HATCHERY SCIENTIFIC REVIEW GROUP

Puget Sound and Coastal Washington Hatchery Reform Project

HATCHERY REFORM

Principles and Recommendations of the Hatchery Scientific Review Group

April 2004

Please cite as:

Hatchery Scientific Review Group (HSRG)–Lars Mobrand (chair), John Barr, Lee Blankenship, Don Campton, Trevor Evelyn, Tom Flagg, Conrad Mahnken, Robert Piper, Paul Seidel, Lisa Seeb and Bill Smoker. April 2004. *Hatchery Reform: Principles and Recommendations of the HSRG*. Long Live the Kings, 1305 Fourth Avenue, Suite 810, Seattle, WA 98101 (available from www.hatcheryreform.org). Cite in text as *HSRG 2004*.

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**The three volumes that constitute Appendix I are available online at www.hatcheryreform.org or by contacting Long Live the Kings at lltk@lltk.org or 206-382-9555 ext 21.*

Introduction

BACKGROUND

In 1999, in response to a request from Washington state's Congressional representatives, a group of leading scientists presented its recommendations to the US Congress in a report entitled The Reform of Salmon and Steelhead Hatcheries in Puget Sound and Coastal Washington to Recover Natural Stocks While Providing Fisheries. The report determined that the potential exists for hatcheries to provide benefits to the recovery of naturally spawning salmon. The report called for a comprehensive hatchery reform effort to conserve indigenous genetic resources; assist with the recovery of naturally spawning populations; provide for sustainable fisheries; conduct scientific research; and improve the quality and cost-effectiveness of hatchery programs. The effort was to be led by an independent panel of scientists called the Hatchery Scientific Review Group (HSRG).

Congress adopted and funded these recommendations in fiscal year 2000, launching the Puget Sound and Coastal Washington Hatchery Reform Project, also known simply as the "Hatchery Reform Project." This project has taken a systematic, science-driven approach to evaluating hatcheries and providing recommendations for how hatcheries can be used to help:

1. conserve naturally spawning salmon and steelhead populations; and
2. support sustainable fisheries.

The appropriations language provided funding to:

- Establish an independent scientific panel to ensure a scientific foundation for hatchery reform;
- Provide a competitive grant program for needed research on hatchery impacts;
- Support state and tribal efforts to implement new hatchery reforms; and
- Provide for the facilitation of a reform strategy by an independent third party.

The role of independent science in the Hatchery Reform Project is to advise fishery managers, agency scientists, legislators, and the public about the benefits and risks of alternative actions that could be undertaken to meet goals for salmonid resources, including the consequences of inaction. This report results from the HSRG's four-year evaluation of the Puget Sound and coastal Washington hatchery system, from 2000-03 and documents their products, processes, recommendations and conclusions.

THE NEED FOR REFORM

There are approximately 100 hatchery facilities in Puget Sound and coastal Washington operated by the Washington State Department of Fish and Wildlife (WDFW), Puget Sound and coastal Indian tribes and nations, and the US Fish and Wildlife Service (USFWS). Some of these hatcheries have been operating for nearly 100 years. Most hatcheries were built to produce fish for harvest, compensating for declines in naturally spawning salmon populations. Funding for these hatchery programs comes from a variety of sources, including federal, state, tribal, local and private sources.

Hatcheries now provide over 80% of Washington's resident trout, over 90% of the inland catch of resident salmonids, 70% of the salmon harvested in Puget Sound, approximately 75% of all coho and Chinook harvested, and 96% of all steelhead harvested state-wide. In 1995, 157 million salmon and 8.9 million steelhead were released into Washington's waters. In the Hood Canal and Puget Sound areas, more than 88 million Chinook, chum, coho, sockeye and pink salmon and steelhead trout were released. Washington gets an annual direct benefit of over $850 million from recreational fishing (which ranks eighth nationally).[1]

Hatcheries also play an important role in meeting tribal treaty harvest obligations. Federal court rulings have affirmed tribal treaty harvest rights and established the tribes as co-managers of the salmon resource. State and federal governments must ensure that there are salmon available for the tribes to harvest. As naturally-spawning salmon stocks declined over the years, the tribal, state and federal governments became dependent on hatcheries to provide a meaningful level of harvest for Indian and non-Indian fishers.

Although hatcheries have generally been successful at providing fish for harvest, societal goals, priorities and circumstances have changed during the 100 years in which hatcheries have been in operation, particularly in the past 30 years. For example:

1. Artificial production programs must be consistent with the sometimes conflicting objectives of various legal mandates relating to fish production and protection throughout Puget Sound and coastal Washington. Resolving these potential conflicts requires legal, policy, and biological judgment. These legal mandates include:

    - Treaty fishing rights of Indian tribes under US v. Washington and Hoh v. Baldridge and the development of a co-management relationship between the state and the tribes;
    - The US/Canada Salmon Treaty;
    - The responsibility of the State of Washington to preserve, protect and enhance fish populations;

[1] *Washington State Hatcheries (brochure); Washington Department of Fish and Wildlife September 1997 Final Environmental Impact Statement for the Wild Salmonid Policy; John Kerwin; Washington Department of Fish and Wildlife, 600 Capitol Way North, Olympia, WA 98501.*

- The U.S. Endangered Species Act (ESA); Numerous mitigation obligations in law and agreement.

2. As better and more complete scientific information has become available, a more complex picture has emerged about the interdependency of natural ecosystems and their respective components. Hatchery production and facilities, including the harvest of hatchery-propagated fish, have been identified as one of the factors contributing to the overall decline of naturally-spawning populations.

3. Population growth and resulting human land use activities have resulted in a continued loss of habitat and a decline of naturally spawning salmon. This has led to different management goals and objectives, including conservation goals.

4. Three Puget Sound stocks are currently listed under the ESA. As part of a larger recovery process, state, tribal and federal managers of Washington's salmon and steelhead must ensure that their hatcheries do not present a risk to listed species.

5. A major change is currently taking place in the economics of fisheries. Aquaculture, including salmon farming, is growing rapidly and competing with commercial fishing in many markets.

Within this context, the Hatchery Reform Project was developed as a cooperative effort to reform a decades-old hatchery system, to meet new purposes. The intent was to let science direct the process of ensuring today's hatchery system matches current circumstances and goals.

PROJECT OVERVIEW

The elements of the Hatchery Reform Project include a unique combination of independent science, coordination by managers, political support, and third-party facilitation. These components are described below.

Independent Science: The Hatchery Scientific Review Group

The Hatchery Scientific Review Group is the scientific panel established and funded by Congress to independently review hatchery programs in Puget Sound and coastal Washington. The objective of the HSRG is to assemble, organize and apply the best available scientific information available to provide guidance and recommendations to the policy makers and technical staff who are responsible for implementing hatchery reforms.

The HSRG is composed of five independent scientists (selected from a pool of candidates nominated by the American Fisheries Society) and four agency scientists designated by WDFW, the Northwest Indian Fisheries Commission (NWIFC), National Oceanic and Atmospheric Administration Fisheries/National Marine Fisheries Service (NOAA Fisheries) and USFWS. Like the independent scientists, the agency scientists are responsible for evaluating scientific merits and are not to represent agency policies. The nine scientists serving on the HSRG have a broad range of experience and expertise, including salmon biology, genetics, ecology, fisheries, fish culture, fish pathology and biometrics. Members have included:

- John Barr, NWIFC (Vice Chair)
- Lee Blankenship, Northwest Marine Technology (Vice Chair)
- Donald Campton, PhD, USFWS
- Trevor Evelyn, PhD, retired, Department of Fisheries and Oceans Canada
- Tom Flagg, NOAA Fisheries Manchester
- Conrad Mahnken, PhD, retired, NOAA Fisheries Manchester
- Lars Mobrand, PhD, Mobrand Biometrics (Chair)
- Robert Piper, retired, USFWS
- Lisa Seeb, PhD, Alaska Department of Fish and Game
- Paul Seidel, WDFW
- William Smoker, PhD, University of Alaska

Policy-Level Involvement: The Hatchery Reform Coordinating Committee

The managers have established a Hatchery Reform Coordinating Committee (Coordinating Committee) as a vehicle for cooperative management and implementation of this reform effort. The purpose of the committee is to ensure a successful working relationship between the HSRG, the managers' decision-makers and their own hatchery reform science teams, and other staff. The Coordinating Committee's immediate adoption of the project's twin goals was an important early sign of leadership, their commitment to the process, and the role of the HSRG. The establishment of the Coordinating Committee also served to recognize the co-manager relationship and the responsibility of the managers to develop policy and ultimately implement hatchery reform.

Committee members include:

- Billy Frank Jr., Chairman/Spokesman, NWIFC
- Jim Anderson, Executive Director, NWIFC
- David Troutt, Natural Resources Director, Nisqually Tribe
- Terry Williams, Commissioner of Fisheries and Natural Resources, The Tulalip Tribes
- Jeff Koenings, Director, WDFW

- Larry Peck, Deputy Director, WDFW
- Dan Diggs, Assistant Regional Fisheries Director, USFWS
- Chuck Dunn, USFWS
- David Stout, Manager for Fisheries and Watershed Assessment, USFWS Division
- Bob Lohn, Regional Administrator, NOAA Fisheries
- Rob Jones, Hatchery and Inland Programs Branch Chief, NOAA Fisheries
- Pete Bergman, former member of the Congressional Hatchery Science Advisory Team
- Frank Haw, former member of the Congressional Hatchery Science Advisory Team
- Terry Wright, NWIFC and former member of the Congressional Hatchery Science Advisory Team
- Barbara Cairns, Executive Director, Long Live the Kings

Support from Elected and Appointed Officials

Many factors have come together to create this opportunity to reform hatchery practices and improve the contribution from hatcheries to salmon conservation and sustainable fisheries. As mentioned above, an important factor has been the support of strong and creative leaders at the fisheries management agencies. Just as important has been the backing of federal, state, tribal and local elected officials. The project has received bipartisan support from many regional leaders, including:

- US Representative Norm Dicks (D-WA)
- Washington Governor Gary Locke (D)
- US Senator Patty Murray (D-WA)
- Former US Senator Slade Gorton (R-WA)
- US Representative Jennifer Dunn (R-WA)
- Billy Frank, Jr., Chair, NWIFC
- Jeff Koenings, Director, WDFW
- William Ruckelshaus, Chair, Washington State Salmon Recovery Funding Board

Agency Science Teams

A portion of the Congressional funding dedicated to supporting state and tribal efforts to implement new hatchery reforms has been used to establish agency science teams. These teams have undertaken a variety of activities that support the hatchery reform process. One of these has been helping the facilitation team (see below) acquire, assemble and make available to the HSRG regional briefing information about the hatcheries, individual hatchery programs and the ecosystems in which they operate. This ensured that the HSRG made its evaluations and recommendations based on the same data the co-managers use to establish their goals and operate programs.

Other valuable functions being provided by the agency science teams include conducting risk analyses on hatchery programs to meet hatchery ESA requirements; conducting and overseeing agency research on hatchery effects and practices that complements the HSRG's research grant program (see below); coordinating the implementation of early reforms; reporting agency activities for Congressional reports; acting as points of contacts for the project within the agencies; interpreting technical literature for hatchery managers; and otherwise providing technical support to the HSRG, the Coordinating Committee, and the regional staff that are participating in the review process.

Project Management, Facilitation and Communications

The third party facilitator for the project, specified by Congress, is Long Live the Kings (LLTK), a private, non-profit organization whose mission is to restore wild salmon to the waters of the Pacific Northwest. LLTK's role includes providing facilitation and project management to the HSRG and the Coordinating Committee; and helping the managers communicate hatchery reform progress to Congress, state legislators, stakeholder groups and the public. LLTK retained Gordon, Thomas, Honeywell to serve with LLTK staff on the facilitation team. The HSRG and LLTK are responsible for annual reporting to Congress on progress made in implementing hatchery reforms. The Regional Hatchery Review chapter describes the role of the facilitation team's project management, facilitation and communications efforts in more detail.

REPORT OVERVIEW

This report provides a detailed description of the HSRG's scientific framework, tools and resources developed for evaluating hatchery programs, the processes used to apply these tools, and the resulting, principles, system-wide recommendations, and program-specific recommendation for reform. It also includes conclusions about the future of hatcheries and a summary of successful hatchery programs.

Foundation for Hatchery Reform

At the beginning of the project, the HSRG recognized that their review process would set a new standard for considering under what circumstances hatcheries can help achieve salmon and steelhead resource goals. Under this new model, productive, available habitat is essential to an effective hatchery program. In addition, managers have to consider whether a hatchery program is the best means to help achieve the stated resource goal, once the risks and benefits from the program are considered. To accomplish this level of evaluation, the HSRG recognized the need for a scientific foundation for its work and tools and resources to conduct an evaluation of the Puget Sound and coastal hatchery system.

Scientific Framework

That scientific foundation was developed in the project's first year from a collation and review of the scientific literature, and by reviewing current analytical tools and operational protocols, and decision making processes used by the state, tribal and federal fisheries managers and scientists. The resulting *Scientific Framework for the Artificial Propagation of Salmon and Steelhead* [2] underlies and informs all of the HSRG's tools, processes and recommendations.

The scientific framework organizes the current state of knowledge, about how actions associated with hatcheries affect the environment and fishery resources, around six key topics:

1. Hatchery Programs: Definitions of Purpose and Type
2. Hatcheries in the Ecosystem Context: The Regional Approach;
3. Hatcheries in the Populations/Species Context;
4. Effects of Hatchery Operations on Harvest and Conservation of the Target Stock; and
5. Effects of Hatchery Fish on Harvest and Conservation of Other Stocks and Species.
6. Monitoring and Evaluation: Managing Hatchery Programs for Accountability and Success

Emerging Issues in Hatchery Reform

These papers are authored by individual HSRG members, task teams or the HSRG as a whole. They are as simple as a few paragraphs or as detailed as an article for a peer-reviewed journal. They represent some of the emerging topics concerning the role and operations of hatcheries in conserving natural populations and supporting fisheries and are intended to serve as an extension of the scientific framework and encourage new thinking and actions in applied science for hatchery management.[3]

Research Grant Program

The HSRG's competitive grant program has funded over two million dollars in projects. These projects are helping to answer questions such as how to reduce the impact of harvest on naturally-spawning fish, avoid adverse genetic effects of hatchery fish on naturally-spawning stocks, avoid adverse ecological interactions, improve hatchery practices, and monitor and measure success. The need for answers to these questions became apparent in the first year of the project as the HSRG drafted a scientific framework to guide the region-by-region review

[2] *See summary in the Foundation of Hatchery Reform chapter and the full framework in Appendix A.*
[3] *See summary in Foundation of Hatchery Reform chapter and Appendix B.*

process (discussed below). Grantees have reported their findings to the HSRG and other scientists at annual research review meetings, and the results have often answered questions and further identified or validated a wide range of research needs for hatcheries. This section of the report provides a description of the research program and a table summarizing each funded research project.[4]

Applied Hatchery Reform

From 2001–03, the HSRG used the tools described previously to systematically review all hatchery programs in Puget Sound and the Washington coast. As a result of this experience, the HSRG produced 3 principles, 18 system-wide recommendations, and over 1000 program-specific recommendations. Success of the hatchery reform effort, will ultimately be measured by effective and on-going implementation of these principles and recommendations by the state, tribal and federal managers in there effort to reform hatcheries toward the twin goals.

Regional Review Process

Early in the process, the HSRG and Coordinating Committee agreed that hatchery programs must be evaluated in the context of (a) the watersheds in which they operate and (b) the goals set for them by the managers for each stock in the watershed. To accomplish this level of evaluation, the scientists and managers worked together to divide Puget Sound and the coast into ten regions. This approach provided an opportunity to make region-by-region recommendations based on: 1) regional management goals for conservation, harvest and other purposes; 2) the status of each stock within a region (biological significance and population viability); 3) the status of the habitat that supports each stock (current and future); and 4) the operational details of each hatchery program.

The HSRG used the scientific framework to develop a series of tools for use in the regional review process and for the managers to use into the future. These included operational guidelines, a benefit/risk tool, and monitoring and evaluation criteria.

For each regional review, the HSRG toured the hatchery facilities, conducted interviews with operators and managers, considered stock and habitat information provided by the managers, applied this information to the benefit/risk tool, met with the managers to discuss the findings, and then produced specific recommendations for reducing the risks and maximizing benefits from each program. This chapter summarizes the review process and the role of the facilitation team.

[4] *See Appendix H for details of each grant by year.*

Principles and System-Wide Recommendations

In order to provide a complete picture of what was needed to achieve hatchery reform, the HSRG concluded that both program-specific recommendations within the context of the goals set by the managers and system-wide recommendations for hatcheries generally that allowed for regional differences were needed. The 18 system-wide recommendations were developed as a direct result of the HSRG's experience in the applying the tools in a regional context. The HSRG has organized these system-wide recommendations under three basic principles of good natural resource management. These principles in the context of hatcheries are: well-defined goals, scientifically defensible programs, and informed decision making.

In order to achieve reform, whereby the hatchery system is a functioning part of an integrated strategy to achieve recovery of naturally spawning populations and provide sustainable fisheries, the HSRG has concluded that these principles and system-wide recommendations must set the standard for successful implementation of hatchery reform. This chapter outlines each principle and system-wide recommendation.

Program-Specific Recommendations by Region

In each of the regions reviewed, the HSRG found significant differences in the quality of the habitat, stock status, the goals the managers have prescribed for each region's salmon and steelhead stocks, and the purposes of each region's hatchery programs. The HSRG's regional review process produced roughly 1,000 program-specific recommendations addressing these specific circumstances. Recommendations ranged from changes in broodstock management, to addressing water quality concerns, to removal of fish passage impediments, and many others. Some program-specific recommendations referenced system-wide recommendations; others were unique to the program.

After each year of reviews, a report was published containing recommendations for each hatchery program reviewed that year. The results of this three year regional review process are summarized in Chapter 3. The program-specific recommendations for each region are available as appendices to this document in three companion volumes.[5]

Conclusions

Because of its Congressional mandate, the Hatchery Scientific Review Group (HSRG) has had a unique opportunity over the last four years to intensively study all aspects of salmon and steelhead hatchery management in Puget Sound and coastal Washington. As a result, the HSRG has formulated a number of conclusions about hatcheries and how they should be operated. This chapter outlines these conclusions and gives examples of successful hatchery programs.

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5 *See Appendix I, Program-Specific Recommendations by Region.*

NEXT STEPS

Through four years of creating a scientific framework, tools and recommendations under the Hatchery Reform Project, the HSRG has outlined new ways to apply science to hatchery management. Recognizing this, the managers of Washington's fish resources have asked the HSRG to stay empanelled beyond the recommendations phase, as the manager's design mechanisms for implementation, monitoring and evaluation, and feedback loops that ensure that new information leads to continuing improvements in decision making, policy and operations.

The HSRG and the managers have agreed that achieving the implementation of hatchery reform must be viewed in the long-term. This approach is necessary because hatchery reform should be an on-going process that continues to change as new information is gained. Additionally, it will take time to secure funding to implement all of the elements of hatchery reform. There is also agreement that implementation of many important elements of hatchery reform can take place in the short-term as well. The manager's efforts to develop an implementation database to track longer term trends and results is critical to successful hatchery reform.

For 2004, the HSRG, the managers, and the facilitation team have developed a work plan to:

- ensure an exchange of knowledge, information and ideas between the HSRG and state, tribal, and federal managers in the hatchery, harvest and science divisions;
- track and communicate implementation progress and significant scientific findings from the project.
- develop a long-term monitoring and evaluation strategy;
- provide facilitated co-manager discussions that address unresolved regional implementation issues;
- hold follow-up workshops in all 10 regions with case studies for how the regional hatchery managers can use the principles, recommendations and tools to continue reviewing hatchery programs in the context of regional goals into the future; and
- encourage further research that addresses significant uncertainties about the uses of hatcheries.

The result of this work plan are intended not only ensure successful implementation of the HSRG's recommendations for Puget Sound and the coast, but should also provide a working model that can be replicated elsewhere in the Pacific Northwest.

Additionally, the Washington state Governor's Office, the Shared Strategy for Salmon Recovery in Puget Sound, and others are relying on the Hatchery Reform Project's results for direction on how hatchery reform can be integrated with habitat recovery at the watershed level. This watershed approach is an essential piece of the recovery plans that those parties have pledged to provide NOAA Fisheries for Puget Sound Chinook salmon, listed as threatened under the ESA in 1999.

It is important to note that the tools and recommendations contained in this document are based upon current goals and the best scientific information available at the time the reviews were conducted. In keeping with the tenets of adaptive management,[6] it will be necessary to review and adapt these tools and recommendations as new scientific information arises and/or goals change.

This and all other Hatchery Reform Project-related publications are available from the project's web site (www.hatcheryreform.org) or by contacting Long Live the Kings at (206) 382-9555.

6 See HSRG System-Wide Recommendation on adaptive management.

Foundation for Hatchery Reform

Early in the project's first year (2000), the Hatchery Scientific Review Group (HSRG) agreed that hatchery programs should no longer be seen as surrogates for lost habitat. Instead, hatchery programs must be viewed as tools that can be managed as part of an integrated strategy to meet watershed or regional resource goals, in concert with actions affecting habitat, harvest rates, water allocation and other factors. Using the best available science, and having considered the benefits and risks to all stocks that will result, a hatchery program should be conducted only if it is deemed the best available tool for achieving those goals.

To scientifically evaluate the hatcheries in Puget Sound and the coast in this new context, the scientists recognized the need for a scientific foundation for their work, a method for updating this foundation, and tools and resources for conducting and evaluation of the Puget Sound and coastal hatchery system. This chapter summarizes the *Scientific Framework for the Artificial Propagation of Salmon and Steelhead*, the emerging issues papers, and the HSRG's research program. The complete framework, all the emerging issues papers, details of funded grants, and the tools used in the regional review process are found in the appendices.

SCIENTIFIC FRAMEWORK

The scientific framework was first published in December 2000, after review by over 200 scientists and stakeholders, and before the rest of the review tools were developed and the regional review process began. The framework was periodically updated throughout the review process to include new information as it became available. Over the last year, this framework was reorganized in order to better serve as a blueprint for achieving scientifically defensible hatchery programs (Principle 2).[7]

The scientific framework forms the basis for all of the HSRG's tools, processes and recommendations and organizes the current state of knowledge, about how actions associated with hatcheries affect the environment and fishery resources, around six key topics:

1. Hatchery Programs: Definitions of Purpose and Type;
2. Hatcheries in the Ecosystem Context: The Regional Approach;
3. Hatcheries in the Populations/Species Context;
4. Effects of Hatchery Operations on Harvest and Conservation of the Target Stock;
5. Effects of Hatchery Fish on Harvest and Conservation of Other Stocks and Species; and
6. Monitoring and Evaluation: Managing Hatchery Programs for Accountability and Success.

[7] *See Applied Hatchery Reform chapter, Principles and System-wide Recommendations section.*

1. Purpose and Type

The HSRG has concluded that each hatchery program must explicitly define its strategies in terms of: a) the purpose or desired benefits to be derived from the program; and b) the type of program desired, relative to the genetic management goals for the broodstock and naturally spawning populations. These purposes and types provide the starting point for evaluating the benefits and risks of a specific hatchery program. Each hatchery program must first define its goals in terms of purpose and type before subsequent program components can be developed or evaluated.

The HSRG recognizes two primary purposes or potential benefits of hatchery programs: 1) help conserve naturally spawning populations, and 2) provide fish for harvest. Many hatchery programs are designed to provide both harvest and conservation benefits. Other purposes of hatchery programs include scientific research, education, and providing cultural benefits, particularly for American Indian tribes.

Hatchery programs for Pacific salmon and steelhead can be classified as either “integrated” or “segregated” based on the genetic management goals and protocols for propagating a hatchery broodstock. Hatchery programs are classified as genetically *integrated* if a principal goal is to minimize potential genetic divergence between the hatchery broodstock and a naturally-spawning population such that natural-origin fish are systematically included in the broodstock each year or generation. Hatchery programs are classified as genetically *segregated* if the broodstock is propagated as a reproductively distinct population primarily, if not exclusively, from adult returns back to the hatchery. In segregated programs, little or no gene flow should occur from a naturally spawning population to the hatchery broodstock.

In the context of managing salmon and steelhead hatcheries, all programs need to identify their broodstocks goal as either genetically integrated or segregated relative to naturally spawning populations. The choice of broodstock goal defines operational guidelines by which each hatchery programs can be evaluated. Successful hatchery programs must conform closely to the guidelines specified by a properly integrated or properly segregated program; no individual hatchery program can be both or intermediate without imposing significant genetic risks to naturally spawning populations.

2. Hatchery Programs in the Ecosystem Context: The Regional Approach

Hatcheries can no longer be regarded as surrogates for lost habitat. In operating hatcheries, consideration must be given not only to the receiving habitat in which they operate but also to the naturally-spawning and hatchery-propagated fish that depend on the existing habitat. In addition, hatcheries must take into account the programs of other hatcheries occurring in the same watershed or region. Only in this way will adverse interactions between salmonid stocks in the watershed or region be minimized.

This chapter outlines how to review hatchery programs in Puget Sound and coastal Washington using a regional approach, taking into account the nature of the watersheds in which the programs occur and the goals for naturally spawning populations and the individual programs set by the regional managers. Each watershed or region differs significantly in the quality and quantity of habitat, the status of its salmonid stocks, the goals set for each stock by the managers, and the purposes of the region's hatchery programs.

3. Hatchery Programs in the Species/Population Context

Hatchery populations of salmonids are subject to many of the same biological processes as their naturally-spawning counterparts. This chapter outlines how these biological processes shape the biological significance and viability of both hatchery and naturally-spawning populations. Assessment of the biological significance and viability of salmonid populations provides an important benchmark for developing both long- and short-term goals and management strategies for a particular population or stock. In the case of integrated hatchery programs, where the management strategy is to maintain hatchery broodstocks as similar as possible genetically to naturally-spawning populations, the combined population (hatchery + wild) shares similar characteristics for biological significance and viability. In the case of segregated hatchery programs, the biological significance is based solely on the composition of the hatchery population, and the viability is linked to the performance of a "hatchery stock" in both the hatchery and natural environments.

4. Effects of Hatchery Operations on Harvest and Conservation of the Propagated Stock

Hatchery operations including broodstock choice and collection, spawning, incubation and rearing protocols as well as the hatchery environment in which fish are reared can affect the short and long-term survival and behavior of the stock that is the target of hatchery propagation. These operations can affect the achievement of harvest goals as well as the goals for biological significance and viability of the target stock. This is true whether the target stock represents only the hatchery stock as in segregated programs or represents a component of the natural stock, as in integrated programs. This chapter describes how hatchery operations can have both long-term genetic effects and short-term, non-genetic effects on the target population.

5. Effects of Hatchery Fish on Harvest and Conservation of Other Stocks and Species

Depending on the number, size, location and other release factors, hatchery fish may directly or indirectly affect other stocks and species through genetic or ecological interactions. The presence of hatchery fish may also alter fishing patterns and thereby affect harvest rates on naturally produced stocks. This chapter describes these potential effects and identifies management actions that can help alleviate adverse impacts.

6. Monitoring and Evaluation: Managing Hatchery Programs for Accountability and Success

Today's salmon and steelhead hatcheries are called upon to help meet conservation, harvest, and/or other goals (e.g., education, research, cultural and ceremonial needs, and indicator stocks), while minimizing adverse impacts on natural-origin salmonids within the watersheds or regions in which they operate. To be successful at meeting these goals, accountability for decisions and actions is required at all levels within the agencies responsible for management and operation of hatcheries. Success will also require an accurate and timely management information system that can measure benefits, evaluate actions, and provide information for hatchery management and operations. This chapter outlines a monitoring and evaluation approach to help ensure accountability and success of hatchery programs.

EMERGING ISSUES IN HATCHERY REFORM

The HSRG—recognizing that the scientific framework needs to be a "living document" that is regularly updated to include new information and issues not identified in its original drafting—decided that significant revisions to the scientific framework should be derived – not just from new published scientific literature – but also from "emerging issue" papers authored by the HSRG or its individuals members. These papers can be as simple as a few paragraphs or as detailed as an essay for a peer-reviewed journal. They are presented collectively in Appendix B under the title Emerging Issues in Hatchery Reform. The HSRG welcomes feedback on these "emerging issues." They are incorporated into the framework once they have been reviewed and refined. Several that have been incorporated to date remain in this chapter as well, to highlight their importance.

These emerging issues papers also relate to two other key elements of the Hatchery Reform Project. They are tied to the hatchery reform research program[8] because they discuss topics that reflect recently available scientific information or an emerging principle derived from the collation of old and new information. In addition, they are tied to the three principles of hatchery reform[9] because developing scientific knowledge in these areas will support hatchery operation and management in the context of well-defined goals, scientifically defensible programs, and informed decision making.

In keeping with their status as "emerging issues," it is important to keep in mind that all of these papers are "works in progress," to be revised as new information comes to light on the issues at hand. They are not to be considered definitive, exhaustive and/or final statements on their respective topics, although some of them may form the basis for publications in the scientific literature if they so warrant.

The current list of emerging issues papers includes:

[8] *See Research Program in Applied Hatchery Reform chapter.*
[9] *See Principles and System-Wide Recommendations in Applied Hatchery Reform chapter.*

RESEARCH GRANTS PROGRAM

The ability to fully achieve hatchery reform goals is compromised by lack of scientific certainty on many subjects. To reduce this uncertainty, the HSRG developed a competitive grant program to fund scientific research projects that could provide new scientific information in support of the goals of hatchery reform in Puget Sound and coastal Washington. This chapter provides a description of the research grant program. A summary of each research project funded by the HSRG can be found in Appendix H.

The HSRG established the following procedures for administering this grant program:

1. The Washington State Interagency Commission for Outdoor Recreation (IAC) shall be the administrative agency for the grant program.

2. The steps involved in the grant program each fiscal year could include:
   a. The HSRG will issue a Request for Pre-Proposals.
   b. Pre-Proposals received will be reviewed and evaluated by the HSRG. Applicants with pre-proposals selected for further consideration will be asked to prepare full proposals.
   c. Full proposals will be reviewed and evaluated by the HSRG. External ad hoc reviewers with scientific expertise complementary to the HSRG may be solicited to assist the HSRG with their reviews of specific proposals.
   d. The HSRG will inform applicants whether their proposal was accepted.
   e. Funds will be disbursed by IAC to accepted research proposals.
   f. Progress reports and final reports will be provided to the HSRG by funded researchers.

3. The HSRG will use its Scientific Framework for Artificial Propagation of Salmon and Steelhead (Scientific Framework) to identify research needs. Innovative research in other areas of Hatchery Reform will also be considered.

4. Proposals will be judged—using a standardized evaluation system— based on scientific merit, the qualifications of the investigators, ability to provide quantifiable results and the potential to achieve results applicable to hatchery reform goals. Preference will also be given to projects that show collaboration among researchers and agencies.

5. To avoid conflicts of interest, agency members of the HSRG will participate in discussion of proposals sponsored by their respective agencies but will excuse themselves from final voting to avoid potential conflicts of interest.

6. Written progress and annual/final reports are required of all funded projects. In addition, an oral presentation describing the project and its progress is required each year. The presentations are given each year (January/February) and open to the public.

7. Multiple-year projects are encouraged, but funds will only be awarded on a year-to-year basis. Successful grants from the previous year must submit pre-proposals to be considered for a second year of funding.

8. Although the HSRG respects and understands the need for protecting the intellectual property contained in research proposals, Washington state law requires that materials submitted in response to this grant announcement shall become the property of the IAC and shall be deemed public records.

9. Applications approved for funding will be required to sign a Project Agreement that incorporates the full proposal, negotiated parameters and any required federal terms and conditions as appropriate.

The HSRG has awarded over two million dollars in research funds to help answer questions such as how to reduce harvest on natural-origin fish, how to avoid adverse genetic effects of hatchery fish on natural-origin stocks, how to avoid adverse ecological interactions, how to improve hatchery practices, and how to monitor and measure success. Grantees have reported back to the HSRG at annual research review meetings and they are making good progress. But there are many questions left to answer and a number of projects that will take several years to provide useful findings.

During HSRG meetings in the early part of each year, research proposals have been evaluated by the group, with projects receiving funding being divided into four general categories for prioritized research: A) Sustainable Fisheries; B) Recovery and Conservation of Naturally Spawning Populations; C) Improvement in Quality and Cost-effectiveness of Hatchery Programs; and D) Protection of Genetic Resources. A list of funded projects is included as Table 1 with details provided in Appendix H.

TABLE 1: Summary of Research Grants

Year Funded	Project Description[10]	Principal Investigators[11]
Category A: Sustainable Fisheries		
2000, 2001	1. Development of Field Methods to Determine the Effects of Hatchery Release Methods on Residualism and Interactions Between Hatchery and Wild Juvenile Salmonids in Relation to Stream Carrying Capacity	Howard Fuss, WDFW; Stephen Riley, NOAA Fisheries

10 *Multiple year projects list the most recent title.*
11 *Multiple year projects list the most recent Principle Investigator(s).*

2000, 2001	2. Test Commercial Selective Harvest Gears	Geraldine VanderHaegen, WDFW
2000	3. Impacts of Size Selective Gillnet Fisheries on Puget Sound Coho Salmon Populations	Curtis Knudsen, Craig Busack, WDFW
2001, 2002, 2003	4. Salmon Marine Trophic Demand-Distribution	David Beauchamp, UW
Category B: Recover and Conserve Natural Spawning Populations		
2000	1. Genetic Characterization of Lake Ozette Sockeye Salmon	Ken Currens, NWIFC; Jim Shaklee, WDFW; Michael Crewson, Makah Tribe
2000	2. White River Acclimation Pond Evaluation	Chuck Baranski,WDFW; Blake Smith, Puyallup Tribe; Richard Johnson, Muckleshoot Tribe
2000, 2001, 2002, 2003	3. Differences in Natural Production between Hatchery and Wild Coho Salmon	Howard Fuss, WDFW; Michael Ford, NMFS
2000, 2001, 2002, 2003	4. Snow Creek Coho Recovery Program	Steve Schroder, WDFW
2000, 2001, 2002, 2003	5. Hamma Hamma River Steelhead Supplementation Evaluation	Barry Berejikian, NOAA Fisheries
Category C: Improve Quality and Cost-Effectiveness of Hatchery Programs		
2000, 2001, 2002, 2003	1. Development of Engineered Streams for Salmon Production	Ernest Brannon, UI
2000, 2001, 2002, 2003	2. Increase Post-Release Survival by Rearing Coho with NATURES Semi-Natural Raceway Habitat	Desmond Maynard, NOAA Fisheries
2000	3. Using Semi-Natural Rearing Habitat to Improve Smolt-Adult Survival of Chinook Salmon	Geraldine VanderHaegen, WDFW; Bill St. Jean, Nisqually Tribe

2001	4. Development of BKD Vaccine	Jed Varney, WDFW
2001	5. Nature vs. Nurture: Do Hatchery Practices Impair Brain Development?	Penny Swanson, NOAA Fisheries
Category D: Protect Genetic Resources		
2000, 2001	1. Interactions between Wild and Hatchery Steelhead: Evaluating Key Assumptions	Thomas Quinn, UW
2001	2. Residualism in Wild Broodstock Steelhead	Cameron Sharpe, WDFW
2001	3. Olfactory Imprinting in Hatchery Salmon	Andrew Dittman, NOAA Fisheries

Hatchery Research Agenda

After three years of administering this program and working to develop program-specific recommendations for 10 regions and over 200 hatchery programs throughout Puget Sound and the Washington coast, the HSRG has concluded that a research agenda must be established to guide funding for applied hatchery research in the Pacific Northwest. Hatchery research answering specific unknowns and that can be directly applied to better, more informed decision making will be essential to the long-term success of hatchery reform.

Hatchery programs must be operated to adapt to changes in the status of naturally spawning stocks, carrying capacity of the receiving waters, ocean productivity and harvest demands. Hatchery research is needed to reduce uncertainty and better evaluate the risks and benefits from hatchery practices. Additionally, new information is required to further understand the impacts of hatchery programs on natural-origin salmonids and on the environment within the watersheds or regions in which they operate.

The development of this agenda will require collaboration among states, institutions and disciplines. The HSRG is developing a proposal for an Applied Hatchery Research Agenda that builds on the outcomes of the HSRG Research Grant Program, uncertainties identified in the development of the HSRG's scientific framework and operational guidelines, and the findings from the three-year regional review process.

Applied Hatchery Reform

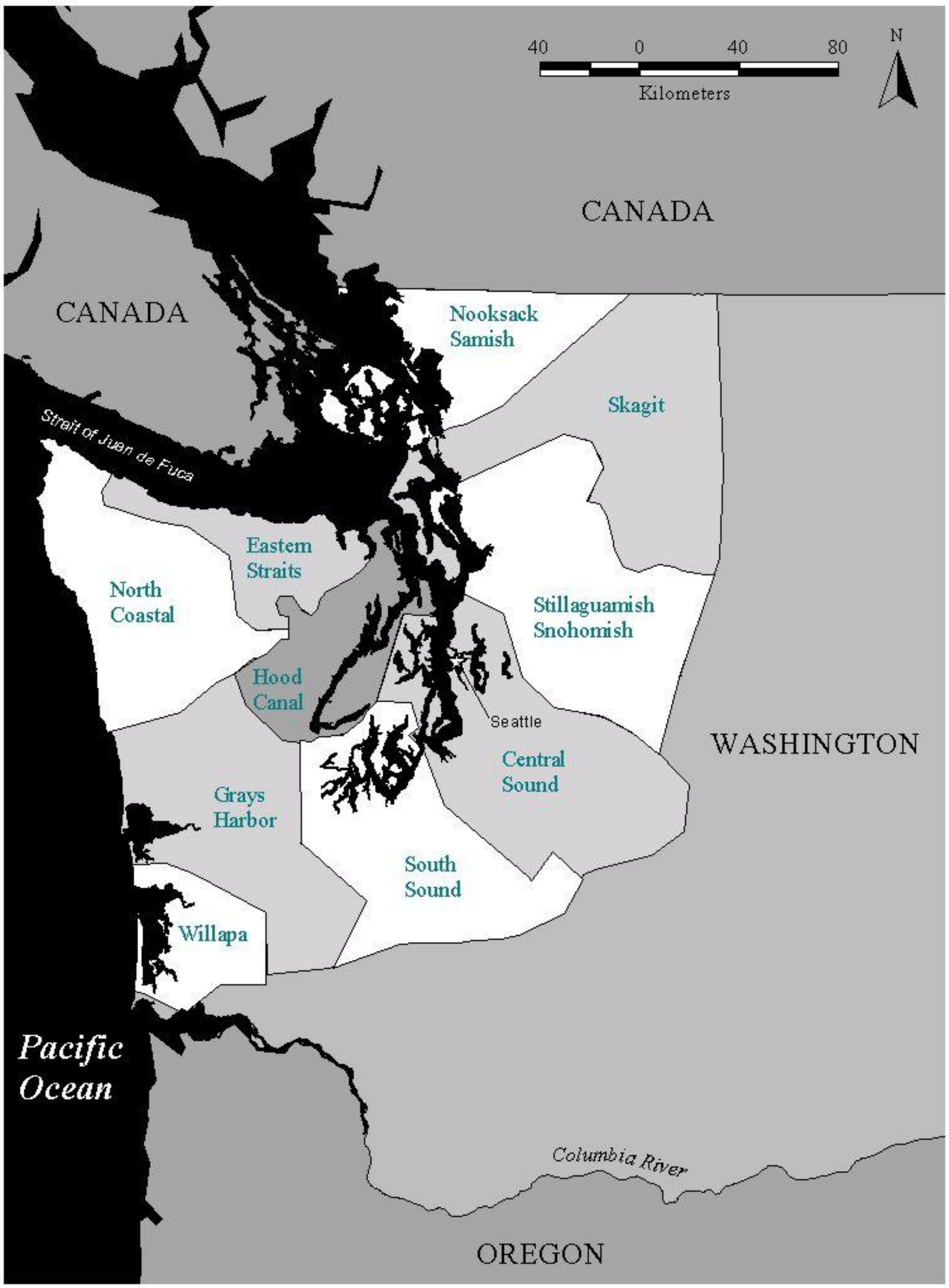
The Puget Sound and Coastal Washington Hatchery Reform Project has provided an unprecedented opportunity to review current hatchery practices at over 100 hatcheries. At the close of 2003, the nine members of the Hatchery Scientific Review Group (HSRG) had spent four years together participating in monthly, three-day work sessions and devoting at least as much time—often more—to the project between meetings. They have discussed and debated the latest scientific thinking on hatcheries; digested 500-plus page briefing books in each of ten regions that detail stock status, habitat conditions, and harvest goals; spoken face-to-face with the people in charge of the day-to-day management of hatchery programs in these regions; weighed the benefits and risks of over 200 stock-specific programs; and come to consensus on 3 principles, 18 system-wide recommendations, and over 1,000 program-specific recommendations for reform. This chapter provides an overview of the HSRG's regional review process and tools; and the resulting principles and recommendations.

