the recommendations from those reviews and how they were being addressed by the co-managers. Several of the supplementation programs have moved to sliding-scale broodstock management, where the proportion of hatchery-origin adult fish used for broodstock and permitted on the spawning grounds is increased in the absence or low abundance of wild broodstock. Implementing conservation/supplementation programs using sliding-scale broodstock management where, over the long-term (decades), the hatchery broodstock has little gene flow from the natural population, but the natural population has a large proportion of hatchery-origin adults, is inconsistent with the scientific framework guidance on the operation of an integrated hatchery program. Operating these programs using the sliding scale over many years carries a high risk that both abundance and productivity of naturally spawning stocks will decrease." (p. iii)

(2) Independent Scientific Review Panel. 2013. Review of the Lower Snake River Compensation Plan Steelhead Program. ISRP-2013-3. 73 pp. http://www.nwcouncil.org/fw/isrp/isrp2013-3.

The review notes that the HSRG and HRT recently reviewed the LSRCP steelhead programs and extensively discusses specific recommendations for each program.

"The concept of Proportionate Natural Influence (PNI) was used by the HSRG (HSRG 2009) to help manage the potential impact of naturally spawning hatchery fish on wild populations. Briefly, the idea is to regulate the relative abundance of hatchery origin adults in hatchery broodstocks and on spawning grounds to ensure that an integrated hatchery population retains its natural adaptations…. A generally accepted goal for most supplementation programs is a PNI value that is greater than 0.5. To reach this goal, Mobrand et al. (2005) recommend that more than 50% of the broodstock used in an integrated hatchery program should be of natural origin and that less than 50% of the naturally spawning population should be comprised of hatchery origin adults. The need to maintain relatively high PNI values is the basis for the following…suggestions." (p. 42)

U.S. Fish and Wildlife Service (USFWS). 2013. Review of U.S. Fish and Wildlife Service hatcheries in Washington, Oregon, and Idaho - region wide issues, guidelines and recommendations, final report. 44 pp. http://www.fws.gov/pacific/Fisheries/Hatcheryreview/Reports/regionwide/HRTRegion-WideIssues2FINALREPORTMay-2013.pdf

"The HSRG reviews of state, tribal, and federal hatchery programs in Puget Sound and coastal Washington…..resulted in more than 1,000 recommended changes to over 200 hatchery programs and 100 facilities. Those reviews provided a new ecosystem perspective and scientific template for managing hatcheries to support sustainable harvests while, at the same time, reducing biological risks to natural populations and contributing to their conservation. The Service was an active participant in those reviews, and the success of the HSRG in Puget Sound and coastal Washington motivated the Service to initiate similar reviews of its federal hatcheries in the Columbia River basin." (p. 2)

Appendix 2

Example Citations of All H Integration

EXAMPLE CITATIONS OF ALL H INTEGRATION

Washington Department of Fisheries and Wildlife. 2009. 21st Century Salmon and Steelhead Initiative. 17 pp. http://wdfw.wa.gov/publications/00036/wdfw00036.pdf

Integrates management goals for wild fish populations, habitat, and hatcheries. Provides a set of specific, quantitative goals in each discipline, and a timeline for reaching goals.

Examples of goals:

***Wild fish:** "Hatchery reform recommendations and current harvest management regimes for all populations are compiled in web tool."*

***Habitat:** "WDFW fish passage inventories are completed on 80% of state owned road crossings."*

***Fisheries:** "Harvest goals, strategies, and actions completed for 100% of populations."*

NOAA Fisheries. 2012. Streamlining restoration project consultation using programmatic biological opinions. Northwest Region Habitat Conservation Division. 7pp. http://www.westcoast.fisheries.noaa.gov/publications/reference_documents/esa_refs/hab-restore-prog.pdf

"NOAA Fisheries developed programmatic consultations to:

1. *Promote more consistent use of conservation measures;*
2. *Address the effects of multiple activities at larger scales;*
3. *Manage workload more efficiently; and*
4. *Provide better customer service." (p. 1)*

Examples of programmatic consultations (pp. 3-7): mostly region-wide habitat restoration projects (e.g., riparian habitat restoration, fish passage improvements).

Northwest Power and Conservation Council. 2009. Columbia River Basin Fish and Wildlife Program 2009 Amendments. 108 pp. https://www.nwcouncil.org/media/115273/2009_09.pdf

Program Coordination - recommendations (pp. 64-65):

- *Data management (storage, management, and reporting)*
- *Monitoring and evaluation (framework and approach)*
- *Developing and tracking biological objectives*
- *Review of technical documents and processes*
- *Project proposal review*
- *Coordination of projects, programs and funding sources within subbasins*
- *Facilitating and participating in focus workgroups on Program issues*
- *Information dissemination (technical, policy, and outreach)*

Independent Scientific Review Panel. 2013. Geographic review final report. Evaluation of anadromous fish habitat restoration projects. ISRP-2013-11. 407 pp. http://www.nwcouncil.org/media/6874426/isrp2013-11.pdf

"The ISRP recently reviewed documents describing three related programs intended to provide a basinwide approach to habitat monitoring and evaluation."

1. Integrated Status and Effectiveness Monitoring Program (ISEMP; Project #2003-017-00).
ISEMP is a "research and development project to test and develop fish and habitat monitoring methods, data management tools, and data analysis methods for general use by Fish and Wildlife monitoring projects across the interior Columbia River Basin."

2. Columbia Habitat Monitoring Program (CHaMP; Project #2011-006-00). *CHaMP's purpose is to "implement a habitat monitoring protocol for fish habitat status and trends throughout the portion of the Columbia Basin that is accessible to anadromous salmonids using a programmatic approach to standardized data collection and management that will allow effective data summarization at various spatial scales important for the management of fish and habitat."*

3. The Action Effectiveness Monitoring (AEM) of Tributary Habitat Improvement: a Programmatic Approach for the Columbia Basin Fish and Wildlife Program (January 2013)*.*
This document was developed to respond to ISRP and Council recommendations to move toward a standardized, programmatic approach to evaluate the effectiveness of habitat restoration actions. This paper provides many of the details of how BPA proposes to move to implement a standardized program in phases beginning as early as 2013.

In the review of these programs, the ISRP found that together ISEMP and CHaMP have achieved major gains in the collection of habitat data, the elucidation of relationships between fishes and their habitats, and the effectiveness of tributary habitat restoration actions….. This understanding has been lacking for the Columbia Basin, and elsewhere in the Pacific Northwest, and has likely severely hampered the effectiveness of restoration efforts over the last thirty years." (p. 10)

"…the full scope and reach of ISEMP or other Intensively Monitored Watersheds (IMWs), CHaMP, and especially AEM are not adequately described in relation to most projects in the Geographic Review. Most proposals simply mentioned that the effectiveness of their project would be addressed by one or more of these regional monitoring programs and did not describe specific monitoring efforts or explain how their project fit into the overall monitoring effort. Fish population data, or reference to how fish response to proposed habitat restoration actions was to be evaluated, were rarely presented in the proposals.

This raised concern within the ISRP that some projects were not fully communicating with monitoring partners and not fully integrated with monitoring efforts…habitat restoration efforts and effectiveness monitoring efforts must be carefully coordinated and integrated, and key personnel of both programs should be well aware of the overall strategy and ongoing effort in the watershed." (p. 11)

"The ISRP has the following recommendations (p. 12-15):
- *Identify Monitoring Efforts Associated with Habitat Projects across the Landscape*
- *Demonstrate Coordination and Integration of Habitat Projects and Monitoring Efforts*
- *Focus Fish RM&E on Key Viable Salmonid Population (VSP) Parameters of Wild Salmonids*

- *Develop Quantitative Objectives for Guiding RM&E and Adaptive Management*

Other recommendations:

- *"The ISRP suggests that the BiOp actions in many subbasins could be improved by increasing the focus on watershed processes at larger spatial scales and on land use activities over longer timeframes." (p. 15)*
- *Improving umbrella projects (p. 18) and coordination among agencies, private landowners, and local communities (p. 19).*

Independent Science Advisory Board (ISAB). 2013. Review of the 2009 Columbia Basin Fish and Wildlife Program. 76 pp. http://www.nwcouncil.org/Media/5950466/Isab2013-1.pdf

Concluding remarks (p. 65):

1. Acknowledge that artificial production alone cannot achieve the Program's biological objectives for salmon and other species, and revise artificial production strategies appropriately. *Adopt a landscape approach and implement strategies that unambiguously establish the necessity and primacy of an environment sufficient to maintain self-sustaining natural fish and wildlife populations.*