REGIONAL REVIEW PROCESS

Early in the project, the HSRG and the Hatchery Reform Coordinating Committee agreed that it is important to evaluate hatchery programs in the context of the watersheds in which they operate and the goals set for them by the managers. For this reason, they divided Puget Sound and coastal Washington into ten regions (see Figure 1 on next page for locations). These ten regions include:

- Eastern Strait of Juan de Fuca
- South Puget Sound
- Stillaguamish/Snohomish Rivers
- Skagit River Basin
- Nooksack/Samish Rivers
- Central Puget Sound
- Hood Canal
- Willapa Bay
- North Coast
- Grays Harbor

FIGURE 1: Hatchery Reform Region Map



The HSRG used the scientific framework to develop a series of tools for use in the regional review process and for use by the managers. These included operational guidelines, a benefit/risk tool, and monitoring and evaluation criteria. The complete tools and example forms are included in the appendices noted.

- Operational Guidelines: The HSRG developed a set of operational procedures consistent with the scientific framework, to address ecological effects, genetic integrity and fish health concerns, and to provide new guidelines for fish rearing and accountability for success. These guidelines inform the questions contained within the part of the benefit/risk tool that examines hatchery operations (see Appendix C).

    - Monitoring and Evaluation Criteria: These criteria were developed from the scientific framework, operational guidelines and benefit/risk tool to help the managers determine the success of a hatchery program. These criteria suggest which information to collect and evaluate relating to the health of out-migrating smolts, stray rates of returning adults, whether or not hatchery rearing has affected fish size and run timing, and other factors (see Appendix D).

- Benefit/Risk Tool**:** The HSRG developed the benefit/risk tool for evaluating the benefits and risks specifically derived from each hatchery program. This tool was adapted and simplified from a tool developed by the co-managers.[12] It allowed the HSRG to evaluate the relative benefits and risks associated with specific actions and choices in hatchery management—in a scientifically sound, methodical manner. This tool was central to the regional review effort in that it allowed for a systematic evaluation of all aspects of hatchery and program operations in the context of the harvest, conservation or other goal for the resource set by the managers (see Appendix G).

The HSRG applied the hatchery review tools to all hatchery programs in ten regions over three full years between 2001 and 2003. This approach provided an opportunity to make region-by-region recommendations based on:

A. regional management goals for conservation, harvest and other purposes;

B. stock status (biological significance and population viability);

C. habitat status (current and future); and

D. the operational details of each hatchery program.[13]

For each hatchery program the HSRG addressed three questions:

1. Are the current hatchery practices consistent with the short- and long-term goals for the target stock?

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[12] *Draft Benefit-Risk Assessment Procedure (BRAP) for Washington State Department of Fish and Wildlife Artificial Propagation Programs, November 17, 2000.*

[13] *See the Benefit/Risk Tool section of the Appendices for detail on how these categories of information are defined.*

2. Is the program likely to attain those goals?
3. Are the current hatchery practices consistent with the goals for other salmonid stocks in the region?

The regional reviews normally took place over two three-day meetings, held in the region over consecutive months. Following an introductory meeting between the HSRG and the regional participants held three months prior to the review meetings, the facilitation team worked with the regional managers and state and tribal agency science teams to assemble a briefing book containing the four key categories of background information for the region, arranged by sub-region and stock (for example, Dungeness Chinook was a sub-regional stock examined in the Eastern Straits region). This briefing book was provided to the HSRG one month prior to the first meeting.

Regional participants from the state, tribal and federal management agencies were provided a detailed regional information instruction form to guide them in assembling information for the briefing book. Other regional participants were provided a regional information key questions form. [14]

For the reviews, the HSRG developed a standardized approach for expressing harvest and conservation goals for the stocks and the environment potentially affected by a hatchery program. Within each region, the current stock status, and short term and long term goals for stock conservation were provided by the co-managers in terms of: a) the biological significance of the stock (i.e., its importance to the Evolutionarily Significant Unit, or ESU, to which it belongs), b) the viability (or genetic fitness) of the stock. Conservation goals in these categories were rated qualitatively as high, medium or low. The current status and short term and long term goals for the suitability of the habitat available to each stock was also provided, also in qualitative terms. Similarly, harvest goals were expressed in terms of the frequency of harvest opportunity (annually, most years, some years, or never).

Day 1: The first day of a regional review meeting (and often the evening before) consisted of field tours arranged by the facilitation team and regional managers, to complement the briefing book information and provide the HSRG with a better understanding of the region and its hatchery facilities.

Day 2: On the second day, the HSRG worked with the regional participants to apply the Benefit/Risk Tool's Part One worksheet Summary of Goals for Affected Stocks and Habitat; Objectives for Current Hatchery Programs.[15] This process ensured that the scientists understood the management goals under which the co-managers are operating their hatchery programs, and the purpose and type of each program being conducted to meet those goals.

Day 3: On the third day (the final day of the first meeting), the HSRG completed its Benefit/Risk Tool Part Two worksheet How Current Operations Compare to HSRG Guidelines. Categories include: 1) accountability and education; 2) genetics and conservation; 3) physiology, morphology and ecology; and 4) culture methods. Regional hatchery managers joined the HSRG during this

[14] *See Appendices E and F, Regional Information Instruction Forms.*

[15] *See Appendix G, Benefit/Risk Tool for a description of these worksheets.*

process to fill in any operations information not provided in the briefing book, tour or previous discussions.

Day 4: On the fourth day (the first day of the second meeting), the HSRG reviewed the information provided by the managers between meetings, to fill in any remaining information gaps. The HSRG then began using in the Benefit/Risk Tool Part Three worksheet Benefit/Risk Analysis; Recommendations and Alternatives. This involved identifying the risks and benefits from each hatchery program to all hatchery and naturally spawning stocks in the region, then making preliminary recommendations for improving the region's hatchery programs.

Day 5: On the fifth day, the HSRG completed the Part Three worksheet. The group then decided how best to present the results to the regional managers at an informal review session.

Day 6: On the sixth and final day, the HSRG provided the regional participants with an informal review of the region. The session involved only oral presentations. No written report was provided at that time. The regional managers had the opportunity to take notes, ask questions and engage in discussion.

In all the regions reviewed, the regional participants chose to hold a follow-up meeting amongst themselves, where they discussed what they heard at the informal review session and prepared feedback to provide to the HSRG for their report writing process. HSRG and facilitation team members did not attend this meeting, in order to promote a free exchange of reactions and opinions.

At the end of the calendar year, the HSRG drafted a written report on the regions reviewed during that year.[16] This report took into consideration any actions taken and information provided by the managers after the informal review session. The HSRG provided the draft report to the managers to check for factual errors or omissions, and to allow the managers to draft concise responses that indicate where they agree or disagree with the recommendations, and describe implementation plans.

Project Management/Facilitation

In general, the role of the Hatchery Reform Project facilitation team has been to manage the project; facilitate interactions between the scientists and the managers; provide internal and external project communications; ensure that all parties involved in the project know their responsibilities, roles, tasks and deadlines; and ensure that these deadlines are met, with a quality product resulting. During the review process, the facilitation team coordinated the agenda, and produced meeting materials for each meeting (including detailed briefing books before each regional review session), and communicated with regional participants (inviting them to introductory and regional review meetings, informing them of assignments and deadlines).

During the meeting, the facilitation team helped keep the group on time and on agenda, helped to resolve problems and impasses, and suggested solutions and alternatives. After each meeting, the facilitation team provided the group with a list of decisions/action items/assignments and

[16] *See Appendix I, Program-Specific Recommendations by Region.*

developed a meeting summary for public distribution. The team also maintains the project's files and archives.

Communications activities by the facilitation team include drafting, sending and tracking project correspondence; fielding inquiries from stakeholders and the public; keeping the project's written materials, web site and PowerPoint presentations updated; providing articles, interviews, editorials and news conferences for local, regional and national media outlets; making briefings and presentations to a wide range of organizations and conferences; and editing and publishing project publications and reports. The HSRG and LLTK are also responsible for annual reporting to Congress on progress made in implementing hatchery reforms.

PRINCIPLES AND SYSTEM-WIDE RECOMMENDATIONS

Over the period of this project, the HSRG has developed a thorough understanding about applying existing science to hatchery management. After three years of regional reviews, the HSRG concluded that while any individual program may be successful in broodstock collection, rearing or other operational considerations, it may still be operating in a manner that does not, for example, adequately take into account risks to other stocks or to the environment, maximize benefits to the target stock, or consider whether adequate habitat will be available over time for the fish it produces.

In each region, the HSRG found:

- If the goals for each stock (conservation, harvest, research, education, etc) were clearly understood by the hatchery operator, the ability to evaluate the benefits and risks of a hatchery program was greatly improved;

- A clearly articulated, scientific rationale for a hatchery program can provide the managers with a science-based foundation for decision making and a range of scientific tools and strategies for achieving goals; and

- Hatchery managers who were able to measure the contribution of a hatchery program toward a particular resource goal had a greater chance of achieving that goal.

Based on these observations, the HSRG developed three principles, based on principles of good natural resource management, to guide the use of hatcheries. These principles include: 1) Well-Defined Goals, 2) Scientific Defensibility, and 3) Informed Decision Making. The HSRG also assembled system-wide recommendations (applicable to programs across the Puget Sound and coastal Washington hatchery system) that serve as hatchery based strategies for achieving these principles. Just as the program-specific recommendations were developed for each hatchery program, system-wide recommendations were developed for hatcheries collectively.

These principles and recommendations are presented here to help guide the managers as they implement hatchery reform, and to help answer how hatcheries can serve as tools for recovering naturally-spawning salmonid populations and providing sustainable fisheries.

Principle 1: Well-Defined Goals

Goals for all affected stocks must be well-defined. These goals should be quantified, where possible and expressed in terms of values to the community (harvest, conservation, education, research, employment, recreation, etc.). Hatcheries can then be managed as tools to help meet those goals. The

HSRG's scientific framework[17] outlines the issues involved with, and conditions required for, hatcheries to be an appropriate contributor to meeting harvest, conservation or other goals.

Harvest and conservation were the most common stock goals encountered by the HSRG. They can be defined as follows:

- Harvest goals promote commercial, subsistence, ceremonial, and recreational fishing
- Conservation goals promote the conservation of indigenous salmonid resources. They include endangered species protection and recovery, gene banking, maintaining native stocks for which natural spawning habitat is lost, and restoring stocks to streams where they have been extirpated.

The HSRG observed that goals for the fish resource were not always explicitly communicated and/or fully understood by the managers and operators of hatchery programs. To be successful, hatcheries should be used as part of an integrated strategy where habitat, hatchery management and harvest are coordinated to best meet resource management goals defined for each stock in the watershed. Hatcheries are by their very nature a compromise, a balancing of benefits and risks to the target stock, other stocks and the environment affected by the hatchery program. The use of a hatchery program is appropriate when benefits significantly outweigh the risks, and when the use of a hatchery program is more favorable than the benefits and risks associated with non-hatchery strategies for meeting the same goals.

The HSRG has developed the following **system-wide recommendations** to help ensure a comprehensive goal setting process.

Set Goals for all Stocks and Manage Hatchery Programs on a Regional Scale

Early in the project, the HSRG and the managers agreed that hatchery programs must be evaluated in the context of the regions and watersheds in which they operate and the goals set by the managers. In designing the review process, the HSRG determined that a review of Puget Sound and coastal hatcheries and their programs as a whole would have led to broad generalities not suited to regional differences in stock and habitat status. Similarly, a hatchery-by-hatchery review would not have allowed for evaluation in the context of each region's current and future habitat, harvest goals, the status of all regional, anadromous salmonid stocks, and the cumulative effects of all regional hatchery programs. The HSRG recommends that the managers continue this regional approach to reviewing and setting goals, managing hatchery programs, and implementing the principles and recommendations. The HSRG further recommends that implementation of hatchery reform recommendations be coordinated by regional technical groups, to ensure that goals for the resource and the role of each hatchery program in achieving those goals are tracked. These regional bodies may currently be in existence or may be patterned after the regional participant lists generated for the HSRG's regional review process.

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17 *See Appendix A, Scientific Framework.*

Measure Success in Terms of Contribution to Harvest, Conservation and Other Goals

The HSRG recommends that the managers measure hatchery contributions to harvest opportunity, the conservation of genetic resources, and other goals for salmon and steelhead populations. It is not uncommon for the direct hatchery output (i.e., numbers or pounds of juveniles released) to be cited as the goal by which a program's success is measured. More appropriate measures of success include:

- The scale and availability of harvest provided.
- The number of returning adults and their ability to reproduce and sustain the stock.
- The relative risks and benefits of each hatchery program.
- Alternative strategies for meeting similar goals.
- Whether the program is part of a comprehensive strategy to meet a stated resource goal.

Have Clear Goals for Educational Programs

The HSRG strongly supports the many educational programs conducted at, or supported by, hatchery facilities across Puget Sound and coastal Washington. These programs are valuable for educating the public on the biology of salmon, the importance of maintaining healthy salmon habitat, and sustainable fisheries.

A clear understanding of a program's specific educational goals needs to be articulated, along with methods for determining if those goals are being met and for reporting educational benefits. It is incumbent upon the fisheries managers, as the professional partners of these often volunteer-driven programs, to ensure that such goal statements are developed for these programs and understood by participants. It is also essential that these programs be operated consistent with the conservation principles they are intended to promote.

Principle 2: Scientifically Defensible Programs

Once the goals for the resource have been established (see above), the scientific rationale for a hatchery program – in terms of benefits and risks - must be spelled out to explain how the hatchery program expects to achieve its goals. The purpose, operation, and management of each hatchery program must be scientifically defensible. The strategy chosen must be consistent with current scientific knowledge. Where there is uncertainty, hypotheses and assumptions should be articulated. In general, scientific defensibility will occur at three stages: (1) during the deliberation stage to determine whether a hatchery should be built and/or a specific hatchery program initiated; (2) during the planning and design stage for a hatchery or hatchery program; and (3) during the operations stage.

This approach ensures a scientific foundation for hatchery programs, a means for addressing uncertainty, and a method for demonstrating accountability. Documentation for each program should include citations from the scientific literature and models that take into account the various factors (e.g., predation assumptions, cumulative effects, etc.). The scientific framework, the Benefit/Risk Tool and the operational guidelines developed by the HSRG to guide the regional review process all provide resources for ensuring scientific defensibility for hatchery programs (see appendices).

The HSRG has developed the following **system-wide recommendations** to help ensure a scientifically defensible hatchery program.

Operate Hatchery Programs within the Context of Their Ecosystems

The benefits and risks of hatchery programs can only be properly evaluated in the context of their ecosystems. Hatchery management requires understanding interactions between species and in particular, managing the risk of negative interactions. This requires knowing the status of the hatchery stocks and of other stocks, understanding the interactions between the stocks, and how well the habitat can support these stocks now and in the future.

The release of hatchery fish into the environment will affect the ecosystem. While these effects are not fully predictable, information about, for example, competitive and predatory relationships among species is available to help avoid unwanted outcomes.

Each ecosystem is unique, based on its history, natural events, (human) land use, and the strategies and goals developed by resource managers. The status and expectation for naturally-spawning stocks and the environment prescribe the potential for success and the limitations on any hatchery program. Therefore, in making decisions about current and future hatchery programs, decision makers should have current and future habitat assessments available to them in order to make informed decisions about goals for other stocks.

Operate Hatchery Programs as either Genetically Integrated or Segregated Relative to Naturally-Spawning Populations[18]

Hatchery broodstocks should be managed as either genetically integrated or genetically segregated. Hatchery programs are classified as *integrated* if a principal goal is to manage the broodstock as an artificially propagated component of a naturally spawning population. In contrast, hatchery programs are classified as *segregated* if the management goal is to propagate the hatchery broodstock as a discrete or genetically segregated population, relative to naturally spawning populations.

In this context, “intermediate” programs cannot exist without potentially posing significant risks to natural populations. The concepts of genetic integration and segregation, as they relate explicitly to hatchery programs, lead to well-defined operational guidelines and objectives for achieving the respective broodstock management goals while minimizing risks to naturally spawning populations. Each concept provides a template for broodstock management and operations. The

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[18] *See Appendix A, Scientific Framework, Applied Hatchery Reform-Regional Review Process, and, Emerging Issues paper on integrated and segregated programs.*

greater the deviation from one of these templates, the greater are the risks to naturally spawning populations with increased likelihood that the benefits of a hatchery program will not outweigh the risks. Consequently, from the outset, each hatchery program must identify one of the two broodstock strategies and follow that strategy as closely as possible to acheive the desired purpose of the program.

Integrated Program – A hatchery program is of an integrated type if the intent is for the natural environment to drive the adaptation of a composite population of fish that spawns both in a hatchery and in the wild. A fundamental goal of an integrated program is for the hatchery broodstock to be as similar genetically as possible to naturally spawning populations, in areas where fish are released and/or collected for broodstock. The long-term goal is to maintain genetic characteristics of a local, natural population among hatchery-origin fish, by minimizing genetic changes resulting from artificial propagation and potential domestication. In an idealized integrated program, natural-origin and hatchery-origin fish are genetically equal components of a common gene pool.

A hatchery supporting an integrated program can be viewed conceptually as an artificial extension of the natural environment where the population as a whole (hatchery + wild) is sustained at a much higher level of abundance than would occur without the hatchery. A properly managed integrated broodstock can potentially serve as a genetic repository in the event of a major decline in the abundance of natural-origin fish.

An integrated program does not imply that natural spawning of hatchery-origin fish is desired or even occurs. Natural spawning (a.k.a., supplementation) relates to the purpose, desired benefits and potential risks of a hatchery program and not to the genetic management goals for a hatchery broodstock, although the two sets of goals are usually correlated. Hatchery-origin fish spawning naturally does not make a hatchery broodstock genetically integrated—only if natural-origin fish are included in the broodstock in a systematic, prescribed manner can the broodstock be considered genetically "integrated." In this context, the management goal of an integrated program is to maintain the genetic characteristics of naturally-spawning fish among hatchery-origin fish, not vice-versa.

Specific recommendations for integrated programs include:

- Develop a detailed, genetic management plan for the hatchery broodstock and the naturally spawning population in the watershed where adults are trapped for broodstock.
- Ensure that an average of 10–20% of the hatchery broodstock is composed of natural-origin adults each year.
- Collect and spawn adults randomly with respect to time of return, time of spawning, age, size and other characteristics related to fitness.
- Impose hatchery management practices that minimize the potential domestication effects of the hatchery environment.

- Use marks, tags or other methods to distinguish natural- and hatchery-origin fish among natural spawners, in hatchery broodstocks, and in harvests.

- Monitor and control natural spawning by hatchery-origin adults so that the percentage of natural spawners composed of hatchery-origin fish is significantly less than the percentage of the hatchery broodstock derived from natural-origin fish. This general rule may be violated in restoration supplementation programs where natural spawning by hatchery-origin adults is an intended purpose of the hatchery program.

- Adjust the size of integrated hatchery programs relative to the size of the naturally spawning population so that the number of natural-origin adults spawning naturally in a watershed is greater than the total number of adults required for broodstock.

- In order to avoid broodstock mining, the natural component of the hatchery broodstock should not cause the number of natural spawners to fall below the escapement goal for natural spawners.

Segregated Program - The fundamental goal of a segregated program is to propagate the hatchery broodstock as a discrete population or gene pool that is reproductively segregated from naturally spawning populations. Once established, segregated broodstocks are composed entirely of returning, hatchery-origin adults. As a consequence, genetically segregated hatchery populations can, and will, change genetically, relative to naturally spawning populations. Such changes may be intentional to maximize the desired benefits of the program, while minimizing risks to naturally spawning populations. However, in contrast to integrated programs, *any* natural spawning by hatchery-origin fish from a segregated program will impose potentially unacceptable risks to natural populations.

Specific recommendations for segregated programs include:

- Release and release fish in areas where opportunities to capture non-harvested adults are maximized, thus minimizing genetic risks to natural populations.

- Rear fish in a manner and/or at a location that minimizes potential straying and opportunities for natural spawning.

- Ensure harvest opportunities are commensurate with potential adult production from segregated programs and take into consideration the potential selective impacts of harvest on the long term viability of segregated programs.

- Ensure hatchery-origin adults constitute no more than one to five percent of natural spawners.

- Use marks, tags, or other methods to distinguish natural- and hatchery-origin fish among natural spawners, in hatchery broodstocks, and in harvests.

- Avoid trapping natural-origin adults, and exclude them from the broodstock.

Size Hatchery Programs Consistent with Stock Goals

Fisheries managers should determine the proper size (number of fish released) of a hatchery program based on clearly defined goals established for the stock. The size of hatchery program must consider two parameters: (1) the number of released fish to meet the purpose of the program and (2) the number of adult spawners necessary to meet *both* the purpose of the program *and* the genetic management goals for the broodstock. In general, the number of fish released should be the smallest number necessary to meet the management goal of the program. In addition, the number and composition (hatchery- or natural-origin) of adults used for broodstock must meet genetic guidelines and constraints consistent with maintaining a viable population.

Hatchery programs that are sized incorrectly present ecological and economic risks. For example, large hatchery releases may interact through competition and predation with natural stocks and other ecological processes in a detrimental way. These “extra” fish may also impact the survival of other populations once they enter the ocean. Resources spent producing these fish may be wasted if returning adults cannot be harvested and/or overwhelm hatchery workers.

Consider both Freshwater and Marine Carrying Capacity in Sizing Hatchery Programs

Freshwater and marine trophic conditions and carrying capacity may limit the ability of a program to contribute to a resource goal.[19]

For example, stocks of coho and Chinook have shown a decrease in survival over the past decade in certain regions of Puget Sound and the coast, such as southern Puget Sound. The decrease may be related to the general decline in productivity of inland, marine waters. There has been a great deal of speculation as to additional cause(s) for the decline in these regions, (e.g., increased bird and marine mammal predation; a general lowering of water quality from urbanization in a body of water with low turnover; continuing loss of freshwater habitat, a shift in the forage base, etc). Whatever the cause, the trophic capacity of southern Puget Sound to support salmonid fishes appears to have diminished in recent years.

Lowered survival may also be related to the total biomass of salmonids presently being released from hatcheries, despite recent reductions in the actual numbers of fish released. Closure of certain unproductive hatcheries and reduced production at other hatcheries may in fact benefit the quality and survival of both naturally spawning and hatchery fish.

Factors that should be considered in sizing a hatchery program may include (but not be limited to) the following:

1. the potential for ecological interactions with natural populations;

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[19] *See HSRG Scientific Framework and Hatchery Review Program, Emerging Issues chapter, section on marine carrying capacity.*

2. the physical capacity of the individual hatchery;
3. the carrying capacity of receiving waters in terms of both juveniles and adults (see recommendations above);
4. changes in ocean productivity; and
5. the ability to control the contribution of hatchery-origin fish to the natural spawning escapement, (e.g., through selective harvest).

Overall, the managers should maintain a repertoire of release strategies that can be adjusted in response to changing environmental or trophic conditions. There must be a defensible rationale for any given level of hatchery production, leading to sustainability and cost effectiveness.

Ensure Productive Habitat for Hatchery Programs

The HSRG has concluded that productive habitat, in which a salmon population conducts the various phases of its life cycle, is necessary to the success of any hatchery program. The fitness of the naturally-spawning population, its productivity, and the number of adult salmon (artificially or naturally produced) returning to the watershed ultimately depend on the natural habitat, not on the output of the hatchery. Silt free incubation gravels and cool, stable incubating water are necessary for the survival of salmon embryos. Flowing streams with complex structure, riparian vegetation, seasonal flow stability, and productive estuaries are necessary to the survival of juvenile salmon. Flowing streams are also necessary for the successful passage and spawning of returning adults.

In particular, habitat is essential to the success of integrated hatchery programs because the hatchery broodstock is directly supported genetically and demographically by the naturally spawning component.[20] Integrated hatchery programs will be limited in scope by the productivity of the natural habitat. Natural populations are expected to increase in fitness and productivity as habitats improve. In addition to the habitat described for all programs, silt free incubation gravels and cool reliably stable irrigating water are necessary for the survival of salmon embryos.

Emphasize Quality, Not Quantity, in Fish Releases

Release the lowest number of fish (consistent with goals for the resource) with the highest quality to maximize potential benefits while minimizing risks to naturally spawning populations. The HSRG's working model is that the best a hatchery program can expect to do is to match a wild salmon template in terms of the physiological, morphological and behavioral traits that affect smolt-to-adult performance. Measures of quality can include affects on physiological, morphological and behavioral fitness, including competency of juvenile fish to migrate, establish territory, and displace other individuals, prey and forage. [21] These fitness characteristics clearly have both genetic and environmental components (nature vs. nurture).

[20] *See HSRG System-wide Recommendation on Integrated and Segregated broodstock management*

[21] *See Emerging Issues paper "Hatchery Smolt Quality and Achieving the Wild Salmon Template"in Appendix B.*

It is important that some measure of the quality, rather than simply the quantity, of fish released from hatcheries be measured and evaluated. In the past, performance has been measured by numbers of juvenile released. As discussed in the recommendation to "Size Hatchery Programs Consistent with Stock Goals," releasing too many fish may have ecological risks and economic costs. In the future, performance should be measured by the level of post-release survival and the rate of adult returns, both of which depend on the quality of the fish released.

Use In-Basin Rearing and Locally-Adapted Broodstocks

Some hatchery programs, for lack of adequate facilities and/or proper escapement management, transfer eggs and/or juveniles between facilities and among watersheds/regions. The HSRG recommends that "backfilling" of broodstock shortages should be terminated. Managers should use in-basin rearing and locally adapted broodstocks to increase the productivity of hatchery programs and minimize risks. Failure to do so results in a loss of local genetic adaptability, increased potential for disease transfer, and lowered productivity of hatchery stocks. This practice of importation and movement of eggs and juveniles into and out of the region should thus be ended.

Spawn Adults randomly throughout the Natural Period of Adult Return

The HSRG recommends that the managers adopt and implement policies that conserve or recover natural life history traits of the various hatchery stocks to assure long-term sustainability. There can be loss of certain life history traits in hatchery stocks through the process of domestication. An example is the shift in spawn timing resulting from selective breeding for early adult return.

Use Genetically-Benign Spawning Protocols that Maximize Effective Population Size

The HSRG recommends that the mating of hatchery fish should be designed 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). This is particularly critical in conservation programs, where populations are small or have experienced significant declines.

To achieve these objectives, male and female hatchery fish can be mated 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. Mixed milt spawning where eggs are fertilized by the simultaneous or sequential addition of sperm should be avoided because of unequal genetic contributions among male spawners and consequential reductions in effective population size.

During its review of hatchery programs, the HSRG has seen a variety of spawning protocols, including modified factorial mating,[22] single family pairing, as well as protocols that pool gametes prior to fertilization. The approaches of single family mating and modified factorial mating have proven to be feasible and effective (up to 94% fertilization), even in some of the largest programs reviewed (up to five million eggs taken per year). Because these methods achieve the two principle objectives and can be implemented relatively easily, the HSRG recommends that all programs, up to the size noted, adopt one of these protocols.

Hatchery spawning protocols prescribed by the managers typically incorporate gametes from all age classes, including jacks (early returning males), to maintain genetic continuity or gene flow among brood years within populations. A common approach by the co-managers is to use jacks for 2% of the adult male spawning population. This rate is probably lower than what occurs among natural spawning populations. The HSRG therefore recommends that jacks be spawned according to their occurrence among returning adults up to a maximum of 10%, with the exception of coho salmon where a *minimum* of 10% jacks among male spawners should be used. The inclusion of jacks to maintain genetic continuity among brood years of coho is especially important, because they mostly mature at three years of age. [23]

Reduce Risks Associated with Outplanting and Net Pen Releases

Releasing smolts in streams geographically removed from a hatchery or adult collection facility is commonly called outplanting. This practice may pose significant genetic risks by promoting stray rates, often exceeding natural levels, to freshwater areas where interbreeding with naturally spawning populations is undesirable.

Steelhead programs in Puget Sound and coastal Washington have often used outplanting to support sport fisheries in a large number of small streams. Similarly, saltwater net pens are used to acclimate and release salmon smolts in marine areas where a targeted marine fishery on returning adults is desired. A common feature of these programs is that they release fish where no facilities exist to trap returning adults that escape target fisheries. Outplanting and net-pen releases from segregated hatchery programs[24] are especially problematic, because of the potentially high level of genetic divergence between the hatchery stock and natural populations where straying and natural spawning may occur.

The HSRG recommends reducing risks associated with outplanting and net-pen releases by reducing the number and/or size of such programs. Risks can also be reduced by:

1) intense, selective harvest and/or the use of adult traps;
2) implementing the HSRG's system-wide recommendations for steelhead, to substantially reduce the geographic range of outplanting;

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[22] *Currens, K.P., J.M. Bertolini, C.A. Busack, and J. Barr. 1998. An Easier Way to Meet Genetic Spawning Guidelines. Pages 41-44 in Proceedings of the 49th Pacific Northwest Fish Culture Conference, Boise, ID*

[23] *Van Doornik, D.M., M.J. Ford, and D.J. Teel. 2002. Patterns of temporal genetic variation in coho salmon: estimates of the effective proportion of two year-olds in natural and hatchery populations. Transactions of the American Fisheries Society. 131: 1007-1019*

[24] *See recommendation above on operating integrated and segregated hatchery programs.*

3) restricting release to areas where adult collection facilities are available or can be easily developed;
4) using locally-adapted and integrated stocks[25] in net pens, so that strays have less of a deleterious effect on natural populations;
5) evaluating the benefits and risks of each program every two or three years, and reducing or terminating programs that impose significant risks relative to benefits;
6) monitoring and evaluating high risk programs to ensure that adverse effects to naturally-spawning populations are minimal, straying risks are appropriately managed, and off-station releases are appropriately located; and
7) developing system-wide, risk management guidelines and protocols for outplanting and net-pen programs.[26]

Develop a System of Wild Steelhead Management Zones (a special case)

Segregated hatchery steelhead programs are used extensively throughout Puget Sound and coastal Washington to provide a harvest opportunity. These segregated steelhead programs often outplant non-native stock with no provision for the recapture of returning adults. This is unlike segregated Chinook and coho hatchery programs, which release fish directly from the hatchery where the returning adults can be recaptured. The HSRG understands it is the intention of the managers to continue segregated steelhead programs into the future. In general, the HSRG believes that the widespread stocking and outplanting of steelhead smolts poses unacceptable ecological and genetic risks to naturally spawning populations, particularly in small streams that receive such outplants or to which hatchery-origin fish stray. The biggest concern is the genetic risk posed by the spawning overlap between the hatchery (Chambers Creek origin), early-timed winter run stock and the native, late-timed winter run stock.

The HSRG recommends that the managers develop a system of “wild steelhead management zones” where entire sub-regions or portions of watersheds for large rivers (e.g. Skagit River) are not planted with hatchery-origin fish but are managed for “wild” steelhead only. This approach will increase protection of native stocks in while still permitting harvest opportunities in areas where the genetic and ecological risks of hatchery releases are substantially less (e.g. where adult recapture facilities exist).

The HSRG recommends that wild steelhead management zones be developed for each of the ten regions within Puget Sound and coastal Washington. Harvest for steelhead may be compatible with this approach, but no hatchery-propagated steelhead would be introduced into the wild steelhead management zones. Such areas would reduce the risk of naturally spawning fish interbreeding with non-native hatchery fish, and provide native stocks for future fisheries programs. The streams selected should represent a balance of large and small streams, habitat

[25] *Ibid.*
[26] *See Emerging Issues, paper on out-planting and net pens.*

types, stock status, etc. Hatchery production may need to be increased in streams selected for hatchery harvest.

The HSRG acknowledges the need to promote segregated hatchery steelhead programs that are self-sustaining. Existing programs are based largely on steelhead of Chambers Creek origin winter and Skamania origin summer steelhead. These stocks have been transplanted to many locations throughout Puget Sound and coastal Washington. Once these segregated stocks have been transplanted they should be maintained as separate broodstocks now maintained with returning adults at those locations so they can adapt to the local environment.

When implementing a segregated steelhead program, it is important to minimize interaction with naturally spawning steelhead, through such tools as differential timing and a decision on benefits versus risks on outplanting in freshwater habitat. Adult collection procedures need to be incorporated to capture adults that are not harvested from the returning segregated population.

The HSRG recognizes the role integrated hatchery programs can serve for conservation or harvest, using native broodstocks. It is important to recognize the differences between integrated stock management, incorporating native origin broodstock, and segregated stock management, using non-native origin broodstock.[27]

Monitoring and evaluation should be a basic component for streams managed for native stocks and those managed for hatchery harvest.

Use Hatchery Salmon Carcasses for Nutrification of Freshwater Ecosystems, while Reducing Associated Fish Health Risks[28]

Returning adult salmon are a unique vector for the delivery of marine nutrients into the freshwater ecosystem. The importance of these nutrients to consumers such as raccoons, bear, eagles and even man has been recognized for some time. Recent research also suggests that a significant portion of nitrogen in plants and animals in streams where adult salmon are abundant is derived from those returning adults. Marine-derived nutrients from returning adult salmon have been found to make a significant contribution to riparian vegetation and even old-growth forests. In streams in interior British Columbia up to 60% of the nitrogen in benthic insects was derived from the carcasses in streams where salmon were abundant. They also found that juvenile salmon show higher growth rates in streams where adult salmon spawn than in streams without spawning adults. Use of hatchery salmon carcasses as a source of these marine-derived nutrients was found to increase the density of age 0+ coho and age 0+ and 1+ steelhead in small, southwestern Washington streams.

The deliberate distribution of hatchery salmon carcasses into watersheds for purposes of nutrification can have a positive ecological benefit to natural salmonid stocks. This practice may, however, also pose a fish health risk to these stocks if those carcasses carry live pathogens and are

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[27] *See System-wide Recommendation above on operating integrated and segregated hatchery programs.*

[28] *See Appendix B, Emerging Issue paper for references and more information on this topic.*

not properly treated or managed prior to distribution. It is well recognized that disease organisms present in salmon carcasses can be transmitted to other salmonids following the release of these organisms into water or through their direct consumption unless appropriate disease risk-aversive measures such as pathogen-free certification are followed.

Principle 3: Informed Decision Making

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.

With clear decision making processes in place that respond to new information, the HSRG believes that hatcheries can be managed in a more flexible and dynamic manner in response to changing environmental conditions, new scientific information, economic value of the resource, and other models where actions are evaluated and modified to determine the best use of limited resources.

This model applied to hatcheries requires that performance standards and indicators be identified so that monitoring activities will focus on key uncertainties and effective evaluation of results can occur. Results of the monitoring and evaluation (M&E) must then be brought forward to a decision making process in a clear and concise way so needed changes can be implemented. This responsive process should be structured to allow for innovation and experimentation so hatchery programs may be responsive to new goals and concepts in culture practice.

The HSRG has developed the following **system-wide recommendations** to help ensure the principle of informed decision making for hatchery programs is achieved.

Adaptively Manage Hatchery Programs

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."[29] 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.

A critical implication is the notion of responsive change—rather than the status quo—as the normal operating procedure. Put simply, adaptive management is learning by doing, assuming

[29] *Lee, K. N. 1993. Compass and gyroscope: integrating science and politics for the environment. Island Press, Washington, DC.*

your program and operations will change regularly to reflect new information and better meet goals, and taking action in the face of scientific uncertainty. However, the actions taken through adaptive management are not selected at random. Rather, action is prescribed through the thoughtful and disciplined application of the scientific method.

The scientific method and adaptive management require a scientific framework for organizing and understanding information and identifying uncertainties. The HSRG has developed such a framework for the context of anadromous salmonid hatcheries[30] and encourages the managers to use this framework and keep it up to date. Equally important is a structured process that assures the right information is collected, analyzed, reported and brought forward in the decision making processes at all levels of hatchery operation. The HSRG encourages the managers to adopt an adaptive management approach to implementing hatchery reform, and offers both the tools it has developed for the regional review process, and the experience it has acquired during the review process, to aid the managers in their creation of this approach.

Incorporate Flexibility into Hatchery Design and Operation

The HSRG recommends that facilities be designed and operated in such a way that they are able to respond relatively easily to changes in harvest and conservation goals and priorities, ocean carrying capacity, stock status, freshwater habitat conditions, and the myriad other factors that will alter current policies and programs. The goal of a hatchery or regional manager should *not* be to “fill the hatchery facility to its biological capacity,” but rather, to manage the facility to achieve programmatic goals.

Programs must also be able to respond to uncertainty and risk. For example, an empty raceway today may be necessary to provide this type of flexibility in the future. The keys to flexibility are having sufficient supplies of land, water quality and quantity, and physical facilities; along with a planning mindset that takes the concepts of flexibility, managing change, and future needs into account.

Evaluate Hatchery Programs Regularly to Ensure Accountability for Success

Achieving successful hatchery programs (where benefits and risks are managed effectively) will require ongoing monitoring and evaluation (M&E), with some level of commonality and standardization across Puget Sound and coastal Washington. Each region of Puget Sound and the coast will need to develop its own M&E program consistent with the goals and programs of that region.

Monitoring should include not only expanded efforts to distinguish hatchery- and natural-origin fish, but also determining the fate of migrants in fresh and saltwater environments following

[30] *See Appendix A, Scientific Framework for the Artificial Propagation of Salmon and Steelhead.*

release. An integrated, region-wide hatchery M&E system needs to be developed that includes the systematic and annual evaluation of the co-mingling of hatchery and naturally-spawning fish.[31]

Furthermore, a modern, centralized M&E database where information can be evaluated annually for adherence to regional and system-wide goals needs to be institutionalized, in order to adaptively manage the system. Individual hatcheries need to be equipped with computers and Internet access that allow them to use and share data from a record collection system developed by the co-managers, such as the HatPro system.

[31] *See Appendix A, Scientific Framework, Monitoring and Evaluation for Accountability and Success.*

PROGRAM-SPECIFIC REGIONAL RECOMMENDATIONS

In each of the regions reviewed, the HSRG found significant differences in the quality of the habitat, stock status, the goals the managers have prescribed for each region's salmon and steelhead stocks, and the purposes of each region's hatchery programs. The HSRG's regional review process produced roughly 1,000 program-specific recommendations addressing these specific circumstances. Recommendations ranged from changes in broodstock management, to addressing water quality concerns, to removal of fish passage impediments, and many others. Some program-specific recommendations referenced system-wide recommendations; others were unique to the program.

This synopsis includes the HSRG's findings for each region reviewed and a list of regional participants. The full analysis and recommendations for hatchery programs in each region can be found in the three separate volumes that constitute this document's Appendix I or electronically at www.hatcheryreform.org.

Hatchery Reform Recommendations February 2002: Eastern Strait of Juan de Fuca, South Puget Sound, and Stillaguamish and Snohomish Rivers

Eastern Strait of Juan de Fuca

This region includes the eastern portion of the Strait of Juan de Fuca, from Point Wilson to the Hoko River. Twelve hatchery programs were reviewed in this region, with 60 specific reforms recommended. Two major restoration efforts are planned in this region: dam removal/watershed restoration on the Elwha River and habitat restoration at the mouth of the Dungeness River. Historically, the Elwha River supported a genetically distinct run of Chinook salmon. These fish regularly attained sizes greater than 50 pounds. A hatchery supported population remains in the lower river with some natural spawning in the river itself, but these do not attain their historic sizes. What happens to an endangered run of Chinook salmon when a dam is removed and a hundred years' of sediment flows downstream? The hatcheries on this river system will play a central role in protecting and restoring this run until the habitat is ready to support them again. Federal, state and tribal managers in this region must determine how best to do this, in keeping with the principle of operating hatchery programs in a scientifically defensible way. The regional review process has helped them answer questions about how long the fish should be reared in captivity and when and where their progeny should be released to reestablish a naturally spawning population. The co-managers are currently developing a detailed, Elwha River Restoration Plan that will prescribe the role of existing hatchery facilities, artificial propagation, and potential outplanting of hatchery-origin fish in the restoration process. The restoration effort will also include coho salmon, sockeye salmon, and steelhead.

Regional Participants - Pat Crain, Mike McHenry and Larry Ward, Elwha Klallam Tribe; Scott Chitwood, Byron Rot and Ann Seiter, Jamestown S'Klallam Tribe; Marianna Alexandersdottir, Kyle Brakensiek and Willy Eldridge, Northwest Indian Fisheries Commission (NWIFC); Brian Winter, Olympic National Park; Chris Weller, Point no Point Treaty Council (PNPTC); Donald Haring, Washington State Conservation Commission; Ann Blakely, Chris Byrnes, Martin Chen, Bill Freymond, Randy Johnson, Thom Johnson, Mark Kimbel, Anne Marshall, Darrell Mills, Don Rapelje, Dick Rogers and Paul Seidel, Washington State Department of Fish and Wildlife (WDFW).

South Puget Sound

This region includes the portion of Puget Sound south of the Tacoma Narrows. The HSRG reviewed 16 hatchery programs in this region, and provided 64 specific recommendations. The region is highly urbanized. Habitat in the region is affected by population growth and development, although instream flows are expected to be relatively stable. Storm water, sedimentation from development, and beach and stream bank channelization are expected to still be significant in the future. Habitat restoration projects are underway in the region, most noteably in the Nisqually River and Delta. Other stream restorations projects such as removal of the Goldsborough dam are also underway, although most are only selected reach-scale restoration efforts.

The managers designated this region a hatchery management zone for many stocks as part of their post-Boldt Decision efforts to provide opportunities for pre-terminal Puget Sound fisheries and adequate fishing opportunities for the Puyallup, Nisqually and Squaxin Island tribes, all of which have “usual and accustomed” fishing areas here. It includes several old trout facilities (formerly under the management of the Washington Department of Game prior to merger) not particularly suited for rearing salmon as well as many facilities without the capability to fully incubate or provided full-term rearing for their programs. These facilities therefore, have been used as intermediate rearing stations for fish from other facilities, requiring a series of interbasin stock transfers to meet program goals. This region previously released up to ten million coho smolts per year, around ten percent of the total releases in Puget Sound and coastal Washington, at its height of productivity. Despite increased smolt releases, adult returns of coho have declined. The scientists strongly recommend an analysis of the carrying capacity of the Sound with a decrease or cap in smolt releases in this region until more scientific understanding is established, in keeping with the principle of managing hatchery programs based on informed decision making.

Regional Participants - Jeanette Dorner, Joan Miniken, Bill St. Jean, David Troutt and George Walter, Nisqually Tribe; Marianna Alexandersdottir, Jim Bertolini, Kyle Brakensiek, Willy Eldridge, NWIFC; Frankie John Jr., Russ Ladley, Chris Phinney and Blake Smith, Puyallup Tribe; Jeff Dickison, Will Henderson, Jim Peters and Andy Whitener, Squaxin Island Tribe; Donald Haring and John Kerwin, Washington State Conservation Commission; Charmane Ashbrook, Chuck Baranski, Debbie Carnevali, Martin Chen, Jeff Davis, Rich Eltrich, Jim Fraser, Darrell Mills, Don Nauer, Denis Popochock, Brian Quinton, Margie Schirato, Paul Seidel, Jack Tipping, Marc Wicke and Dan Wrye, WDFW.

Stillaguamish/Snohomish Rivers

This region includes the watersheds contained by the Stillaguamish and Snohomish rivers and Tulalip Bay. The HSRG reviewed 16 hatchery programs in this region and provided 94 specific recommendations. Habitat in the Stillaguamish River system has been heavily altered and compromised by land use activities such as logging, diking, housing development and dairy farming. This region is becoming increasingly urbanized, particularly in the lower reaches of the respective river valleys. The Skykomish River features relatively undisturbed habitat. While the Snoqualmie is wild-like above North Bend, in rural, eastern King County it has been affected by agriculture and development. When the Skykomish and Snoqualmie join and form the Snohomish, the effects of development are even clearer. In addition to programs operating within the larger river systems, the Tulalip Tribes operate a facility with numerous hatchery programs meant to contribute to terminal harvest in Tulalip Bay. The HSRG emphasized the need to determine whether adult fish from these and other programs are straying to other regional streams and presenting risks to naturally spawning salmon. Another distinguishing characteristic of this region is its popular steelhead sport fishery. This region is one where the HSRG's "wild steelhead management zones" concept[32] was a particular focus of the recommendations.

Regional Participants - Marianna Alexandersdottir, Kyle Brakensiek, Willy Eldridge and Bruce Stewart, NWIFC; John Drotts, Kip Killebrew, Pat Stevenson and Shawn Yanity, Stillaguamish Tribe; Cliff Bengston, Marla Maxwell, Kurt Nelson, Kit Rawson and Francis Sheldon, The Tulalip Tribes; Kevin Amos, Charmane Ashbrook, Dave Brock, Mike Chamblin, Doug Hatfield, John Kerwin, Larry Klube, Curt Kraemer, Chuck Lavier, Darrell Mills, Steve Moore, Tony Opperman, Eric Pentico, Chuck Phillips, Jed Varney, Ron Warren and Dan Wrye, WDFW.

Hatchery Reform Recommendations March 2003: Skagit River Basin, Nooksack and Samish Rivers, and Central Puget Sound

Skagit River Basin

This region includes the watersheds contained by the Skagit River Basin (including the mainstem Skagit, Baker, Sauk, Cascade and Suiattle rivers) and Whidbey Island. Eleven hatchery programs were reviewed in this region with 48 specific recommendations provided. The Skagit River Basin is the largest watershed in Puget Sound and supports all six species of anadromous salmonids native to Washington state. A significant amount of natural habitat is still available in this region, though it has been affected by hydropower and other land uses. The Skagit Basin is an important region for the recovery of Puget Sound salmon stocks. Strong spring, summer and fall Chinook runs existed in the past and there is still a fair amount of this diversity left. However, there are conservation concerns for several stocks, including Chinook, coho and steelhead. The region has a number of hatchery programs serving as indicator stocks for the US/Canada Treaty and other

[32] *A full description of this concept is included in the Applied Hatchery Reform chapter, Principles and System-Wide Recommendations.*

processes. These are important to fisheries management, but not central to recovery or direct harvest. Natural production goals are key for all species in this region. Therefore, in keeping with the principle of operating hatchery programs based on clear goals for the resource, the HSRG recommended the managers size these indicator programs to meet indicator stock needs, but not above that level. The group also noted Baker Lake sockeye as an example of a hatchery program that is meeting its conservation purpose by maintaining a stock that would otherwise go extinct.

Regional Participants - Steve Fransen, NOAA Fisheries; Marianna Alexandersdottir, Kyle Brakensiek, Ken Currens, Willy Eldridge, Grant Kirby, Bruce Stewart, NWIFC; Doug Bruland, Puget Sound Energy; Dave Pflug, Seattle City Light; Eric Beamer, Bob Hayman, Scott Schuyler, Larry Wasserman, Skagit System Cooperative; Charmane Ashbrook, Brett Barkdull, Kurt Buchanan, Pete Castle, Deborah Cornet, Chuck Johnson, John Kerwin, Kevin Kurras, Chuck Lavier, Darrell Mills, Steve Moore, Chuck Phillips, Gary Sprague, Steve Stout, Jack Tipping, Jed Varney, WDFW.

Nooksack/Samish Rivers

This region includes the watersheds contained by the Nooksack and Samish rivers and the San Juan Islands. Nineteen hatchery programs were reviewed in this region, with 89 specific recommendations provided. Some similarities exist between the Nooksack/Samish region and the Stillaguamish/Snohomish region where habitat has been altered by land use activities. Because of this, natural production has been severely impaired. Spring Chinook stocks, in particular, are dependent on hatchery programs for recovery. Management goals for the region's stocks have emphasized hatchery production for harvest, especially on Chinook and coho. This region was in the past the center of Puget Sound Chinook harvest, but both hatchery production and harvest have been reduced over the last decade or so. The HSRG recommended the managers ensure their hatchery programs are consistent with conservation goals, in particular those for spring Chinook. The group pointed out the importance of making sure recovery programs do not produce numbers of fish that exceed the capacity of the limited habitat into which they are released and to which they return. If this occurs, a program might be rebuilding one stock, while at the same time producing strays that compete with natural stocks in other streams, thereby not meeting the principle of scientific defensibility.

Regional Participants - Earl Steele, Bellingham Technical College; Michael O'Connell, Long Live The Kings (LLTK); Alan Chapman, Randy Kinley, Lummi Nation; Ned Currence, Nooksack Tribe; Marianna Alexandersdottir, Kyle Brakensiek, Deborah Cornett, Willy Eldridge, Grant Kirby, NWIFC; Scott Schuyler, Skagit System Cooperative; Charmane Ashbrook, Pete Castle, Chuck Johnson, John Kerwin, Darrell Mills, Chuck Phillips, Steve Seymour. Ted Thygesen, Jack Tipping, Jed Varney, WDFW.

Central Puget Sound

This region includes the central portion of Puget Sound, including the Puyallup River, Green River, Lake Washington and watersheds along the eastern shore of the Kitsap Peninsula. Thirty-one hatchery programs were reviewed in this region, with 149 specific recommendations provided. Central Puget Sound is where the largest concentration of the human population lives in

Puget Sound and coastal Washington, putting particular focus on issues surrounding how salmon and people coexist. The HSRG reviewed four sub-regions within Central Puget Sound and found that each had its own distinct character.

The Puyallup River sub-region has been affected by land use and hydropower and is home to White River Chinook, the last remaining spring Chinook stock in South and Central Puget Sound. White River Chinook owes its recent rebound to a successful hatchery intervention. The HSRG said this program has been successful enough that it is time to begin locally-adapting the stock, moving away from out-of-basin rearing and increasing the program's scientific defensibility.

The East Kitsap sub-region features smaller, shorter streams and is only now beginning to confront the rapid population growth and corresponding pressure on habitat that much of Central Puget Sound has already experienced. Consistent with its short streams, hatchery programs in this sub-region have emphasized chum production. Though the harvest benefits derived from these programs are not always large, the HSRG saw them as good examples of how hatcheries can be used for environmental education, in that they make extensive use of volunteers from the general public, many drawn from the new arrivals who need to learn about protecting salmon stocks and their habitat.

Purposes other than conservation and harvest (i.e., education and research) are featured at hatchery facilities in the Lake Washington sub-region, such as Issaquah Hatchery and the University of Washington. Another major effort in this sub-region is the conservation and harvest hatchery program directed on Lake Washington sockeye. The HSRG provided a number of recommendations for allowing fish from this program to more closely emulate the natural life history pattern of sockeye in the Cedar River and Lake Washington, increasing its scientific defensibility.

The Green River sub-region has more than a century's history of hatchery and natural production existing side-by-side on a Chinook stock that has remained relatively healthy. The region also features several net pen programs, which acclimate and release smolts in marine areas where a targeted fishery of returning adults is desired. Accordingly, this region is one where the HSRG's recommendations about reducing straying risks from outplanting and net pen programs[33] were a particular focus.

Regional Participants - Paul Hage, Richard Johnson, Mike Mahovlich, Dennis Moore, Isabel Tinoco, Muckleshoot Tribe ; Marianna Alexandersdottir, Kyle Brakensiek, Ken Currens, Willy Eldridge, Bruce Stewart, NWIFC; Frankie John Jr., Russ Ladley, Chris Phinney, Blake Smith, Puyallup Tribe; Rich Brooks, Mike Huff, Rob Purser, Jay Zischke, Suquamish Tribe; Brodie Antipa, Charmane, Ashbrook, Chuck Baranski, Deborah Cornett, Tom Cropp, Jeff Davis, Bob Everitt, Steve Foley, Doug Hatfield, Chad Jackson, Chuck Johnson, John Kerwin, Kirk Lakey, John Long, Darrell Mills, Travis Nelson, Don Nauer , Chuck Phillips, Denis Popochock, Brian Quinton, Doris Small, Chad Stussy, Joan Thomas, Jack Tipping, WDFW.

[33] *See Emerging Issues paper on Outplanting and Net Pen Releases; and recommendations on this subject in Principles and System-Wide Recommendations.*

Hatchery Reform Recommendations March 2004: Hood Canal, Willapa Bay, North Coast, and Grays Harbor

Hood Canal

This region includes the watersheds draining into Hood Canal. Twenty-two hatchery programs were reviewed in this region, with 99 specific recommendations provided. The region featured primarily, but not entirely, hatchery harvest programs. Chum stocks are biologically significant here; and Hood Canal summer chum are listed as threatened under the Endangered Species Act. The HSRG found that the Summer Chum Salmon Conservation Initiative being conducted by a partnership of state, tribal, federal and non-governmental organizations represents a very well designed and operated approach to restoring Hood Canal summer chum, and recommended continuing this program. In one stream (the Big Quilcene River), the HSRG determined that the managers had met their rebuilding goal and recommended discontinuing this program a year earlier then planned. Summer-fall Chinook in Hood Canal are also listed as threatened under the Endangered Species Act as part of the Puget Sound ESU. The HSRG recommended developing a locally adapted, integrated stock of Chinook in the Skokomish River Basin that could biologically serve as a “core populations” for Hood Canal. This population will need to be sustained by hatcheries until the time that improved habitat can support a natural, self-sustaining population. Under the HSRG’s principle of managing hatchery programs based on clear goals, the group recommended that a number of hatchery programs within this region be adjusted to meet current harvest needs, either by reducing the number of fish released or by increasing harvest. And the HSRG determined that the managers need to take into account facility water and space availability in determining the optimum species mix at the region’s hatcheries.

Regional Participants - Lee Boad, Dan Hannifous, Eileen Palmer, and Neil Werner, Hood Canal Salmon Enhancement Group; Rick Endicott and Joy Lee, LLTK; Kyle Brakensiek, Willy Eldridge and Marcia House, NWIFC; Chris Weller, PNPTC; Tim Seachord, Port Gamble S’Klallam Tribe; David Herrera, Skokomish Tribe; Dan Adkins, Martin Chen, Kent Dimmitt, Kirt Hughes, Thom Johnson, Ed Jouper, Steve Kalinowski, Bob Leland, Darrell Mills, Denis Popochock, Brad Sele, Doris Small, Jack Tipping and Ron Warren, WDFW; and Judy Gordon, Tom Kane, Sonia Mumford, Larry Telles, Ron Wong, Bob Wunderlich and Dave Zajac, USFWS.

Willapa Bay

This region includes the watersheds draining into Willapa Bay. Twenty hatchery programs were reviewed in this region, with 120 specific recommendations provided. This and the other two coastal regions (North Coast and Grays Harbor) differ from the Puget Sound regions in that they feature numerous, smaller, independent systems that drain into the bay or directly into the Pacific Ocean and the Strait of Juan de Fuca. This means the HSRG had many more stocks and programs to consider per region, as compared to Puget Sound where the smaller drainages tended to flow into larger rivers. Another difference is that the managers reported a higher number of relatively healthy natural stocks in this region, most likely due in large part to less urbanization.

Unlike the other regions, all hatcheries in Willapa Bay are owned and operated solely by WDFW. However, the regional fisheries enhancement group has views that differ from WDFW as to which stocks should be a priority within the region. In light of this, the HSRG recommended that WDFW, along with local stake-holders, develop a region-wide strategic plan for managing all stocks. This will require developing a better understanding of stock structure and identifying core populations for each species, and designing hatchery programs and strategies around this structure. For Chinook, the HSRG determined that—given the limited potential for Chinook habitat in the Nemah River, the uncertainty of the stock structure, and the history of hatchery releases in this watershed—developing viable stocks in the Naselle and Willapa rivers may better meet the stock goals for the region than attempting to create a properly integrated Nemah River Chinook program. In this region, the HSRG re-emphasized the importance of using in-basin rearing and locally-adapted broodstocks. Importing and moving eggs and juveniles into and out of a watershed inhibits natural biological processes related to homing fidelity, viability, and local adaptation. Ensuring that naturally-spawning stocks drive the adaptation will require increasing the number of natural-origin fish brought into the hatchery broodstocks each year. Distinguishing hatchery and natural origin during spawning will also be necessary. The HSRG also found that there is less monitoring and evaluation occurring in this region than in any other. This lack of information prevents the managers from knowing what benefits the programs provide or risks they create.

Regional Participants - Kyle Brakensiek and Willy Eldridge, NWIFC; Charlie Stenvall, USFWS; and Randy Aho, Robert Allan, Jim Bauer, William Campbell, Larry Durham, Rich Ereth, Manuel Fariñas, Kirt Hughes, Ken Jansma, Dave Kloempke, Darrell Mills, Ike Queral, Chad Stussy, Jack Tipping, and Ron Warren WDFW; Don Amend and Ron Craig, Willapa Bay Fisheries Enhancement Group; and Jim Mitby, Willapa Bay Gillnetters Association.

North Coast

This region includes the coastal drainages west of—and including—the Hoko River and north of Grays Harbor. Twenty-eight hatchery programs were reviewed in this region, with 188 specific recommendations provided. The North Coast provided several examples of hatchery programs—Chinook in particular—that meet the HSRG's guidelines for properly integrated programs, meaning that a sufficient number of natural-origin fish are included in the hatchery broodstock and the number of hatchery-origin fish on the spawning grounds is kept low enough to allow natural-origin spawners to drive the adaptation of the stock. Meeting these guidelines also requires that the programs be sized to suit the available receiving habitat, so as not to compete with natural production. Hatchery programs also need to be sized to take into account facility limitations and conditions (such as water quality, quantity and temperature, and rearing space). The HSRG saw several such challenges in this region, especially at Makah National Fish Hatchery.

In addition, the group expressed concern about the use of introduced stocks in Quillayute system. The HSRG agreed that improved rearing and incubation facilities were needed at several regional facilities in order to implement the group's recommendations. Some of the tribes, in particular, are undertaking significant conservation programs without the necessary infrastructure to ensure the success of these programs, and are relying on creativity and patch-work solutions. The HSRG concluded that the tribal conservation program for Lake Ozette sockeye was well designed and efficiently operated and should continue as planned. Steelhead survival rates on the coast are currently significantly higher than in Puget Sound. Consequently, this region features the most successful steelhead harvest programs of any region the HSRG has reviewed in terms of making a significant contribution to harvest. However, the HSRG found that additional investment in adult capture facilities for steelhead may be necessary to reduced risks to naturally spawning populations.

Regional Participants - Jim Jorgenson, Hoh Tribe; Joe Hinton, Al Jensen and Caroline Peterschmidt, Makah Tribe; John Meyer, National Park Service, Marianna Alexandersdottir, Kyle Brakensiek, Willy Eldridge and Sandy Zeiir, NWIFC; Mark Galloway and Kris Northcutt, Quileute Tribe; Guy McMinds, Mark Mobbs and Steve Meadows, Quinault Indian Nation; Ray Brunson, Joy Evered, Paul Hayduk, Tom Kane, Dan Sorensen and Dave Zajac, USFWS; and Martin Chen, Manuel Farinas, Mike Gross, Darrell Mills, Scott Moore, Don Rapelje, Jack Tipping, Ron Warren and Scott Williams, WDFW.

Grays Harbor

This region includes all the rivers and streams draining into Grays Harbor, including the Chehalis River Basin. Thirty-one hatchery programs were reviewed in this region, with 230 specific recommendations provided. The HSRG recommended that the managers identify fall, spring and summer Chinook stocks in this region; determine the status of these stock components; and minimize impacts on natural spawners during adult collections targeting a specific stock or race. In addition, the group called for marking and tagging all hatchery Chinook and coho, to determine their contribution to harvest and the proportion of hatchery-origin versus natural-origin fish on the spawning grounds. The HSRG also recommended the managers take steps to maintain and encourage regional coho diversity in this large, geographically diverse region. DNA analysis has shown that coho are more genetically diverse than was previously assumed. This will require further analysis of regional stock structure and the use of locally-adapted broodstocks. It was unclear to the HSRG that there was a need for the chum conservation programs in this region. The HSRG suggested an alternative to its Wild Steelhead Management Zones approach for this region because many of the Grays Harbor steelhead programs are using locally-derived integrated stocks, as opposed to the introduced, segregated stocks that typify steelhead programs in other regions. As part of this approach, the HSRG recommended that the managers dedicate WRIA 23 to integrated, native stocks only, and dedicate the Wishkah River to only natural production. Grays Harbor featured the largest amount of educational and cooperative programs the HSRG has seen. While strongly supportive of education programs, the HSRG said these need to exemplify proper program design and operations, with clear educational objectives, consistent with conservation needs.

Regional Participants - Lonnie Crumley, Jim Dunn, Joe Durham, Doug Fricke and Dave Hamilton, Chehalis Basin Fisheries Task Force; Terry Baltzell, LLTK; Marianna Alexandersdottir and Kyle Brakensiek, NWIFC; Steve Meadows, Quinault Indian Nation; and Randy Aho, Rob Allan, Gary Bell, Bill Campbell, Rich Ereth, Manuel Farinas, Curt Holt, Kirt Hughes, Ken Isaksson, Joel Jaquez, Dave Kloempken, Joe Rothrock, Jack Tipping, Ron Warren and Kevin Young, WDFW.

Conclusions

THE FUTURE OF HATCHERIES

Because of its Congressional mandate, the Hatchery Scientific Review Group (HSRG) has had a unique opportunity over the last four years to intensively study all aspects of salmon and steelhead hatchery management in Puget Sound and coastal Washington.[34] As a result, the HSRG has formulated a number of conclusions about hatcheries and how they should be operated:

- Hatcheries do have a role in the future, as **part of an integrated strategy** (alongside harvest management and habitat protection/restoration) to meet conservation and harvest goals on a sustainable basis.
- Hatcheries of the future must be different from those of the past. There is both need and opportunity to make them better by ensuring that they are more consistent with ecological and genetic/evolutionary principles.
- Sustainability of salmon stocks and harvest opportunities in the Pacific Northwest must be based on protection and restoration of natural populations and their habitats. Hatcheries cannot be simply regarded as surrogates for lost habitat.
- Hatchery programs must be planned and operated with consideration of the potential for genetic and ecological interactions with natural stocks.
- Hatcheries are by their nature a compromise, a balancing of benefits and risks to the target stock, other stocks, and the environment affected by the hatchery program. A hatchery program is the right solution only if it is better, in a benefit/risk sense, than alternative means for achieving the same or similar goals.
- A detailed set of operational guidelines for all hatchery programs should be adopted and implemented by the co-managers. These guidelines should address all life stages of propagated fish, be derived from an explicit scientific framework, and be tailored to the specific purpose (conservation and/or harvest) and type (integrated or segregated) of each hatchery program.
- While all hatchery programs are classified by intent as either integrated or segregated, most programs do not achieve the guidelines for proper integration or proper segregation. Plans should be developed and implemented for each program to meet those guidelines.

[34] *The HSRG met monthly for four years, typically for three days, and systematically reviewed over 200 hatchery programs.*

- The performance of each hatchery program should be routinely evaluated and reported. This evaluation should address consistency with resource goals and coordination with other strategies to meet those goals. A system for effective and timely collection, analysis and dissemination of data and information must be implemented.

- A research agenda must be established to guide funding for applied hatchery research in the Pacific Northwest. This agenda must be directed towards an increased understanding of the benefits and risks from hatchery programs. Knowledge and information gained from this research should be incorporated into an explicit and comprehensive scientific framework that informs decision-making.

- Hatchery programs and resource management plans should be consistent with the principles of: 1) establishing well-defined goals, 2) being scientifically defensible, and 3) using informed decision making. Implications of this include:

    - Hatchery programs must have well-defined goals to direct their operations and permit meaningful program evaluation. Once the goals for the resource have been established, a scientific rationale for designing, building and/or operating each hatchery and hatchery program must be developed to guide the hatchery program in achieving its desired outcomes. The use of hatcheries as part of the strategy to meet these resource goals must be scientifically defensible.

    - Integrated hatchery programs are linked very closely to a naturally spawning stock. For these programs, some broodstock must be derived from the natural stock, and broodstock collection and hatchery operations must be consistent with allowing the natural environment to drive the adaptation of the combined natural-/hatchery-origin population.

    - Local adaptation is important for the sustainability of all populations. Thus, stock transfers between watersheds are likely to interfere with local adaptation and should be avoided. Hatchery broodstock should be managed to foster local adaptation.

    - The sizing of hatchery programs (number of fish released) should take into account current and expected future conditions of the available habitat (including habitat limitations), potential genetic and ecological interactions with natural stocks, as well as economic and cultural goals. Hatchery program should always be sized to take into account the potential for negative effects on naturally spawning stocks and the environment.

    - Hatcheries can impair existing habitat and naturally spawning fish, by virtue of their associated structures. In designing hatcheries, particular care should be taken so that water intakes, effluent treatment facilities, juvenile release locations and adult collection structures do not impair habitat or naturally spawning fish.

- Because of inevitable uncertainty, hatcheries should be designed for flexibility and their operations adapted to changing environmental conditions, stock status and new scientific information.

- To be successful, hatcheries must develop and maintain an up-to-date and unified database that allows resource managers to regularly evaluate and adjust hatchery programs, taking into account changes in the status of natural stocks, the carrying capacity of receiving waters, ocean productivity and harvest needs.

- All watersheds are different. Thus, hatchery programs must be designed and operated consistent with current and expected future condition of habitats and the natural stocks that depend on those habitats.

- Hatcheries must take into account the programs of other hatcheries occurring in the same watershed or region, so that they are complimentary to each other and are collectively consistent with resource goals in the watershed or region.

- The value of hatcheries can no longer be judged solely by the number of fish released and returning. Rather, hatchery programs should also be evaluated based on: 1) the degree to which they have taken into account the ecosystems they might effect, 2) their willingness to adapt to changing conditions in those ecosystems, both freshwater and marine, 3) whether they are indeed the "best" strategy for meeting resource goals, and 4) whether they are compatible with (i.e., complementary to, and integrated with) other strategies.

EXAMPLES OF SUCCESSFUL HATCHERY PROGRAMS

During 2001–03, the HSRG reviewed over 200 hatchery programs, in ten identified regions of Puget Sound and coastal Washington. This systematic, science-based review found a number of programs that stand out as examples of hatchery programs that are being conducted in the context of clearly articulated goals for the resource, and are the right tool for helping to successfully achieve those goals, given the particular circumstances. A few of these programs are presented below as examples of hatchery programs that are: 1) helping to recover and conserve naturally spawning populations; 2) supporting sustainable fisheries; or 3) providing other benefits, such as education. This is not to say that these programs are all without flaw or could not be improved. But they are, overall, in keeping with the HSRG's key principles of operating hatcheries in the context of clear goals, scientifically defensible programs, and informed decision making. The HSRG notes that for all integrated hatchery programs, success will ultimately depend on good habitat being available to both the hatchery- and natural-origin components of the population.

Conservation

White River Chinook

In 1977, fewer than 50 naturally-spawning spring Chinook returned to spawn in the White River. Responding to this crisis, a multi-agency recovery effort by the Muckleshoot Indian Tribe, Puyallup Tribe of Indians, Washington Department of Fish and Wildlife (WDFW), US Fish and Wildlife Service (USFWS), US Forest Service, National Oceanic and Atmospheric Administration/National Marine Fisheries Service (NOAA Fisheries), Nisqually Tribe and Squaxin Island Tribe developed the White River Chinook Recovery Plan. This plan has used captive breeding and multiple juvenile rearing and release strategies to increase the number of adults returning to spawn. As a direct result of this program, nearly 1,000 adults returned to spawn naturally in each of the last two years. Without intervention, this unique stock of Chinook would be extinct today.

Elwha Chinook

This cooperative effort between WDFW, the Lower Elwha Tribe and the National Park Service is a good example of a long-term gene banking program. It is successfully maintaining a naturally spawning population of Elwha Chinook until recolonization of the upper watershed can occur, after the scheduled removal of two dams on the Elwha River that have blocked this unique Chinook stock's access to pristine habitat for nearly 100 years.

Snow Creek Coho

This conservation program, operated by WDFW, is a well-conceived and science-based plan for recovering a threatened, native coho population. Prior to intervention, spawning escapement was below 100 fish (and often as low as 20), per year over a 20 year period. Every adult was captured, artificially spawned and its eggs were incubated in a hatchery. After that, groups of fry were exposed to a variety of rearing and release strategies, to increase the possibility that one or more would prove successful. A five-fold increase in adult survival has been realized from these efforts, thus avoiding imminent risk of extinction for this stock.

Lake Ozette Sockeye

The purpose of this well-designed and efficient program, operated by the Makah Tribe, is to achieve the recovery of this Endangered Species Act (ESA)-listed stock by augmenting the river-spawning component of the population and establishing self-sustaining runs in underused habitat in Lake Ozette tributaries. This stock is all the more valuable because genetics studies indicate it is a native stock, with little or no history of fish transfers into the basin, and no evidence of interbreeding. Reintroductions into the tributaries have been increasingly successful in reestablishing spawning aggregations. Domestication selection risk is reduced by the small size and early life history stage at which the fish are released from the hatchery.

Hood Canal Summer Chum Conservation Initiative

Hood Canal and Strait of Juan de Fuca summer chum experienced a severe drop in abundance in the 1980s, and returns decreased to all-time lows of less than 1,000 spawners. The Summer Chum Salmon Conservation Initiative (SCSCI) is a well-designed, well-conducted program that appears to be achieving its goals of recovering these ESA-listed fish. Adult returns have increased substantially in chum streams across the program area. SCSCI is an example of a successful conservation program and partnership among state, tribal, private, and federal entities. Partners include WDFW, the Point No Point Treaty Council (PNPTC), Hood Canal Salmon Enhancement Group, Long Live the Kings (LLTK), NOAA Fisheries and USFWS. The program, which may serve as a prototype for similar efforts in the future, has met the HSRG's first key principle of beginning with a solid goal setting process. The plan also calls for collecting and analyzing the data necessary to evaluate the program's success. Ensuring complete monitoring and evaluation of this program will be crucial to meeting the HSRG's second and third principles—scientific defensibility and informed decision making.

Hamma Hamma Steelhead

Hood Canal winter steelhead numbers began to show a serious decline two decades ago. The number of naturally spawning adults has remained precipitously low since then. A partnership between LLTK, HCSEG, NOAA Fisheries, PNPTC, USFWS, and WDFW, this well-designed and scientifically-sound recovery program for Hamma Hamma winter steelhead features the only captive brood and two year-old smolt programs in Washington state. Fish for this program are thought to be indigenous, with little or no history of stock transfers, introductions, or artificial propagation. The rearing program includes exercise for the captive brood fish, and smolts are fed on a schedule that mimics nature. Initial results indicate that the program has a good chance of achieving the goals for the stock, though low ocean survival trends for steelhead from this region may make this more difficult. If this program is successful in the long-term, it could serve as a model for steelhead conservation programs.

Harvest

Green River Hatchery Fall Chinook

The Washington Department of Fish and Wildlife's Green River Hatchery has propagated Chinook and provided harvest on these fish for over 100 years. Harvest goals are consistently achieved within Washington waters. Significant numbers of natural-origin adults are used each year for broodstock, integrating this hatchery stock with the natural stock. As a result, the hatchery stock also contributes to meeting natural production goals for fall Chinook in a compromised habitat.

Tulalip Bay Hatchery Chum

This hatchery program, operated by the Tulalip Tribes and directed at a stock that is kept genetically segregated from natural stocks in the region, meets its goal of high harvest rates, without apparent adverse effects on other regional stocks. The hatchery fish are marked and monitored, to ensure that straying into adjacent watersheds does not have an adverse affect on naturally spawning stocks.

Wynoochee Winter Steelhead

This program, operated by WDFW is a mitigation program for the Wynoochee River Dam. Fish for this WDFW program originated from—and are kept genetically integrated with—native Wynoochee River fish, unlike the non-local, segregated stocks that typify steelhead programs in other regions. The program is being operated consistent with short- and long-term stock goals, and is providing harvest benefits. The likelihood of attaining these goals is high, due to relatively good survival of coastal steelhead stocks in recent years. The HSRG recommended that the managers monitor the natural spawning population and take steps to reduce hatchery-origin fish spawning naturally by following HSRG spawning and integrated population management guidelines.

Education

Issaquah Hatchery

This Washington Department of Fish and Wildlife hatchery has become a cherished asset to the urban community in which it is located—Issaquah, Washington. A dedicated group of volunteers called Friends of Issaquah Salmon Hatchery (FISH) provides both casual visitors and organized classes with detailed information about salmon life history, species identification, migration patterns, the importance of functional habitat, and other environmental education topics. Signs, interactive displays, and viewing areas for observing daily operations are used heavily by the public. The hatchery is an integral part of Issaquah's annual Salmon Days festival, when over 300,000 visitors tour the facility during a single weekend.

Pipers Creek Chum, Carkeek Park

Located in a highly urbanized part of Seattle, this is another example of a grass-roots program whose efforts have expanded into a productive, environmental-based cooperative between local community supporters and public agencies. The program began as an effort to reintroduce salmon to a creek where they had been extirpated for several decades. The program has grown into a fully-functional, environmental education center.

Cooperative Programs

The managers are fortunate to have the dedication, energy and resourcefulness of many non-governmental, educational and citizens groups to assist them in meeting conservation, harvest and other goals for Puget Sound and coastal Washington salmonids. Fourteen Regional Fisheries Enhancement Groups, dozens of Salmon in the Classroom programs, a number of not-for-profit organizations, and hundreds of private citizens and volunteers augment and expand what the state, tribal and federal operators of the hatchery system are able to do on behalf of the area's salmonids. In this way, their efforts go beyond meeting educational goals, to in fact playing an essential role in meeting conservation and harvest goals for the resource.

Appendices

A. Scientific Framework for the Artificial Propagation of Salmon and Steelhead

CONTENTS

OVERVIEW

Early in the project's first year (2000), the Hatchery Scientific Review Group (HSRG) agreed that hatchery programs should no longer be seen as surrogates for lost habitat. Instead, hatchery programs must be viewed as tools that can be managed as part of an integrated strategy to meet watershed or regional resource goals, in concert with actions affecting habitat, harvest rates, water allocation and other factors. Using current scientific knowledge, and consideration of the benefits and risks to all affected stocks, a hatchery program should be conducted only if it is deemed the best available tool for achieving those goals.

Under this model, healthy, available habitat is essential to an effective hatchery program. In addition, resource managers have to consider whether a hatchery program is the best means to achieve the goal, once the risks and benefits from the program are considered. To scientifically evaluate the hatcheries in Puget Sound and coastal Washington in this new context, the scientists recognized the need for a scientific foundation for their work.

The HSRG's scientific framework is the foundation for evaluating the benefits and risks of hatchery programs in Puget Sound and coastal Washington. Its purpose is to provide a detailed review and evaluation of the scientific literature as justification for the recommendations developed through the Regional Review Process that occurred in 2001-2003. The results of this review effort are detailed in three separate volumes (Appendix I) and are available at www.hatcheryreform.org.

The framework informs all the HSRG's tools, processes and recommendations and provides the scientific approach for achieving Principle 2: Scientific Defensibility.[35] The framework organizes the current state of knowledge, about how actions associated with hatcheries affect the environment and fishery resources, around six key topics:

1) Hatchery Programs: Definitions of Purpose and Type
2) Hatcheries in the Ecosystem Context: The Regional Approach
3) Hatcheries in the Populations/Species Context
4) Effects of Hatchery Operations on Harvest and Conservation of the Target Stock
5) Effects of Hatchery Fish on Harvest and Conservation of Other Stocks and Species
6) Monitoring and Evaluation: Managing Hatchery Programs for Accountability and Success

The framework begins by classifying hatcheries in terms of their purpose and type. This classification reflects a new way of thinking about and defining hatcheries, and provides a foundation for describing and reviewing them in a systematic and scientific manner. The next two topics deal with the effects of hatcheries on the ecosystem and on other fish populations. Topics four and five address the effects of

[35] *See Applied Hatchery Reform chapter, Principles and System-wide Recommendations*

hatcheries on resource goals for the target stock and other stocks. The final topic deals with accountability through monitoring and evaluation.