2. Acknowledge that adaptive management is not being practiced as originally intended and seek opportunities for "intentional learning" as part of the adaptive management cycle. *As well, it would be timely to explore institutional changes (adaptive governance) to focus on diversity, redundancy, and multiple levels of management to include local knowledge and actions.*

3. Encourage Structured Decision Making (SDM) as a tool within the Program. *SDM can augment the adaptive management cycle with a decision process that addresses uncertainty and engages stakeholders, scientists, and decision-makers in an iterative manner.*

4. Revise the scope of projects and project selection process to capture the best professional skills in the region. *Key aspects of the Program would benefit from broader analyses and better communication, and these require appropriate projects. Outcomes may include province-scale analyses of restoration actions; a basinwide understanding of how fish biodiversity contributes to recovery and resilience; better decisions and increased local responsibility through SDM; and improved leadership in addressing complex issues like chemical contaminants.*

Recovery Implementation Science Team (RIST). 2009. Hatchery reform science - a review of some applications of science to hatchery reform issues. 93 pp. http://www.nwfsc.noaa.gov/trt/puget_docs/hatchery_report_april92009.pdf

"Many of the scenario building tools currently available to recovery planners, including for example AHA, SHIRAZ and SLAM, could be readily adapted to take into account existing information on ecological interactions between hatchery and wild salmon. Better information is needed concerning the cumulative effects of multiple hatchery releases on wild fish survival in estuaries and the ocean." (p. 6)

HSRG. 2004. Lars Mobrand (chair), John Barr, Lee Blankenship, Don Campton, Trevor Evelyn, Tom Flagg, Conrad Mahnken, Robert Piper, Paul Seidel, Lisa Seeb and Bill Smoker. Hatchery reform: principles and recommendations of the HSRG. Long Live the Kings, 1305 Fourth Avenue, Suite 810, Seattle, WA 98101. www.hatcheryreform.us

"Assuming that goals for the resource have been established (see Principle 1), and the scientific rationale and defensibility for a particular hatchery program have been developed into a comprehensive management and operational plan, the HSRG further recommends that the managers' decisions be informed and modified by continuous evaluations of existing programs and by new scientific information. Such an approach will require a substantial increase in scientific oversight of hatchery operations, particularly in the areas of genetic and ecological monitoring."

"The HSRG recommends that adaptive management is particularly important in the context of hatchery reform. Adaptive management, as related to ecosystems, is defined as an "adaptive policy that is designed from the outset to test clearly formulated hypotheses about the behavior of the ecosystem being changed by human use" (Lee 1993). There is a significant amount of scientific uncertainty about the effects and proper uses of hatcheries, and a great need for flexibility and adaptation to changing goals, new scientific knowledge, and new information about the condition of stocks and habitat. A structured adaptive management program will be a key component of a strategy for success in these circumstances." (p. 43)

Appendix 3

Examples of Hatchery Reform in the Pacific Northwest Since 2004

EXAMPLES OF HATCHERY REFORM IN THE PACIFIC NORTHWEST SINCE 2004

Table A-3-1 Puget Sound programs reviewed by the HSRG in 2004 and 2012.

Name	Population Type	Hatchery Purpose	No. of Releases	HSRG Recommendations (2004)	Program Improvements (2012 HGMPs)	Additional HSRG Recommendations (2012)
Elwha Summer/Fall Chinook (Elwha Integrated)	Integrated	Conservation	2,220,000	Improve quality and diversity of smolts in order to achieve the required number of adult broodstock. Ensure security of stock with diverse rearing and release strategies and redundant facilities.	Identified as a Primary population. Adopted four biological phases of restoration and HSRG standards for a Primary population. Triggers for transition between phases based on VSP criteria. New hatchery facilities.	Develop clear set of decision rules for triggers. Revise triggers so that they are realistically achievable. State pHOS objective and develop actions to achieve it (e.g., weirs, selective fisheries). Develop plan to mark all hatchery releases.
Green River Fall Chinook (Soos Icy Integrated)	Integrated	Harvest	3,475,000	Reduce pHOS. Select broodstock to represent entire run timing. Incorporate NORs into broodstock based on HSRG guidelines.	Broodstock selected from entire run. Population currently identified as Contributing (draft WDFW).	Lacks specific, quantifiable goals. No targets for PNI, pNOB, or pHOS are provided. Method of integrating NORs into broodstock not clearly described.
Hamma Hamma Fall Chinook	Integrated	Conservation	--	Develop locally adapted, integrated broodstock.	From HGMP (no HSRG review): • Broodstock will be collected from the entire run and will be representative of run timing, age composition, size, etc. • Annual surveys will be conducted to estimate pHOS. • Population currently identified as Primary (draft WDFW).	No targets for PNI, pHOS, or pNOB.
Minter Creek Fall Chinook (Hatchery)	Segregated	Harvest	1,800,000	Select broodstock to represent entire run timing.	Broodstock selected from entire run.	Conduct surveys to ensure that straying is not an issue (determine if program size needs to be reduced). No specific quantifiable goals.

Table A-3-1 Puget Sound programs reviewed by the HSRG in 2004 and 2012 (continued).

Name	Population Type	Hatchery Purpose	No. of Releases	HSRG Recommendations (2004)	Program Improvements (2012 HGMPs)	Additional HSRG Recommendations (2012)
NF-MF Nooksack Spring Chinook (Kendal Creek Integrated)	Integrated	Conservation	800,000	Reduce size of program to reduce number of strays. Collect broodstock from entire run (spatial considerations).	Identified as a Primary population. PNI targets identified (short and long term).	Develop time frames for reaching PNI and pHOS goals.
Puyallup Fall Chinook (Voights Creek Integrated)	Integrated	Harvest & Conservation	2,000,000	Conduct surveys to determine pHOS. Manage broodstock based on HSRG guidelines.	Managed as a Stabilizing population (pHOS, pNOB, PNI standards at current level).	Establish specific, quantifiable goals.
Skykomish Summer Chinook (Wallace Integrated)	Integrated	Harvest	1,350,000	Improve broodstock management by integrating ~10% NORs. Improve spawning protocols.	Program uses a genetic approach to integrate NORs into the broodstock, while limiting pNOB to less than 20% to protect the natural spawning population. Population currently identified as Primary (draft WDFW).	None
Snohomish/SF Skykomish Coho (Wallace)	Integrated	Harvest	--	Consider converting from segregated to integrated program to address concerns about natural spawning.	Program has converted to integrated harvest program. Population currently identified as Primary (draft WDFW).	No specific, quantifiable goals, and no targets for PNI, pHOS, or pNOB.
North Fork Nooksack River Chum	Integrated	Harvest & Conservation	--	Discontinue program or convert to properly integrated program. Initiate new broodstock with 100% NORs. Thereafter, use 10-20% NORs in broodstock.	None in focal areas of review. Population currently identified as Primary (draft WDFW).	No specific, quantifiable goals to justify program size. Lacks specifics on broodstock management and integration of NORs.
Deschutes Fall Chinook (Tumwater Falls Hatchery)	Segregated	Harvest	3,800,000	None in focal areas of review.	None in focal areas of review.	Develop specific, quantifiable harvest goals.
Hood Canal Winter Steelhead	--	--	--	Capture as many returning adults as possible to prevent interbreeding with naturally spawning population.	No HSRG review of HGMP.	From HGMP (no HSRG review): • All returning HORs allowed to spawn naturally because program is in supplementation phase. • pHOS is monitored annually but there is no target.

Table A-3-2 Columbia River programs reviewed by the HSRG (2009) and revised to incorporate HSRG principles.

Washington Programs	Population Type	Hatchery Purpose	Historical Releases	Current/ Proposed Releases	HSRG Recommendations	Recent Program Changes
Lower Cowlitz Early Winter Steelhead	NA	NA	300,000	0	Reduce total hatchery production from the three Cowlitz winter steelhead programs to meet standards for a Contributing population, or change designation to Stabilizing population.	Program discontinued. This non-native program was causing genetic introgression into the native late winter population.
Lower Cowlitz Late Winter Steelhead	Integrated	Harvest	280,000	478,000	Transition to integrated program, reduce pHOS.	WDFW is developing an integrated program, and installed weirs in tributaries to trap wild adults and control pHOS.
Cowlitz Fall Chinook	Segregated/ Integrated	Harvest	4,800,000	3,500,000	Consider changing population designation to Primary. Develop broodstock management program integrating NORs. Manage and monitor composition on spawning grounds (pHOS).	Currently developing a "Stepping-stone program" (integrated and segregated components). Will manage Broodstock composition and pHOS to meet standards for a Primary population.
Elochoman Fall Chinook	NA	NA	2,000,000	0	Convert program to smaller, integrated conservation program. Install weir on lower river to reduce strays and collect broodstock.	Hatchery closed and program discontinued.
North Fork Toutle Coho	Integrated	Harvest	800,000	150,000	Reduce program size, manage as an integrated program. Use existing retention dam to collect NORs for broodstock and manage pHOS.	Converted to integrated program, reduced program size to less than 20% of historical releases.
North Fork Toutle Fall Chinook	Integrated	Harvest	2,500,000	1,400,000	Consider designating as a Primary population. Manage as an integrated program. Develop program to collect NORs for broodstock. Monitor pHOS on spawning grounds.	Designated as a Primary population. Converted to integrated program and reduced program size to less than 60% of historical releases.
Washougal Coho	Segregated	Harvest	500,000	150,000	Revise management to be consistent with designation as a Contribution population. Intent is to manage as integrated program, but pNOB 0%. Suggested "stepping-stone program" to transition to integrated program.	Converted to segregated program, reduced program size to 30% of historical releases.