The framework was first released to the public in December 2000, after extensive peer and stakeholder review and prior to development of the review tools and inception of the regional review process. It has subsequently been updated to incorporate recent scientific and technical information that became available or was developed in 2001-2003 through the review process.

CHAPTER 1. PURPOSES AND TYPES OF HATCHERY PROGRAMS

Hatcheries have propagated Pacific salmon and steelhead in the Pacific Northwest for nearly 130 years (reviewed by Lichatowich 1999). The first hatchery in the Puget Sound area was established on the Baker River in 1896. Most hatcheries in Puget Sound and coastal Washington have been in operation for decades and were built to produce fish for harvest, compensating for declines in naturally spawning populations. Hatchery-origin fish are important to the North Pacific recreational and commercial fishing economy and to meeting tribal treaty harvest needs.

The abundance and productivity of salmon and steelhead stocks has varied throughout the period that records have been maintained. For example, in 1977 returns of adult salmon and steelhead began to decline precipitously. These declines occurred despite increasing numbers of hatchery fish released during the preceding 20 years. This decline is presumed to be related to a major decadal shift in ocean conditions, associated with increased marine temperatures in the northeast Pacific Ocean (Cooper and Johnson 1992, Beamish and Bouillon 1993, Lichatowich 1993, Olsen and Richards 1994, Cramer 2000). Increased urbanization and poor land-use practices also contributed to declines in the abundance of Pacific salmon and steelhead. These declines ultimately led to the 1999 threatened listing of Puget Sound fall Chinook and Hood Canal summer chum salmon under the federal Endangered Species Act (or ESA, Fed. Reg. 1999).

Fishery scientists have identified hatcheries as one of the factors contributing to declines in abundance of naturally-spawning salmon populations (e.g., Waples 1991; Hilborn 1992; Reisenbichler and Rubin 1999; Levin et al. 2001). For example, some facilities have negatively affected natural populations by inhibiting freshwater migrations of adult and juvenile fish and removing sexually mature adults for broodstock. In addition, ecological and genetic interactions between hatchery- and natural-origin fish have been postulated as factors affecting the viability of natural populations. The once-common practice of transferring and releasing hatchery fish between watersheds or rivers is now recognized as a potential risk to natural populations.

As a consequence of the ESA listings, federal, state and tribal fishery managers must demonstrate that their hatcheries do not present unacceptable risks to naturally spawning populations. Harvest restrictions to protect natural populations, including compliance with ESA, limit the ability of commercial, tribal and recreational fishers to harvest relatively abundant fish from successful hatchery programs. Minimizing these risks, while at the same time maintaining sustainable fisheries, presents a major challenge to fishery managers.

The HSRG has concluded that in order to review benefits and risks of hatchery programs in a systematic and scientific manner, each program must explicitly be defined in terms of its purpose and type. The purpose of the program spells out what the hatchery program is expected to accomplish in relation to goals set for the resource (e.g., harvest and/or conservation). The type of program defines its genetic management goal. This goal defines the relationship between the propagated stock and the natural stock (i.e., integrated or segregated). The purpose and type of each hatchery program must be defined before program components can be developed or evaluated.

1.1 Purposes of Hatchery Programs

The HSRG recognizes two primary purposes of hatchery programs: 1) help conserve naturally spawning populations and their inherent genetic resources, and 2) provide fish for harvest. Many hatchery programs are designed to provide both harvest and conservation benefits. Other purposes of hatchery programs include scientific research, education, and providing cultural benefits, particularly for American Indian tribes. Each of these identified purposes is briefly described below.

1.1.1 Conservation

Hatchery programs with conservation goals vary substantially in size and scope. The ultimate goal of such programs is to conserve natural populations and their genetic resources. Captive breeding of endangered populations is one extreme example (Schiewe et al. 1997). On the other hand, a hatchery program propagating a native population for harvest may also have conservation objectives, if a long-term goal is to conserve the genetic resources of that population. Conservation goals impose additional operational requirements on hatcheries, as compared to simply producing fish for harvest. However, such conservation-motivated objectives may also help support sustainable fisheries in the long-term. Consequently, the HSRG recognizes conservation as a very important purpose of hatcheries, both from the standpoint of conserving genetic resources and supporting sustainable fisheries.

1.1.2 Harvest

Most hatchery programs in Washington state were developed for the single purpose of producing fish for harvest. That harvest can take place in recreational, commercial, ceremonial, and subsistence fisheries. Hatchery programs also provide fish for indicator/index stock programs that inform and direct harvest management. Harvest continues to be the primary purpose for the majority of hatchery programs. However, simply producing fish for harvest may not be sufficient to meet long-term resource goals; rather, hatcheries must be managed in a manner that helps support and maintain sustainable fisheries, while minimizing negative impacts to naturally spawning populations.

1.1.3 Education and Research

Hatcheries are in a unique position to provide educational and research opportunities because they represent “living laboratories” where the biology of the fish can be studied and populations monitored. As a place where citizens can see and work with salmonids from their egg to adult stages, each hatchery has the potential to serve as a venue for community involvement and education, and a source of data and information about salmonid biology, fisheries and ecology.

1.2 Types of Hatchery Programs

Hatchery programs for Pacific salmon and steelhead can be classified as either integrated or segregated based on the genetic management goals and protocols for propagating a hatchery broodstock. Hatchery programs are classified as genetically integrated if a principal goal is to manage the hatchery broodstock as a genetic component of a naturally-spawning population such that the natural environment drives the adaptation of the composite population made up hatchery and natural fish. Hatchery programs are classified as genetically segregated if the broodstock is propagated as a reproductively discrete population primarily, if not exclusively, with adult returns back to the hatchery. In segregated programs, little or no gene flow should occur from a naturally spawning population to the hatchery broodstock. In the context of managing salmon and steelhead hatcheries, all programs should be either genetically integrated or segregated relative to naturally spawning populations. This defines the intent of the program, therefore, no program can be classified as both or intermediate.

1.2.1 Genetically Integrated Programs

Hatchery programs can be classified as integrated if: a) a principal management goal is to minimize genetic divergence between the hatchery broodstock and a naturally spawning population; and b) natural-origin fish are regularly included in the hatchery broodstock at a level sufficient to prevent such genetic divergence. In an idealized integrated program, natural- and hatchery-origin fish simply represent two genetically-equal components of a common gene pool within the watershed where adults are trapped for broodstock and progeny fish released. A fundamental goal of an integrated program is to minimize genetic changes resulting from artificial propagation; thereby reducing genetic risks of hatchery-origin fish to a naturally spawning population.[36] Another goal is for hatchery fish to represent a potential genetic repository for the natural population, in case of a major decline in abundance (e.g., as a result of stochastic environmental events, over-fishing, etc.). Under this idealized integrated concept, the hatchery represents an artificial extension of the natural environment, thereby increasing the total reproductive capacity of the target population. This increased reproductive capacity can conceptually yield both harvest benefits to fishers and demographic benefits to the target population. However, integrated programs will invariably represent trade-offs between ease of culture and achievement of genetic management goals.

An integrated hatchery program does not imply that gene flow from the hatchery component into the naturally spawning component necessarily occurs or is desired; on the contrary, the goal of an integrated program is not for hatchery-origin fish to necessarily spawn naturally but, rather, to maintain the genetic characteristics of a natural population in the hatchery broodstock. This goal necessitates a minimum amount of gene flow from the natural population to the hatchery broodstock each generation, while controlling or restricting gene flow from the hatchery component to the natural component.[37] Deliberate gene flow from the hatchery broodstock to a natural population relates strictly to the purposes and intended benefits of hatchery-propagated fish after release (e.g. restoration or recovery of natural populations) and not directly to the genetic management goals for the hatchery broodstock. Indeed, if the natural population component is self-sustaining and can supply natural-origin fish to the hatchery broodstock each year—albeit,

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[36] *See this Scientific Framework's section on domestication.*

[37] *See Appendix B, Emerging Issues paper on Integrated and Segregated hatchery programs.*

without reducing natural productivity below a level necessary for the natural population to sustain itself—then no demographic need would exist for hatchery fish to spawn naturally.

1.2.2 Genetically Segregated Programs

Hatchery programs are classified as segregated if the hatchery population is propagated as a genetically discrete or segregated population relative to naturally spawning populations. The principal goal of a segregated broodstock program is to create a new, hatchery-adapted population to meet co-manager needs for harvest or other purposes. Hatchery broodstocks (and programs) are considered genetically segregated if the broodstock is maintained primarily or exclusively from adults returning back to the hatchery. As a consequence, little or no gene flow from a natural population to the hatchery broodstock is intended to occur in a segregated program.

Segregated hatchery broodstocks are expected to diverge genetically from the source founding population or local natural populations, due to genetic drift and potential domestication effects. Moreover, segregated hatchery broodstocks are often selectively bred for particular traits (e.g., early run-timing) to facilitate ease of culture and/or to help achieve harvest benefits. Segregated programs are usually managed in a way that maximizes productivity or efficiency of hatchery operations. Natural spawning of returning adults from a segregated hatchery program is usually considered highly undesirable; because of the genetic risks those fish pose to natural populations. In addition, hatchery-origin fish from segregated programs may pose significant ecological risks if those fish directly compete with, or prey upon, natural-origin fish. Indeed, properly managed segregated programs must ensure that hatchery-origin fish do not stray or spawn naturally, or do so at very low rates to minimize biological risks to natural populations. In this context, not only is the broodstock segregated genetically from a natural population, but released fish from that broodstock must be ecologically and genetically segregated from natural-origin fish as much as possible in the natural environment. Consequently, segregated programs usually represent major trade-offs between maximizing operational efficiency of the hatchery program and minimizing biological risks to naturally spawning populations.

CHAPTER 2. HATCHERY PROGRAMS IN THE ECOSYSTEM CONTEXT: THE REGIONAL APPROACH

Hatcheries can no longer be regarded as surrogates for lost habitat. In operating hatcheries, consideration must be given not only to the receiving habitat in which they operate but also to the hatchery propagated and naturally-spawning fish that depend on the existing habitat. In addition, hatcheries must take into account the programs of other hatcheries occurring in the same watershed or region. Only in this way will adverse interactions between salmonid stocks in the watershed or region be recognized. Hatcheries also have the potential to impair existing habitat and naturally-spawning fish populations by virtue of their associated structures and by the inappropriate sizing of their programs. In designing hatcheries and their programs, these factors have, therefore, to be borne in mind.

No longer can the value of hatcheries and their programs be judged solely by the size of their releases and returns. Rather, hatcheries and their programs will also have to be evaluated on the degree to which they have taken into account the ecosystem on which they might have an impact and on their willingness to adapt to changing conditions in the ecosystem, both freshwater and the marine. The fitness of naturally spawning populations, their productivity, and the numbers of adult salmon returning to individual watersheds, ultimately depend on the natural habitat and on climatic conditions affecting its productivity.

Therefore, it is appropriate to review hatchery programs in Puget Sound and coastal Washington using a regional approach, taking into account the nature of the watersheds in which the programs occur and the goals set for the programs by the managers. Each watershed or region differs significantly in the quality and quantity of habitat, the status of salmonid stocks within those regions, and the regional goals.

A review of the Puget Sound/coastal Washington hatchery system as a whole would result in general recommendations not suited to regional differences in habitat and management goals. Decision making program-by-program or hatchery facility would fail to consider how best to use the hatchery system as a whole and would fail to take into account cumulative, regional effects.

2.1 Receiving Habitat

Healthy habitat that can support the life cycle of a salmon population is necessary to the success of any hatchery program. The environmental conditions experienced by hatchery fish following their release vary depending upon when and where they are released. The health and viability of hatchery populations are dependent upon quality, complexity and connectivity, and quantity of the receiving habitat; and temporal climatic changes affecting habitat.

2.1.1 Quality of the Receiving Environment

The quality of the receiving environment refers to the condition of the habitat available to hatchery-origin fish following their release from the hatchery (Bjornn and Reiser 1991; Reeves et al. 1991; Doppelt et al. 1993; Beechie et al. 1994; Bilby et al. 1996; Mobrand et al.1997). Significant departures from optimal habitat quality conditions may result in failure to meet natural productivity requirements. Factors affecting the quality of the receiving environment vary by habitat type (freshwater, estuarine, marine near-shore, and marine off-shore). Among the factors to consider are channel stability, riparian condition, habitat diversity, water flow, sediment load, nutrient load, obstructions, oxygen, chemicals, pathogens, temperature, competition, predation, food, and salinity (Lichatowich et al. 1995).

2.1.2 Complexity and Connectivity of Receiving Environment

The complexity and connectivity of the receiving environment affect survival and life history diversity of hatchery populations. Life history diversity, which is the species' solution to a dynamic environment, is determined both by genetic and phenotypic traits and by the ability of the habitat to support multiple life history pathways (Mobrand et al. 1997). The latter is determined by the patterns of connected, high quality habitat segments (see also 2.3 and 3.1.3).

2.1.3 Quantity of Receiving Habitat

The abundance potential of a hatchery population is in part a function of the quantity of food and space available in the receiving natural habitat (Hall and Field-Dodgeson 1981; Nickelson et al. 1986; Hunter 1991; Reeves et al. 1991; Nickelson et al. 1993). The availability of food and space affects the survival of hatchery fish through density-dependent mechanisms such as competition and predation. Generally, survival decreases with increasing population density. Density is determined by the quantity of key habitat, the abundance of hatchery fish and their rate of dispersal (Lestelle et al. 1996).

The present hatchery system for Pacific salmon was developed to meet fishery demands and compensate for losses in salmonid habitat. The hatchery goal has traditionally been to produce increasingly higher numbers of fish that would grow to harvest size in an oceanic ecosystem, believed to be constant and near limitless in its capacity to provide food and space for hatchery salmon. The modern view of the ocean ecosystem is, however, one characterized by ecological uncertainty (Mahnken et al. 1998).

2.1.4 Temporal Climatic Changes Affecting Habitat

Decadal and inter-annual changes in productivity of salmon populations are an increasingly well recognized phenomenon, and it apparently reflects the stochastic and deterministic effects of environmentally driven changes in salmonid habitat. Studies on abundance of salmonid stocks in widely separate geographic areas over time have indicated oceanic conditions are primarily responsible for changes in annual returns of adult salmon (Cooper and Johnson 1992, Beamish and Bouillon 1993, Lichatowich 1993, Olsen and Richards 1994, Cramer 2000). The way in which physical, chemical, and biological processes in the ocean impact fish populations and production trends is reasonably well known.

2.2 Habitat – Current Status and Short and Long-term Goals

One of the factors to be taken into account in reviewing hatchery programs is the status of the freshwater habitat into which the hatchery fish are to be released. Both the current and the future status of the habitat should be considered. Silt free incubation gravels and cool, stable incubating water are necessary for the survival of salmon embryos. Flowing streams with complex structure, riparian vegetation, seasonal flow stability, and productive estuaries are necessary to the survival of juvenile salmon. Flowing streams are also necessary for the successful passage and spawning of returning mature adults. In reviewing hatchery programs, several categories of freshwater habitat are recognized. These freshwater habitat categories are defined in some detail in the HSRG's Benefit-Risk Tool.[38]

In addition, there is increasing evidence that the size of hatchery releases should take into account changing marine conditions. Based on an analysis of climatic trends and the productivity of salmon fisheries in the North Pacific, Beamish and Bouillon (1993) noted that the strategy of releasing large numbers of artificially reared smolts during a period of decreasing marine survival is not scientifically defensible. Although harvest rates are generally scaled back when the abundance or productivity of naturally-spawning stocks is low and regime shifts become evident, hatchery production is not scaled back. Given that the carrying capacity of the ocean has a primary impact on salmon returns, it is eminently sensible that hatchery releases should be reduced during periods of poor ocean survival to protect naturally-spawning fish. Furthermore, regime shifts, or major changes in ocean productivity, are becoming increasingly predictable and therefore should be a consideration in managing hatchery programs.

2.3 Effects of Hatchery Operations on Habitat and Ecological Function

The productivity of an ecosystem (e.g., a receiving habitat) can be gauged on the basis of the heterogeneity of life and habitat within it and by the biomass it supports. The productivity of the system is a function of the collection of biological, chemical, and physical factors/processes that govern the flow of energy and material through it. The ecological function of a particular event in an ecosystem is the effect that the event has on the system. As described below, hatchery structures and operations can affect ecological function.

The functioning of an ecosystem is important because it affects the productivity of the system (Golley 1993; Norton 1994; Haskell et al. 1992; Karr 1992). In this regard, the riparian environment is of primary importance to the proper functioning of riverine, aquatic ecosystems, and to resident or migratory salmonids. The structural complexity and species diversity of this habitat determine both the

[38] *See Appendix G.*

carrying capacity and quality of smolts produced in (or introduced into) these habitats. Vegetation provides shade, moderates stream water temperatures, and provides cover in the form of large woody debris and stream bank overhangs created by roots. Riparian vegetation stabilizes stream banks, binds soil particles, holds water in the flood plain, and provides a source of carbon and nitrogen for the organisms upon which juvenile salmon feed. Rocks and gravel substrate provide structure and features around which salmon establish territory. These complex, dynamic ecosystems are essential for maintaining adaptive behavioral patterns and moderating stress in juvenile salmon.

Nutrients released from hatcheries may affect the productivity of systems into which they drain, the resulting benefit or harm being based on the nutrient loading that occurs. Also, salmon released from hatcheries may serve as prey for a large number of native and non-native fishes. In addition, salmon produced in hatcheries may increase the productivity of a particular drainage by virtue of the nutrients brought back from the sea and released to the water and riparian environment from their carcasses following spawning (Bilby et al. 1996). Returning adult salmon are a unique vector for the delivery of marine nutrients into the freshwater ecosystem. The importance of these nutrients to consumers such as raccoons, bear, eagles, and even man, has been recognized for some time. Recent research also suggests that a significant portion of nitrogen in plants and animals in streams where adult salmon are abundant is derived from those returning adults (Mathison 1988, Kline et al. 1993).

Marine-derived nutrients from returning adult salmon have been found to provide a significant contribution to riparian vegetation and even old growth forests (Reimchen 1994, Bilby et al. 1996). In streams in interior British Columbia, Johnston et al. (1997) found that where salmon carcasses were abundant, up to 60% of the nitrogen in benthic insects was derived from the carcasses. They also found that juvenile salmon show higher growth rates in streams after adult salmon spawn than in streams without spawning adults. Use of hatchery salmon carcasses as a source of these marine derived nutrients was found to increase the density of age 0+ coho salmon and age 0+ and l+ steelhead in small southwestern Washington streams (Bilby et al. 1998). Any structures (such as hatchery weirs; see below) or practices that reduce the nutrient influx from salmon carcasses may reduce the productivity of the system.

The value of nutrient input has been demonstrated in British Columbia where artificial fertilization has been (and is being) used to enhance salmonid production in nutrient-deficient systems. In British Columbia, lake fertilization has been used in place of hatcheries for enhancing sockeye production (Hyatt and Stockner 1985), an approach that is currently also been used for kokanee. In addition, following on the earlier stream fertilization studies of Stockner and Shortreed (1978) and Mundie et al (1983, 1991), stream fertilization is being tested, with promising results, as an interim measure for recovering certain natural salmonid stocks that have been in decline for reasons not related to hatchery practices (McCubbing and Ward 2000, Larkin and Slaney 1996).

Hatchery operations may impact the community structure of an ecosystem. When hatcheries release large numbers of fish, the capacity of the ecosystem to handle the released juveniles or returning adults may be exceeded. Alternately, when hatchery fish are released outside their historic range they may cause new competition and predation impacts to established communities. The end result may be increased competition between naturally-spawning and hatchery propagated fish for rearing or spawning areas and the displacement of naturally-spawning fish (RASP, 1992; see also Chapter 5).

2.4 Effects of Hatchery Structures on Fish

The physical structures of hatcheries are located in riparian areas. Sufficient infrastructure, space, and water are required for incubation of eggs, juvenile rearing, and adult collection, maturation and spawning. Some hatchery structures have severe adverse effects on naturally-spawning fish populations by creating (for example) obstacles to migration, changes in in-stream flows, and loss of water quality. Most effects of hatchery structures are quantifiable. Water quality of hatchery effluent and changes in in-stream flows are relatively easy to measure. Impassible barriers to migration are identifiable and delays in migration can be estimated. Hatchery structures may affect naturally-spawning fish and the environment in various ways.

2.4.1 Downstream Fish Passage

Hatcheries require sufficient water for juvenile rearing and adult attraction. Water is usually drawn from an adjacent stream via pumps or gravity. Improperly designed and maintained water intakes can impinge migrant or resident juveniles (Pearce and Lee 1991, Washington Department of Fish and Wildlife 2000). Improperly sized screens can allow natural-origin juveniles to enter and be trapped in hatchery rearing vessels. Many hatchery water intakes were designed over 40 years ago. These often do not meet current design standards for screen mesh size and approach velocity. Adequate maintenance of properly designed intakes is also important.

2.4.2 Upstream Fish Passage

Adult salmonids have a high fidelity for returning to their natal rearing areas to spawn and will return to their respective hatcheries or native spawning grounds if unimpeded (Brannon et al. 1984, Van der Haegen and Doty 1995). Fish collected for broodstock require sufficient and unique flows for attraction and separation into the hatchery, but fish intended to spawn naturally need to be able to pass through hatchery structures, such as intake dams or adult weirs, in a timely manner (Clay 1961, Fleming and Reynolds 1991). Identification and passage of natural-origin and hatchery salmon is important to maximize use of natural habitat and minimize "broodstock mining". Allowing separation of hatchery- and natural-origin adults to their respective natal rearing areas is also important to minimize negative ecological and genetic interactions (see sections 1.2.1, 1.2.2, 2.3, 4.1, 5.1 and 5.2).

2.4.3 Volitional Entry to Hatchery

Hatcheries can attract returning adults to an artificial stream created by water passing through hatchery rearing containers. The unique scent of attraction of the hatchery effluent can selectively influence the return of hatchery adults (Brannon 1982, Dittman et al. 1996). If attraction is sufficient to selectively influence the return of only hatchery fish, negative genetic and ecological interactions between natural-origin and hatchery-origin adults can be reduced (see sections 4.1,5.1 and 5.2.)

2.4.4 Instream Flow

Hatcheries usually divert water from adjacent streams for fish cultural purposes. Diverted water is often returned at significant distances downstream. Water diversion through hatcheries from relatively small streams can significantly reduce the amount of water for juvenile rearing and upstream adult migration between the area of intake and discharge. In small streams, flows in the section of stream between the intake and discharge should not be reduced so that upstream migration by adult salmonids is not prevented or delayed during the usually dry fall season (Bell 1986, Stalnaker et al. 1995, Washington Department of Ecology 2002).

2.4.5 Discharge Quality

Discharge quality is the physical and chemical qualities of water leaving the hatchery and entering the adjacent stream. These qualities include temperature, settleable solids, suspended solids, nitrite levels, nitrate levels, and phosphorous levels (Kendra 1991). Unregulated discharge and poor water quality can alter the native flora and fauna below the point of discharge (Willoughby et al. 1972, Kanaga and Evans 1982). The United States Environmental Protection Agency and Washington State Department of Ecology require adherence to state and federal water quality standards at all hatcheries in the state (Boersen and Westers 1986, Cho and Bureau 1997).

2.4.6 Modification of Riparian Areas

The physical structures of hatcheries are often located adjacent to riparian areas where natural habitat has been replaced with hatchery buildings and juvenile rearing vessels. Negative effects of these physical structures, such as increased surface run-off, decreased near-shore cover, loss of shade and reduced water quality in the immediate vicinity, should be minimized (Shepherd 1991, Beechie and Sibley 1997, Keith et al. 1998).

2.4.7 Harassment from Humans

Adult salmonid collection facilities at hatcheries concentrate returning adults prior to spawning. These concentrations are often highly visible and predictable, attracting fishers and non-consumptive users. Illegal activities such as poaching and harassment can also occur. These activities can have a negative effect by reducing spawning success.

CHAPTER 3. HATCHERY PROGRAMS IN THE SPECIES/POPULATION CONTEXT

Hatchery populations of salmonids are subject to many of the same biological processes as their naturally-spawning counterparts. These biological processes shape the biological significance and viability of both hatchery and naturally-spawning populations. Assessment of the biological significance and viability of salmonid populations provides an important benchmark for developing both long- and short-term goals and management strategies for a particular population or stock. In the case of integrated hatchery programs, where the management strategy is to minimize genetic divergence between the hatchery broodstock and naturally-spawning population, the combined population shares similar characteristics for biological significance and viability. In the case of segregated hatchery programs, the biological significance is based solely on the biological origin and attributes of the hatchery population with the viability linked to the performance of the stock in both the hatchery and natural environments.

3.1 Biological Significance

The biological significance of a stock is a function of the origin of the stock and its inherent genetic diversity, its biological attributes, uniqueness, local adaptation, and the genetic structure of this population relative to other con-specific populations. A population can be considered highly significant if it exhibits unique genetic and biological attributes that are not shared with other adjacent stocks. These attributes may include unique life history, physiological, morphological, behavior, and disease resistance characters with a genetic basis.

3.1.1 Genetic Diversity

Genetic diversity refers to the magnitude and distribution of genetic variation among individuals. Genetic variation is important because it provides the foundation for responses to selection (natural or artificial) and local adaptations (Falconer and MacKay 1996). Phenotypic variation refers to the variation in measurable traits (e.g., size at reproduction) among individuals. It is determined by the combined effects of genetic and environmental variation among those individuals.

Genetic diversity can be measured by molecular and quantitative genetic methods. Molecular methods examine genetic variation at the level of individual genes or DNA sequences. Most of the variation detectable at the molecular genetic level of biological organization is assumed to be "selectively neutral," thus reflecting the ancestral history of a population. Quantitative genetic methods statistically partition the phenotypic variation (or variance) of measurable traits into genetic and environmental components. These latter methods attempt to understand the biological significance of phenotypic variation, in terms of fitness and potential responses to selection, under specific or varying environmental conditions. Estimating the genetic and environmental components of phenotypic variance requires knowledge of the familial relationships among a portion, or sample, of individuals within a population. These kinds of data are extremely difficult to obtain for salmon because parental identities of individual fish are usually unknown.

3.1.2 Local adaptation

Local adaptation is the response of a local population, observed as changes of phenotypes and mediated by genetic change, to natural selection in a particular environment over time. The process of local adaptation occurs when the population's phenotypes (traits related to survival and reproduction such as size, fecundity, and disease susceptibility) become 'best suited', or adapted, genetically to the population's local environment. Local adaptation of many salmon population traits has been inferred from observations of trait differences between populations (Ricker 1972; Taylor 1991).

Rigorous demonstration of local adaptation is difficult because it requires detection of a genetic basis for variations of fitness traits and demonstration that a local population has a higher mean fitness (viability, reproductive success, etc.) under its local conditions than do non-local populations (Chilcote et al. 1986; Leider et al. 1990; Fleming and colleagues 1992, 1993, 1994; McGinnity et al. 1997; Taylor 1991; see also series of experiments described by Gharrett and Smoker 1993a,b; Smoker et al. 1994; Smoker et al. 1998; Geiger et al. 1998; McGregor et al. 1998; Hebert et al. 1998). Nevertheless, compelling examples apparently demonstrating local adaptation come from comparative studies of fitness traits among conspecific populations of sockeye and pink salmon. Several studies have demonstrated different rheotaxis in fry from inlet- and outlet-spawning sockeye salmon and indeterminate rheotaxis in intercrosses; Offspring of inlet spawners are appropriately negatively rheotactic and would, in nature, swim downstream to their native lake; Offspring of outlet spawners are positively rheotactic (Raleigh 1971; Brannon 1967). With respect to reproductive fitness, pink salmon spawn earlier in cool, mainland streams and high altitude streams than in comparatively warmer, island and low altitude streams (Sheridan 1962; Brannon 1987). The inference is that natural selection favors earlier spawners in cooler streams because developing eggs laid by later spawners would not have sufficient time to complete embryonic development before the onset of the spring growing season. In addition, mean embryonic development is more rapid in eggs from cool water populations than warm water populations, when incubated together at the same temperature. In addition, significant genetic variation for incubation rate exists within populations (Hebert et al. 1998). Genetic variation exists also for arrival date of pink salmon to their spawning streams (Smoker et al. 1998) and ovulation/spawn date of rainbow trout (Siitonen and Gall 1995). Collectively, these studies illustrate a wide of range of phenotypic responses—probably reflecting local adaptations—that have been shown experimentally to have significant genetic components.

Some natural level of straying occurs continually among salmonid populations but observed local adaptation presumably results from the scarcity of strays or lower reproductive success relative to locally adapted salmon. This observation is consistent with the generally poor survival of transplanted salmon relative to naturally-spawning populations (Quinn 1997).

Life history diversity within populations buffers the populations during periods of change or environmental instability (Hilborn et al. 2003). Salmonids inhabit variable environments characterized by annual, decadal, and other cyclical climatic events. Catastrophic habitat changes from natural occurrence such as floods, earthquakes, and droughts, as well as human-induced changes such as logging and stream diversion also characterize salmonid habitats. Genetic diversity of life history traits among individuals within populations contributes to successful reproduction and population persistence under variable habitat and climatic conditions

3.1.3 Genetic Structure

Genetic population structure refers to the spatial and temporal partitioning of genetic variation into populations, subpopulations, year classes, and other discernible groups (Gilpin 1993; Harrison and Taylor 1997). Structure reflects a deviation from random interbreeding among all individuals constituting a species or population. Population structure enhances the ability of species to persist over time in a variable environment and buffers populations during catastrophic events.

Spatial Variability among Populations

Spatial genetic structure refers to genetic heterogeneity among geographically separate spawning aggregations among which gene flow is restricted. Populations may be separated by spawning location, spawning substrate, or other geographic features (e.g. lake or river system, inlet or outlet, beach or stream). Spatial genetic structure is usually measured in terms of the phenotypic or genetic variance within and between populations or by Wright's F-statistics (or gene diversity statistics), which reflect deviations from panmixia at various hierarchical levels of structure. Each spatially partitioned subclass may be characterized by an effective population size (see Section 3.2.1).Spatial structure buffers a species against localized, detrimental effects and provides a mechanism for fine-tuning natural selection and local adaptation.

Temporal Variability

Temporal genetic structure refers to the partitioning of a species' gene pool into separate temporal classes. Temporal structure occurs both within years (e.g. early versus late run time) and among year classes. Many salmonid populations exhibit temporal genetic structuring within years through divergent run times. This structuring is often associated with specific life-history characteristics that have evolved in response to varying environmental conditions. Phelps et al. (1984) observed significant genetic differences between summer-run and fall-run chum salmon originating from Hood Canal. Fall-run chum salmon from Hood Canal are genetically more similar to other geographically-distant fall-run populations than to summer-run populations from Hood Canal. Summer-run chum salmon typically spawn in the mainstem of rivers in periods of high water temperature, suggesting a specialized life history adaptation. Similar temporal genetic divergence occurs between "even" and "odd" year classes of pink salmon, a species with a strict two-year life history, thus leading to two temporally-discrete populations that often spawn in the same stream, every other year.

Connectivity of wild salmonid populations

Homing to natal streams is an important biological characteristic of salmonid fishes, allowing evolution of local adaptations in life history and other fitness traits (Quinn 1993; Altukhov and Salmenkova 1994; Quinn et al. 2001). Stock-specific, genetically-based adaptations include size and age at sexual maturity, adult return and spawn-timing, pre-hatch developmental rate, length of freshwater residence prior to outmigration, and marine migration patterns (Smoker et al. 1998; Sato et al. 2000). Despite the biological importance of homing, natural straying also plays an important function related to colonization of new habitats and maintaining connectivity between geographically adjacent populations (Quinn 1993). Many studies have shown that salmon and steelhead seek alternative spawning habitats if no appropriate habitat is immediately available (Pascual and Quinn 1994). Such behavior is most apparent when natal streams are blocked by catastrophic, environmental events. For example, siltation resulting from the 1980 eruption of Mount St. Helens resulted in significant numbers of Chinook salmon and steelhead straying from the Cowlitz River to the Kalama and Lewis rivers (Leider 1989; Quinn et al. 1991). Although, some natural level of straying occurs continually among salmonid populations, observed local adaptation presumably results from the scarcity of strays or their lower reproductive success relative to locally adapted salmon. This observation is consistent with the generally poor survival of transplanted salmon relative to naturally-spawning populations (Quinn 1997).

Historically, many salmonid populations could be characterized by a metapopulation structure and a level of connectivity between populations. Under these concepts, populations were spatially structured into assemblages of local breeding populations and migration among the local populations influenced local dynamics and provided the possibility of population reestablishment following extinction. However the cumulative effect of habitat degradation, dams, channelization, logging, and other effects of urbanization have resulted in a loss of connectivity among some populations of Puget Sound and coastal Washington. Some former metapopulations have been reduced to single isolated populations. While formerly a population within a larger metapopulation would not have been deemed highly significant because it shared biological attributes with other populations, an isolated remnant would now be considered highly biologically significant.

3.2 Viability

3.2.1 Effective population size

One of the most important parameters affecting genetic diversity is effective population size (Ne). Effective population size places an upper limit on the amount of genetic diversity that can be maintained in a population in relation to its pedigree history and potential losses due to genetic drift. Some general guidelines for maintaining minimum N_e in distinct, or semi-isolated, populations have been proposed:

- *$N_e > 50$ to prevent inbreeding depression and a detectable decrease in viability or reproductive fitness of a population (Franklin 1980).*

- *N_e > 500 to maintain constant genetic variance in a population resulting from a balance between loss of variance due to genetic drift and the increase in variance due spontaneous mutations (Franklin 1980; Soule 1980; Lande 1988)*

- *N_e > 5,000 to maintain a constant variance for quasi-neutral, genetic variation that can serve as a reservoir for future adaptations in response to natural selection and changing environmental conditions (Lande 1995). The rationale here is that N_e needs to be large enough to minimize genetic drift and the potential loss of "neutral" alleles that may confer fitness advantages under changing environmental conditions and new selection regimes. The N_e > 5,000 rule applies primarily to an entire ESU or species over evolutionary time spans, whereas N_e > 50 applies primarily to closed, local populations.*

A more detailed analysis of N_e in fluctuating populations similar to what might occur in a hatchery involves a distinction between the inbreeding effective number (N_{eI}) and the variance effective number (N_{eV}) (Crow 1954; Simberloff 1988). The inbreeding effective size quantifies the increase in inbreeding while the variance effective size specifies the amount of genetic drift and the rate of loss of heterozygosity (Ryman et al. 1995). When population numbers are stable, N_{eI} and N_{eV} are identical and constant over time. In a rapidly growing population N_{eV} may be much larger than N_{eI} while the opposite is true for declining populations, and, in these situations, a distinction should be made between the two measures (Hedrick and Hedgecock 1994).

3.2.2 Age class structure

Age class structure leads to temporal structuring of populations across years and varies substantially among species. It must be taken into account in estimation of effective population size. Age class structuring is absolute in pink salmon, with a strict, two-year life cycle. It is slightly more diverse in coho salmon, where a three-year life cycle predominates but is augmented largely by jacks (two-year old spawners) and a small number of four-year old spawners Age class structures for sockeye salmon, Chinook salmon, and chum salmon are more complex with multiple year classes contributing to a single generation. Age class structures are even more complex in steelhead, cutthroat trout and other species that undergo repeat spawning at variable ages. A complex age structure also tends to diminish the likelihood of a small population going extinct in a particular year in which an environmental disaster occurs.

Temporal structuring decreases as the variance in age at maturity increases. Populations showing temporal stability in abundance have comparatively low variances in the effective number of breeders per year. The effective population size of an entire population (and generation) is approximately the harmonic mean of the effective number of breeders per year, multiplied by the generation time in years (Waples 1990). Generation time is defined as the average age of parents at the time of reproduction.

3.2.3 Trends and variance in abundance over time

Viable salmon populations, whether natural or hatchery subsidized, exhibit high intrinsic population growth. When abundance is reduced (e.g. due to catastrophic events or harvest) the population will subsequently respond with a rapid increase in abundance, provided habitat of sufficient quantity and quality is available. When populations remain depressed over extended periods of time, it is evidence either of poor habitat (including the hatchery environment) or poor genetic viability. Thus trends and variance abundance over time can be indicators of population viability. More specifically trends in productivity (adult progeny per parent - recruits/spawner), under stable environmental conditions and when corrected for density dependent factors are good measures of population viability.

CHAPTER 4: EFFECTS OF HATCHERY OPERATIONS ON HARVEST AND CONSERVATION OF THE PROPAGATED STOCK

Hatchery operations - including broodstock choice and collection, spawning, incubation, and rearing protocols - and the hatchery environment itself can affect the short and long-term survival and behavior of the propagated stock. Hatcheries can affect the achievement of harvest goals as well as the goals for biological significance and viability for the target stock. This is true whether the target stock represents a genetically segregated hatchery population or a component of the natural stock as a genetically integrated broodstock. Hatchery operations can affect both the long-term genetic constitution of a population and the short-term and the short-term phenotypic performance of the target population.

4.1 Hatchery Operations as they affect the genetic characteristics of the Propagated Stock

Hatcheries represent unique environments that are not part of the natural evolutionary history of anadromous salmonid fishes. However, hatcheries now represent a major component of the range of environmental conditions that salmon and steelhead experience during their lifetimes. Indeed, a significant proportion of all returning adults in Puget Sound, the Washington coast, and the Columbia River are the progeny of hatchery-spawned adults. Consequently, from a regional perspective, hatcheries represent a significant component of the overall, environmental landscape experienced by salmon and steelhead in Washington state (Williams et al. 2003).

Hatcheries also represent unique environments that can cause populations to change genetically over time relative to naturally spawning populations. From a conceptual viewpoint, populations are characterized genetically by the suite of genotypes and genes represented by all individuals in a population. By definition, "genetic change" refers to changes in gene frequencies between generations, or between a parental population and a progeny population (offspring) when measured at the same life history stage.

Populations can change genetically as a result of four fundamental processes: random genetic change, natural or artificial selection, migration (gene flow) from other populations, and mutation. Mutation is generally considered an important factor only over evolutionary time scales and will not be discussed here, although recent theoretical work suggests that it could be a factor in highly domesticated populations (Lynch and O'Hely 2001).

In this section, we describe the mechanisms by which hatchery propagated populations can change genetically over time. These genetic changes can affect both the biological significance of a population and its viability.

4.1.1 Changes in Biological Significance

Biological significance, in the context of anadromous salmonid fishes, refers to the biological uniqueness of a population relative to other populations within an ESU (Section 3.1). For example, the spring Chinook population in the White River is considered biologically unique within the Puget Sound ESU and is thus classified as "high" biological significance. In contrast, a large number of coho salmon populations throughout Puget Sound express very similar life histories with respect to age class composition and run timing, and many of those coho populations are thus considered to have low biological significance. The concept of biological significance is associated with the concept of "local adaptation" and biological attributes.

The biological significance of a hatchery-propagated population can change over time (i.e. generations) as a result of genetic changes to the population itself or changes in the abundance and significance of other populations within the ESU. The focus here is on genetic changes to hatchery propagated populations that directly affect their biological significance. These changes can occur via two principal processes: (1) domestication and (2) stock transfers into the hatchery.

Domestication

Domestication is the process of a population becoming genetically adapted over multiple generations to an artificial or human-controlled environment. Three principal factors can lead to domestication: (1) relaxation of natural selection that would otherwise occur in the wild (e.g. spawning behavior); (2) artificial or inadvertent selection imposed by the hatchery environment; and (3) direct selective breeding of adult spawners by hatchery personnel. In general, domestication results in increased fitness under hatchery conditions but decreased fitness under natural conditions (Price 1984; Kohane and Parsons 1988; Hemmer 1990). Domestication thus represents some level of local adaptation to hatchery conditions and reduced productivity under natural conditions (Reisenbichler and Rubin 1999). Domestication resulting from genetic change can be detected from morphological, physiological, and behavioral differences between fish from hatchery and natural populations when those fish are hatched and reared under identical, experimental conditions.

Understanding the potential domestication effects of hatcheries and artificial propagation is currently an active research area. Many studies have demonstrated that fish from long standing hatchery populations exhibit greater swimming activity, greater surface orientation, and increased agonistic feeding behavior relative to fish from natural populations (Ruzzante 1994; Campton 1995; Berejikian et al. 1996; Reinhardt 2001). These domestication effects appear to reflect genetic responses to artificial selection for competitive ability under high density rearing and pulsed, surface feeding in hatchery environments. The progeny of hatchery-origin adults may also exhibit increased genetic vulnerability to predators under natural conditions (Berejikian 1995). Juvenile fish from domesticated hatchery populations may also displace locally adapted fish from their native habitats due to behavioral dominance and aggression (Nickelson et al. 1986; Berejikian et al. 1996).

Differences in adult spawning behavior between fish from hatchery and natural populations have also been observed: adults from hatchery populations are generally less aggressive and behaviorally submissive to adults from natural populations (Fleming and Gross 1994; Fleming and Petersson 2001). These latter domestication effects may also affect reproductive success of hatchery-origin adults under natural conditions.[39]

Domestication due to artificial selection within the hatchery environment is often difficult to detect or observe directly. For example, recent studies have confirmed earlier hypotheses that the benign conditions of a hatchery environment may directly select for increased fecundity of females with a correlated reduction in mean egg size (Heath et al. 2003). In general, egg size and egg number are negatively correlated within and among populations, both phenotypically and genetically (Fleming and Gross 1990; Beacham and Murray 1993; Kinnison et al. 1998; Einum and Fleming 2000a). As a consequence, artificial selection for increased egg number is expected to cause a decrease in mean egg size over multiple generations (but see Quinn et al. 2004). Under natural conditions, egg size is believed to be under strong natural selection because a positive correlation exists among egg size, post-emergent fry size, and survival (Beacham and Murray 1990; Kinnison et al. 1998; Einem and Fleming 1999, 2000b). However, under the benign conditions of a hatchery environment, natural selection associated with large egg size and increased survival is relaxed. Consequently, females with higher fecundities for a given age are expected to produce more offspring and adult progeny relative to females of the same age with lower fecundities if survival probabilities of progeny are independent of fecundity. Sperm competition resulting from mixed-milt fertilizations in single containers (e.g. 5 males X 5 females) can also result in domestic changes in life history traits if those traits are correlated phenotypically with sperm potency and fertilization success in vitro (Campton 2004).

Genetic change contributing to domestication can also result from direct selective breeding by hatchery personnel. Hatchery populations have often been selected for early within-season run timing and early spawn-timing by selecting the earliest returning fish and excluding late-returning fish from the broodstock. As a consequence, several hatchery stocks of steelhead coho salmon in Washington and Oregon now exhibit a range of return times and spawn times that are significantly earlier than natural populations (Ayerst 1977; Rosentreter 1977; Flagg et al. 1995; Mackey et al. 2001; Quinn et al. 2002). The biological significance of those hatchery stocks relative to natural populations is substantially reduced because those hatchery stocks no longer represent the genetic resources of the ESUs from which they were derived (i.e. due to domestication). Some of those hatchery stocks have been transplanted throughout western Washington resulting in several, independently propagated populations of the same, domesticated hatchery stock (e.g. Chambers Creek winter-run steelhead).

Selective breeding for reduced age/size class variation has also been extensive, primarily by selectively breeding for larger, older fish and excluding “jacks” (two-year old coho, fall Chinook, and steelhead males) from broodstocks. For hatchery stocks of coho salmon, such selective breeding disrupts the natural genetic continuity among brood years (Van Doornik et al. 2002), thus resulting in three discrete populations of hatchery of coho salmon, each composed almost exclusively of three-year old fish, instead of a single genetic population composed of two or more age classes. Two year old “jack” males should, thus, be used for

[39] *See framework Chapter 5.*

broodstock at a rate comparable to their relative abundance among returning adults. Increasing the proportion of jacks in coho broodstocks appears to have little effect on the proportion of jacks among returning adults relative to the much greater effects of accelerated growth rate and increased size at release of smolts (Appleby et al. 2003). Moreover, including jacks in coho broodstocks has little effect on post-release survival or mean size of age 3 adults (Appleby et al. 2003). On the contrary, excluding jacks from hatchery broodstocks represents a form of selective breeding that contributes to domestication.

Potential solutions for retarding the deleterious effects of domestication include systematic gene flow from naturally-spawning populations to the hatchery population (Olson et al. 1995; Ford 2002), modified hatchery environments that more closely resemble natural conditions (Maynard et al. 1995; Berejikian et al. 2000, 2001; Fuss and Byrne 2002), protocols for selecting and mating spawners designed to minimize genetic change between adults and their progeny (Campton 2004), matching hatchery life cycles to local natural life cycles (e.g. subyearling fall Chinook rather than yearling smolts; but see Bugert et al. 1997 for compromised habitats), and limits on the duration of supplementation programs where the goal is to rebuild natural populations (Bugert 1998).

Stock transfers and genetic introgression

Backfilling egg or spawner shortages at one hatchery from surpluses at another hatchery has been a common practice among salmon hatcheries in Washington and other states in the Pacific Northwest. The net result of such transfers is a general decrease in between-population genetic variation (e.g. Simon et al. 1986; Utter et al. 1989). The transfer of eyed eggs among hatchery populations of coho salmon in Oregon may have especially contributed to genetic and phenotypic similarities among hatchery stocks and dissimilarities to wild stocks (Hjort and Schreck 1982). Such transfers can potentially compromise stock specific, or geographic specific, local adaptations related to run timing, spawn timing, embryonic developmental rate, disease resistance, and other traits known to be heritable and responsive genetically to local environmental conditions. In many instances, fish or gamete transfers have often taken place over hundreds of miles and between ecological provinces or regions (e.g. Puget Sound, Washington coast, and the Columbia River). Reductions in mean fitness of the receiving hatchery stock is the expected outcome of such transfers (Emlen 1991; Gharrett et al. 1999). Consequently, a shortage of adults returning to a particular hatchery should not be viewed as a deficiency, per se, but rather the result of natural selection acting on the hatchery population.

The HSRG strongly discourages "fish transfers" or the "backfilling" of egg shortages at one facility with surpluses from another facility, particularly when the two facilities are in geographically-distinct watersheds or regions. The HSRG has concluded that egg or fish transfers inhibit the development of viable, self-sustaining populations in local watersheds, regardless of whether those populations are propagated by natural spawning or hatcheries. Homing fidelity in anadromous salmonid fishes has a heritable component; consequently, transferred fish and fish resulting from eyed egg transfers stray at a higher rate as returning adults than “native” fish that are released on site from where their parents returned and spawned (Quinn 1993, 1997). Not only does the transfer of fish between watersheds impose potential genetic risks to local populations, but increased straying from the release site (or facility) can result in undesirable natural spawning of transferred fish (or their progeny) in non-target watersheds.[40]

The HSRG believes that hatchery programs incapable of sustaining their own broodstocks may be over-harvested and/or are not properly managed. The recommended solution to broodstock shortages is to address the hatchery or harvest management problem, not backfill shortages with transfers from another facility or watershed to meet a release "quota". As noted above, broodstock shortages may represent the results of "natural selection" at work. As a general working model, the basic biological principles used to manage natural populations of salmon and steelhead should be applied equally to hatchery-propagated populations. This working model precludes the transfer of fish or eyed eggs among regions, facilities, or watersheds to meet an escapement goal.

4.1.2 Changes in Viability

Viability refers to the ability of a population to sustain itself demographically over multiple generations. Population viability is a function of two independent factors: (1) the intrinsic genetic characteristics or fitness of the population and (2) the habitat or environmental conditions encountered by individuals of a population throughout their life cycle. Populations with high viability exhibit positive intrinsic rates of increase over time, whereas populations with low viability exhibit negative intrinsic rates of increase. Populations may exhibit low viability because of low genetic fitness, poor environmental conditions, or a mismatch between the genetic characteristics of the population and the particular environmental conditions encountered within a single generation. The principal emphasis here is on the genetic fitness of a population and how hatchery propagation can result in genetic changes in that fitness.

Founder effects, genetic drift, and loss of genetic variation

Hatchery-propagated populations can lose genetic variation by founder effects relative to their source, natural population. The founding broodstock of a hatchery population is simply all the adult fish that were used to initiate the hatchery program. These adults typically represent a finite sample from the source population. Genetic variation of the hatchery population cannot exceed that of the founding broodstock or source population. Founder effects occur when genetic variation of the founding broodstock is substantially less than that of the source population because a relatively small number of adults was used to initiate the broodstock. The genetic composition of the founding broodstock provides the genetic foundation for the phenotypic fitness and productivity of the hatchery population in future generations. Founder effects may be more problematic in segregated programs than integrated programs because the former are typically propagated exclusively with returnees back to the hatchery. Recent reviews of hatchery programs in the Puget Sound area by the HSRG have revealed a potential

[40] *See framework Chapter 5.*

founder effect associated with the hatchery program for spring Chinook salmon on the Skagit River.[41]

Genetic drift can also lead to loss of genetic variation in artificially propagated populations. Genetic drift refers to random changes in allele or gene frequencies between brood years (e.g. spawners and recruits) and between generations due to small effective number of breeders and population sizes, respectively, resulting from the random sampling of genes from the parental gene pool to yield the offspring gene pool. As a result, alleles initially occurring at low frequencies (e.g $p < 0.05$) can easily be loss in genetically small populations due to genetic drift. Indeed, computer simulations indicate that low frequency alleles are subject to rapid extinction in populations of Pacific salmon with an $Nb < 100$ spawners per year (Waples 1990). As noted in Section 3.2.1, effective population sizes should be greater than $N_e = 500$ to minimize genetic drift and the potential loss of alleles.

Understanding the genetic composition of a hatchery population may require detailed records of the founding broodstock (e.g. population sources, number of male and female parents, mating protocols, etc.), the number of male and females spawners each year, and the manner in which male and female gametes are combined (i.e. breeding protocols). However, identification of founding broodstocks and their genetic contributions to existing hatchery populations may not be straightforward if multiple population sources were used to initiate a population. In addition, the manner in which males and females are mated is rarely documented in most hatchery programs. On the other hand, molecular genetic methods can be used to compare the genetic composition of existing hatchery populations to the source population (or populations) from which the hatchery population was derived. For example, several studies have documented significant losses of genetic variation or changes in allele frequencies for hatchery populations of non-anadromous salmonid fishes (Allendorf and Phelps 1980; Ryman and Stahl 1980; Cross and King 1983; Stahl 1983; Vuorinen 1984).

Only a few published studies have actually documented loss of genetic variation, or significant allele frequency changes, in hatchery populations of Pacific salmon and steelhead relative to their source populations. For example, Steward and Bjornn (1990) noted that they "found few cases of reduced levels of genetic variability among hatchery stocks of Pacific salmon and steelhead." On the other hand, considerable evidence now exists that hatchery populations of coastal coho salmon in Oregon have suffered significant genetic drift effects resulting from relatively small effective population sizes (Simon et al. 1986; Waples and Smouse 1990; Waples and Teel 1990; reviewed in Campton 1995).

Sperm competition and reduced effective number of breeders

Salmon hatcheries in the Pacific Northwest historically spawned adults by combining eggs fro several females with milt from several males in a single container. This mixed-milt approach leads to significant sperm competition and highly unequal genetic contributions from male spawners (Gharrett and Shirley 1985; Withler 1988; Withler and Beacham 1994; Gile and Ferguson 1995). Sperm competition substantially reduces the genetic effective number of

[41] *See HSRG March 2003 regional recommendations for Skagit River Hatchery Spring Chinook Salmon*

breeders (Nb) relative to the actual number of spawners (Ns) such that Nb << Ns. Sperm competition in vitro can also result in undesirable artificial selection for life history traits (e.g. age/size at maturity) if those traits are correlated phenotypically with sperm potency and fertilization success (Campton 2004). For example, precocious male parr and other males exhibiting “sneaker” spawning behavior (e.g. “jacks”) produce milt with greater sperm concentrations and volumes relative to their body size than older larger males (Gage et al. 1995; Taborsky 1998; Vladic and Järvi 2001; Koseki and Maekawa 2002; Liljedal and Folstad 2003). Relationships between age/size at maturity and sperm characteristics have been demonstrated most conclusively with Atlantic salmon (Salmo salar) where sexually mature parr have greater proportions of motile spermatozoa and greater sperm ATP content than anadromous males, including greater fertilization success relative to anadromous males in experimental crosses (Vladic and Järvi 2001). Similarly, sperm concentration in the milt of 1-year old rainbow trout males is greater than the concentration for three-year old males (Liley et al. 2002), and such variation can significantly influence in vitro fertilization success in mixed-milt spawnings (Gile and Ferguson 1995).

A large number of salmon hatcheries in coastal Washington and Puget Sound continue to use mixed-milt fertilization (5 males X 5 females) despite documented genetic effects and potential risks. As a general rule, salmon hatcheries should discontinue mixed-milt fertilization and institutionalize alternative spawning protocols that preclude or minimize sperm competition in vitro. Three alternative protocols are recommended: pairwise spawning, nested spawning, and factorial or matrix spawning (Campton 2004). The underlying premise of these latter protocols is that every adult selected for broodstock should have an equal opportunity, and probability, of producing an equal number of progeny. One goal of most hatchery programs should be to minimize genetic change between the pool of returning adults available for broodstock each year and the progeny of parents selected for broodstock from that pool. To achieve this latter goal, spawning protocols should maximize the genetic effective number of breeders and minimize artificial selection associated with hatchery propagation. These goals and objectives may require increased genetic oversight of hatchery operations comparable to the level of fish health oversight (pathogen monitoring and disease prevention) currently practiced in salmon hatcheries throughout the Pacific Northwest.

4.2 Hatchery Operations as they affect the non-genetic characteristics of the Propagated Stock

In addition to their genetic makeup, the survival and reproductive success of juvenile hatchery fish depends upon their non-genetic characteristics at the time of release as well. These non-genetic characteristics include the physiological, morphological, behavioral, and health status of the fish being reared. Hatchery operations and the hatchery environment can affect each of these characteristics and influence the achievement of harvest or conservation goals for the propagated stock.

4.2.1 Changes in Physiology

Physiological fitness is the ability of fish to grow, smoltify and resist disease in the hatchery and natural environments. Following release, good physiological fitness allows hatchery fish to rapidly migrate downstream, adapt to seawater, survive in the ocean environment, and return to successfully reproduce. Physiological fitness is controlled by environmental factors such as weather, water quality, temperature, feed availability, and day length (photoperiod). These factors affect growth, development and metabolism, which ultimately influence genetically programmed variations in life history patterns that vary within and between populations. Various salmon stocks have evolved successful adaptive strategies and tactics based on emergence timing, freshwater residence, seasonal patterns of growth, age and timing of smoltification, periods of imprinting and homing, and age and timing of reproductive migration and maturation.

Anadromous salmonids undergo a major metamorphic-like change, the parr-smolt transformation, as they prepare for migration to the sea. Fully smolted (transformed) juveniles exhibit rapid downstream migration, increased hypo-osmoregulatory capability, sustained growth in the ocean and high survival to adulthood. The link between smoltification, growth rate, seawater tolerance and migration rate has been observed and reported frequently in the literature (Wagner et al. 1969; Clarke et al. 1988; Varnavsky et al. 1992; Beckman et al. 1998, 1999). These processes are under hormonal control and are mediated primarily by photoperiod. The same hormones that control growth (growth hormone, insulin-like growth factor-I) also stimulate the development of seawater tolerance in salmonids (Sakamoto and Hirano 1993; Dickhoff et al. 1997). The sharp increase in growth of some species of wild fish concomitant with smoltification (Beckman et al. 2000) is similar to the rapid growth of high quality smolts in hatcheries (Beckman et al. 1999). Enhanced seawater tolerance is also characteristic of successful smoltification (Hoar 1988).

Producing high quality hatchery smolts with greater smolt-to-adult survival will allow equivalent hatchery contribution to adult harvest with fewer smolts released. Releasing actively migrating, healthy smolts from hatcheries will reduce opportunities for hatchery-wild fish interactions and minimize negative impacts of hatchery fish on wild fish. Rapidly migrating smolts will be less likely to residualize and imprint on inappropriate stream sites. Therefore, they will be less likely to stray during their homing migration, thus reducing the likelihood of introgression of hatchery fish on non-target populations. The method of release is particularly important because it affects the rate of migration, predation, level of residualism, inter- and intra-species interactions, and imprinting or level of straying (Hillman et al. 1989; Vander Haegen and Doty 1995; McMichael et al. 1999). Additionally, the time of year and size at which smolts are released into the natural habitat can be used to minimize inter and intra-species competition, straying and residualism (Tipping and Blankenship 1993; Tipping 1997). Survival can be greatly increased if releases occur when food is abundant in the receiving habitat. The size and quality of a juvenile salmonid affects its ability to compete, escape predators, adapt to seawater, migrate rapidly, mature at the appropriate age, and most importantly recruit into the fishery or spawning population (see 4.2.2, and 4.2.3).

Physiological fitness can be measured during the parr-smolt transformation and in reproductive adults. The timing, magnitude, and duration of the parr-smolt transformation are surrogates for physiological fitness. Some specific physiological measures of smoltification status include gil

Na-K ATPase enzyme activity, blood concentrations of thyroid hormones, growth hormone, insulin-like growth factor, and body lipid levels, among others. Physiological fitness can also be estimated during the parr-smolt transformation by examining the pattern of juvenile growth (Beckman et al. 1999). In reproductive adults, physiological fitness can be measured in terms of their morphology (e.g. size and age at maturity); see section 4.2.2, development of secondary sexual characteristics, egg size and fecundity, and endocrine cycles.

Hatcheries can affect the physiology of juvenile and adult salmon by creating an environment that either simulates or departs from the natural patterns in which the stock has evolved. For example, typically higher than natural water temperatures may result in earlier emergence by accelerating embryonic development. Higher growth rates due to high dietary ration in the hatchery may advance the timing of smoltification, e.g., autumn rather than spring smoltification in spring Chinook salmon. The lack of seasonal patterns of growth and development in hatchery fish contrast substantially to that seen in wild fish (Beckman et al. 2000). A more natural seasonal cycle of physiological development and high spring growth may enhance smoltification and survival to the adult stage (Beckman et al. 1999). High growth rates of fish in the hatchery may also alter the age of maturation, producing exceptionally high numbers of precocious males (Larsen et al. 2004). The use of high energy diets produce hatchery fish with greater body fat content compared to wild fish, which can also advance male maturation age (Silverstein et al. 1998). Thus, it is important to regulate growth at appropriate times to enhance smoltification and migration, but not contribute to high rates of precocious male maturation.

Water and feed quality including harmful contaminants will also affect physiology. Heavy metals such as copper, lead, zinc, cadmium, and mercury can be toxic to fish and can result in dysfunctional growth, poor reproduction, incomplete smoltification, and death. Likewise, organic chemicals like pesticides, polychlorinated biphenyls (PCBs), herbicides, and endocrine disruptors interfere with a variety of metabolic processes essential to growth, smoltification, reproduction and homing imprinting (Pennell and Barton 1996).

4.2.2 Changes in Morphology

Morphological fitness embodies a suite of visible traits including size, coloration, body form, fin shape and development, secondary sexual characteristics, body musculature, and fecundity. Morphological fitness is important to foraging, migration, reproduction, and juvenile camouflage. These morphological traits can be controlled or modified through hatchery rearing protocols prior to the release of juveniles and can affect the expression of morphological traits in returning adults.

Juvenile Size—The size of a juvenile salmonid affects its ability to compete for food and space, escape predators, adapt to seawater, migrate rapidly, mature at the appropriate time, and most importantly survive and recruit into the fishery or spawning population. Natural populations generally contain fish within a size range governed by emergence time, available food resources, and climatic conditions. In intra-specific contests over food and space, all else being equal, the largest fish usually win and are able to establish prime territory (Hoar 1951; Chapman 1962; Mason and Chapman 1965; Jenkins 1969; Noakes 1980; Abbot et al. 1985; Maynard 1987).

No other factor affects the development and growth of fish as much as water temperature. Metabolic rates of fish increase rapidly as water temperature increases. Biological processes such as spawning and egg hatching are governed by annual temperature changes in the natural environment. Successful hatchery operations depend on a detailed knowledge of such temperature influences relative to the operational goals of the hatchery. Time and fish size at release have been shown to affect overall survival, age at maturity and growth (Hager and Noble 1976; Fowler and Banks 1980; Bilton 1980, 1984; Hard et al. 1985; Hankin 1990; Holtby et al. 1990; Henderson and Cass 1991).

Coloration—In nature, salmonid eggs incubate, and alevins develop in the darkened matrix-rich environment of the gravel substrate in the redd. Following hatch, juveniles rear in a complex, lighted environment of shade, sunlight filtering through riparian vegetation, and light-absorbing, dark, gravel substrate. This environment produces cryptic coloration and body camouflage patterns most likely to reduce vulnerability to predators.

Body Shape—Body shape of wild salmonids changes with season and nutritional resources. During winter, a period of low feed availability or even starvation, body weight and condition (relationship between body length and weight) drops, resulting in a slimmer fish with lower body fat. In spring, prior to smoltification, resident non-migratory juveniles feed heavily and regain body fat and condition. During the parr-to-smolt transformation, as the period of downstream migration nears, the condition index changes again. A slimmer, more streamlined silver-colored smolt with reduced pigmentation is produced.

Size at Maturity—Large body size has been shown to confer a competitive advantage to males competing for temporary access to females during spawning (Hanson and Smith 1967; Schroeder 1981; Keenleyside and Dupuis 1988; Fleming et al. 1996; Berejikian et al. 1997). Breeding success of male coho salmon (O. kisutch) depends on their ability to obtain access to spawning females (Fleming and Gross 1992, 1994). Only males that enter the nest and release milt during oviposition have a chance of fertilizing eggs. Males that enter the nest first have the greatest fertilization success (Schroder 1982; Chebanov et al. 1983; Mjolnerod et al. 1998; but also see Foote 1997). Size at maturity can influence offspring survival. For example, larger females are better able to dig deeper redds, giving greater protection to ova against streambed movement.

Secondary Sexual Characteristics—Certain morphological characteristics independent of body size have been demonstrated to influence male breeding success in Pacific salmon. For example, Quinn and Foote (1994) found that hump height was positively correlated with breeding success of male sockeye salmon. Those investigators also demonstrated that coho salmon males with longer snouts (kypes) attained greater access to spawning opportunities and greater estimated fertilization success than males with shorter snouts. Caudal peduncle depth has been correlated with female breeding success (Fleming and Gross 1994), perhaps related the capability to dig redds. Physical appearance has also been shown to be important in competitive asymmetries observed in other fish species. For example, male nuptial coloration plays an important role in determining dominance during reproduction (e.g., Kodric-Brown 1995; Baube 1997). The importance of spawner morphology in eliciting reproductive behavior has been seen in captively reared vs. wild coho salmon, implying that many of the differences between cultured and wild fish are a result of hatchery rearing (Berejikian et al. 1997; Hard et al. 2000).

Fecundity —The fecundity (number of eggs per mature female) of Pacific salmon females represents the potential for production in the next generation. Fecundity is generally related to body size but varies by species, latitude, time of return and brood year, with Chinook being the most variable (Healey and Heard 1984; Healy 1991; Sandercock 1991; Beacham and Murray 1993).

Juvenile hatchery fish are normally reared under conditions were feed availability and rearing densities in hatcheries far exceed those found in natural streams. Growth rate, body size, and proximate body composition of hatchery fish are often quite different than wild fish (Forster and Hardy 1995, Beckman et al. 2000, Larsen et al. 2004). Hatchery reared fish generally have a higher percent body fat compared to wild fish (Beckman et al. 2000). In addition to having a different shape, juvenile hatchery reared fish are generally less variable in size than naturally reared fish (Taylor and Larkin 1986). Studies have indicated that hatchery-induced morphological differences can affect swimming speed and therefore the ability to escape predators (Bams 1967, Taylor and McPhail 1985). Studies have also suggested that hatchery rearing may result in decreased crypsis (camouflage coloration) for stream environments due to rearing against uniform (e.g., concrete) hatchery backgrounds (Donnelly and Whoriskey 1991; Maynard et al. 1995, 1996). Feed and feed additives may also affect the external pigmentation of cultured salmonids, with fish fed natural prey supplements having more wild-like pigmentation than fish fed formulated feeds (Hickson and Leith 1996, Maynard et al. 1996).

Inadequate rearing conditions may affect external morphological parameters (e.g., fin condition) and ultimate health. Several potentially causative factors have been identified, including under feeding, overcrowding, poor water quality, excess exposure to direct sunlight (sunburn), and abrasion from contact with raceway walls (Kindschi 1987, Kindschi et al. 1991, Winfree et al. 1998). Hatchery management factors have been implicated in both decreases in age and size of maturity in Pacific salmon stocks (Bigler et al. 1996). Causative factors appear to be combinations of high hatchery growth rates triggering early onset of maturity (physiology), density-dependent growth after release (ocean carrying capacity), and size selection of larger, older fish by selective fisheries (genetic selection). Decreased body size at reproduction produces attendant potential reductions in reproductive behavior, fecundity, egg size, and survivorship of progeny (Bigler et al. 1996; Berejikian et al. 1997, 1999, 2000; Heath et al. 2003).

Underfeeding has often been cited as a cause of fin erosion in salmonids. Deterioration of fins among steelhead trout fed at restricted levels has been attributed to increased aggression and competition for a limited food resource (Larmoyeux and Piper 1971). Aggressive behavior in pen-reared juvenile steelhead includes frontal nipping and counterattacks directed toward the dorsal fin, resulting in loss of one-third or more of the tissue (Abbot and Dill 1985). According to Wolf (1938) and Klontz (1992), feeding to satiation can improve fin quality in trout, but results of other published studies have been inconsistent. Supplementation of diets based on fish meal with krill and squid protein or ash, or with sodium, magnesium, and copper have been found to improve dorsal fin quality of trout (Barrows and Lellis 1999). In nature, insects and other invertebrates are a rich source of copper in fish diets.

4.2.3 Changes in Behavior

Behavioral characteristics that are important to productivity can be grouped into four categories: 1) social behavior including territoriality, schooling, and reproduction; 2) migration behavior including downstream migration, ocean migration, and homing migration; 3) predator avoidance behavior expressed through recognition of predators and escape response; and 4) foraging ability, the capability to recognize and capture suitable feeds.

Territorial behavior allows stream-resident juveniles to establish feeding territories. Juvenile salmonids have been shown to reduce their territory size as fish density increases (McNicol and Noakes 1984). It has also been suggested that territory size may limit the maximum density of juvenile salmonids in streams (Grant and Kramer 1990). Photoperiod-induced changes in behavior allow smolts to aggregate in “schools” and migrate to the sea. Imprinting and subsequent homing behavior results in the return of adults to suitable home stream habitat and the perpetuation of locally adapted populations. Good predator avoidance behavior increases the probability that individuals will survive to adulthood. Foraging behavior assures an adequate food supply.

Culture conditions within hatcheries can have a major effect on behavior. Migratory behavior, for instance, is under the complete control of the hatchery operator. Depending on the water temperature in the hatchery and its release protocols, this behavior in hatchery fish may coincide with natural out-migration in terms of timing and duration or may be completely different in either or both aspects.

Social divergence of cultured fish may begin as early as the incubation stage. Unnatural hatchery incubation environments have been shown to induce excess alevin movement, resulting in lowered energetic efficiency, reduced size, and, in some wild stocks, death (Poon 1977, Leon and Bonney 1979, Mighell 1981, Murray and Beacham 1986, Fuss and Johnson 1988). Feed availability and rearing densities in hatcheries far exceed those found in natural streams, and may contribute to increased aggressive behavior and lowered fright responses compared to wild fish (Symons 1968; Bachman 1984; Grant and Kramer 1990; Olla and Davis 1989, 1998; Uchida et al. 1989; Olla et al. 1998; Berejikian 1995a,b; Maynard et al. 1995; Berejikian et al. 1996). The traditional hatchery practice of providing feed at the water surface may condition hatchery fish to approach the surface of the water column (Maynard et al. 1995, Olla et al. 1998, Uchida et al. 1989), and this behavior may increase susceptibility to avian predation. Numerous studies have suggested that hatchery water supplies or temperature profiles that do not follow natural patterns (e.g., well water) may result in incomplete or inappropriately timed growth profiles, smoltification, outmigration, and homing (e.g., Pascual et al. 1995; Grant 1997; Beckman et al. 1999, 2000; Larsen et al. 2004)

Studies have indicated that increased avian and piscivorous predator vulnerability of released hatchery fish may be related to decreased crypsis (camouflage coloration) for stream environments caused by rearing against uniform (e.g., concrete) hatchery backgrounds (Donnelly and Whoriskey 1991; Maynard et al. 1995, 1996a). In addition, cultured and naturally-reared salmonids may respond differently to habitat in the post-release environment. In most cases, wild fish use both riffles and pools in streams, while newly released hatchery fish have been shown to primarily use pool environments that are similar to their raceway rearing experience (Allee 1974, Dickeson and MacCrimmon 1982, Bachman 1984, Uchida et al. 1989, Olla et al. 1998, Berejikian 1995a).

4.2.4 Changes in Fish Health

Fish health, in the fish hatchery context, is a term used when considering the well being of fish populations in hatcheries. The term does not indicate whether the fish are diseased or healthy. The latter are ones that are free of disease, be it of infectious or non-infectious cause.

Health of the fish is important to the productivity and success of the hatchery for a number of reasons. First, losses experienced during rearing of healthy fish are usually much less than those for diseased fish. Second, the cost of trying to correct disease problems in hatcheries can be considerable. Third, rearing healthy fish obviates the need for using antimicrobial compounds.[42] Finally, healthy fish are more likely than sick fish to survive following release from the hatchery.

Fish health in a hatchery can be gauged by noting the absence or presence of epizootics (The re-occurrence of epizootics indicates that something is fundamentally wrong with the operation or physical set-up of the hatchery). In the absence of epizootics in the hatchery, there may be chronic health problems compromising efficient fish production. Evidence of such problems includes reduced growth and/or a high prevalence of abnormal gill structure, e.g., gill clubbing. A number of fish health manuals dealing with the identification and control of salmonid diseases exist. One of particular relevance to salmonid hatcheries in the Pacific Northwest is listed (see Washington Department of Fish and Wildlife 1997). In addition, excellent publications outlining cultural conditions optimal for the rearing of healthy salmonids are available (e.g., Piper 1992, Wedemeyer 1996). Use of such publications will greatly assist in ensuring that disease problems are avoided in salmonid hatcheries. Finally, early diagnosis of disease problems and prompt action to implement needed treatments are critical if disease problems are to be successfully held to a minimum.

The quality of the water supply in hatcheries has a strong bearing on fish health in hatcheries. Water supplies that are not fish-free can be source of a number of fish pathogens and the temperature regimes in some surface water supplies can be conducive to disease outbreaks because temperature extremes stress fish, thus allowing disease outbreaks to occur. Other water quality factors also influence hatchery fish performance. Several dissolved gases have implications for effective hatchery management, including oxygen and nitrogen. Levels of ammonia and nitrite are also important water quality parameters because both are toxic to fish. Fish excrete ammonia and nitrifying bacteria oxidize ammonia to nitrite. These products can occur in high concentrations, particularly where water is being reused through a culture system and biofilters are not functioning properly. The toxicity of these metabolites is pH dependent and varies with species of fish. Natural waters contain additional dissolved gases that must be kept below critical concentrations. Inappropriate concentrations of dissolved gases in source waters can create added expense for water treatment facilities. Excessive mortality in salmonids can occur at pH above 9.0 (Pennell and Barton 1996). As water passes through a hatchery, fish remove oxygen, excrete carbon dioxide, urea, and ammonia, and deposit feces. Long-term exposure to high levels of carbon dioxide may cause calcium deposits in the kidneys of fish. Chronic high levels can lead to increased stress on the fish, affecting their ability to use oxygen. Uneaten food can accumulate

[42] *Some of these (e.g., formalin) may be harmful to hatchery personnel if not used strictly according to directions; others (e.g., antibiotics) can result in the selection/production of antibiotic resistant fish pathogens (Dixon 1994) and enhance the levels of the resistant forms present in the environment (Herwig et al 1997).*

in the pond and can be a source of disease, reduced growth, and reduced survival (Warren 1991; Piper et al. 1992; Wedemeyer 1996). Suspended solids, made up of waste feed and feces are particularly irritating to gills. This is a serious problem with newly ponded fry, where feeding is inefficient and gills seem to be sensitive to particulate matter.

Culture conditions within hatcheries have a major bearing on the health status of fish being reared. As mentioned above, the accumulation of dead fish and the build-up of wastes in hatchery containers should be prevented if disease problems are to be avoided. In addition, practices and situations likely to result in chronic stress in hatchery fish should be avoided (e.g., frequent fish handling, holding of fish in high activity areas, overcrowding). Inappropriate rearing conditions can lead to diseases, both infectious and non-infectious, either of which can adversely affect growth and survival. The rearing of fish in hatcheries at densities exceeding guidelines often leads to disease outbreaks. Care must therefore be taken to ensure that overcrowding in hatcheries does not occur.

4.2.5 Nutrition

Nutrition is another important factor affecting fish health in the hatchery. The conditions under which diets are used and the way in which they are fed can influence the growth and health of hatchery fish. If the fish-holding units are difficult to clean or are not cleaned regularly enough, the build-up of uneaten feed and fecal matter can cause growth and health problems (Warren 1991; Piper et al. 1992; Wedemeyer 1996). The effects can be direct or indirect. Direct effects, such as mechanical irritation of the gills in very young fish caused by “fines” in the ration, can result in mucus build-up on, and bacterial colonization of, the gills, and can lead to respiratory difficulty. Indirect effects can include reduced dissolved oxygen levels, due to the increased biological oxygen demand caused by the organic loading in the water, and the production of toxic substances such as ammonia or nitrite in the water. The indirect effects are more likely to occur in large ponds than in well-flushed raceways. In large ponds, unwitting overfeeding can compound this problem. In such ponds it is difficult to keep accurate track of fish losses and thus the biomass of fish to be fed is often not known with any accuracy. Further, manual cleaning of large ponds is often impractical (especially dirt-bottomed ponds), and flushing rates in ponds are usually insufficient to prevent the build-up of uneaten feed and fecal matter.

Nutrition and diet management entails providing the correct amount and type of food to achieve desired growth rate, body composition, and condition factors, which are important for maximizing survival. Trace elements such as selenium have been implicated in disease resistance (Felton et al. 1989). Fat and protein percentages have also been shown to be important. In general, wild smolts differ from hatchery smolts in three ways: 1) wild fish show rapid growth rate during the smolting period (as assessed by plasma levels of insulin-like growth factor-I); 2) wild smolts have less body fat than hatchery smolts (hatchery salmon are generally three to five times fatter than wild fish); and 3) wild smolts show a more dynamic change in physiological and metabolic status from over-wintering to the spring smolting period. Growth rates, body composition and condition factors observed in local wild populations can serve as a guide or model for food and data management.

Proper nutrition is a prerequisite for the growth and health of hatchery fish, and considerable research has been done in developing diets for salmonids. The research has identified the protein and amino acids, lipids and fatty acids, vitamins, and minerals that salmonids require (NRC, 1993; Higgs et al., 1995a; Li and Hardy, 2000; Higgs and Dong, 2000; Lall, 2002). Diets high in protein and lipids, preferably of fish origin, are ideal for salmonids (Higgs et al., 1995a; Higgs and Dong, 2000) but because of the high cost of fish-derived proteins and lipids, research has shown that less costly vegetable sources can be used to satisfy some of these needs (Higgs et al., 1995b; Dosanjh et al., 1998; Higgs and Dong, 2000; Li and Hardy, 2000). Problems in diets related to the tendency of lipids to become rancid can now be avoided (Hardy and Roley, 2000) and the instability of certain vitamins (notably vitamin C) has now largely been solved (Gabaudan and Hardy, 2000). Moreover, dry and semi-dry diets that do not require refrigeration, and are capable of being stored for extended periods under cool, dry conditions have largely replaced the use of moist and semi-moist diets that require frozen storage (WDFW 1996). Diets appropriate for the life-stage of the fish being fed are now available, both in terms of formulation and pellet size, and the feeding rates required to bring about desired growth rates are known (WDFW 1996). In short, if the feed manufacture's instructions are followed, there is every reason to expect that the fish will do well, assuming that other cultural conditions are satisfactory. The only possible goal that current commercial diets do not apparently yet achieve is the production of hatchery smolts that mimic wild smolts in their chemical make-up. Research on this topic and on the advantages of producing such smolts is still in its infancy (Higgs et al., 1995a).

The method of feeding fish can also affect fish health. If feeding is infrequent enough to cause significant hunger, and if the feed is dispensed in a highly localized manner rather than being broadcast over a wide area, the localized feeding frenzy that results can cause minor injuries such as scale loss that can contribute to infections. Further, such feeding is likely to produce fish that vary considerably in size due to intense competition (WDFW 1996). Various types of automatic feeders are available but some hand feeding is always advisable, particularly in ponds, as it allows the fish culturist to determine when to stop feeding, thereby reducing the chances of feed waste and organic matter accumulation. In addition, hand feeding allows the operator to assess fish health on the basis of feeding behavior (WDFW 1996). In short, hand feeding and cleaning are the two opportunities when hatchery workers can directly observe the behavior and overall health of the animals they are attending.

4.3 Desired Qualities of Propagated Fish

The success of hatchery programs is determined by the contribution of the propagated stock to meeting harvest goals, the conservation of the species, or other goals for the resource. This should be measured in terms of how many adults return to fisheries or return to the natural environment to reproduce and sustain the stock. It should also be measured by the age class structure, time of return, and genetic composition of those returning adults (i.e. measures of "quality"). In order to contribute to these goals, hatchery populations must survive and reproduce at rates sufficient to be self-sustaining and to support harvest or natural production objectives. One of the primary conditions for hatchery success is that anadromous salmon and steelhead populations reared in and released from the artificial environment must be healthy and viable. Population health and viability are measured in terms of productivity, abundance, diversity, and population structure (McEllaney et al. 2001). These factors are determined by the biological (phenotypic) characteristics of the population and the condition of the environment (hatchery and natural) available to the population. The population's biological characteristics, in turn, are the influenced by both genetic and environmental factors.