Table A-3-2 Columbia River programs reviewed by the HSRG (2009) and revised to incorporate HSRG principles (continued).

Washington Programs	Population Type	Hatchery Purpose	Historical Releases	Current/ Proposed Releases	HSRG Recommendations	Recent Program Changes
Washougal Fall Chinook	Integrated	Harvest	4,000,000	3,000,000	Use "stepping-stone" approach to convert to integrated program. Segregated component would release fish in Lower Columbia net pens. Install weir in lower river to manage consistent with Primary designation.	Converted to integrated program, installed weir in lower river, and reduced program size by 25%. Difference will be moved to net pens in Lower Columbia (Deep River and other programs).
Okanogan Spring Chinook	Segregated/ Integrated	Harvest & Conservation	0	900,000	Develop locally adapted broodstock and incorporate increasing proportion of NORS in broodstock as population recovers. Consider establishing segregated harvest program below Chief Joseph Dam.	New program. Will establish locally adapted broodstock and restore natural spawning distribution. Includes segregated harvest component.
Okanogan Summer/Fall Chinook	Integrated	Harvest & Conservation	575,000	2,000,000	Consider managing population consistent with designation as Primary population. Manage all sport fisheries as selective fisheries. Begin research on selective gear for the commercial fishery in the Upper Columbia River.	Will transition to local broodstock, operate program consistent with designation as Primary population. Research on selective gear has been initiated. All sport harvest are selective.
Walla Walla Chinook	Integrated	Conservation	250,000	250,000	Transition to local broodstock as soon as new hatchery facilities are available. Maintain current program releases until natural production begins to recover.	Proposes to establish local broodstock, use all-H approach to restore natural spawning population.
Okanogan Steelhead	Integrated	Harvest	150,000	100,000	End the Wells Hatchery outplant program and establish an integrated program with a locally adapted broodstock.	Proposes using a phased approach to develop integrated harvest program, to reduce releases by 33%. Will develop locally adapted broodstock. Steelhead from locally adapted hatchery population will be introduced into Okanogan subbasin as habitat improves.

Table A-3-2 Columbia River programs reviewed by the HSRG (2009) and revised to incorporate HSRG principles (continued).

Washington Programs	Population Type	Hatchery Purpose	Historical Releases	Current/ Proposed Releases	HSRG Recommendations	Recent Program Changes
Lower Columbia Segregated Steelhead programs	Segregated	Harvest	--	--	**Region wide programmatic recommendations:** Establish a regional system of wild steelhead management zones with no hatchery releases. In remaining streams, use 100% locally adapted (even if non-native) broodstock, maintain early spawn timing through broodstock management, early release dates for smolts to minimize interaction with later wild runs, only release smolts from facilities with collection capabilities. Reduce smolt releases where needed to stay within pHOS guidelines for native populations.	Wild steelhead management zones have been (or are being) designated by WDFW. In hatchery streams, WDFW uses only in-basin stock, only releases from facilities with collection capabilities, and uses spawning cut-off dates to maintain spawn timing differences with wild populations. Specific changes to several programs are identified below.
Skamania Early Winter Steelhead (White Salmon River releases)	Segregated	Harvest	20,000	0	See Programmatic recommendations above.	Moved releases to Rock Creek to avoid interactions with native population.
Skamania Summer Steelhead (White Salmon River releases)	Segregated	Harvest	24,000	0	See Programmatic recommendations above.	Moved releases to Drano Lake to avoid interactions with native population.
Skamania Early Winter Steelhead (EF Lewis River releases)	Segregated	Harvest	90,000	38,000	See Programmatic recommendations above.	Program discontinued. EF Lewis River designated as wild steelhead gene bank.
Skamania Summer Steelhead (EF Lewis River releases)	Segregated	Harvest	30,000	15,000	See Programmatic recommendations above.	Program discontinued. EF Lewis River designated as a wild steelhead gene bank.
Skamania Summer Steelhead (SF Toutle River releases)	Segregated	Harvest	25,000	20,000	See Programmatic recommendations above.	Reduced number of smolts released to stay within HSRG pHOS limits for native population.

Table A-3-2 Columbia River programs reviewed by the HSRG (2009) and revised to incorporate HSRG principles (continued).

Washington Programs	Population Type	Hatchery Purpose	Historical Releases	Current/ Proposed Releases	HSRG Recommendations	Recent Program Changes
Skamania Summer Steelhead (NF Toutle/ Green River releases)	Segregated	Harvest	25,000	20,000	See Programmatic recommendations above.	Program discontinued. NF Toutle/Green River designated as a wild steelhead gene bank.
Puget Sound Segregated Steelhead programs (not included in HSRG 2009 reviews)	Segregated	Harvest	--	--	See Programmatic recommendations above.	Wild steelhead gene banks have been designated by WDFW. In hatchery streams, WDFW uses only locally-adapted stock, only releases from facilities with collection capabilities, and uses spawning cut-off dates to maintain spawn timing differences with wild populations.
Oregon Programs	**Population Type**	**Hatchery Purpose**	**Historical Releases**	**Current/ Proposed Releases**	**HSRG Recommendations**	**Recent Program Changes**
Sandy Hatchery Spring Chinook	Segregated	Harvest	300,000	132,000	Develop alternate strategies for managing broodstock and monitoring spawning composition after removal of Marmot Dam.	Program size reduced by 56%. In process of establishing additional weirs to remove excess hatchery origin fish and strays from spawning grounds; developing sliding scale broodstock management to integrate NORs.
McKenzie Hatchery Spring Chinook	Integrated	Harvest & Conservation	1,000,000	832,000	Upgrade trapping facilities to collect NORs and manage spawning composition upstream of Leaburg Dam.	Program size reduced by 17%. Difference moved to Net Pens in Lower Columbia River.
Clackamas Hatchery Spring Chinook	Segregated	Harvest	1,200,000	861,000	No specific recommendations. Noted that an integrated program of similar size could provide additional conservation benefits.	Program size reduced by 28%. Difference moved to Net Pens in Lower Columbia River.

Table A-3-2 Columbia River programs reviewed by the HSRG (2009) and revised to incorporate HSRG principles (continued).

Oregon Programs	Population Type	Hatchery Purpose	Historical Releases	Current/ Proposed Releases	HSRG Recommendations	Recent Program Changes
Sandy Hatchery Coho	Segregated	Harvest	700,000	200,000	Continue to monitor the contribution and distribution of hatchery-origin fish on the spawning grounds.	Program size reduced by more than 50%. New fish trapping facility is complete and operational.
Columbia River Gorge Hatchery Coho	Segregated	Harvest	727,000	500,000	Increase coded-wire tag program to monitor straying. Consider transferring some releases to Lower Columbia net pens.	Program size reduced by more than 30%. Difference moved to Net Pens in Lower Columbia River.
Big Creek Hatchery Fall Chinook	Segregated	Harvest	5,800,000	3,700,000	This program is a major contributor to out-of-basin strays. Develop a reliable estimate of the stray rate for this program and implement actions to reduce strays in non-target streams (increase terminal harvest, improve homing, install weirs, reduce program size).	Program size reduced by more than 35% to make room for Select Area Bright Fall Chinook.
Umatilla River Fall Chinook	Segregated	Harvest	1,050,000	1,200,000	Develop two-stage “stepping-stone program”.	“Stepping stone program” changed to segregated harvest program.
Umatilla River Coho	Segregated	Harvest	1,530,000	1,000,000	Transition to using locally adapted broodstock.	Transitioning to local broodstock; reduced program size by 35% from historical releases.
Imnaha Spring Chinook	Integrated	Harvest & Conservation	360,000	490,000	Upgrade weir to improve broodstock and spawning ground management and remove more HORs. Develop a 2-stage conservation and harvest program with differential marking and broodstock management.	New weir to be installed to improve broodstock management and remove surplus HORs based on 2009 HSRG recommendation.