With rare exceptions, hatchery programs only have control over the propagated stock from the time adults return until juveniles are released. Hatcheries must, therefore, provide the type of rearing environment and operational protocols to produce juveniles with the proper genetic composition and diversity to ensure long-term survival of the hatchery population. Hatcheries must also produce juveniles with the biological characteristics that will allow them to survive to adulthood and have the desired qualities - as adults - to meet the goals of the hatchery program.

The long-term survival of all hatchery populations, regardless of the type or purpose of an individual program, is influenced by the genetic compositions of those populations, which – in turn – are the products of the founding broodstock, local adaptation, domestication and gene flow resulting from stock transfers or natural straying. It is also influenced by the genetic diversity of the population, which, in the hatchery environment is controlled by the number of spawners, the selection of spawners, and the spawning protocols of the program.

The desired qualities of propagated fish, in terms of genetic characteristics, depend on the purpose of the hatchery program (harvest or conservation) and the type of program (segregated or integrated). Where a hatchery program has conservation as one of its goals, maintaining the genetic composition and diversity of natural population among hatchery-origin fish is critical. Maintaining the characteristics of the local natural population requires a genetic management plan that maintains an adequate effective population size, mediates proper gene flow, and attempts to minimize the genetic effects of potential domestication (Campton 2004). These latter constraints and guidelines are particularly important in conservation programs.

In segregated harvest programs, however, many characteristics of natural populations that are important to reproduction in the natural environment may be less important than the traits important to meeting the harvest goal or allowing efficient operation of the hatchery. In this case, certain genetic guidelines may be relaxed and broodstocks may be bred selectively for particular traits such as early run timing. Since the hatchery population is meant to be reproductively isolated from natural populations, certain types of artificial selection are acceptable. However, other principles such as maintaining adequate effective population sizes and fostering local adaptation are still applicable. There should also be recognition that purposeful artificial selection for one trait, such as early run timing may lead to inadvertent or correlated selection for another trait that may not be conducive to long-term survival of the population. Understanding the genetic and phenotypic correlations among all important traits is desirable. Hatcheries must also produce juveniles with biological qualities that will allow them as adults to meet the goals of the hatchery program. The survival and reproductive success of juvenile hatchery fish depends upon their physiological, morphological, behavioral, and health characteristics at the time of their release. One template for achieving healthy and viable hatchery populations is the biological characteristics of local wild fish populations. Since these populations have persisted for thousands of years, it is difficult to argue that these characteristics are not successful once the fish are released into the natural environment. Operators of hatchery programs need to understand the importance of these characteristics within the context of the natural environment and for certain types of programs should emulate them in the hatchery to the extent possible. Achieving the characteristics of these locally adapted stocks, including their physiology, morphology, behavior, and fish health, as well as their natural life history patterns, may provide benefits to hatchery stocks as well as reduce negative interactions with naturally produced fish. Deviation from this wild salmon template in terms of these factors, while possible and perhaps successful in the short-term may have significant consequences to hatchery and natural stocks in the long-term.[43]

Like genetic guidelines, certain biological guidelines are important no matter what the type and purpose of the program. Providing a hatchery environment and operational protocols that lead to good fish health is a necessity in every program. While the goal to produce fish with good physiological, morphological, and behavioral fitness is a desired outcome in every hatchery program, the means by which this is accomplished may vary depending on the type and purpose of the program.

In integrated harvest and conservation programs for instance, mimicking the growth pattern, size, and out-migration timing of natural fish is likely to produce smolts prepared for rapid migration to salt-water, as well as having the ability to survive and grow. Adopting natural life history characteristics by allowing volitional out-migration during the normal timing of natural stocks may also provide long-term survival benefits when conditions in the receiving habitat vary. Following the wild fish template is also likely to produce adults with the morphological characteristics important to successful reproduction in the natural environment.

In other types of programs such as segregated harvest or segregated conservation programs, producing fish with the proper physiological, morphological and behavioral characteristics is still necessary. However, using the wild salmon template, may not be the only way to accomplish the goals for such programs. In these cases, adoption of operational protocols that lead to better hatchery efficiency, or that maximize the survival of the propagated stock may be the overriding factor rather than the desire to produce adult fish more suited to reproducing in the wild. When these approaches are chosen, however, it must be recognized that deviation from the characteristics that have been derived through long-term adaptation of natural stocks, may have undesirable outcomes.

4.4 Achieving Harvest Goals through the Hatchery Environment and Operational Protocols

Meeting harvest goals requires that hatchery populations must be sufficiently productive and abundant to support fisheries. Harvestable fish must also be available at the proper time and place to allow fishery access. Harvest contribution is affected by the size of the hatchery program and the survival of hatchery fish through their life cycle. The health and viability of hatchery populations are affected by the environment in which the fish are reared and depends on the operational protocols of the hatchery program. Determining the requirements of the hatchery environment and the selection of operational protocols to meet harvest goals is dependent on the type of hatchery program being operated, either segregated or integrated. Certain requirements, such as the proper water quality for rearing and operational protocols that protect fish health are necessary in any program to meet the basic biological needs of the cultured fish. However, other environmental factors, such as the appropriate temperatures

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43 *See Emerging Issue Paper ….add info here on location of Wild Fish Template*

for rearing, nutrition and diet management, and pond loading and densities may be different depending on the type of the hatchery program. Other operational protocols including broodstock choice and collection, incubation, rearing, and release strategies may also be different.

4.4.1 Segregated Harvest Programs

Segregated harvest programs are most appropriate when nearly all returning hatchery-origin adults can be harvested or recaptured, or where the habitat or natural environment cannot support natural populations of salmonids. They may also be the most appropriate where the only goal for the program is harvest and the potential for genetic and ecological interactions between hatchery-origin and natural-origin fish is minimal, or the biological effects of those interactions are considered inconsequential. The size of segregated harvest programs must not exceed thresholds above which natural stray rates would pose significant genetic or ecological risks to natural populations in the target watershed or other watersheds. Stray rates as low as one to two percent for a large, segregated harvest program may pose unacceptable risks to natural populations.

Hatchery environments appropriate for supporting segregated harvest programs may also have few limitations. It must simply provide an adequate water supply suitable for culture of salmonids. Other limitations such as the use of water temperatures that would synchronize development of hatchery stocks with their natural counterparts is not as important as it might be in other programs, therefore, the use of pathogen-free water for segregated harvest programs is preferable.

Operational guidelines for segregated harvest programs should be appropriate to maximize the productivity of the hatchery stock prior to and after release. Since every hatchery stock experiences a unique combination of rearing conditions in the hatchery as well as in the receiving environment, these guidelines should be based on site-specific studies at each facility. Additionally, guidelines for genetic and biological characteristics including physiology, morphology, behavior, and fish health need to be followed to contribute to the long-term success of the program. Important guidelines to achieve this goal are provided below. These guidelines are not comprehensive but are meant to highlight the important factors that need to be achieved to meet the goals of a segregated harvest program relative to the hatchery stock only.[44]

Important genetic guidelines include the following:

- *Maintain an effective population N_e of at least 500 fish;*
- *Avoid the use of broodstock from natural populations or other hatchery populations;*
- *Mark or tag all hatchery-released fish, so that the proportions of natural- and hatchery-origin fish among natural spawners and in the broodstock can be monitored and controlled.*

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[44] *A complete compilation of guidelines for segregated harvest programs can be found in Appendix B, p.2-25. Important guidelines that are pertinent to the effects of propagated fish on other stocks are provided in framework Chapter 5.*

Important guidelines for physiological, morphological, and behavioral characteristics include the following:

- *Produce fish that have the physiological fitness to migrate rapidly to saltwater and to survive in that environment through growth regimes that promote smoltification;*
- *Produce fish that have the morphological characteristics to meet harvest goals;*
- *Produce fish that have the behavioral characteristics, such as adult migration timing, to meet harvest goals.*

Important measures for controlling/preventing diseases in hatcheries include the following:

- *Avoid crowding and build-up of wastes and dead fish in fish holding units;*
- *Monitor fish health regularly and implement needed treatments immediately;*
- *Use prophylaxis by vaccination where feasible;*
- *Use adequate diets that have been stored for only short periods;*
- *Avoid practices and situations likely to result in chronic stress (e.g., frequent fish handling, holding of fish in high activity areas, overcrowding);*
- *Use locally-adapted stocks that are likely to have developed reasonable resistance to any pathogens likely to be present in the water supply.*

These measures for controlling/preventing diseases apply to each type and purpose of hatchery program.

4.4.2 Integrated Harvest Programs

A fundamental goal of an integrated harvest program is to minimize genetic divergence of the hatchery broodstock from the naturally spawning population in areas where fish are released and/or collected for broodstock. The long-term goal of an integrated harvest program is to maintain genetic characteristics of a local, natural population among hatchery-origin fish by minimizing genetics changes resulting from artificial propagation and potential domestication. In an idealized integrated program, natural-origin and hatchery-origin fish are genetically equal components of a common gene pool.

Integrated harvest programs may be most appropriate when conservation is one of the purposes of the program or when significant genetic and ecological interactions cannot be avoided through the use of a segregated harvest program.

The hatchery environment that is appropriate for supporting an integrated harvest program has more requirements than the environment necessary to support a segregated harvest program. In addition to the water supply being simply suitable for the culture of salmonids, the hatchery should use a water supply with a temperature regime that would synchronize development of hatchery stocks with their natural counterparts. In this case, it is likely that this will require the use of surface water, which is not likely to be pathogen-free.

Since the goal of integrated harvest programs is to minimize divergence from the naturally spawning population, strict broodstock management protocols as well other hatchery management practices that minimize the potential domestication effects of the hatchery environment should be used. Operational guidelines for integrated harvest programs should not be designed to maximize the productivity of the hatchery stock, as in segregated harvest programs. Rather, they should focus on producing fish with life history strategies providing sufficient productivity to meet harvest goals, while minimizing the potential ecological and genetic risks to the composite population. In this case, the wild fish in the watershed may provide the best template for how hatchery fish should be produced: that is, they should attempt to emulate natural fish in size, growth rate, physiology, morphology, and behavior. Important guidelines to achieve this goal are provided below. These guidelines are not comprehensive but are meant to highlight the important factors that need to be achieved to meet the goals of an integrated segregated harvest program relative to the propagated stock.[45]

Important genetic guidelines include the following:

- *Develop a detailed genetic management plan for the hatchery broodstock and the naturally spawning population in the watershed where adults are trapped for broodstock;*
- *Maintain an effective population size (N_e) in the hatchery of at least 500 fish;*
- *Ensure that an average of 10 – 20% of the hatchery broodstock is composed of natural-origin adults each year;*
- *Collect and spawn adults randomly with respect to time of return, time of spawning, size and other characteristics related to fitness*
- *Rear in a hatchery environment and with operational protocols that ensure all portions of the population are treated equally and have the same opportunity to contribute to the release population;*
- *Mark or tag all hatchery-released fish, so that the proportions of natural- and hatchery-origin fish among natural spawners and in the broodstock can be monitored and controlled;*
- *Monitor and control natural spawning by hatchery origin adults, so that the percentage of natural spawners composed of hatchery-origin fish is less than the percentage of the hatchery broodstock derived from natural-origin fish.*

Important guidelines for physiological, morphological, and behavioral characteristics include the following:

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[45] *A complete compilation of guidelines for integrated harvest programs can be found in Appendix B, p.2-25. Guidelines that are pertinent to other stocks are provided in Chapter 5 of Appendix A.*

- *Use a hatchery environment that allows synchronization of adult maturation, incubation and emergence, and out-migration with natural populations;*
- *Use a hatchery environment and rearing protocols that produce juvenile fish similar to natural populations in growth rate and size to reduce competition with natural counterparts and to maintain the age structure of the natural population;*
- *Rear fish at reduced densities in enriched environments to improve cryptic coloration, territorial fidelity, and social behavior;*
- *Allow some controlled contact with predators to acquire a predator avoidance response;*
- *Release fish volitionally during the out-migration timing of the natural stock.*

The important measures for controlling/preventing diseases in hatcheries are the same as for segregated harvest programs.

4.5 Achieving Conservation Goals through the Hatchery Environment and Operational Protocols

Conservation hatcheries[46] can play a vital part in the recovery of threatened and endangered species by maintaining their genetic diversity and natural behavior, and by reducing the short-term risk of extinction. Under proper conditions, conservation hatcheries can maintain severely depleted natural stocks in captive culture in gene banks to avoid extinction. Hatcheries have the capability to maintain large breeding populations of wild stocks to minimize the risk of demographic loss from unpredictable environmental events. Hatcheries, when operating in the conservation mode, can supplement under-recruited wild populations that are below their natural carrying capacity. Finally, in cases where wild stocks have been extirpated, conservation hatcheries have the capability to introduce and maintain naturally spawning stocks until they are self-sustaining. The conservation hatchery concept implies that following the recovery of target populations and receiving habitat, these programs will be terminated. In order to be effective, conservation hatchery programs must be integrated with habitat and harvest management programs that provide for rebuilding of self-sustaining, naturally spawning populations.

It is well recognized that the artificial rearing conditions within a hatchery can produce fish distinctly different from their wild cohorts in behavior, morphology, and physiology. Hatchery methodologies can impose different selective pressures on fish, and these can change overall fitness in many ways. Conventional hatchery rearing practices can alter genetic fitness through spawning, fertilization and rearing protocols. Hatcheries can inadvertently select for fish adaptable to high densities and feeding levels, and fish that cannot adapt may be selected against and not survive to release. Similarly, conventional practices may deliberately seek to reduce size variability. Within a hatchery population this may be desirable, but in the long-term this can be detrimental if fish are expected subsequently to rear and spawn in the wild. The wide natural variability in development and timing characteristics of

[46] *A conservation hatchery is defined as one where the purpose is to recover and conserve naturally spawning populations.*

wild fish may be inherent factors that enable these fish to adapt to changing freshwater and marine conditions.

As in harvest programs, determining the requirements of the hatchery environment and the selection of operational protocols to meet conservation goals is dependent on the type of hatchery program being operated, either segregated or integrated. Again, certain requirements, such as the proper water quality for rearing and operational protocols that protect fish health are necessary in any program. Additionally, since the stocks propagated in conservation programs usually exist in relatively low numbers that are maintained primarily in the hatchery environment, special care must be taken to provide security for the stocks to prevent against catastrophic loss. Other recommended environmental factors and operational protocols may change depending on the type of conservation program being operated.

4.5.1 Segregated Conservation Programs

Segregated conservation programs are appropriate in extreme circumstances where the natural environment can no longer support an important stock, and the stock is in rapid decline or is in imminent risk of extinction. The goal of these programs is to conserve the population and maintain its genetic resources while habitat supporting the stock is recovered or adverse environmental conditions leading to decline are corrected. At some point in time, the goal of these programs is to re-introduce the stock to a natural environment; consequently, it is critical that operational protocols are designed to maintain the genetic diversity of the propagated stock. Rearing and release protocols should generally be designed to maximize the productivity of the stock, but when there are multiple approaches with a high likelihood for success, different strategies should be employed to reduce risk.

The hatchery environment appropriate for supporting a segregated conservation program will vary depending on the rearing approach that is used. Security of the stock, however, is critical, and hatcheries involved in these types of programs should have multiple water supplies that are pathogen-free and redundant systems to provide security. It is also advisable to use multiple facilities to provide added security.

Since the goal of segregated conservation programs is to maintain the propagated stock until it can be re-introduced into the natural environment, broodstock protocols should be employed that maximize the genetic diversity of the stock, including the potential use of cryo-preserved gametes when necessary. Operational guidelines for segregated conservation programs should focus on producing juvenile fish similar to their natural counterparts. In extreme cases, the need to maximize the survival of each individual may be important enough to use alternative approaches such as captive rearing. Important guidelines to achieve the goals of segregated conservation are provided below. These guidelines are not comprehensive but are meant to highlight the important factors that need to be achieved to meet the goals of a segregated harvest program relative to the hatchery stock only.[47]

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[47] *A complete compilation of guidelines for segregated conservation programs can be found in Appendix B, p.2-25. Important guidelines that are pertinent to the effects of propagated fish on other stocks are provided in framework Chapter 5.*

Important genetic guidelines include the following:

- *Collect and spawn adults randomly with respect to time of return, time of spawning, size and other characteristics related to fitness;*
- *Use mating protocols that maximize the effective population size (N_e) in the hatchery, including factorial mating, maintenance of individual pedigrees and cryopreserved gametes when necessary;*
- *Rear in a hatchery environment and with operational protocols that ensure all portions of the population are treated equally and have the same opportunity to contribute to the release population;*
- *Tag all hatchery-released fish to ensure correct identification for use in future broodstocks or in other monitoring programs.*

Important guidelines for physiological, morphological, and behavioral characteristics include the following:

- *Use a hatchery environment that allows synchronization of adult maturation, incubation and emergence, and out-migration with natural populations;*
- *Rear fish at reduced densities in enriched environments to improve cryptic coloration, territorial fidelity, and social behavior;*
- *Release fish volitionally during the out-migration timing of the natural stock;*
- *Use a hatchery environment and operational protocols that maximize the survival of each individual including captive rearing.*

The important measures for controlling/preventing diseases in hatcheries are the same as for segregated harvest programs.

4.5.2 Integrated Conservation Programs

Integrated conservation programs are similar to integrated harvest programs with the exception that the fish produced are intended to contribute to natural production rather than harvest, and might be viewed at a transitional step between a segregated conservation program and an integrated harvest program. They are appropriate when demographic risks to the natural population outweigh the genetic risk from allowing hatchery-origin fish to spawn naturally. Broodstock management protocols should be designed to maintain the genetic diversity of the propagated stock, but strict adherence to a specific goal for the composition of the hatchery-origin or natural-origin fish on the spawning grounds is relaxed. However, as the number of natural-origin fish returning to the watershed increases over time, the number of hatchery-origin adults allowed to spawn naturally would be restricted in order to allow selection in the natural environment to overcome any natural selection in the hatchery. Rearing and release protocols in the hatchery should be similar to those used in integrated harvest programs and should produce fish similar to the naturally produced fish of the same species.

The hatchery environment that is appropriate for supporting an integrated conservation program would be the same as that for an integrated harvest program. Integrated harvest programs may also have conservation goals, although natural spawning by hatchery-origin fish may not be an explicit purpose of a harvest-motivated program.

Important guidelines to achieve the goals for integrated conservation programs are provided below. These guidelines are not comprehensive but are meant to highlight the important factors that need to be achieved to meet the goals of an integrated harvest program relative to the propagated stock.[48]

Important genetic guidelines include the following:

- *Develop a detailed genetic management plan for the hatchery broodstock and the naturally spawning population that adapts to changes in the number of natural-origin spawners in the watershed;*
- *Maintain an effective population size (N_e) in the hatchery of at least 500 fish;*
- *Collect and spawn adults randomly with respect to time of return, time of spawning, size and other characteristics related to fitness;*
- *Rear in a hatchery environment and with operational protocols that ensure all portions of the population are treated equally and have the same opportunity to contribute to the release population;*
- *Mark or tag all hatchery-released fish, so that the proportions of natural- and hatchery-origin fish among natural spawners and in the broodstock can be monitored and controlled.*

Important guidelines for physiological, morphological, and behavioral characteristics include the following:

- *Use a hatchery environment that allows synchronization of adult maturation, incubation and emergence, and out-migration with natural populations;*
- *Use a hatchery environment and rearing protocols that produce juvenile fish similar to natural populations in growth rate and size to reduce competition with natural counterparts and to maintain the age structure of the natural population;*

48 *A complete compilation of guidelines for integrated conservation programs can be found in Appendix B, p.2-25. Guidelines that are pertinent to other stocks are provided in framework Chapter 5.*

- *Rear fish at reduced densities in enriched environments to improve cryptic coloration, territorial fidelity, and social behavior;*
- *Allow some controlled contact with predators to acquire a predator avoidance response;*
- *Release fish volitionally during the out-migration timing of the natural stock.*

The important measures for controlling/preventing diseases in hatcheries are the same as for segregated harvest programs.

CHAPTER 5: EFFECTS OF HATCHERY FISH ON HARVEST AND CONSERVATION OF OTHER STOCKS AND SPECIES

Depending on the number, size, location and other release factors, hatchery fish may directly or indirectly affect other stocks and species through genetic or ecological interactions. The presence of hatchery fish may also alter fishing patterns and thereby affect harvest rates on natural produced stocks. In the following section we describe these potential effects and identify management actions that can help alleviate adverse impacts.

5.1 Genetics Effects (including changes in biological significance and viability)

5.1.1 Changes in Biological Significance

Hatchery populations directly affect the genetic composition and biological significance of natural populations through gene flow, the transfer of genes from hatchery populations into naturally spawning populations. Gene flow is influenced by the straying or stocking rate of hatchery populations into natural populations, as well as by the reproductive success of the hatchery fish. The effects of this gene flow are unpredictable and depend on the genetic composition of the hatchery population.

Genetic changes in natural populations, particularly those related to fitness, are difficult to measure. Genetic effects on natural populations depend on factors including the frequency and consequence of the interaction. Hatchery fish contribute to gene flow only when they reproduce successfully. The magnitude of genetic effects is also influenced by genotypic and phenotypic dissimilarity between hatchery and wild populations. The greater the genetic distance, and the more dissimilar the hatchery and wild fish, the greater the potential deleterious effects (Withler 1997). Further, the duration and magnitude of interbreeding, as well as the size of the natural population, also influence the potential for genetic effects. The proportion of genes incorporated into the local population (rather than the absolute size of the local population) determines the rate of gene flow and the potential genetic effects.

Although the factors influencing genetic effects are well characterized (Grant 1997), predicting the magnitude of genetic effects is difficult due to their inherent complexity and our inability to accurately measure natural processes on salmonid populations (Busack and Currens 1995; Campton 1995).

Change of Diversity Among Populations

Hatchery populations can cause a loss or, less commonly, an increase in diversity among natural populations. These changes are measured as changes in numbers of alleles, in the relative frequencies of alleles, and in the distribution of alleles across populations (within and among-population diversity).

A reduction in among-population diversity can result from propagation of a single hatchery stock over a wide area, if these fish successfully interbreed with wild fish (Hindar et al. 1991; McGinnity et al. 1997). Loss of variation is influenced both by the level of straying (stray or stocking rate) and the success of hatchery fish in reproducing in the wild (rate of gene flow). As these rates increase, allele frequency differences among populations decrease. The loss may be particularly rapid if the hatchery population has reduced within-population variability as a result of hatchery practices and successfully interbreeds in large numbers with wild fish (Hjort and Schreck 1982; Simon et al. 1986; Waples and Teel 1990).

Increases in among-population genetic variation can result from a non-native hatchery stock interbreeding extensively with a wild population, if the hatchery population is not straying to adjacent wild populations. However, the general expectation is that such interbreeding is likely to result in a decrease in fitness (Campton 1995; Reisenbichler and Rubin 1999).

Studies have attempted to specifically address not only the rate of gene flow, but also the success of hatchery fish in reproducing in the wild. These studies have typically used genetic tagging or marking, so the progeny of hatchery fish can be detected and monitored (Leider et al. 1990; Seeb et al. 1990; Tallman and Healey 1994). New DNA methods now allow complete reconstruction of pedigrees, thus allowing the reproductive success of individual fish to be estimated.

Some studies suggest that hatcheries have substantial genetic effects in reducing diversity, while others support the hypothesis that wild patterns of diversity have been maintained despite repeated stock transfers. Bugert et al. (1995) suggest that high rates of straying of Columbia River fall Chinook into the Snake River have influenced the genetic composition of Snake River fall Chinook salmon. Other studies found that wild patterns have been maintained, despite large levels of stocking of non-native fish, presumably because the introduced fish were poorly adapted to the environment (Wishard et al. 1984; Currens et al. 1990).

Change of Diversity Within Populations

The same processes that lead to changes in diversity among populations can lead to change of diversity within individual populations receiving hatchery fish. In addition to replacement of alleles, a reduction in diversity and in the effective size of the wild population can result from "genetic swamping," where a large number of hatchery fish from relatively few parents interbreed with wild fish. This is particularly likely if the effective population size of the hatchery population is substantially less than that of the wild population (Ryman and Laikre 1991; Ryman et al. 1995).

An increase in within-population diversity may result from interbreeding of hatchery fish into a population with very low effective population numbers. The consequence of this interbreeding would depend on the origin of the hatchery individuals.

5.1.2 Changes in Viability

Decreases in viability can occur when two genetically divergent populations interbreed or hybridize. These decreases are commonly termed outbreeding depression (Emlen 1991; Lynch 1991). Outbreeding depression has two possible sources: 1) loss of adaptation (Hindar et al. 1991; Reisenbichler and Rubin 1999); and 2) breakup of favorable gene complexes (Templeton 1986; Lynch 1997). Loss of adaptation occurs when non-local genes that evolved in a different environment replace locally adapted genes, reducing the frequency of favorable genes. This loss may be immediately apparent in the first generation. The second cause of outbreeding depression occurs as a result of breakup of favorable combinations of genes or gene complexes and may not be apparent until the second generation or later (Lynch 1997).

Reisenbichler and Rubin (1999) reviewed evidence for genetic changes from artificial propagation that affect productivity and viability of wild populations. They concluded that fitness in natural spawning and rearing environments can be rapidly and substantially reduced by artificial propagation.

Decreases in viability can be measured as a change in productivity between the original local population and the hatchery fish. As individuals mate with increasingly genetically-dissimilar individuals, outbreeding depression is expected to increase. However, the effects of outbreeding depression may not appear for a few generations. Empirical evidence of outbreeding depression can be found in experiments in which outbred and control fish are released into natural environments and is more likely to be detected if the source populations are genetically different, either as a consequence of isolation or of local adaptation. Gharrett and Smoker (1991) evaluated hybrids of genetically isolated odd- and even-year pink salmon from the same stream by fertilizing eggs with cryo-preserved milt, releasing marked fry into the sea, and recovering marked adults at maturity at the natal stream. The returns of F2 individuals were apparently low, and the F2s had increased bilateral asymmetry, apparent evidence that co-adapted allele complexes were disrupted by outbreeding depression, Decreased survival of F2 hybrids was confirmed in a later study of two generations in two independent brood lines of pink salmon naturally spawning in the same stream (Gharrett et al. 1999). Gilk et al (2003) observed second-generation hybrids of pink salmon populations naturally isolated by 1000km of geographic distance and naturally adapted to different local environments; they detected reduced fitness (survival at sea) in both even-year and odd-year broodlines, evidence again of disruption of favorable gene complexes. Granath et al (2003) observed evidence of diminished adaptation in first-generation hybrids formed among three coho salmon populations naturally separated by 220 – 400km; they observed maladaptive embryonic development rates in hybrids compared to embryos formed within the three populations and observed in a laboratory environment shared in common with the hybrids.

5.2 Ecological Effects (predation, competition, fish health, disease, nutrient enhancement)

Flagg et al. (2000) reviewed almost 300 references on ecological and behavioral impacts of artificial production on wild salmonids. The intent of the review was to determine the major impacts of different salmonid hatchery production strategies on abundance, competitive social interactions, predation, health, migration, and population trends. Based on a combination of theoretical considerations and available data, the review was in most cases able to identify the directional trend of the effects to wild populations of release of hatchery fish. In general, the review indicated that: 1) Except in situations of low wild fish density, increasing release numbers of hatchery fish can negatively impact wild fish. This appeared true regardless of whether out-of-basin or local stocks were released. 2) Competition of hatchery fish with wild fish almost always has the potential to displace wild fish from portions of their habitat even where hatchery fish are less competitive on a one-to-one basis. 3) Only species that spend extended periods in freshwater habitats after their release have a strong potential to decrease the food resources available to wild fish. 4) Potential predation effects were documented whenever hatchery fish were significantly larger than comingling wild fish. Negative effects of hatchery fish on predator/prey dynamics, through such mechanisms as predator concentration, appeared possible at all life stages. 5) Releases of hatchery fish appeared to have the potential to affect the health of wild fish, although there was little evidence to suggest that disease transmission to wild stocks is routine. 6) Some reports have indicated that the presence of large numbers of outmigrating hatchery smolts may hasten the migration of wild smolts. However, neither the frequency of the phenomenon, the conditions under which it occurs, nor the effect on ultimate survival of wild fish has been documented.

The ecological effects on freshwater habitat carrying capacity from nutrients derived from decomposing salmon carcasses (marine-derived nutrients) are recognized to play an important role in the ecology of anadromous salmonids (Bilby et al. 1996, Gresh et al. 2000). In the Northwest, river systems in which salmon spawn and rear are often nutrient poor and the delivery of marine-derived nutrients by returning salmon carcasses is a key component to potential growth and survival of juvenile fish in the system (Larkin and Slaney 1997, Bilby et al. 1996, 1998, 2001; Cederholm et al. 1999). However, currently only a small fraction of historic marine-derived biomass (returning adults) is available to rivers in the Northwest. Thus, in many stream systems in the Northwest the macro-invertebrate communities may currently be below thresholds necessary to sustain increased fish production from supplementation releases without causing potential severe competitive interactions between supplemented and naturally produced fish. While the deliberate distribution of hatchery salmon carcasses into watersheds for purposes of nutrification can have a positive ecological benefit to natural salmonid stocks. It is well recognized that disease organisms present in salmon carcasses can be transmitted to other salmonids following the release of these organisms into water or through their direct consumption. Thus, this practice may also pose a fish health risk to these stocks if not properly managed.

5.3 Harvest Effects

Hatchery fish can indirectly affect natural stocks through harvest in two ways. First, hatchery populations typically can sustain far greater harvest rates than natural stocks, hence mixed stock fisheries that are conducted to harvest abundant and productive hatchery stocks will cause natural stock to be over harvested (e.g. Flagg et al. 1995). Secondly, abundant hatchery populations may mask the abundance of co-mingled natural stocks, causing imprecision in stock assessment and perhaps failure to recognize when a natural stock is depressed and in need of protection.

5.4 Actions to Achieve Desired Outcome

5.4.1 Genetics Actions

Actions to minimize detrimental genetic effects of hatchery populations on other stocks can be taken both within and outside the hatchery environment. Within the hatchery environment, actions include choosing an appropriate broodstock (Section 3.1) and using appropriate mating strategy to maintain a viable and genetically diverse broodstock (Section 4.1.1). Actions outside the hatchery environment include controlling the number of hatchery fish allowed on the spawning grounds (Section 4.2.2), and minimizing straying of hatchery fish to the non-target stock from both integrated and segregated programs. These latter actions will typically require identification of the hatchery stocks through tagging or marking programs to properly control interactions with naturally-spawning populations.

Programs relying on outplanting may pose an elevated genetic risk by promoting stray rates, often exceeding natural levels, to freshwater areas where interbreeding with naturally spawning populations is undesirable. Tagging and genetic studies have shown that outplanting and net pen programs promote stray rates that far exceed natural levels (Candy and Beacham 2000; Mackey et al. 2001). Steelhead programs in Puget Sound and coastal Washington have often used outplanting to support sport fisheries in a large number of small streams. Similarly, saltwater net pens are used to acclimate and release salmon smolts in marine areas where a targeted marine fishery on returning adults is desired. A common feature of these programs is that they release fish where no or limited facilities exist to trap returning adults that escape target fisheries. Outplanting and net-pen releases from segregated hatchery programs carry a potentially higher level of risk, because of the likelihood of significant genetic divergence between the hatchery and natural populations (see Section 5.1) and the potential for loss of among population diversity should hatchery populations interbreed with natural fish.

5.4.2 Ecological Actions

As described in Flagg et al. (in press), in order to reduce ecological and behavioral interactions between hatchery and wild fish, conservation-minded hatchery operations should include incubation and rearing vessels with options for habitat complexity to produce fish more wild-like in appearance, and with natural behaviors and higher survival. Rearing goals should be based on growth patterns of natural fish and size at emigration on natural population parameters. Conservation hatcheries should use low rearing densities to improve juvenile survival during rearing and to increase adult quality and return percentage.

Recommended guidelines for reducing ecological and behavioral interactions include:

- *Determine growth rates, body size and composition, spawning, hatching, and emergence times of fish in the local populations and duplicate these in the hatchery by controlling factors such as photoperiod, water temperature, and diet composition and feeding rate to natural profiles;*

- *Provide matrix substrates, darkened environments, and temperature control for egg incubation and alevin development;*
- *Rear fish for their entire juvenile freshwater lives in water from the intended return location to imprint natural odors and reduce straying of returning adults, or acclimate juveniles at selected release sites where this approach is not possible;*
- *Reduce rearing density and maximize fish health;*
- *Promote development of body camouflage coloration in juvenile fish by creating more natural environments in hatchery rearing vessels; for example through use of overhead cover, and in-stream structure, and substrate;*
- *Condition young fish to orient to the bottom rather than the surface of the rearing vessel by using appropriately positioned feed delivery systems;*
- *Release smolts within the size range of wild smolts from which the population is derived (except in a case when imminent extinction requires maximal survival, where release of large smolts may be warranted);*
- *Allow fish to emigrate volitionally to maintain within-population variability in outmigration timing found in local wild populations and allow non-smolts (parr) to remain in the hatchery, and either smolt, residualize, or perish through natural selection;*
- *Adopt strategies for restricting numbers of hatchery-reared juveniles released to not exceed carrying capacities of receiving waters and migration pathways (e.g., estuaries).*

In this regard, it appears critical to provide for increases in freshwater habitat carrying capacity through such things as nutrient enhancement in order for supplementation programs to minimize competitive interactions between hatchery releases and wild fish.

Recommended guidelines when using hatchery carcasses for nutrient enhancement include:

- *Certifying that adult broodstock is free of viral pathogens prior to 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;*
- *Freezing carcasses prior to planting to reduce the infectious titers of pathogenic organisms in the salmon carcasses. This measure will decrease the risk of transmission of certain of these disease organisms (see, for example, Margolis 1977 for a metazoan parasite, and Evelyn 2001 for two important bacterial fish pathogens);*

- *Planting carcasses only within the historic range of the species being used for nutrient enhancement;*

- *Avoiding the planting of adults or juveniles that may have died of infectious disease. This would include pre-spawning adult mortalities and juvenile mortalities from hatchery ponds.*

5.4.3 Harvest Actions

The requirement to protect stocks of concern has increasingly imposed more frequent and significant limitations on harvest opportunities. These increased restrictions have created challenges to fully harvesting many hatchery populations. Tools available to provide harvest access to productive stocks, while protecting weaker ones, include: location of hatchery and release sites, selection of broodstock, and time-area harvest management policies. Additional tools, such as mass marking of hatchery fish coupled with harvest methods that allow fishers to release unmarked fish unharmed, are being developed, and may be appropriate to supplement traditional fishery management methods. New and creative ways to target hatchery fish without harming stocks of concern should be developed, tested, and implemented if successful.

CHAPTER 6: MONITORING AND EVALUATION: MANAGING HATCHERY PROGRAMS FOR ACCOUNTABILITY AND SUCCESS

Today's salmon and steelhead hatcheries are called upon to help meet conservation, harvest, and/or other goals (e.g., education, research, cultural and ceremonial needs, and indicator stocks), while minimizing adverse impacts on natural-origin salmonids within the watersheds or regions in which they operate. To be successful at meeting these goals, accountability for decisions and actions is required at all levels within the agencies responsible for management and operation of hatcheries. Success will also require an accurate and timely management information system that can measure benefits, evaluate actions, and provide information for hatchery management and operations. This means that information about hatchery programs and natural stocks must be available in an up-to-date database that allows the managers to regularly adjust hatchery programs in response to changing conditions in their watersheds. These include changes in the status of natural stocks, carrying capacity of the receiving waters, ocean productivity, and harvest needs.

The co-managers and the HSRG are currently engaged in an effort to develop a comprehensive operational monitoring and evaluation plan. This chapter should be viewed as a preliminary report on a work in progress.

6.1 Evaluating Hatchery Success

Managers routinely monitor the operation of hatcheries to evaluate the biological and operational performance of individual hatcheries. This information must be used to evaluate the overall effectiveness of the system in meeting predetermined goals, and translated into performance measures for the system as a whole. Thus it is important that each hatchery program have clearly stated goals, not only for the performance of the hatchery stock, but for stocks affected by the hatchery program as well. These goals need to be sufficiently detailed to provide accountability for performance and for evaluating the benefits actually derived. Currently, protocols for monitoring are determined and reported separately by each of the co-managers, often in different dimensions and formats. This makes system-wide evaluation difficult. Furthermore, there is little standardization of monitoring criteria both within and between the co-management systems. To address these complex issues, managers and operators of hatchery programs must have access to, and must use, common tools and procedures that aid in: a) recording, organizing and reporting existing and emerging data and information; and b) monitoring and evaluating biological uncertainties.

Monitoring hatchery programs for success must include two major phases:

> **Hatchery Culture** *Phase* - This phase involves the tracking of fish culture procedures within the hatchery to determine whether conditions in the hatchery are conducive to the production of healthy and viable fish, and whether the hatcheries are operating in the most cost-effective manner.

Post-Release *Phase* - This phase involves the tracking of released juveniles and returning hatchery adults to determine the ecological and genetic interactions between hatchery and wild fish in the natural environment, and the contribution of hatchery fish to the stated goals for the target stock(s).

In order to evaluate the success of a program, specific performance indicators for each phase need to be identified. Success should be measured in terms of specific goals (validation monitoring) and performance benchmarks (performance and effectiveness monitoring) and based on adequate data. Further, because of the dynamic nature of ecosystems and the likelihood that interaction effects may be small but cumulative, the data gathering and evaluation process must be ongoing and comprehensive.

Effective monitoring and evaluation programs, including implementation, performance, effectiveness, and validation monitoring should be developed for all hatchery programs. Data collection protocols should be developed and implemented to assure that the data needed for evaluation of both the hatchery culture and post-release phase of hatchery programs are available. In particular, standard data collection protocols should be developed to assure that information is available to evaluate the genetic and ecological consequences of hatchery actions on fish and habitat outside the hatchery. Hatchery reporting should document results from the monitoring program as well as any requirements from the agencies and funding sources. Tools that streamline standardized record keeping and data storage should be implemented.

Timely and reliable information feedback at all levels of decision making and hatchery operation is an absolute requirement for hatchery programs to meet their goals without unnecessary costs. Effective feedback systems require that the necessary data be collected and disseminated in a manner that is useful and timely to decision makers, operators, scientific advisors and the public. Effectiveness of this system presumes a decision making process that is receptive and prepared to act on the information provided.

Coordinated data collection protocols and information dissemination procedures are absolutely essential for informed decision making at all levels. Without them, the goals of hatchery reform cannot be achieved.