Table A-3-2 Columbia River programs reviewed by the HSRG (2009) and revised to incorporate HSRG

principles (continued).

Oregon Programs	Population Type	Hatchery Purpose	Historical Releases	Current/ Proposed Releases	HSRG Recommendations	Recent Program Changes
Big Creek Chum	Integrated	Conservation	NA	100,000 to 200,000 fry	Recommended that managers could consider establishing a small conservation hatchery program.	Implementing an integrated conservation hatchery program (first releases in 2011). Grays River stock used to produce initial fry releases. Plan to develop local broodstock with adult returns to Big Creek. Long-term goal is to re-establish self-sustaining chum salmon runs in tributaries on the Oregon side of the Lower Columbia River. All fry releases are marked. Ongoing habitat surveys identifying suitable sites for future releases.
Umatilla Spring Chinook	Segregated/ Integrated	Harvest & Conservation	925,000	810,000	Recommended developing a two-stage "stepping-stone program", differential marking of fish from the two programs, and releasing smolts from the conservation program in the watershed.	Initiated a "stepping-stone program" in 2009 following the HSRG recommendation; designated Primary population; marking all releases.

Table A-3-2 Columbia River programs reviewed by the HSRG (2009) and revised to incorporate HSRG

principles (continued).

Idaho Programs	Population Type	Hatchery Purpose	Historical Releases	Current/ Proposed Releases	HSRG Recommendations	Recent Program Changes
Snake River/ Springfield Sockeye	Integrated	Conservation	150,000	1,000,000	Increase the number of returning adults to use in the broodstock management program by increasing number of smolts released or capturing adults at Lower Granite Dam.	Phased approach to population recovery. Increased program size in order to develop locally adapted broodstock and transition away from captive broodstock program.
Clearwater Spring Chinook	Segregated	Harvest	2,400,000	2,800,000	Coordinate management of the four hatcheries releasing spring Chinook in this watershed.	This remains a segregated harvest program. Broodstock is collected at terminal area weirs (e.g., locally adapted).
Pahsimeroi Summer Chinook (Hatchery)	Segregated/ Integrated	Harvest	1,000,000	1,000,000	Implement a two-stage “stepping-stone program” to support natural population and harvest. Develop sliding-scale broodstock management.	The program is implementing an integrated conservation component (200,000 smolts) and a segregated harvest component (800,000 smolts). For the integrated component, a sliding scale broodstock management plan based on NOR and HOR abundance is followed.

Table A-3-2 Columbia River programs reviewed by the HSRG (2009) and revised to incorporate HSRG principles (continued).

Idaho Programs	Population Type	Hatchery Purpose	Historical Releases	Current/ Proposed Releases	HSRG Recommendations	Recent Program Changes
S Fork Salmon Summer Chinook	Segregated/ Integrated	Harvest	1,000,000	1,000,000	See recommendations above for Pahsimeroi.	Same as Pahsimeroi Summer Chinook (Hatchery).
Upper Salmon Spring Chinook	Segregated/ Integrated	Harvest	1,200,000	1,800,000	See recommendations above for Pahsimeroi.	The program is implementing an integrated conservation component (200,000) and a segregated harvest component (1,600,000 smolts). Sliding scale management is followed for the integrated program.
Panther Creek Spring Chinook	Integrated	Harvest	0	600,000	No specific recommendations (population extirpated).	Proposed integrated harvest program using locally adapted broodstock.
Yankee Fork Spring Chinook	Integrated	Harvest	0	400,000	Adopt a sliding scale broodstock/escapement management program. Monitor spawning composition.	Proposed integrated harvest program using locally adapted broodstock; includes sliding scale plan for broodstock, escapement, and harvest management.
E Fork Salmon Steelhead	Integrated	Harvest	180,000	60,000	Install a new weir to collect broodstock and manage spawning composition; develop sliding scale broodstock management plan.	Developed first integrated steelhead program in Idaho. Reduced program size to 33% of historical releases. Plan to install new weir to collect broodstock and manage spawning ground composition (funding still being identified). Plan to use 100% NORs as broodstock.
S Fork Clearwater B-run Steelhead	Segregated	Harvest	900,000	900,000	Develop integrated program with locally adapted broodstock.	Implementing phased transition to locally adapted broodstock. If broodstock development is successful, program may transition to integrated harvest program.
Upper Salmon B-run Steelhead	Segregated	Harvest	660,000	660,000	Transition to using locally adapted broodstock.	Implementing phased transition to locally adapted broodstock.

Appendix 4

Recent studies reviewing relative reproductive success (RRS) in Pacific salmon and their relationship to HSRG (2009) recommendations

RECENT STUDIES REVIEWING RELATIVE REPRODUCTIVE SUCCESS (RRS) IN PACIFIC SALMON AND THEIR RELATIONSHIP TO HSRG (2009) RECOMMENDATIONS

Study:

Anderson, J. H., P. L. Faulds, W. I. Atlas, and T. P. Quinn. 2013. Reproductive success of captively bred and naturally spawned Chinook salmon colonizing newly accessible habitat. Evolutionary Applications 6(2):165-179.

Species: Chinook

System: Cedar River, WA

Major Finding: Captively reared animals can provide demographic boost but may reduce fitness of colonizing populations. Hatchery males are less productive than naturally-spawning males. Sex ratio favors males. Early spawners were generally more productive, and larger fish had greater RS.

HSRG Recommendation Number: 15, Research on RRS and long-term fitness

Relationship to HSRG Recommendation: For reintroductions that employ captive breeding, the degree to which selection in captivity differs from the wild will ultimately govern a population's ability to adapt to new environment.

Study:

Araki, H., W. R. Ardren, E. Olsen, B. Cooper, and M. S. Blouin. 2007a. Reproductive success of captive-bred steelhead trout in the wild: evaluation of three hatchery programs in the Hood River. Conservation Biology 21(1):181-190.

Species: Steelhead

System: Hood River, OR

Major Finding: Captively bred steelhead of local origin that spawned naturally had RS indistinguishable from wild fish. No sign of reduced fitness from single generation but crosses between hatchery fish were less fit, suggesting an interaction effect.

HSRG Recommendation Number: 15, Research on RRS and long-term fitness

Relationship to HSRG Recommendation: Provides evidence for the environmental phenotypic component (i.e., reproductive success of first generation hatchery-origin fish).

Study:

Araki, H., R. S. Waples, W. R. Ardren, B. Cooper, and M. S. Blouin. 2007b. Effective population size of steelhead trout: influence of variance in reproductive success, hatchery programs, and genetic compensation between life-history forms. Molecular Ecology 16(5):953-966.

Species: Steelhead

System: Hood River, OR

Major Finding: Estimated N_e from demographic data and parentage data for 15 years and found the ratio of N_e to the estimated census population size (N) was 0.17-0.40, with large variance in reproductive success among individuals being the primary cause of the reduction in N_e /N. Traditional hatchery fish had negative effect on N_b, but N_b was stable over years.

HSRG Recommendation Number: 15, Research on RRS and long-term fitness

Relationship to HSRG Recommendation: Large variance in mean reproductive success increasing variance among breeding populations in N_b from non-local stocks leading to reduced ratio, but no sign from stocks from local origin.

Study:
Araki, H., B. Cooper, and M. S. Blouin. 2009. Carry-over effect of captive breeding reduces reproductive fitness of wild-born descendants in the wild. Biology Letters 5(5):621-624.
Species: Steelhead
System: Hood River, OR
Major Finding: Used parentage analysis to estimate reproductive fitness of wild-born descendants of captive-bred parents. Relative reproductive fitness was only 37% in wild-born fish from two captive-bred parents W[cxc] and 87% in those from one captive-bred and one wild parent (relative to those from two wild parents) W[cxw]. Carryover (effect in wild-born descendants of captive-bred parents) reduced population fitness by 8%.
HSRG Recommendation Number: 15, Research on RRS and long-term fitness
Relationship to HSRG Recommendation: Suggests carryover effect of captive breeding looking at F2 generation, cumulative impact on wild populations.