6.2 Factors Necessary for a Successful Monitoring and Evaluation Program

6.2.1. Decision Making at the Implementation, Effectiveness, Performance and Validation/Research Levels

Existing hatchery programs should be regularly examined to determine whether they are being conducted in a manner consistent with resource goals. Managers should use the following recommendations in planning new hatchery programs, or altering existing programs when monitoring and evaluation (M&E) provides data indicating that changes are needed. This process of change and adaptive management must include staff at all levels of hatchery decision making and operation—hatchery personnel, field biologists, support scientists and management.

An inevitable consequence of any hatchery M&E program is that decisions have to be made about hatchery operations that are found to be not meeting the stated goals. Effective M&E programs including four levels of decision making (*implementation, effectiveness, performance,* and *validation/research*) should be developed for all hatchery programs. Using fish health as an example, and starting at the hatchery level of decision making upwards to the management level, one might ask the following questions:

1) **Implementation Level:** What are the most significant disease problems at the hatchery? Are disease control measures being undertaken in an attempt to control them?
2) **Effectiveness Level:** Are the disease control measures being used actually effective at controlling the disease? The forgoing question focuses on the effectiveness or adequacy of the current disease control policies and approaches.
3) **Performance Level**: Are the program objectives being met in terms of the number of healthy fish released and the number of adults that return to spawn successfully? Do disease control methods assure that harvest and conservation goals for the stock are achieved? Are the disease risks posed to the target stock and other stocks of such a magnitude that, given the treatment options available, the program should be changed or even terminated?
4) **Validation/Research Level**: What are the critical uncertainties in disease management? Where should research be focused to permit better decision making at the three lower levels relating to disease control?

6.2.2. Tools for Evaluating Hatchery Performance

The hatchery operational guidelines developed by the HSRG[49] contain a list of critical questions used to determine if individual hatcheries are being operated according to their stated goals. They also provide a general checklist of evaluation questions to be asked during the operation of a hatchery program. These guidelines, in turn, lead to the HSRG's monitoring and evaluation criteria,50 which identify the type of data that must be collected to permit evaluation to occur. The HSRG envisions that the co-managers will develop a detailed list of standardized, system-wide monitoring parameters that will be recorded at all hatcheries and that will address both segregated and integrated programs.

The HSRG's monitoring and evaluation criteria for the hatchery culture phase are organized according to six chronological hatchery culture stages, from broodstocking to release:

1) Broodstock choice
2) Broodstock collection
3) Spawning

[49] *See Appendix C, Hatchery Operational Guidelines.*
[50] *See Appendix D, Monitoring and Evaluation Criteria.*

4) Incubation
5) Rearing
6) Release

The HSRG Monitoring and Evaluation criteria for the post-release phase are organized into four categories:

1) Habitat quality/quantity
2) Genetic interactions
3) Ecological Interactions
4) Migration barriers

In the hatchery culture phase, evaluation questions are posed with respect to: 1) genetics, 2) physiology, morphology and ecology, and 3) culture of the stock on which the program is targeted. In the post-release phase, questions are posed with respect to the interactions between hatchery-origin fish, or recruits (HORs), and natural-origin fish, or recruits (NORs). The net result is that there are 130 evaluation questions to be considered for each hatchery program, which, in turn lead to 60–85 monitoring criteria for which data should be collected, depending on whether the hatchery program is integrated or segregated[30]. In addition to the standardized set of parameters that would be monitored at all hatcheries, other parameters could be selected for monitoring, based on the goals for stocks subject to individual hatchery programs.

Evaluation Modules

Monitoring data gathered during the two collection phases can be assembled into evaluation modules, depending on the performance level being evaluated. For example, the hatchery culture phase might be comprised of the following evaluation modules:

- A *hatchery water quality module* containing measures of settleable solids, pH, ammonia, and phosphorus can be used to determine if Washington State Department of Ecology (DOE) or US Environmental Protection Agency (USEPA) standards are being met.
- A *physiology, behavior and morphology module* containing measures of silvering, migration readiness, condition index and gill Na-K ATPase can be employed to determine if the hatchery fish are smolting properly or meeting the "wild salmonid template."[51]
- An *operational efficiency module* could be developed to contain a variety of measures. The cost of supplies, utilities, labor and overhead will be some of the inputs required to determine the cost effectiveness of the hatchery, along with how the cost per unit of smolt produced compares with other hatcheries in the system.

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[51] *See Emerging Issues in Hatchery Reform paper on this topic, Appendix B*

- A *growth evaluation module* would be used to compare in-hatchery growth to a pre-determined standard, based on feeding rate and water temperature, or to evaluate growth modulation.
- A *broodstock module* would allow managers to determine, for example, if sufficient NORs had been incorporated into the hatchery population, or if spawning protocols had been met.
- A *survival module* would allow managers to evaluate where within the hatchery culture phase any unusual mortality was taking place.
- A *tagging/marking module* would be essential in determining adult survival, contribution to fisheries and the number of HORs spawning naturally.

Examples of modules that might be developed to aid in evaluating the success or failure of hatchery fish during the post-release phase might include the following:

- A *genetic integration module* might be used to determine the ratio of HORs to NORs on the spawning grounds, and the relative reproductive success of the two components.
- A freshwater survival module would provide a census of wild and hatchery fish within a seeded area until migration. The census would depend on population counts at weirs and smolt traps, and on other methods such as snorkeling or other appropriate techniques.
- A *habitat suitability module* would map rearing and spawning habitat and evaluate both the quantity and quality of habitat suitable for spawning and rearing.
- A *freshwater habitat carrying capacity module* would require a census of all wild juveniles, their residence time and average size, and an estimate of the capacity of the receiving habitat to accommodate additional hatchery smolts of a given size and population density.
- A *predation module* would evaluate the capacity of hatchery fish to prey on, or be preyed upon by, wild salmonids. Input would require knowledge on the size (length) of hatchery fish at release, the size range of all resident wild fish and the distribution in time and space of predators and prey species.
- A *competition module* would evaluate the competitive interaction between wild and hatchery fish for food resources and space. It would require measures of territoriality, gut contents, habitat carrying capacity, and hatchery release procedures.
- A *juvenile migration module* would be comprised of measures of the timing and magnitude of juvenile outmigration, and would evaluate the emigration of juvenile hatchery fish in relation to wild fish emigration. These data are important in matching the wild salmonid template, determining the duration of predation, and estimating survival of the populations.

- An *adult migration module* would map the distribution of naturally-spawning NORs and HORs in the target watershed. Measures of reproductive success, distribution of spawning adults (redds), timing of spawning, redd superimposition, and age distribution would be required.

These evaluation modules for the *hatchery culture phase* and the *post-release phase* would vary in their monitoring parameters, depending on the objectives of the hatchery program and whether the hatchery program is segregated from or integrated with the local natural population. The above list of modules is by no means complete but it should serve as an example of the types of data required to evaluate the Puget Sound and coastal Washington hatchery system.

6.2.3. An Accessible and Unified Data-Gathering System

The HSRG envisions a readily accessible, computerized and unified data repository of information assembled by the co-managers, allowing them to provide descriptive and quantitative information on the state of their hatcheries and programs in a timely manner. Co-managers would be responsible for analysis of information, evaluation of results and the publication of an annual report on the "state of the hatchery system". The database would be available to all interested parties.

Funding to provide the necessary hardware, software, and personnel may be required to facilitate the gathering, recording, and processing of M&E information so that it is immediately available to, and comprehendible by, all who need to act on it.

SOURCES AND REFERENCES

The references section of this appendix lists sources cited in the framework and other relevant literature. In addition to the sources cited in the text, this framework draws ideas from several key background reports. These include the National Marine Fisheries Service's *Viable Salmonid Populations and the Recovery of Evolutionarily Significant Units*, the co-managers' *Policy of Washington Department of Fish and Wildlife and Western Washington Treaty Tribes Concerning Wild Salmonids*, the Washington Department of Fish and Wildlife's additional policy guidance on deferred issues concerning wild salmonid policy, the Integrated Hatchery Operations Team's *Policies and Procedures for Columbia Basin Anadromous Salmonid Hatcheries*, the Independent Scientific Advisory Board's *Review of the Draft Performance Standards and Indicators for Artificial Production in the Northwest Power Planning Council's Artificial Production Review* and Jim Lichatowich's *Salmon Without Rivers: A History of the Pacific Salmon Crisis*.

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B. Emerging Issues in Hatchery Reform

CONTENTS

OVERVIEW

The HSRG—recognizing that the scientific framework needs to be a "living document" that is regularly updated to include new information and issues not identified in its original drafting—decided that significant revisions to the scientific framework should be derived – not just from new published scientific literature – but also from "emerging issue" papers authored by the HSRG or its individuals members. These papers can be as simple as a few paragraphs or as detailed as an essay for a peer-reviewed journal. The HSRG welcomes feedback on these "emerging issues." They are incorporated into the framework once they have been reviewed and refined. Several that have been incorporated to date remain in this chapter as well, to highlight their importance.

These emerging issues papers also relate to two other key elements of the Hatchery Reform Project. They are tied to the hatchery reform research program[52] because they discuss topics that reflect recently available scientific information or an emerging principle derived from the collation of old and new information. In addition, they are tied to the three principles of hatchery reform[53] because developing scientific knowledge in these areas will support successful hatchery operation and management in the context of well-defined goals, scientifically defensible programs, and informed decision making.

In keeping with their status as "emerging issues," it is important to keep in mind that all of these papers are "works in progress," to be revised as new information comes to light on the issues at hand. They are not to be considered definitive, exhaustive and/or final statements on their respective topics, although some of them may form the basis for publications in the scientific literature if they so warrant.

[52] *See Research Program in Applied Hatchery Reform chapter.*

[53] *See Principles and System-Wide Recommendations in Applied Hatchery Reform chapter.*

MANAGEMENT GOALS FOR HATCHERY BROODSTOCKS: GENETIC INTEGRATION VERSUS SEGREGATION

Background

More than 200 hatcheries and satellite facilities propagate Pacific salmon (Oncorhynchus spp.) and steelhead (O. mykiss) throughout the Pacific Northwest. More than 100 of these facilities exist in Washington state alone. This extensive hatchery system was developed over a 100-year period with a principal goal of producing fish for harvest, largely to mitigate for the effects of overfishing, land-use practices, hydropower development, and losses of freshwater habitats (see Lichatowich 1999 for a historical review). In general, hatcheries have been very successful at providing fish for harvest. Hatchery-origin fish support nearly all commercial, tribal and recreational salmon fisheries in Washington, and they also contribute to salmon fisheries in British Columbia and Alaska.

A new conservation role for salmon hatcheries has been emerging in the Pacific Northwest in recent years. This new role has been motivated by significant declines in the abundance of naturally-spawning salmon and steelhead since the mid-1970s. These declines culminated in the listing of 26 Evolutionarily Significant Units, or ESUs (Waples 1995), of Pacific salmon and steelhead under the U.S. Endangered Species Act (ESA; see www.nwr.noaa.gov). Hatchery programs with conservation goals include captive rearing of endangered species (Schiewe et al. 1997), maintenance propagation of imperiled populations (Bugert et al. 1995), and supplementation, natural spawning by hatchery-origin adults (Carmichael and Messmer 1995; Hedrick et al. 2000). Several hatchery programs with conservation goals exist in western Washington, including programs for genetically distinct populations of Chinook salmon (O. tshawytscha) on the Elwha, Dungeness and White rivers, and summer chum salmon (O. keta) in the Hood Canal region of Puget Sound.

Concerns regarding potential genetic and ecological impacts of hatchery-origin fish on naturally spawning populations have raised questions regarding the future role of salmon and steelhead hatcheries in the Pacific Northwest (Hindar et al. 1991; Waples 1991; Hilborn 1992; Busack and Currens 1995; Campton 1995; Currens and Busack 1995; Reisenbichler and Rubin 1999; Levin et al. 2001). These concerns began in the mid-1970s (e.g. Reisenbichler and McIntyre 1977) and reached a peak of criticism in the early 1990s (e.g. Meffe 1992). In response, hatchery programs are currently undergoing reform measures to reduce genetic and ecological risks to naturally spawning populations, while continuing to provide harvest and conservation benefits (Maynard et al. 1995; Flagg and Nash 1999; see also www.hatcheryreform.org).

The mandates of hatchery reform and the need to recover ESA listed populations have motivated a fundamental reevaluation of the basic biological premises under which hatchery programs are designed, managed and operated. This reevaluation requires that each hatchery program operate in a manner consistent with fundamental biological principles, including the constraints imposed by the aquatic ecosystems within which those programs occur. This reevaluation requires that each program explicitly state: 1) the specific purpose and desired benefits to be derived from hatchery-origin fish; and 2) the genetic management goals of each hatchery broodstock relative to naturally spawning populations. In the past, these purposes and goals have not always been clearly defined, quantified or distinguished.

Here we describe two distinct types of hatchery programs that reflect fundamentally different genetic management goals for hatchery broodstocks. We refer to these two types of programs as "integrated" and "segregated." Hatchery programs are classified as integrated if the principal goal is to manage the broodstock as an artificially propagated component of a naturally spawning population or gene pool. An implicit goal of an integrated program is to artificially increase the demographic size or productivity of a population, while preventing genetic divergence between the hatchery and naturally-spawning components. Conversely, hatchery programs are classified as segregated if the principal goal is to develop and manage a broodstock as a genetically discrete or segregated population relative to naturally spawning populations. Segregated broodstocks are managed as if they are distinct populations or species relative to natural populations; no explicit genetic constraints are placed on segregated broodstocks except those necessary to achieve desired benefits while minimizing genetic and ecological risks to naturally spawning populations. In practice, all hatchery programs must fall into one of the two categories; "intermediate" programs cannot exist without imposing significant risks to natural populations because of fundamental differences in the biological principles underlying the two types of programs.

Terms similar to integrated and segregated (e.g. "integrated" and "isolated") have been used elsewhere to describe hatchery programs in the Pacific Northwest; however, those other definitions are based primarily on the presence and absence, respectively, of natural spawning by hatchery-origin fish[54]. Such definitions only reflect past or hypothesized consequences of hatchery programs on natural populations and do not provide genetic management goals or future guidance for hatchery programs or their broodstocks. In contrast, the definitions presented here for *integrated* and *segregated* refer explicitly to the genetic management goals for hatchery broodstocks relative to naturally spawning populations, irrespective of the presence or absence of natural spawning by hatchery-origin fish. For example, "integrated" programs do not imply that natural spawning by hatchery-origin fish has occurred or is desired. Similarly, segregated programs do not imply that released hatchery-origin fish do not spawn naturally or interact biologically with natural-origin fish.

In our descriptions below, we first describe the general concepts, goals, and operational constraints for each of the two types of programs. We then provide operational guidelines and specific recommendations for their implementation. The major emphasis here is on integrated programs, because they represent a relatively new conceptual approach to hatchery management in Puget Sound and coastal Washington.

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[54] *Those other definitions may have developed as a misinterpretation of the concepts and definitions described here when these latter definitions were first conveyed orally to the comanaging agencies.*

Integrated Hatchery Programs

General concepts and goals

A fundamental goal of an integrated hatchery program is to minimize genetic divergence of a hatchery broodstock from a naturally spawning population in areas where fish are released and/or collected for broodstock. The long-term goal of an integrated program is to maintain genetic characteristics of a local, natural population among hatchery-origin fish by minimizing the genetic effects of potential domestication. Another goal is to reduce the genetic risks that hatchery-origin fish may pose to naturally spawning populations. In an idealized integrated program, natural-origin and hatchery-origin fish represent two genetically equal components of a single gene pool.

A hatchery supporting an integrated program can be viewed conceptually as an artificial extension of the natural environment such that the population as a whole (hatchery plus natural) is sustained at a higher level of abundance than the level sustainable by the natural habitat without a hatchery. A properly-managed, integrated broodstock can potentially serve as a genetic repository for a natural population in the event of a major decline in the abundance of natural-origin fish (e.g. due to a catastrophic event, change in marine survival, etc.).

As noted previously, integrated programs do not imply that natural spawning of hatchery-origin fish is desired or necessarily occurs. Natural spawning and reproduction by hatchery-origin fish does not make a hatchery broodstock genetically integrated with a natural population. A principal goal of an integrated program is to maintain the genetic characteristics of a natural population among hatchery-origin fish, not vice-versa.

Integrated programs may be most appropriate when: a) conservation is one of the programmatic goals; or b) significant genetic and ecological risks cannot be avoided. For example, if genetic divergence between hatchery- and natural-origin fish within a watershed is minimized, then the genetic risks to natural populations imposed by naturally-spawning hatchery fish may also be minimized. Ecological risks may also be reduced relative to segregated programs (see below) because competition or predation between hatchery- and natural-origin components of a single gene pool is conceptually equivalent to the same interactions resulting from increased abundance of individuals within a single natural population.

Operational constraints

Explicit hatchery practices are needed to achieve an integrated broodstock that achieves the desired genetic management goals. These practices include the following: a) incorporation of sufficient numbers of natural-origin adults into the broodstock each year to overcome the potential effects of random genetic drift, domestication and divergent natural selection in the two environments (Ford 2002); b) strict protocols for trapping and spawning adults such that the means and variances of phenotypic characters related to fitness (e.g., run timing) equal those of the parental natural population; and c) efforts be made to minimize natural selection and other domestication effects in the hatchery. For example, it may be desirable to implement spawning protocols that tend to equalize parental genetic contributions, to reduce the potential effects of domestication selection (Allendorf 1993; Hedrick et al. 2000; Heath et al. 2003; Campton 2004). It may also be desirable to modify hatchery rearing conditions to reduce the selection effects of hatchery environments (Zydlewski et al. 2003). Integrated programs will invariably represent trade-offs between ease of culture and achievement of genetic management goals.

A major biological uncertainty for integrated programs is the proportion of a hatchery broodstock that needs to be composed each year of natural-origin adults to overcome the potential effects of genetic drift, domestication selection, and divergent natural selection in the two environments. Theoretical models indicate that one-way gene flow is a powerful force that can minimize the divergent effects of natural selection in two different environments (Appendix 1). Those models indicate that 10–20% of a population derived genetically from another population each generation can largely overcome the divergent effects of genetic drift and natural selection. However, gene flow in the opposite direction (i.e., hatchery to wild) needs to be restricted to allow the natural environment to dominate the natural selection process for the population as a whole. The major obstacles for developing operational guidelines from those models are scientific unknowns regarding the magnitude of the difference in mean phenotypic values for the integrated population that optimize fitness in the hatchery and natural environments, respectively.

Another general conclusion emerging from those theoretical models (Appendix 1) is that the rate of gene flow from the natural environment to the hatchery environment must exceed the reverse rate of gene flow for the mean fitness of hatchery-origin fish, and the population as a whole, to be closer to the optimum fitness for the natural environment than to the optimum fitness for the hatchery environment. In other words, the proportion of a hatchery broodstock composed of natural-origin fish must exceed the proportional genetic contribution of hatchery-origin fish to the naturally spawning population if selection regimes in the natural environment are to dominate the mean fitness of the population as a whole. For example, if natural-origin adults constitute—on average—20% of a hatchery broodstock each year, then the genetic contribution of hatchery-origin fish to the naturally spawning component must be less than 20% per year. By controlling gene flow in both directions (i.e., by ensuring sufficient gene flow into the hatchery and controlling natural spawning of hatchery-origin adults), the genetic risks imposed by an integrated hatchery program to a naturally spawning population can be substantially less than the risks posed by a segregated program of equal size (see segregated hatchery programs below).

Further guidelines and constraints for integrated hatchery programs can be gleaned from several pseudo-examples (Appendix 3). For example, the number of adult spawners in the hatchery must be less than the number of natural-origin adults returning to the watershed where adults are trapped for broodstock if integrated programs are to meet their genetic management goals. Indeed, integrated hatchery programs have the greatest likelihood of achieving their goals if the number of returning natural-origin adults is at least twice the number of adults required for broodstock. Clearly, naturally spawning populations must be viable and largely self-sustaining if they are to support successful, integrated programs that, in turn, can provide excess adults for harvest or other purposes.

Many hatchery programs are designed to rebuild or restore naturally spawning populations by purposefully allowing hatchery-origin fish to spawn naturally. In such situations, demographic goals will initially outweigh genetic management goals, and 50% or more of the natural spawners may be composed of hatchery-origin fish. However, as the number of natural-origin fish returning to a watershed increases over time (i.e. assuming that population restoration is successful), then the number of hatchery-origin adults allowed to spawn naturally would have to be reduced for selection regimes in the natural environment to dominate natural selection in the hatchery environment. An example of this latter situation is given in Appendix 4.

Operational guidelines

- Naturally spawning populations must be viable and self-sustaining for hatchery broodstocks to be genetically integrated with a naturally spawning component. The long-term goal is to make the natural environment drive the fitness of the population as a whole, not vice versa. Such requirements underscore the need to maintain healthy habitat conditions necessary for viable, self-sustaining natural populations.
- The maximum size of hatchery broodstocks is restricted by the size of the naturally spawning component. At equilibrium, the number of spawners in a hatchery must be less than the number of natural-origin fish returning to a watershed. The ability of integrated hatchery programs to achieve their genetic management goals will be optimized if the number of natural-origin adults returning to a watershed is at least twice the total number of adults (hatchery plus natural) needed for broodstock.
- Although genetic integration may be a long-term goal of a hatchery program, low abundance or viability of a natural population may preclude short-term achievement of genetic integration goals. In such situations, rebuilding of a natural population may be necessary before complete genetic integration is possible (see Appendix 4).

Recommendations for integrated hatchery programs

- Develop a detailed, genetic management plan for the hatchery broodstock and the naturally spawning population in the watershed where adults are trapped for broodstock.
- Ensure that an average of 10–20% of the hatchery broodstock is composed of natural-origin adults each year. A sliding scale can be developed that reduces the desired percentage in low-return years but increases this percentage in high return years.
- Collect and spawn adults randomly with respect to time of return, time of spawning, size and other characteristics related to fitness.
- Impose hatchery management practices that minimize the potential domestication effects of the hatchery environment. This may include spawning more hatchery-origin adults than required, but then culling each full-sib family to a predetermined number of eyed eggs. It may also include modified hatchery environments (e.g., raceway covers, underwater feeders, etc.) that reduce potential domestication effects and natural selection differences between the two environments.
- Mark or tag all hatchery-released fish so that the proportions of natural- and hatchery-origin fish among natural spawners and in the broodstock can be monitored and controlled.

- Monitor and control natural spawning by hatchery-origin adults so that the percentage of natural spawners composed of hatchery-origin fish is less than the percentage of the hatchery broodstock derived from natural-origin fish. In most cases, hatchery-origin adults are expected to have a lower natural reproductive success than natural-origin adults (irrespective of any genetic factors), so the actual genetic contribution of hatchery origin fish to natural reproduction is expected to be less than their relative proportion on the spawning grounds. A maximum risk limit of 30% hatchery-origin adults among natural spawners (minimum two-to-one ratio of natural:hatchery fish) is thus recommended in all cases except in restoration supplementation programs where natural spawning by hatchery-origin adults is an intended purpose of the hatchery program.
- Adjust the size of integrated hatchery programs relative to the size of the naturally spawning population, so that the number of adults used for broodstock is less than the number of natural-origin adults spawning naturally in the same watershed. The number of natural-origin adults returning to a watershed should be at least twice the number of adults used for broodstock in integrated programs that have achieved genetic equilibrium with their naturally spawning components. In some cases, natural populations will need to be restored or rebuilt to a higher level of abundance before the number of natural-origin adults returning to a watershed is sufficient to achieve the genetic management goals of a genetically-integrated hatchery program.

Segregated Hatchery Programs

General concepts and goals

The principal goal of a segregated hatchery program is to maintain the hatchery broodstock as a reproductively distinct or genetically segregated population. Once such programs are established, the broodstock is derived exclusively from returning hatchery-origin fish. Hence, little or no gene flow occurs, or is intended to occur, from a natural population to the broodstock. In a segregated program, the hatchery population is managed as a distinct gene pool and is expected to diverge genetically from the founding natural population due to genetic adaptation to the hatchery environment, domestication and genetic drift. Many, if not most, hatchery programs for Pacific salmon and steelhead historically followed this segregated approach, either purposefully or inadvertently (e.g. Waples and Teel 1990). Segregated programs are usually intended to achieve harvest goals in the most efficient manner possible; consequently, this segregated approach can result in significant genetic change in a hatchery population after several generations (Campton 1995).

Segregated hatchery programs may have conservation goals under some circumstances. For example, hatcheries often propagate native populations for which spawning habitat is no longer available because a dam blocks upstream migration to historical spawning areas. Genetic maintenance of a native population is often a long-term goal of such programs. In addition, fish from a segregated hatchery population may be introduced into a watershed where the native population has been extirpated. The long-term goal of these latter programs is for hatchery-origin fish to spawn successfully and initiate restoration of a natural population. In this latter situation, the hatchery program would initially be classified as "segregated," because no naturally spawning population may be associated genetically with the hatchery broodstock. Over time, however, such a program could evolve into an integrated program if hatchery-origin fish spawn successfully and returning, natural-origin adults are subsequently included in the broodstock in a prescribed, systematic manner (Appendix 4). A new, locally-adapted broodstock integrated genetically with a naturally spawning population would, in theory, evolve. Many restoration programs for Pacific salmon may attempt this latter approach as dams are removed and/or other natural habitats are restored. Intense genetic and ecological monitoring will be necessary to scientifically evaluate the efficacy of such programs.

Operational constraints

Segregated programs, particularly those with only harvest goals, typically have few operational constraints. Segregated hatchery broodstocks may be bred selectively for particular traits (e.g. early run-timing), to facilitate ease of culture and/or to help achieve desired benefits (e.g., harvest). In general, segregated programs are managed in a way that maximizes productivity (i.e., recruit per spawner) or efficiency of a hatchery irrespective of the ability of returning adults to reproduce naturally or confer any benefits to naturally spawning populations. Indeed, hatchery-origin fish from a genetically segregated program can impose unacceptable genetic and ecological risks to natural populations (Busack and Currens 1995). As a result, segregated programs often represent major trade-offs between minimizing biological risks to naturally spawning populations and maximizing efficiency and harvest benefits of the hatchery program.

Many segregated hatchery programs have selectively bred adults, either purposefully or inadvertently, for "early" spawn or run timing, primarily by excluding late-returning adults from broodstocks. Many hatchery stocks of salmon and steelhead now return and spawn several weeks earlier than their natural-origin counterparts. Differences in return timing between natural- and hatchery-origin adults can be used as a management tool to focus fisheries on "early-returning hatchery fish," while protecting "late-returning natural fish". This approach can facilitate fisheries management from an agency perspective. However, if non-harvested fish spawn naturally, then these segregated programs can impose significant genetic risks to naturally spawning populations. Indeed, any natural spawning by fish from these broodstocks may be considered unacceptable because of the potential genetic impacts on natural populations. Proponents of such "segregated" programs argue that "early-returning" hatchery fish are mis-timed biologically to stream flows and water temperatures and, thus, fail to reproduce successfully even if they do spawn in nature. However, empirical and experimental evidence indicates that such "early-returning" hatchery fish do indeed reproduce successfully, albeit at a reduced rate relative to natural-origin fish (Chilcote et al. 1986; Campton et al. 1991; Mackey et al. 2001). Although these hatchery-origin fish have a lower reproductive success relative to their natural-origin counterparts, their overall genetic contributions can be substantial if hatchery-origin fish outnumber natural-origin spawners (Chilcote et al. 1986; Leider et al. 1990).

Clearly, the degree to which segregated hatchery programs are successful depends significantly on the degree to which genetic and ecological risks to natural populations can be minimized. Most hatchery programs for Pacific salmon and steelhead have historically been managed as segregated broodstocks with no concerted effort to include natural-origin fish in the broodstocks or to control natural spawning by hatchery-origin fish within a watershed. Such programs essentially treat hatcheries as "fish farms," or ocean ranching operations where a small proportion of fish surviving to adulthood are recaptured for broodstock each year to propagate the stock and maintain the program over time. Although this approach can maximize the efficiency of a salmon hatchery for achieving fishery benefits, it also overlooks the ecological and genetic risks that these hatchery stocks may pose to naturally spawning populations. After several generations of artificial propagation, segregated hatchery broodstocks may pose genetic and ecological risks to naturally spawning populations that are not unlike those imposed by exotic or introduced species. Many segregated hatchery broodstocks also represent the genetic products of historical stock transfers among facilities or regions, thus further confounding the genetic and ecological risks that those programs may impose on naturally spawning populations. To minimize these risks, segregated hatchery programs need to be located in areas where virtually all returning adults can be harvested or recaptured, or where natural spawning or ecological interactions with natural-origin fish are considered minimal or inconsequential. Outplanting from such programs should also be discontinued (see emerging issue paper on this topic).

Operational guidelines

- Segregated hatchery programs are most appropriate where nearly all returning hatchery-origin adults can be harvested or recaptured, or where the habitat or natural environment cannot support natural populations of salmon or steelhead. Segregated programs may also be most appropriate where: a) the only goal of the program is harvest; and b) the potential for genetic and ecological interactions between hatchery- and natural-origin fish is minimal, or the biological effects of those interactions are considered inconsequential.
- The size of segregated hatchery programs must not exceed thresholds above which natural stray rates would pose significant genetic or ecological risks to natural populations. Stray rates as low as one to two percent for a large, segregated hatchery program may pose unacceptable biological risks to natural populations.

Recommendations for segregated hatchery programs

- Release fish in areas that minimize potential straying and natural spawning, and where opportunities to recapture non-harvested adults are maximized.
- Mark all released hatchery-origin fish to maximize potential harvest, and to assess stray rates and genetic risks to naturally spawning populations.
- Release fish in a manner and/or at locations that ensure hatchery-origin adults constitute no more one to five percent of natural spawners in a watershed.
- Adjust the size of segregated hatchery programs as environmental conditions change to maintain total adult returns and potential stray rates within biologically-accepted limits.
- Avoid trapping natural-origin adults and exclude them from the broodstock.

Summary and Conclusions

Every hatchery program must be identified as either integrated or segregated, with operational procedures and facilities designed to achieve the specific goals for one of those two types of programs. In this context, “intermediate” programs cannot exist because the operational procedures and underlying biological constraints differ substantially between the two types of programs.

Integrated hatchery programs are intended to minimize genetic risks to naturally spawning populations, while also achieving harvest and/or conservation objectives; however, they also represent potential trade-offs between ease of culture and attainment of genetic management goals. Segregated programs are usually intended to provide only harvest benefits in the most efficient manner possible. Consequently, they must be operated in a manner that prevents returning adults from interbreeding with naturally spawning populations.

In contrast to most segregated programs, properly-developed (or idealized) integrated programs can potentially confer genetic and/or demographic benefits to naturally spawning populations because such programs are designed to increase the total number of spawners and the effective number of breeders (Appendix 2) for those natural populations. However, regardless of the degree of genetic integration, significant phenotypic differences between natural- and hatchery-origin fish can still arise due to single-generation environmental effects associated with early rearing in a hatchery environment. Nevertheless, integrated programs do provide a conceptual mechanism for hatcheries to achieve both harvest and conservation objectives under the legal and legislative mandates of fishery compensation (i.e., harvest opportunities) and natural resource protection (e.g., ESA). The key to the success of an integrated hatchery program is the ability to distinguish natural- and hatchery-origin fish as returning adults so that separate management strategies can be applied to the two gene pool components (hatchery and natural) in accordance with their different population dynamic parameters and natural selection regimes. Segregated hatchery programs are inherently simpler to operate, but they can also inhibit recovery of naturally spawning populations if hatchery-origin fish interact ecologically or genetically with depressed natural populations.

Recognizing the fundamental distinction between genetically integrated and genetically segregated hatchery programs is the critical first-step towards reforming salmon hatcheries in the Pacific Northwest. This first step is not a facility- or hardware-driven goal, but is rather a conceptual or philosophical goal associated with recognizing the biological constraints and consequences of hatchery programs. This first step is also intended to improve hatchery management practices in a scientifically-defensible manner to achieve desired benefits while reducing risks to natural populations (see Busack and Currens 1995). In the past, most fish were released from hatcheries unmarked or untagged, and the relative proportions of hatchery- and natural-origin fish in broodstocks and on natural spawning grounds was largely unknown. Both integrated and segregated hatchery programs clearly require that hatchery- and natural-origin adults are readily distinguishable to (a) hatchery workers who are spawning fish and (b) field fishery biologists who are monitoring stray rates and potential natural spawning. Understanding the distinction between integrated and segregated programs and adhering to their respective operational constraints, including monitoring of harvest contributions and natural spawning escapements, is the underlying foundation of hatchery reform in Washington state.

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Appendix 1. Theoretical population genetic foundations for recommended gene flow rates between natural and hatchery components for integrated hatchery programs.

Genetic drift effects

The basic principles of population genetics indicate that a relatively small amount of *gene flow* between two populations is sufficient to overcome the divergent effects of random *genetic drift* alone. The magnitude of this divergence represents a balance between: a) gene flow, which makes populations more similar genetically, and b) random genetic drift which makes populations more dissimilar genetically. The expected magnitude of this divergence at equilibrium can be quantified by the parameter F_{ST}[55] according to the well-known expression for a drift-migration, island population model (Wright 1969, eq. 12.2):

$$F_{ST} = \frac{(1\text{-}m)^2}{2N_e - (2N_e\text{-}1)\,(1\text{-}m)^2} \qquad (1)$$

where m = the migration (gene flow) rate or proportion of a subpopulation derived from migrants (i.e. immigrants) from other subpopulations each generation, and N_e = the genetic effective population size of each subpopulation (see Appendix 2 for a discussion of effective population size). The product N_em is thus the effective number of migrants per generation. Solving for m and N_em in equation (1) yields the minimum values of those parameters necessary for achieving a maximum desired value of F_{ST} (Fig. 1).

According to the relationship between gene flow and genetic drift (eq. 1), approximately 23–24 migrants (Nm) per generation are needed to establish an equilibrium F_{ST} = 0.01 for effective population sizes (N_e) greater than 500 individuals per generation (Fig. 1a). The proportion of migrants per generation (m) must similarly be greater than five percent (0.05) to achieve F_{ST} = 0.01 for N_e = 500 (Fig. 1b). Those values of m and N_m would need to be nearly doubled to achieve a F_{ST} = 0.005 (Figs. 1c, 1d). However, the proportional amount of gene flow (m) necessary to achieve a desired value of F_{ST} decreases as effective population size increases (Figs 1b, 1d), although the required number of migrants remains relatively constant (Figs. 1a, 1c). Hence, approximately 50 natural-origin adults would need to be included in a hatchery broodstock each generation to overcome the divergent effects of genetic drift alone and achieve an F_{ST} = 0.005. This latter value of F_{ST} is considered the maximum desired value between hatchery and natural-origin components in integrated hatchery programs. In other words, one goal of integrated hatchery programs should be to achieve F_{ST} < 0.005.

[55] *FST, commonly called the fixation index, varies from 0.0 to 1.0 and measures the proportion of the total genetic variation in a population that is due to allele frequency divergence among subpopulations constituting that population. FST = 0 implies two populations have identical allele frequencies. FST = 1.0 implies two populations share no alleles in common.*

Natural selection effects

A major limitation of the preceding calculations and Figure 1 is that they assume no natural selection in the two environments occupied by the two populations. One of the principle concerns of hatchery programs is the unknown effect and intensity of domestication selection for traits directly related to fitness. Mills and Allendorf (1996) noted that natural selection will not have a major effect on the distribution of allele frequencies in a subdivided population if the divergent selection coefficients ("s" and "t") in the two environments are less than the migration rate (m) between them (Wright 1940). Consequently, a minimum gene flow rate from a natural population to a hatchery broodstock of 10% per year is expected to significantly retard the genetic divergence between two populations, or gene pool components, if the magnitude of the divergent selection coefficients in the two environments is minor to moderate (i.e. $s, t < 0.1$). Greater selection coefficients would necessitate higher levels of gene flow to attain the same desired F_{ST} value.

Ford (2002) has recently modeled potential genetic effects of domestication selection and gene flow from a captive hatchery stock to a naturally spawning population where the goal is to supplement natural spawning with the progeny of a captively-bred population. By reversing the fitness and gene flow parameters of Ford's (2002) model, one can use his results to interpret the genetic effects of gene flow from a "closed" natural population to a hatchery broodstock where the goal is to prevent genetic divergence between the hatchery and natural components of a single gene pool. As shown in Fig. 2a of Ford (2002), the receiving population (in our case, the hatchery) quickly achieves the optimum fitness level of the donor (i.e. natural) population with one-way gene flow rates of 10-20% per generation for a wide range of phenotypic differences in optimum fitness between the two environments (indicated by θ_C in Ford 2002). These latter results (Fig. 2a of Ford 2002) apply to the situation where hatchery fish are not allowed to spawn naturally.

However, if hatchery-origin adults constitute 20% of the natural spawners and natural-origin adults constitute 20% of the hatchery broodstock each generation, then the mean equilibrium fitness of hatchery-produced fish is only slightly greater than 50% of the difference in mean optimum fitness of fish in the two different environments (Fig. 2b of Ford 2002). Moreover, if 20% of the naturally spawning population is comprised of hatchery-origin fish each generation, then approximately 40% of the hatchery broodstock needs to be derived from natural-origin fish each generation to achieve a fitness level for hatchery fish that is within approximately 25% of the fitness optimum in the natural environment (relative to the hatchery environment) over all ranges of fitness differences modeled by Ford (2002). In addition, under these quantitative genetic and gene flow models where hatchery-origin fish spawn naturally, the maximum fitness achievable by the natural population will always be less than its optimum fitness when hatchery-origin fish are not allowed to spawn naturally. We are currently using equations adapted from Ford (2002) to model these specific situations for integrated hatchery programs (Campton et al., in prep.). In the meantime, the equations and graphs of Ford (2002) provide guidance regarding the amount of gene flow necessary to overcome divergent natural selection between the hatchery and natural environments. Nevertheless, the general conclusion from Ford (2002) is that gene flow from the hatchery environment to the natural environment must be restricted for integrated hatchery programs to achieve their goals. A conservative rule of thumb is that gene flow from the natural environment to the hatchery environment should be approximately twice the rate of gene flow from the hatchery environment to the natural environment when the latter parameter exceeds 10%.

The major conclusion from Ford (2002) is that one-way gene flow is a powerful force that can overcome divergent selection pressures to retard genetic divergence of hatchery-origin fish from their natural-origin origin counterparts. The major obstacles for developing operational guidelines from those models are scientific unknowns regarding the magnitude of the difference in mean phenotypic values that optimize fitness for traits under different selection regimes in the two environments.

Conclusions

The theoretical considerations presented above indicate that a minimum of 10-20% of the hatchery spawners need to be composed of natural-origin adults for integrated hatchery broodstocks to meet their genetic goals and overcome the divergent effects of natural selection in the two environments. In addition, the proportion of natural spawners composed of hatchery origin fish must be less than the proportion of a hatchery broodstock composed of natural-origin fish for selection regimes in the natural environment to dominate the mean fitness of the population as a whole.