Study:
Berejikian, B. A., T. Johnson, R. S. Endicott, and J. Lee-Waltermire. 2008. Increases in steelhead (Oncorhynchus mykiss) redd abundance resulting from two conservation hatchery strategies in the Hamma Hamma River, Washington. Canadian Journal of Fisheries and Aquatic Sciences 65(4):754-764.
Species: Steelhead
System: Hamma Hamma, WA
Major Finding: Rearing and releasing adult steelhead showed an increase in the number of redds compared with the pre-supplementation period. Environmentally induced differences in spawn timing between the adult release group and anadromous adults of hatchery and natural origin may explain why the adult release group and anadromous adults assortatively formed pairing combinations on the spawning grounds.
HSRG Recommendation Number: 13, Maximize survival of hatchery fish, release at appropriate time and size
Relationship to HSRG Recommendation: Captively reared adults produced the majority of redds, but RRS is uncertain.

Study:
Berejikian, B. A., D. M. Van Doornik, J. A. Scheurer, and R. Bush. 2009. Reproductive behavior and relative reproductive success of natural- and hatchery-origin Hood Canal summer chum salmon (Oncorhynchus keta). Canadian Journal of Fisheries and Aquatic Sciences 66(5):781-789.
Species: Chum
System: Hood Canal, OR
Major Finding: Study compared the adult to fry reproductive success of natural-origin summer chum salmon with that of first- to third-generation hatchery-origin salmon in an experiment that included four replicate breeding groups. Relative reproductive success (hatchery/natural = 0.83). Male body size was positively correlated with access to nesting females and reproductive success.
HSRG Recommendation Number: 15, Research on RRS and long-term fitness
Relationship to HSRG Recommendation: --

Study:
Berejikian, B. A., D. A. Larsen, P. Swanson, M. E. Moore, C. P. Tatara, W. L. Gale, C. R. Pasley, and B. R. Beckman. 2012. Development of natural growth regimes for hatchery-reared steelhead to reduce residualism, fitness loss, and negative ecological interactions. Environmental Biology of Fishes 94(1):29-44.

Species: Steelhead
System: Hood Canal, OR
Major Finding: Three hatchery populations of steelhead in Hood Canal, WA were reared under growth regimes designed to produce a more natural age at smoltification (age-2) to aid in rebuilding their respective natural populations. Mean smolt sizes and size variability at age-2 were within the range of wild smolts for two of the three populations. The third population reared at a different facility under similar temperatures exhibited high growth rate variability and high male maturation rates (20% of all released fish).
HSRG Recommendation Number: 13, Maximize survival of hatchery fish, release at appropriate time and size
Relationship to HSRG Recommendation: Investigations of optimum rearing strategies to avoid residualisms.

Study:
Berntson, E. A., R. W. Carmichael, M. W. Flesher, E. J. Ward, and P. Moran. 2011. Diminished reproductive success of steelhead from a hatchery supplementation program (Little Sheep Creek, Imnaha Basin, Oregon). Transactions of the American Fisheries Society 140(3):685-698.
Species: Steelhead
System: Imnaha Basin, OR
Major Finding: Investigated the relative reproductive success (RRS) by creating pedigrees for hatchery and natural spawning steelhead. RRS of hatchery-origin fish was 30-60% that of their natural-origin counterparts. The greatest effects on RRS were origin (natural versus hatchery), length, return date, and the number of same-sex competitors. Natural parents were less negatively affected by same-sex competitors.
HSRG Recommendation Number: 15, Research on RRS and long-term fitness
Relationship to HSRG Recommendation: Greatest effect on reduced RRS was from origin, length, return date, and number of competitors.

Study:
Blankenship, S. M., M. P. Small, and J. D. Bumgarner. 2009. Temporal stability of genetic variation within natural populations of summer steelhead receiving mitigation hatchery fish. Transactions of the American Fisheries Society 138(5):1052-1064.
Species: Steelhead
System: Lyons Ferry, WA
Major Finding: Surveyed (Tucannon and Touchet) for seven consecutive years and the Lyons Ferry Hatchery stock (LFH) for four years. Observed statistically significant differences in allele frequencies between replicated collections. One of 21 genic tests for the Tucannon River collections. Nine of 21 genic tests for the Touchet River collections, and all genic tests regarding LFH collections were statistically significant. Genetic data were consistent with the potential for gene flow between the Tucannon River and LFH populations.
HSRG Recommendation Number: 6, Select an integrated or segregated broodstock strategy
Relationship to HSRG Recommendation: LFH is from Wells and Wallowa, segregated program for harvest, but some past or continuing gene flow was found.

Study:
Busack, C. 2007. The impact of repeat spawning of males on effective number of breeders in hatchery operations. Aquaculture 270(1-4):523-528.
System: NA (modeling study)

Major Finding: Derived new equation for repeat male spawners for N_b.
HSRG Recommendation Number: 14, Regularly review goals and performance of hatchery programs
Relationship to HSRG Recommendation: Comprehensive reviews of hatchery programs should be on-going to monitoring progress towards achieving expected benefits.

Study:
Chilcote, M. W., K. W. Goodson, and M. R. Falcy. 2011. Reduced recruitment performance in natural populations of anadromous salmonids associated with hatchery-reared fish. Canadian Journal of Fisheries and Aquatic Sciences 68(3):511-522.
Species: Coho, Steelhead, Chinook
System: NA
Major Finding: Found a negative relationship between the reproductive performance in natural, anadromous populations and the proportion of hatchery fish in the spawning population. The magnitude of this negative relationship is such that the authors predict the recruitment performance for a population composed entirely of hatchery fish would be 0.128 of that for a population composed entirely of wild fish. No support was found for the hypothesis that a population's reproductive performance was affected by the length of exposure to hatchery fish.
HSRG Recommendation Number: 15, Research on RRS and long-term fitness
Relationship to HSRG Recommendation: Concluded that measures that minimize the interactions between wild and hatchery fish will be the best long-term conservation strategy for wild populations.

Study:
Chittenden, C. M., C. A. Biagi, J. G. Davidsen, A. G. Davidsen, H. Kondo, A. McKnight, O. P. Pedersen, P. A. Raven, A. H. Rikardsen, J. M. Shrimpton, B. Zuehlke, R. S. McKinley, and R. H. Devlin. 2010. Genetic versus rearing-environment effects on phenotype: hatchery and natural rearing effects on hatchery-and wild-born coho salmon. Plos One 5(8).
Species: Coho
System: Chehalis, BC
Major Finding: Wild- and hatchery-born coho salmon adults (*Oncorhynchus kisutch*) returning to the Chehalis River in British Columbia, Canada, were crossed to create pure hatchery, pure wild, and hybrid offspring. A proportion of the progeny from each cross was reared in a traditional hatchery environment, whereas the remaining fry were reared naturally in a contained side channel. The resulting phenotypic differences between replicates, between rearing environments, and between cross types were compared. While there were few phenotypic differences noted between genetic groups reared in the same habitat, rearing environment played a significant role in smolt size, survival, swimming endurance, predator avoidance and migratory behavior.
HSRG Recommendation Number: 13, Maximize survival of hatchery fish, release at appropriate time and size
Relationship to HSRG Recommendation: Rearing environment played a significant role in smolt size, survival, swimming endurance, predator avoidance and migratory behavior.

Study:
Christie, M. R., M. L. Marine, and M. S. Blouin. 2011. Who are the missing parents? Grandparentage analysis identifies multiple sources of gene flow into a wild population. Molecular Ecology 20(6):1263-1276.
Species: Steelhead
System: Hood River, OR

Major Finding: Juvenile hatchery steelhead that 'residualize' (become residents rather than go to sea as intended) provide a previously unmeasured route for gene flow from hatchery into wild populations. From pedigree analysis, for fish with only one anadromous parent 83% were identified as having a resident father while 17% were identified as having a resident mother.
HSRG Recommendation Number: 15, Research on RRS and long-term fitness
Relationship to HSRG Recommendation: Residualization of hatchery fish can increase gene flow particularly from resident males.

Study:
Christie, M. R., M. L. Marine, R. A. French, and M. S. Blouin. 2012a. Genetic adaptation to captivity can occur in a single generation. Proceedings of the National Academy of Sciences 109(1):238-242.
Species: Steelhead
System: NA
Major Finding: Hypotheses for reduced fitness include environmental effects of captive rearing, inbreeding among close relatives, relaxed natural selection, and unintentional domestication selection (adaptation to captivity). Used pedigree analysis to demonstrate that domestication selection can explain the precipitous decline in fitness observed in hatchery steelhead. First-generation hatchery fish had nearly double the lifetime reproductive success (measured as the number of returning adult offspring) when spawned in captivity compared with wild fish spawned under identical conditions, which is a clear demonstration of adaptation to captivity. Found 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. Specifically, captive-born individuals with five (the median) or more returning siblings (i.e., offspring of successful broodstock) averaged 0.62 returning offspring in the wild, whereas captive-born individuals with less than five siblings averaged 2.05 returning offspring in the wild.
HSRG Recommendation Number: 15, Research on RRS and long-term fitness
Relationship to HSRG Recommendation: Investigated domestication fitness of first generation hatchery fish spawned in captivity compared to wild fish. Also looked at success of wild broodstock in hatchery compared to wild.

Study:
Christie, M. R., M. L. Marine, R. A. French, R. S. Waples, and M. S. Blouin. 2012b. Effective size of a wild salmonid population is greatly reduced by hatchery supplementation. Heredity 109(4):254-260.
Species: Steelhead
System: Hood River, OR
Major Finding: Showed that the effective number of breeders producing the hatchery fish (broodstock parents; N-b) was quite small (harmonic mean N-b = 25 fish per brood-year vs 373 for wild fish), and was exacerbated by a high variance in broodstock reproductive success among individuals within years. Decreased allelic richness, increased average relatedness, more loci in linkage disequilibrium and substantial levels of genetic drift in comparison with their wild-born counterparts. Also documented a substantial Ryman-Laikre effect whereby the additional hatchery fish doubled the total number of adult fish on the spawning grounds each year, but cut the effective population size of the total population (wild and hatchery fish combined) by nearly two-thirds. Ryman-Laikre effect is most severe in this population when (1) > 10% of fish allowed onto spawning grounds are from hatcheries and (2) the hatchery fish have high reproductive success in the wild.
HSRG Recommendation Number: 15, Research on RRS and long-term fitness
Relationship to HSRG Recommendation: Found low N_b and high variance in RS, Ryman Laikre effect most severe when >10% of fish are on spawning ground and hatchery fish have high RRS in the wild.

Study:

Dittman, A. H., D. May, D. A. Larsen, M. L. Moser, M. Johnston, and D. Fast. 2010. Homing and spawning site selection by supplemented hatchery- and natural-origin Yakima River Spring Chinook Salmon. Transactions of the American Fisheries Society 139(4):1014-1028.

Species: Spring Chinook

System: Yakima River, WA

Major Finding: Examined the homing patterns of supplemented spring Chinook salmon released from satellite acclimation facilities after common initial rearing at a central facility. Final spawning location depended strongly on where fish were released as smolts within the upper Yakima River basin, but many fish also spawned in the vicinity of the central rearing hatchery, suggesting that some fish imprinted to this site. While homing was clearly evident, the majority (55.1%) of the hatchery fish were recovered more than 25 km from their release sites, often in spawning areas used by wild conspecifics.

HSRG Recommendation Number: 13, Maximize survival of hatchery fish, release at appropriate time and size

Relationship to HSRG Recommendation: Results suggest that genetics, environmental and social factors, or requirements for specific spawning habitat may ultimately override the instinct to home to the site of rearing or release.

Study:

Ford, M., A. Murdoch, and S. Howard. 2012. Early male maturity explains a negative correlation in reproductive success between hatchery-spawned salmon and their naturally spawning progeny. Conservation Letters 5:450–458.

Species: Spring Chinook

System: Wenatchee River, WA

Major Finding: Evaluated a large three-generation pedigree of an artificially supplemented salmon population and found that the fish with the highest reproductive success in captivity produce early maturing male offspring that have lower than average reproductive success in the wild.

HSRG Recommendation Number: 15, Research on RRS and long-term fitness

Relationship to HSRG Recommendation: Individuals with highest RRS produce early maturing males with low RRS. Chilcote et al. 2011 found negative fitness interaction in both sexes in steelhead; difference may be attributed to life history diversity in Chinook relative to steelhead.

Study:

Gow, J. L., P. Tamkee, J. Heggenes, G. A. Wilson, and E. B. Taylor. 2011. Little impact of hatchery supplementation that uses native broodstock on the genetic structure and diversity of steelhead trout revealed by a large-scale spatio-temporal microsatellite survey. Evolutionary Applications 4(6):763-782.

Species: Steelhead

System: British Columbia

Major Finding: Evaluated the effects of stocking with native genotypes from a native steelhead trout broodstock hatchery over a period of 58 years. No changes were detected in estimates of effective population size, genetic variation or temporal genetic structure within any population, nor of altered genetic structure among them. Genetic interactions with non-migratory O. mykiss, the use of substantial numbers of primarily native broodstock with an approximate 1:1 male-to-female ratio, and/or poor survival and reproductive success of hatchery fish may have minimized potential genetic changes.

HSRG Recommendation Number: 15, Research on RRS and long-term fitness

Relationship to HSRG Recommendation: The use of only native broodstock and large effective size (1:1 male to female ratio) combined with poor survival of hatchery fish may lessen hatchery effects.

Study:
Hankin, D. G., J. Fitzgibbons, and Y. M. Chen. 2009. Unnatural random mating policies select for younger age at maturity in hatchery Chinook salmon (Oncorhynchus tshawytscha) populations. Canadian Journal of Fisheries and Aquatic Sciences 66(9):1505-1521.
Species: Chinook
System: NA (modeling study)
Major Finding: Explored the long-term consequences of three mating regimes on age and sex structure of wild and hatchery populations of Chinook salmon: 1) completely random, 2) completely random but excluding jacks (age-2 males), and 3) male length greater than or equal to female parent length. In unexploited populations, regime 1 leads to substantial long-term selection for younger age at maturity, an effect that is somewhat reduced by regime 2, but greatly reduced under regime 3. Equilibrium age and sex structures for wild and hatchery populations under regime 3 are similar to those of natural populations, whereas mating regime 1 generates age structure that is greatly shifted toward younger ages and jacks.
HSRG Recommendation Number: 13, Maximize survival of hatchery fish, release at appropriate time and size
Relationship to HSRG Recommendation: Comprehensive reviews of hatchery programs should be on-going to monitoring progress towards achieving expected benefits.

Study:
Hayes, M. C., R. R. Reisenbichler, S. P. Rubin, D. C. Drake, K. D. Stenberg, and S. F. Young. 2013. Effectiveness of an integrated hatchery program: can genetic-based performance differences between hatchery and wild Chinook salmon be avoided? Canadian Journal of Fisheries and Aquatic Sciences 70(2):147-158.
Species: Chinook
System: Warm Springs NFH, OR
Major Finding: The WW juveniles emigrated from the hatchery at two to three times the rate of HH fish in the fall (HW intermediate) and 35% more HH than WW adults returned (27% more HW than WW adults). Performance in the stream did not differ statistically between HH and WW fish, but outmigrants (38% WW, 30% HW, and 32% HH fish) during the first 39 days of the 16-month sampling period composed 74% of total outmigrants.
HSRG Recommendation Number: 15, Research on RRS and long-term fitness
Relationship to HSRG Recommendation: WW emigrated at 2-3X rate, but 27% more HH returned than WW. Selection against fall emigration may be domestication effect.

Study:
Hess, M. A., C. D. Rabe, J. L. Vogel, J. J. Stephenson, D. D. Nelson, and S. R. Narum. 2012. Supportive breeding boosts natural population abundance with minimal negative impacts on fitness of a wild population of Chinook salmon. Molecular Ecology 21(21):5236-5250.
Species: Chinook
System: Johnson Creek, ID
Major Finding: On average, fish taken into the hatchery produced 4.7 times more adult offspring, and 1.3 times more adult grand-offspring than naturally reproducing fish. Of the wild and hatchery fish that successfully reproduced, we found no significant differences in RS between any comparisons, but hatchery-reared males typically had lower RS values than wild males. Mean relative reproductive success (RRS) for hatchery F1 females and males was 1.11 (P=0.84) and 0.89 (P=0.56), respectively. RRS of hatchery-reared fish (H) that mated in the wild with either hatchery or wild-origin (W) fish was generally equivalent to WxW matings. Mean RRS of HxW and HxH matings was 1.07 (P=0.92) and 0.94

(P=0.95), respectively. We conclude that fish chosen for hatchery rearing did not have a detectable negative impact on the fitness of wild fish by mating with them for a single generation.
HSRG Recommendation Number: 13, Maximize survival of hatchery fish, release at appropriate time and size; 15, Research on RRS and long-term fitness
Relationship to HSRG Recommendation: Hatchery-reared males typically had lower RS values than wild males.

Study:
Knudsen, C. M., S. L. Schroder, C. Busack, M. V. Johnston, T. N. Pearsons, and C. R. Strom. 2008. Comparison of female reproductive traits and progeny of first-generation hatchery and wild upper Yakima River Spring Chinook Salmon. Transactions of the American Fisheries Society 137(5):1433-1445.
Species: Spring Chinook
System: Yakima River, WA
Major Finding: Hatchery and wild female Chinook salmon were compared to determine whether their reproductive traits had diverged after a single generation of artificial propagation. Hatchery spring Chinook salmon were significantly smaller than wild females over the four brood years examined. After brood year and body length (when necessary) were accounted for, wild females had an average of 8.8% more total gamete mass, 0.8% more individual egg mass, 7.7% greater fecundity, and 0.8% greater reproductive effort than hatchery females. Relative fecundity (the number of eggs per centimeter of body length) was on average 1.3% greater in hatchery females. The relationships between reproductive traits and body length were not significantly altered by a single generation of hatchery exposure. However, because hatchery females had smaller body sizes, the distributions of linked traits, such as total gamete mass and fecundity, differed by as much as 0.6 SD, probably resulting in sonic fitness loss. Data support that a single generation of state-of-the-art conservation hatchery propagation can produce fish with reproductive traits similar to those of wild fish, given comparable body size.
HSRG Recommendation Number: 15, Research on RRS and long-term fitness
Relationship to HSRG Recommendation: Data support that a single generation of state-of-the-art conservation hatchery propagation can produce fish with reproductive traits similar to those of wild fish, given comparable body size.

Study:
Larsen, D. A., B. R. Beckman, and K. A. Cooper. 2010. Examining the conflict between smolting and precocious male maturation in Spring (Stream-Type) Chinook Salmon. Transactions of the American Fisheries Society 139(2):564-578.
Species: Spring Chinook
System: Yakima River, WA
Major Finding: During spawning, precocious males employ a "sneaker'' strategy to fertilize eggs in competition with full-size anadromous adults. Hatchery rearing practices may increase the incidence of this phenotype beyond its natural levels. Previous research reported high rates (>40%) of precocious male maturation at age 2 (minijacks) in the Yakima River spring Chinook salmon supplementation program. This investigation examined the physiology of a unique phenotype in which smoltification and downstream migration appear to occur in fish that have already initiated the maturation process. These results suggest that hatchery programs with high minijack rates may produce significant numbers of fish that are maladapted for either smoltification or competing on the spawning grounds, and it is likely that they die in the freshwater environment before contributing to subsequent generations.
HSRG Recommendation Number: 13, Maximize survival of hatchery fish, release at appropriate time and size

Relationship to HSRG Recommendation: Fitness is lost due to premature maturation and production of minijacks.

Study:
Naish, K. A., T. R. Seamons, M. B. Dauer, L. Hauser, and T. P. Quinn. 2013. Relationship between effective population size, inbreeding and adult fitness-related traits in a steelhead (Oncorhynchus mykiss) population released in the wild. Molecular Ecology 22(5):1295-1309.
Species: Steelhead
System: Forks Creek, WA
Major Finding: Reconstructed the pedigree of 6,602 migratory hatchery steelhead over four generations, to determine the incidence and fitness consequences of inbreeding. The hatchery maintained an effective population size, Ne=107.9 from F0 to F2, despite an increasing census size (N), which resulted in a decreasing Ne/N ratio (0.35 in F0 to 0.08 in F2). The reduced ratio was attributed to a small broodstock size, nonrandom transfers and high variance in reproductive success (particularly in males). We observed accumulation of inbreeding from the founder generation (in F4, percentage individuals with inbreeding coefficients f>0=15.7%). Generalized linear mixed models showed that body length and weight decreased significantly with increasing f, and inbred fish returned later to spawn in a model that included father identity. However, there was no significant correlation between f and age at return, female fecundity or gonad weight. Similarly, there was no relationship between f and reproductive success of F2 and F3 individuals, which might be explained by the fact that reproductive success is partially controlled by hatchery mating protocols.
HSRG Recommendation Number: 15, Research on RRS and long-term fitness
Relationship to HSRG Recommendation: This study is one of the first to show that small changes in inbreeding coefficient can affect some fitness-related traits in a monitored population propagated and released to the wild.

Study:
Neely, K. G., J. M. Myers, and J. J. Hard. 2012. A Comparison of early development between a domesticated stock of coho salmon and its parental stock. Transactions of the American Fisheries Society 141(6):1504-1509.
Species: Coho
System: Domsea Farms vs. Wallace River (Skykomish), WA
Major Finding: Compared the rate of early development and yolk conversion efficiency in a domesticated stock of coho salmon that had been selected for improved growth to pan size (350 g) over 18 generations with that of its hatchery-origin unselected parental stock. Fish from both the domesticated stock and the parental stock were spawned and incubated under similar conditions. The domesticated fish produced significantly smaller eggs; comparisons of later embryonic growth rates show a clear distinction between the domesticated stock and parental stock, the domesticated stock exhibiting a growth rate significantly faster than that of parental stock for exogenous feeding.
HSRG Recommendation Number: 13, Maximize survival of hatchery fish, release at appropriate time and size
Relationship to HSRG Recommendation: Demonstration of growth rate differences in domesticated coho salmon stock.

Study:
Pearsons, T. N., C. L. Johnson, B. Ben James, and G. M. Temple. 2009. Abundance and distribution of precociously mature male Spring Chinook Salmon of hatchery and natural origin in the Yakima River. North American Journal of Fisheries Management 29(3):778-790.
Species: Chinook
System: Cle Elum, Yakima River, WA
Major Finding: Investigated the abundance and distribution of precociously mature male spring Chinook salmon of hatchery and natural (wild) origin during the spawning season (4-7 months after hatchery release). Precocious hatchery and wild males were both found throughout the spawning range during the spawning season, but significant differences in distribution between origins were detected. Precocious hatchery males were proportionately more abundant in the most downstream sampling reach and less abundant in a tributary with no hatchery facilities, In addition, most precocious hatchery males were found downstream of spawning areas during the spawning season. It appears that many precocious hatchery males migrate downstream from release and fail to migrate back to the spawning grounds, or they die within the Yakima River before spawning.
HSRG Recommendation Number: 13, Maximize survival of hatchery fish, release at appropriate time and size
Relationship to HSRG Recommendation: Precocious males from hatchery production do not contribute favorably to harvest and may pose ecological risks to other taxa; most have relatively low reproductive success.

Study:
Schroder, S. L., C. M. Knudsen, T. N. Pearsons, T. W. Kassler, S. F. Young, E. P. Beall, and D. E. Fast. 2010. Behavior and breeding success of wild and first-generation hatchery male Spring Chinook Salmon spawning in an artificial stream. Transactions of the American Fisheries Society 139(4):989-1003.
Species: Spring Chinook
System: Cle Elum, Yakima River, WA
Major Finding: Chinook were placed into an artificial stream to evaluate the effect of a single generation of hatchery culture on spawning behavior and reproductive success. The effects of body weight, spawning ground longevity, attack frequency, social dominance, courting frequency, and mate number on breeding success were evaluated. Male breeding success increased with body weight, while spawning ground longevity was negatively associated with breeding success. Body weight had a lesser effect on male breeding success than did social dominance. Males with high attack and courting frequencies produced the most progeny; of the traits examined, the number of female spawning partners explained the greatest amount of variation (average r(2) = 80%) in male breeding success. Wild males exhibited higher attack rates and greater social dominance than did hatchery males. However, the observed inequalities in agonism and dominance appeared to be largely caused by differences in body weight: wild males were, on average, 9% heavier than hatchery males. No differences were observed in the frequency of courting behaviors or in the number of mates. Hatchery and wild males had comparable breeding success values. Consequently, a single generation of hatchery exposure appeared to have a low effect on spring Chinook salmon male breeding success in our experimental setting.
HSRG Recommendation Number: 15, Research on RRS and long-term fitness
Relationship to HSRG Recommendation: A single generation of hatchery exposure appeared to have a low effect on male breeding success in an experimental setting.

Study:
Schroder, S. L., C. M. Knudsen, T. N. Pearsons, T. W. Kassler, E. P. Beall, S. F. Young, and D. E. Fast. 2012. Breeding success of four male life history types of spring Chinook Salmon spawning in an artificial stream. Environmental Biology of Fishes 94(1):231-248.
Species: Spring Chinook
System: Cle Elum, Yakima River, WA
Major Finding: Conditions at the hatchery increase abundance but also significantly elevated the occurrence of jacks and yearling precocious males. The potential genetic effect of early maturing males was examined in an artificial stream. Seven independent groups of fish were placed into the stream from 2001 through 2005. Males with four different life history strategies, large anadromous, jacks, yearling precocious, and sub-yearling precocious were used. Their breeding success or ability to produce offspring was estimated by performing DNA-based pedigree assessments. Large anadromous males spawned with the most females and produced the greatest number of offspring per mate. Jacks and yearling precocious males spawned with more females than sub-yearling precocious males. However, jacks, yearling and sub-yearling precocious males obtained similar numbers of fry per mate. In the test groups, large anadromous males produced 89%, jacks 3%, yearling precocious 7%, and sub-yearling precocious 1% of the fry.
HSRG Recommendation Number: 15, Research on RRS and long-term fitness
Relationship to HSRG Recommendation: Large anadromous males generate most of the fry in natural settings when compared to early maturing life history strategies.

Study:
Seamons, T. R., L. Hauser, K. A. Naish, and T. P. Quinn. 2012. Can interbreeding of wild and artificially propagated animals be prevented by using broodstock selected for a divergent life history? Evolutionary Applications 5(7):705-719.
Species: Steelhead
System: Forks Creek, WA
Major Finding: Study evaluated two broodstock management strategies: (i) integration of wild and captive populations and (ii) segregation of released individuals from the wild population. Study tested the efficacy of segregation by divergent life history where hatchery fish were selected to spawn months earlier than the 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 was hatchery/wild hybrids. Regression model selection analysis showed that the proportion of hatchery ancestry smolts was lower in years when stream discharge was high, suggesting a negative effect of flow on reproductive success of early-spawning hatchery fish.
HSRG Recommendation Number: 6, Select an integrated or segregated broodstock
Relationship to HSRG Recommendation: Divergent life history (spawning time) failed to prevent interbreeding between a segregated program of steelhead when physical isolation was ineffective.

Study:
Small, M. P., K. Currens, T. H. Johnson, A. E. Frye, and J. F. Von Bargen. 2009. Impacts of supplementation: genetic diversity in supplemented and unsupplemented populations of summer chum salmon (Oncorhynchus keta) in Puget Sound (Washington, USA). Canadian Journal of Fisheries and Aquatic Sciences 66(8):1216-1229.
Species: Chum
System: Hood Canal, WA
Major Finding: Study documents impacts of 5-10 years of supplementation on threatened summer-run chum salmon in Hood Canal (HC) and Strait of Juan de Fuca (SJF) in Washington State and compares

them genetically with un-supplemented summer- and fall-run chum salmon from HC and South Puget Sound. Genetic relationships followed a metapopulation pattern of isolation by distance, similar to patterns prior to supplementation. In most supplemented subpopulations, no effects on diversity and N(e) were detected, but high variance in individual pairwise relatedness values indicated over-representation of family groups. In two subpopulations, hatchery impacts (decreased diversity and lower N(e)) were confounded with extreme bottlenecks. Rebounds in census sizes in all subpopulations suggest that general survivorship has improved and that possible hatchery effects on genetic diversity will be overcome.
HSRG Recommendation Number: 15, Research on RRS and long-term fitness
Relationship to HSRG Recommendation: Census sizes increased with no decrease in genetic diversity in most, but not all, populations.

Study:
Smith, C. T., and R. Engle. 2011. Persistent reproductive isolation between sympatric lineages of Fall Chinook Salmon in White Salmon River, Washington. Transactions of the American Fisheries Society 140(3):699-715.
Species: Fall Chinook
System: White Salmon River, WA
Major Finding: Little White Salmon National Fish Hatchery has been releasing upriver "brights" (URBs) adjacent to what was historically exclusively tule spawning habitat in the White Salmon River for approximately 22 years. The two lineages migrate together through portions of the lower Columbia River but spawn allopatrically, but now spawn in sympatry in the White Salmon River. Assignment tests revealed that juveniles leaving the White Salmon River from March to early May resembled tules, while those leaving from late May to June resembled URBs. Model-based hybrid detection revealed that between 4.3% and 15.0% of the juveniles in each year were tule x URB hybrids. No hybrid adults were detected in any of the collections examined. Although hybrid juveniles are produced in the wild, we found no evidence that they survive to return as adults or successfully cross back into the parental populations. The separation between the two fall Chinook salmon lineages thus appears to be based on intrinsic as well as extrinsic factors.
HSRG Recommendation Number: 6, Select an integrated or segregated broodstock; 15, Research on RRS and long-term fitness
Relationship to HSRG Recommendation: Divergent life history failed to prevent interbreeding between a segregated program as evidenced by hybrid juveniles. However, separations of the two Chinook lineages appeared be maintained by intrinsic factors as no hybrid adults were detected.

Study:
Thériault, V., G. R. Moyer, L. S. Jackson, M. S. Blouin, and M. A. Banks. 2011. Reduced reproductive success of hatchery coho salmon in the wild: insights into most likely mechanisms. Molecular Ecology 20(9):1860-1869.
Species: Coho
System: Umpqua River, OR
Major Finding: 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. Study reports three lines of evidence pointing to the absence of sexual selection in the hatchery as a contributing mechanism for fitness declines of hatchery fish in the wild: (i) hatchery fish released as unfed fry that survived to adulthood still had low RS relative to wild fish, (ii) age-3 male hatchery fish consistently showed a lower relative RS than female hatchery fish (suggesting a role for sexual selection), and (iii) age-2 jacks, which use a sneaker mating strategy, did not

show the same declines as 3-year olds, which compete differently for females (again, implicating sexual selection).

HSRG Recommendation Number: 15, Research on RRS and long-term fitness

Relationship to HSRG Recommendation: Causal mechanism for lowered fitness is not associated only with the juvenile stage of the life cycle, but also involves some effect during the adult mating phase or during incubation of eggs or newly hatched fry since effect was seen in unfed fry releases.

Study:

Van Doornik, D. M., B. A. Berejikian, L. A. Campbell, and E. C. Volk. 2010. The effect of a supplementation program on the genetic and life history characteristics of an Oncorhynchus mykiss population. Canadian Journal of Fisheries and Aquatic Sciences 67(9):1449-1458.

Species: Steelhead

System: Hamma Hamma, WA

Major Finding: Study investigated the effect that the program has had on genetic diversity and effective population size and any changes to an important life history trait (residency or anadromy). Supplementation did not cause substantial changes in the genetic diversity or effective size of the population, most likely because a large proportion of all of the steelhead redds in the river each year were sampled to create the supplementation broodstock.

HSRG Recommendation Number: 13, Maximize survival of hatchery fish, release at appropriate time and size; 15, Research on RRS and long-term fitness

Relationship to HSRG Recommendation: Captively reared fish released as adults successfully produced parr, and there was an increase in the proportion of anadromous ancestry vs. resident ancestry.

Study:

Van Doornik, D. M., R. S. Waples, M. C. Baird, P. Moran, and E. A. Berntson. 2011. Genetic monitoring reveals genetic stability within and among threatened Chinook Salmon populations in the Salmon River, Idaho. North American Journal of Fisheries Management 31(1):96-105.

Species: Chinook

System: Salmon River, ID

Major Finding: Monitored nine populations of Chinook salmon to determine how the genetic characteristics within and among these populations have changed over time. Found no evidence of change in the level of heterozygosity or allelic richness over three to four generations in eight of the populations. This is probably due to the fact that the populations all maintained a sufficiently large effective size, even though a few of the populations did show a decline in effective size. Also, the genetic structure among the populations did not change appreciably over time.

HSRG Recommendation Number: 13, Maximize survival of hatchery fish, release at appropriate time and size; 15, Research on RRS and long-term fitness

Relationship to HSRG Recommendation: No changes in diversity or structure over eight generations in most populations; attributed to sufficiently large effective size.

Study:

Williamson, K. S., A. R. Murdoch, T. N. Pearsons, E. J. Ward, and M. J. Ford. 2010. Factors influencing the relative fitness of hatchery and wild spring Chinook salmon (Oncorhynchus tshawytscha) in the Wenatchee River, Washington, USA. Canadian Journal of Fisheries and Aquatic Sciences 67(11):1840-1851.

Species: Spring Chinook

System: Wenatchee River, WA

Major Finding: Used a DNA-based parentage analysis to measure the relative reproductive success of hatchery- and natural-origin in the natural environment. Size and age had a large influence on male fitness, with larger and older males producing more offspring than smaller or younger individuals. Size had a significant effect on female fitness, but the effect was smaller than on male fitness. For both sexes, run time had a smaller but still significant effect on fitness, with earlier returning fish favored. Spawning location within the river had a significant effect on fitness for both sexes. Hatchery-origin fish produced about half the juvenile progeny per parent when spawning naturally than did natural-origin fish. Hatchery fish tended to be younger and returned to lower areas of the watershed than wild fish, which explained some of their lower fitness.
HSRG Recommendation Number: 15, Research on RRS and long-term fitness
Relationship to HSRG Recommendation: Hatchery fish tended to be younger and returned to lower areas of the watershed than wild fish, which explained some of their lower fitness and relative reproductive success.

On the Science of Hatcheries

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