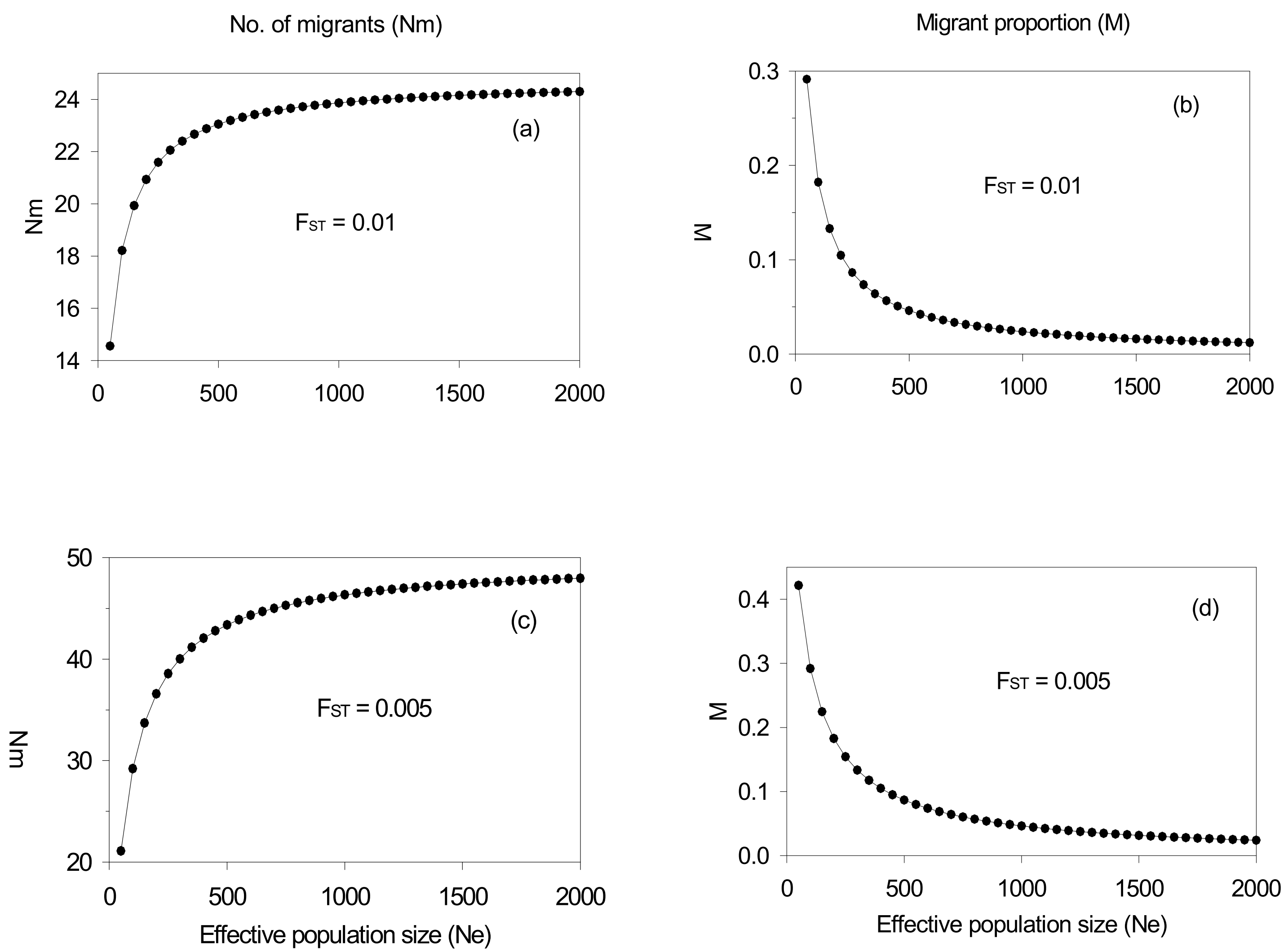

Figure A1. Theoretical relationship among effective population size (N_e), the proportion of a population derived from migrants or immigrants (m) each generation, and the number of migrants (immigrants) per generation (Nm) at equilibrium to counterbalance the effects of random genetic drift to achieve F_{ST} = 0.01 (a, b) or F_{ST} = 0.005 for the island model of population structure (eq. 12.2, Wright 1969).

Appendix 2. Effective population size.

Effective population size (N_e) is a theoretical parameter that indirectly quantifies the amount of genetic variation that can be transmitted from parental to offspring generations within a population, either in terms of potential levels of inbreeding or the variance in gene frequencies between generations. N_e is highly influenced by sex ratio of spawners and population bottlenecks (i.e. major fluctuations in abundance between generations). For example, the genetic effective size of a population composed of different numbers of male and female spawners is approximated by the following equation:

$$N_e = 4N_mN_f / (N_m+N_f), \qquad (1)$$

where N_m and N_f = the number of male and female spawners, respectively. The preceding expression assumes that males and females are randomly mated, although the sex ratio may be skewed.

A single generation of Pacific salmon is composed of several brood years where each brood year is produced by independent spawning events. The relationship between effective population size (N_e) for a single generation and the effective number of breeders in a single year (N_b) is given by the following relationship (Waples 1990):

$$N_e \approx (N_b) \cdot t, \qquad (2)$$

where t = the generation time in years, or the mean age of adults at reproduction. For example, the genetic effective size of a hatchery population spawning 500 chinook salmon per year, with a mean age at spawning of four years, is $N_e \approx 2{,}000$, assuming that multiple brood years contribute to the adults spawning in a single year and all adult spawners fertilize an equal number of eggs (Campton 2004).

Equation (2) does not apply to populations in which all the adults in that population spawn in a single year. For example, pink salmon have a discrete, two-year life cycle; hence, $N_e = N_b$ because the entire population (even or odd) spawns in a single year, every other year. Similarly, $N_e = N_b$ for hatchery populations of coho salmon in which jacks (2-year old males) are excluded from spawning and all other adults return and spawn at three years of age. In this latter situation, the hatchery "population" would actually consist of three discrete populations with potentially separate effective population sizes that reflect the number of spawners every three years. This latter issue for coho salmon has motivated system-wide recommendations for coho salmon that require jacks constitute a minimum of 10% of the male spawners in hatchery broodstocks.

Appendix 3: Pseudo-examples of the demographic relationships between numbers of adult spawners in hatchery broodstocks and the number of natural-origin adults returning to a watershed for integrated hatchery programs

The following tables (Tables 1-4) represent a series of pseudo-examples for two sets of situations. Tables 1 and 2 examine the demographic consequences and constraints for varying numbers of returning, natural-origin (NOR) adults when a hatchery broodstock requirement is 500 and 1,000 adults, respectively. Tables 1 and 2 also examine the minimum recruit-to-spawner ratio necessary among NOR adults for genetic integration to be successful demographically when (a) 10% or (b) 20% of the hatchery broodstock is derived each year from NOR adults. Conversely, Tables 3 and 4 examine the demographic consequences and constraints for varying numbers of adult spawners in a hatchery broodstock assuming 10% or 20%, respectively, of the broodstock is derived each year from 1,000 returning NOR adults. Tables 3 and 4 also examine the maximum number of hatchery-origin (HOR) adults and their maximum allowable stray (gene flow) rates to the naturally spawning component under the constraint that the percent of natural spawners composed of HORs has to be less than the percent of hatchery spawners composed of NORs. This latter constraint is necessary for the mean fitness of the population as a whole (hatchery + natural) to be closer to the optimum for the natural environment than the hatchery environment. Maximum stray rates are also given for HORs constituting a maximum of 33% of the natural spawners, a situation that should be considered an upper risk limit for integrated programs except those in which supplementation spawning is deliberate to help restore or rebuild a naturally spawning populations. R/S is assumed to equal 1.0 for all natural spawners (NORs + HORs) in Tables 3 and 4 but is assumed to equal 5.0 for hatchery spawners in all four tables (Tables 1-4).

Table 1. Broodstock and natural spawning escapement guidelines and constraints for *integrated* hatchery programs where the goal is to maintain the hatchery broodstock and natural spawners as two components of a single gene pool. The table below is based on a broodstock requirement of 500 adult fish for the hatchery each year. Each row represents a different example based on the number of natural-origin adults (spawners) returning to the watershed and potentially intercepted by the hatchery. For each row, two scenarios are presented: either 10% or 20% of the broodstock is derived from NOR fish; hence, either 50 (10% of 500) or 100 (20% of 500) NOR adults, respectively, would be retained for broodstock each year. The column "Minimum. R/S required" is the minimum recruit-to-spawner ratio required for the naturally spawning component to replace itself each year after adult NOR fish are removed for broodstock and without counting HORs among the natural spawners. The hatchery program is assumed to have a R/S = 5.0, thus resulting in 2500 HOR adult returns from the spawning of 500 adults. The column "Max. No. of HORs in escapement" represents the maximum number and, in parenthesis, the maximum percent of the total number of HORs that should be allowed to spawn naturally under each of the two scenarios, respectively, under the constraint that the percent of natural spawners composed of HOR adults should be less than the percent of the hatchery broodstock composed of NOR adults.

Hatchery broodstock requires 500 adults per year

10% of hatchery broodstock derived from NORS. 20% of hatchery broodstock derived from NORS

Number of NORs	%ofNORS removed for broodstock	Number of NORs passed upstream	Max.No.(%) ofHORsin escapement	Minimum R/Srequired	%ofNORS removedfor broodstock	Numberof NORspassed upstream	Max.No.(%) ofHORsin nature	Minimum R/Srequired
100	50.0%	50	6(0.2%)	2.00	100%	0	NA	NA
250	20.0%	200	22(0.9%)	1.25	40%	150	37(1.5%)	1.67
500	10.0%	450	50(2.0%)	1.11	20%	400	100(4.0%)	1.25
750	6.7%	700	78(3.1%)	1.07	13%	650	162(6.5%)	1.15
1,000	5.0%	950	106(4.2%)	1.05	10%	900	225(9.0%)	1.11
1,500	3.3%	1,450	161(6.4%)	1.03	7%	1,400	350(14.0%)	1.07
2,000	2.5%	1,950	217(8.7%)	1.02	5%	1,900	500(20.0%)	1.05

Table 2. Same as Table 3 except 1,000 adult fish are required for the hatchery broodstock each year. Under the 10% and 20% broodstock scenarios for NORs shown below, either 100 (10% of 1,000) or 200 (20% of 1,000) NOR adults would be retained for broodstock each year. The hatchery program is still assumed to have a R/S = 5.0, thus resulting in 5000 HOR adult returns from the spawning of 1000 adults.

Hatchery broodstock requires 1,000 adults per year

10% of hatchery broodstock derived from NORS. 20% of hatchery broodstock derived from NORS|

Numberof NORs	%ofNORS removedfor broodstock	Numberof NORspassed upstream	Max.No.(%) ofHORsin escapement	Minimum R/Srequired	%ofNORS removedfor broodstock	Numberof NORspassed upstream	Max.No.(%) ofHORsin nature	Minimum R/Srequired
200	50%	100	11(0.2%)	2.00	100%	0	NA	NA
250	40%	150	17(0.3%)	1.67	80%	50	12(0.2%)	5.00
500	20%	400	44(0.9%)	1.25	40%	300	75(1.5%)	1.67
750	13%	650	72(1.4%)	1.15	27%	550	137(2.7%)	1.36
1,000	10%	900	100(2.0%)	1.11	20%	800	200(4.0%)	1.25
1,500	7%	1,400	156(3.1%)	1.07	13%	1,300	325(6.5%)	1.15
2,000	5%	1,900	211(4.2%)	1.05	10%	1,800	450(9.0%)	1.11
4,000	2.5%	3,900	433(8.7%)	1.03	5%	3,800	950(19.0%)	1.05

Table 3. Broodstock and natural spawning escapement guidelines and constraints for integrated hatchery programs where the goal is to maintain the hatchery broodstock and natural spawners as two components of a single gene pool. The table below is based on an annual return of 1,000 natural-origin (NOR) adults back to the watershed in which the hatchery is located. The examples below assume a recruit-to-spawner ratio of 5.0 for hatchery spawners and 1.0 for natural spawners. Each row represents a different example based on the number of adults (spawners) required for the broodstock each year (column 1) and the requirement that 10% of the broodstock is composed of NOR adults each year (column 3). For each row, two scenarios for the maximum number of HOR adults spawning naturally are provided: (1) HOR adults constitute a maximum of 10% (= to the proportion of NOR adults in the broodstock) or (2) 33% of the total number of adults on the spawning grounds (#NORs : #HORs = 2).

Hatchery-origin adults Natural-origin adults 10% of natural spawners are HORS 33% of natural spawners are HORs

No.of spawners inthe hatchery	NoofHOR recruits R/S=5.0	No.of NORsin broodstock 10%rule	%of NORSremovedfromwild	No.ofNORS leftin wild	Max.No. ofHORs spawning naturally 10%rule	TotalNo. of natural spawners	Max. stray rateofHORs (%)	Max.No. ofHORs spawning naturally 33%rule	TotalNo. of natural spawners	Max. stray rateof HORS (%)
100	500	10	1%	990	110	1,100	22%	495	1,485	99%
200	1,000	20	2%	980	109	1,089	11%	490	1,470	49%
300	1.500	30	3%	970	108	1,078	7.2%	485	1,455	32%
400	2,000	40	4%	960	107	1,067	5.4%	480	1,440	24%
500	2,500	50	5%	950	106	1,056	4.2%	475	1,425	19%
600	3,000	60	6%	940	104	1,044	3.5%	470	1,410	16%
700	3,500	70	7%	930	103	1,033	2.9%	465	1,395	13%
800	4,000	80	8%	920	102	1,022	2.6%	460	1,380	11%
900	4,500	90	9%	910	101	1,011	2.2%	455	1,365	10%
1,000	5,000	100	10%	900	100	1,000	2.0%	450	1,350	9.0%
1,500	7,500	150	15%	850	94	944	1.3%	425	1,275	5.6%
2,000	10,000	200	20%	800	89	889	0.9%	400	1,200	4.0%

Table 4. Same as Table 1 except that 20% of the broodstock is composed of NOR adults each year (column 3) and HOR adults constitute a maximum of 20% or 33% of the total number of adults on the spawning grounds.

Hatchery-origin adults Natural-origin adults 20% of natural spawners are HORS 33% of natural spawners are HORs

No.of spawners inthe hatchery	NoofHOR recruits R/S=5.0	No.of NORsin broodstock 20%rule	%of NORSremovedfromwild	No.ofNORS leftin wild	Max.No. ofHORs spawning naturally 20%rule	TotalNo. of natural spawners	Max. stray rateofHORs (%)	Max.No. ofHORs spawning naturally 33%rule	TotalNo. of natural spawners	Max. stray rateof HORS (%)
100	500	20	2%	980	245	1,225	49%	490	1,470	98%
200	1,000	40	4%	960	240	1,200	24%	480	1,440	48%
300	1.500	60	6%	940	235	1,175	16%	470	1,410	31%
400	2,000	80	8%	920	230	1,150	12%	460	1,380	23%
500	2,500	100	10%	900	225	1,125	9.0%	450	1,350	18%
600	3,000	120	12%	880	220	1,100	7.3%	440	1,320	15%
700	3,500	140	14%	860	215	1,075	6.1%	430	1,290	12%
800	4,000	160	16%	840	210	1,050	5.3%	420	1,260	10%
900	4,500	180	18%	820	205	1,025	4.6%	410	1,230	9.1%
1,000	5,000	200	20%	800	200	1,000	4.0%	400	1,200	8.0%
1,500	7,500	300	30%	700	175	875	2.3%	350	1,050	4.7%
2,000	10,000	400	40%	600	150	750	1.5%	300	900	3.0%

Appendix 4. An example of a plan to restore a naturally spawning population of steelhead from an established hatchery population with the goal of developing a genetically integrated broodstock

The U.S. Fish and Wildlife Service is proposing to restore a naturally spawning population of steelhead in Battle Creek, California, from a native hatchery stock propagated at the Coleman National Fish Hatchery (NFH). Battle Creek is a tributary to the upper Sacramento River near Anderson, California. Coleman NFH is located on Battle Creek, approximately six miles upstream from its confluence with the Sacramento River.

The hatchery stock was developed during the 1950s from natural-origin adults trapped in the mainstem Sacramento River as partial mitigation for construction and operation of Shasta Dam, a mainstem barrier to upstream migration. Several small diversion dams used by a private utility for hydropower generation on Battle Creek are being removed or provided with fish passage which will provide nearly 20 miles of additional stream access to salmon and steelhead upstream from Coleman NFH.

Coleman NFH is equipped with a permanent barrier weir on Battle Creek which allows the hatchery to trap all upstream migrating adults and control upstream passage. The long-term goal is to restore a naturally spawning population upstream from the hatchery and develop a genetically integrated broodstock with a minimum of 2,000 natural-origin spawners in the upper watershed and 800 spawners in the hatchery each year.[56] As the number of natural-origin adults trapped at Coleman NFH increases over time, the number of hatchery-origin fish released upstream to spawn naturally will be reduced until no hatchery-origin fish are released.

The restoration program began in 1995, when hatchery-origin fish were first passed upstream. During the 2002–03 return year, more than 500 natural-origin adults were trapped at Coleman NFH, of which approximately 40 were retained for broodstock and 487 were passed upstream to spawn naturally. In addition, nearly 800 hatchery-origin fish were passed upstream for supplementation spawning.

The table below shows one proposed sliding scale for controlling the number of hatchery-origin (HOR) and natural-origin (NOR) fish passed upstream to spawn naturally, as a function of the total number of NOR fish trapped at Coleman NFH.

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56 The plan is to spawn 800 adults for the hatchery each year, but the number of eyed eggs for each full-sib family would be culled by approximately 50% for those families in which both parents were of hatchery-origin. This approach is designed to double the effective population size of the broodstock and equalize family size. Genetic integration is being initiated by spawning 760 HOR and 40 NOR adults. These numbers will eventually evolve to 720 HOR and 80 NOR adults with the goal that NOR adults will make a 20% genetic contribution to released progeny each year.

Number of NORs Trapped at Coleman NFH			Numbers of fish passed upstream in Battle Creek			
Total	No. for hatchery	% of total	NORs	HORs	Total	%HORs
200	40	20.0%	160	320	480	67%
500	40	8.0%	460	920	1380	67%
750	40	5.3%	710	1290	2000	65%
1000	50	5.0%	950	1050	2000	52%
1500	75	5.0%	1425	575	2000	29%
1750	80	4.6%	1670	330	2000	17%
2000	80	4.0%	1920	80	2000	4%
2080	80	3.8%	2000	0	2000	0%
>2080	80	<3.8%	>2000	0	>2000	0%

USING HATCHERY SALMON CARCASSES FOR NUTRIFICATION OF FRESHWATER ECOSYSTEMS WHILE REDUCING ASSOCIATED FISH HEALTH RISKS.

Returning adult salmon are a unique vector for the delivery of marine nutrients into the freshwater ecosystem. The importance of these nutrients to consumers such as raccoons, bear, eagles and even man has been recognized for some time. Recent research also suggests that a significant portion of nitrogen in plants and animals in streams where adult salmon are abundant is derived from those returning adults (Mathison 1988, Kline et al. 1993). Marine-derived nutrients from returning adult salmon have been found to make a significant contribution to riparian vegetation and even old-growth forests (Reimchen 1994, Bilby et al.1996). In streams in interior British Columbia, Johnston et al. (1997) found that where salmon carcasses were abundant, up to 60% of the nitrogen in benthic insects was derived from the carcasses. They also found that juvenile salmon show higher growth rates in streams where adult salmon spawn than in streams without spawning adults. Use of hatchery salmon carcasses as a source of these marine-derived nutrients was found to increase the density of age 0+ coho and age 0+ and 1+ steelhead in small, southwestern Washington streams (Bilby et al. 1998).

The deliberate distribution of hatchery salmon carcasses into watersheds for purposes of nutrification can have a positive ecological benefit to natural salmonid stocks. This practice may, however, also pose a fish health risk to these stocks 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 these organisms into water or through their direct consumption. In order to reduce this risk, the HSRG recommends:

- Certifying that adult broodstock is free of viral pathogens prior to 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.
- Freezing carcasses prior to planting to reduce the infectious titers of pathogenic organisms in the salmon carcasses. This measure will decrease the risk of transmission of certain of these disease organisms (see, for example, Margolis 1977 for a metazoan parasite, and Evelyn 2001 for two important bacterial fish pathogens).
- Planting carcasses only within the historic range of the species being used for nutrient enhancement.
- Avoiding the planting of adults or juveniles that may have died of infectious disease. This would include pre-spawning adult mortalities and juvenile mortalities from hatchery ponds.

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HATCHERY SMOLT QUALITY AND ACHIEVING THE WILD SALMON TEMPLATE

Smoltification

Anadromous salmonids undertake a metamorphosis, the parr-smolt transformation, as they prepare for migration to the sea. Photoperiod-induced changes in physiology, body shape, and behavior transform the cryptic, bottom-oriented resident form, or parr, to the migratory, schooling form. This metamorphosis is termed smoltification and the resulting migrant is termed a smolt. The process of smoltification is a major life history event, with fundamental changes in body form and function likened to the metamorphosis of a frog to a prince (Grimm's Fairy Tales).

Timing and duration of the metamorphosis and downstream migration to the sea is determined by a species-specific, genetically-determined life history pattern and environmental events governing growth rate and size. For example, chum and pink salmon smoltify almost immediately upon absorption of their yolk sacs and swim up in the late winter or early spring. Chinook, coho, sockeye, and steelhead normally smolt as yearlings or two year-olds during the period of increasing day length in late spring. Depending on life history type (stream or ocean form), or the size attained in their first year of life, some Chinook may smoltify as yearlings or sub-yearlings. In some instances, Chinook salmon may exhibit smolt-like characteristics during declining photoperiod in the fall of the year, and migrate seaward to the estuary.

Smolted salmonids exhibit rapid downstream migration, increased hypo-osmoregulatory capability (enhanced seawater tolerance), sustained growth in the ocean and high survival to adulthood. The linkage between smoltification, growth rate, and seawater tolerance and migration rate has been reported frequently in the literature (Wagner et al. 1969; Varnavsky et al. 1992). These processes are under hormonal control and mediated primarily by photoperiod. The same hormones controlling growth rate (growth hormone, insulin-like growth factor-I) also stimulate the development of seawater tolerance in salmonids (Sakamoto and Hirano 1993). It is also recognized that survival is not the only valuable quality measure of released hatchery fish, especially in integrated conservation programs,[57] where fish are released to intermingle with their wild counterparts.

Defining Quality Hatchery Smolts

During the course of its regional reviews of hatchery programs, the HSRG has noted that the *quality* of hatchery-origin fish was almost always described in terms of size, numbers, or condition index of fish produced, and whether they meet a pre-determined time window for release. Fish *size at release* almost invariably seems to be used as a surrogate for fish *quality*. In some cases, the health of released fish is discussed as a measure of quality at the time of release from the hatchery,

[57] *See Emerging Issues paper on Integrated vs. Segregated programs.*

but rarely is fish quality adequately described, or monitored, prior to or following release. Most hatchery personnel have difficulty defining smolt or fingerling quality beyond obvious behavioral and silver coloration changes, yet the scientific literature is rich in descriptions of physiological, morphological, and behavioral definitions of a quality smolt. This deficiency may stem from past hatchery practices and the focus and direction of past research.

It is interesting to note that following the advent of the coded wire tag, most hatchery improvement studies were aimed at manipulating the size and time of release of smolts to maximize survival. Additionally, some researchers concentrated on the role of nutrition (proximate composition, constituent quality, etc.) in optimizing adult survival. But in most cases, optimization has meant manipulating fish size and timing of release. In contrast to the 1970s and 1980s, the hatchery operator now has many additional tools with which to measure and manipulate the quality of smolts during the culture phase.

The *quality of a smolt* is embodied in the rate and completeness of the parr-smolt transformation. In the hatchery, the timing, magnitude, and duration of the metamorphosis are a surrogate for smolt quality and can be quantified using *physiological, morphological*, and *behavioral* measures. Therefore, it is strongly recommended that the definition of smolt quality be expanded to include additional physiological, morphological, and behavioral measurements taken throughout the culture cycle. Examples include some specific physiological measures of smoltification status linked to improved survival such as gill Na-K ATPase enzyme activity, blood concentrations of thyroid hormones, growth hormone, insulin, insulin-like growth factor, and body lipid levels, among others. A simple measure of physiological smolt development easily measured at the hatchery is the rate of change in growth rate, immediately preceding and during the parr-smolt transformation (Beckman et al., 1996). The definition of a quality hatchery smolt is therefore equal to the definition of a quality natural smolt. Smolt quality is defined as a metamorphosed, anadromous salmonid that exhibits rapid downstream migration, increased hypo-osmoregulatory capability (enhanced seawater tolerance), sustained growth in the ocean, and high survival to adulthood. Smolt quality is measured along a continuum of physiological, morphological, and behavioral changes that occur during the metamorphosis from fingerling to migrant.

Wild Salmon Template

In the years following ESA listings, researchers and managers have recognized the need to conserve and recover depleted natural stocks and have used hatcheries as one potential tool. Research emphasis is now concentrated on the physiological, morphological and behavioral traits of hatchery fish that may impart benefits when released. In these programs, the wild fish may provide the best template for duplicating a quality hatchery smolt. For example, mimicking the growth pattern, size, and out-migration timing of natural fish has been shown to produce higher quality hatchery smolts with greater smolt-to-adult survival. An added advantage would be an equivalent hatchery contribution to adult harvest with fewer smolts released. Producing, high quality smolts that migrate downstream rapidly reduces opportunity for hatchery-wild fish interactions and minimizes negative ecological impacts of hatchery fish on wild fish. Rapidly migrating smolts will be less likely to residualize and imprint on inappropriate stream sites, and therefore be less likely to stray during their homing migration.

If one were to use wild salmon as a template, for juvenile hatchery fish, what morphological, behavioral, physiological, and genetic fitness traits would characterize locally adapted stocks? The following dialogue gives examples of physiological, morphological and behavioral templates characteristic of wild fish:

Physiology

Conditions in the hatchery environment affect physiological fitness. Water quality affects the duration and rate of smolt development and other physiological processes in the hatchery environment. Primary amongst these are temperature and photoperiod. Physical and chemical characteristics such as suspended solids; dissolved gases, pH, and mineral content may also control physiological processes such as fish health (immune resistance) and osmoregulation.

Energy reserves and growth rate affect physiological fitness. Growth, survival and the physiological processes of smoltification and maturation in salmonids are controlled in part by the availability and quality of forage organisms. During periods of declining day length, circulating levels of the metabolic hormones IGF-1 and growth hormone are low and protein synthesis rates in the body are reduced. Fish convert both dietary protein and lipid into stored body fat during these periods. In contrast, when day lengths increase, as during the period of spring smolting, body metabolism patterns change, with increases in protein synthesis rates and lypolysis, resulting in lower percentage whole body fat levels. In late autumn and early winter wild fish reduce growth rate, feeding activity, and metabolism and lose substantial amounts of body fat over the winter (Beckman et al. 1998). In late winter and early spring, wild yearlings dramatically increase feeding, accumulate body fat, resume growth and exhibit a dynamic pattern of physiological development (Dickhoff et al. 1997). In contrast, hatchery salmonids are fed diets high in lipids at feeding levels that encourage sustained rapid growth, even during cold winter periods when growth of natural fish is zero. In natural salmonids there is a positive relation between growth rate during the two months immediately proceeding out migration and survival to adulthood (Dickhoff et al. 1995). Furthermore, increased spring growth of spring Chinook salmon improves their downstream movement.

In general, wild smolts differ from hatchery smolts in four ways; wild fish are generally smaller than hatchery fish; show more rapid growth rate during the smolting period; have less body fat than hatchery smolts; and show a more dynamic change in physiological and metabolic status from over-wintering to the spring smolting period.

Morphology

Conditions in the hatchery environment should promote morphological fitness by emulating natural fish body size, body shape, and coloration. For example, body size affects foraging effectiveness, vulnerability to predators, fecundity and reproductive success.

The size of a juvenile salmonid affects its ability to compete with its peers, escape predators, adapt to seawater, migrate rapidly, mature early, and most importantly, survive and recruit into the fishery or spawning population (Bilton et al. 1982, Martin and Wertheimer 1989). Natural populations generally contain fish within a size range governed by hatch time, available food resources, and environmental conditions.

Releasing young, high-quality smolts within a size range similar to the natural population from which they are derived, as opposed to releasing larger smolts, will reduce competition with wild smolts and minimize selection pressures that occur when there is clear disparity in size.

Cryptic coloration. In nature, salmonid eggs incubate, and alevins develop, in the darkened, matrix-rich environment of the gravel substrate of the redd. Following hatch, juveniles rear in a complex lighted environment of shade, sunlight filtering through riparian vegetation, and light-absorbing dark gravel substrate. This environment produces cryptic coloration and body camouflage patterns most likely to reduce vulnerability to predators. At smoltification, guanine is deposited in the epidermal tissues, and the fish becomes silvery in appearance as it undertakes its downstream migration. Hatcheries can simulate these conditions through the use of enriched environments.

The body shape of a wild salmonid changes with the season of the year and the availability of nutritional resources. During winter, a period of low feed availability or even starvation, body weight and condition (relationship between body length and weight) drops, resulting in a slimmer fish with lower body fat. In spring, prior to smoltification, resident non-migratory juveniles feed heavily and regain body fat and condition. During the parr-to-smolt transformation, and as the period of downstream migration nears, the condition index changes again and a slimmer, more streamlined, silvery smolt is produced.

Overall, fecundity is generally lower in hatchery fish, owing to juvenile rearing protocols and smaller age at maturity. In some species, the release of large hatchery fish results in a larger percentage of precocious males in the population, early return of females to the hatchery, and smaller age and lowered fecundity at return.

Behavior

Conditions at the hatchery should promote the competency of juvenile fish to migrate, establish territory, and displace other individuals, prey and forage.

Social behavior Juvenile salmonids have been shown to reduce their territory size as fish density increases. Territory size may limit the maximum density of juvenile salmonids in streams (McNicol and Noakes 1984). Density is an important factor in adult survival, with high-density culture causing a breakdown in social hierarchies in cultured salmonids.

Migration/homing/straying Before out-migration, juvenile salmon learn odors associated with their natal streams, which guide their homing migrations as adults. Imprinting in salmon may occur at multiple life history stages. To maximize imprinting opportunity, juvenile salmon must experience the odors of their natal system at various times and physiological states when the odors can be learned. It is well-known that olfactory imprinting occurs during sensitive periods associated with surges in plasma thyroxin levels during parr-smolt transformation (Dittman et al 1995). This may indicate the occurrence of multiple pre-smolt imprinting periods.

Predation avoidance behavior Natural salmon juveniles experience and observe predation of their cohorts by birds, fish and a variety of mammals. Observed predation, or attempted predation on themselves and other salmonids, results in expression of an innate predator-avoidance response that protects natural salmon juveniles. Because they are protected in the hatchery environment, hatchery salmon are lacking this naturally learned predator-avoidance response.

Foraging ability From the time of first feeding to returning as adults, natural salmon learn to feed on a variety of swimming, moving, prey organisms. The recognition of a specific type of prey movement is probably recognizable to naturally rearing salmon juveniles. By comparison, hatchery salmon are fed a regimen of prepared feeds that are generally uniform in size, color and movement. Hatchery fish have been shown to be less successful in stalking and capturing natural prey organisms.

Genetics

Genetic changes from artificial propagation can affect both the productivity and viability of wild populations (Reisenbichler and Rubin 1999). To produce a quality smolt for use in conservation and recovery of wild populations, hatchery practices should minimize both random and directional selective changes that contribute to domestication and loss of local adaptation. Domestication is the process of a population changing over time in response to an artificial or human-controlled environment and is manifested in directly-measurable genetic characteristics (e.g. allele frequencies) as well as in physiological, morphological, and behavioral traits discussed above. Principal factors that lead to domestication include relaxation of natural selection that would naturally occur in the wild, natural selection to the hatchery environment, and direct human-controlled selective breeding.

Maintenance and Selection of Broodstock

The goal of developing a wild-template smolt is to minimize the changes that contribute to domestication. The level of domestication selection is affected by both hatchery practices and the amount of exchange between hatchery and wild populations. Hatchery practices that minimize changes in physiological, morphological and behavioral traits, as well as such traits as time, age and size of return will decrease the risk of domestication, as many of these traits have inheritable components.

Broodstocks should be selected from locally-adapted populations. Introduction of spawners from exogenous populations should be avoided, to minimize risks of outbreeding depression. The periodic infusion of adults of natural-origin spawners retards the rate and level of domestication, but may not completely eliminate its effects (Ford, in press).

Effective population size

Hatchery practices should be designed to maximize effective population size to maintain genetic diversity and reduce potential detrimental effects of inbreeding. Small effective population sizes can increase the likelihood of deleterious effects by random drift, even in the absence of an altered selective environment. Effective population size is defined in terms of numbers of reproducing adults (breeders) per year and the generation time of the population. Techniques that ensure every adult has an equal probability of producing progeny maximize effective population size. These techniques include equal sex ratio, equal family size, and mating protocols that equalize contributions among individuals.

The effective population size of the hatchery program can also directly affect the health and viability of the wild population. A reduction in diversity and in the effective size of the wild population can result from "genetic swamping," where a large number of hatchery fish from relatively few parents interbreed with wild fish. This is particularly likely if the effective population size of the hatchery population is substantially less than that of the wild population, (Ryman and Laikre 1991).

Achieving the Wild Fish Template in the Hatchery

How would a hatchery manager rear fish to approximate the wild fish template? The following section describes hatchery methods that can be employed to mimic the wild fish template in hatchery fish:

Physiology

Swimming efficiency (stamina, stride efficiency)

> **Solution:** exercise, growth modulation.

Smolt development (silvering-guanine deposition, hormonal and enzyme cycles, hypo-osmoregulatory ability)

> **Solution:** growth modulation, dietary salt, photoperiod control, rearing density.

Energy stores (whole body proximates, liver glycogen, hepatosomatic index)

> **Solution:** feed amount, growth modulation. Simulate proximate composition by controlling diet composition.

Morphology

Growth pattern (seasonal change in length, weight, and condition factor).

> **Solution:** growth modulation. Simulate growth rate and body size by controlling water temperature and feeding rates. Slow growth during winter followed by rapid growth during spring ensures better quality smolts.

Length frequency distribution (mean length/weight, variance, skewness)

Solution: feed amounts and frequency of feeding, staggered egg take, thermal control of incubation, rearing density, feed schedule. Fish are grown using methods of feed ration and/or water temperature manipulations to match growth cycles of hatchery fish to growth patterns of wild fish. Growth of hatchery fish will be reduced in the winter and accelerated in the spring.

Smolt development (condition factor, coloration, body shape, fin quality, dentition, cloacal folds)

Solution: dietary salt, growth modulation, rearing density, environmental enrichment.

Out-migration timing

Solution: volitional, forced, staggered release.

Behavior

Competition for feed.

Solution: environmental enrichment, forage training on live foods, rearing density.

Competition for space (territoriality)

Solution: environmental enrichment, reduced rearing density.

Migratory behavior (schooling, downstream orientation, restlessness, migration)

Solution: growth modulation, exercise?

Predator avoidance

Solution: exercise, predator conditioning, avoid human feeder imprinting.

Genetics

Minimize Domestication Selection (selection in the hatchery environment)

Solution: select locally adapted broodstock, periodically infuse wild spawners.

Run timing

Solution: monitor run timing, adjust egg take to emulate wild timing, modulate developmental rates to emulate wild timing, cull as needed.

Age at maturity (age structure, precocity)

Solution: utilize cohorts in proportion to wild run.

Size at maturity (average size at age)

Solution: monitor size at age changes within hatchery relative to wild populations; minimize directional changes in hatchery by equalizing contributions of individuals irrespective of size within age cohort within the bounds of the wild template.

Maximize effective population size (inbreeding and variance effective population size)

Solution: equalize sex ratio, follow fertilization protocols that equalize contributions among individuals (e.g. factorial matings, pairwise matings), equalize family size, cull as needed.

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BENEFITS OF HATCHERY FISH AS A SOURCE OF FOOD

In the development of its *Scientific Framework for the Artificial Propagation of Salmon and Steelhead*, the Hatchery Scientific Review Group recognized that hatcheries will likely experience more frequent large surpluses of returning adults because of increased protection of co-mingled natural stocks. Because of this, it is important for the hatchery operators and fishery managers to devise creative solutions for providing harvest opportunities, and to use surplus returns in ways that provide additional benefits from the hatchery programs.

One creative use of hatchery surplus fish is as a source of food. Historically, a small portion of fish returning to state hatcheries has been used as food for state institutions or distributed to tribes for subsistence purposes. The majority has been sold to buyers who use the carcasses primarily for products such as fish meal for pet food. Tribal hatcheries have generally been the exception to this rule. Most tribal hatcheries have considered distribution of salmon to tribal members as the preferred use of this resource. Some, like the Nisqually and Skokomish tribes, have expanded their distribution system to include charitable organizations, food banks and even members of the general public that visit the hatchery on spawning days specifically to pick up fish to be used for food. In the last ten years, the Nisqually Tribe alone has distributed an average of 70,000 pounds of hatchery returns annually for use as food (Bill St. Jean, Nisqually Indian Tribe and Dave Herrera, Skokomish Indian Tribe, personal communications).

In the past few years, the State of Washington has also recognized the value of fish returning to hatcheries as a food source. Under state law, the Washington State Department of Fish and Wildlife (WDFW) has the authority to donate hatchery returns, as excess state property, to needy citizens of the state. Current recipients of hatchery fish include 40 different organizations ranging from small groups such as senior centers, Salvation Army branches, churches and gleaning organizations that receive from 10–200 fish per visit, to a large, statewide distribution network that has an outlet in every county of the state.

The small organizations arrange to pick up hatchery adults from a specific hatchery in their area and handle the processing and distribution to their organization themselves. In the case of the statewide network, a contracted processor picks up the hatchery adults, processes and freezes them as skinless fillets, and distributes them statewide through Seattle First Harvest. In order to defray his cost, the processor keeps the by-products: skeletal remains, skin, and eggs (which are used for fish meal), bait eggs and caviar.

In the first year of operation (2000), this program took 30,000 pounds of hatchery adults and distributed them as food. In 2001, 450,000 pounds of fish were used to produce fillets. Projections for 2002 were for 1.5–2.0 million pounds of fish to be used to produce 500,000–700,000 pounds of frozen skinless fillets; the equivalent of 2.0–2.8 million servings of protein. Because of the success of this program, providing hatchery fish to feed needy residents is now a high priority for good quality fish, second only to meeting the needs of the hatchery program and providing fish for natural spawning areas (Andy Appleby, Washington Department of Fish and Wildlife, personal communication).

In 2002, the State of Oregon placed a higher priority on using surplus hatchery adults as a food source. The Oregon Department of Fish and Wildlife has made arrangements with the same processor used by WDFW. In exchange for the right to process and sell the by-products, fish are processed into skinless fillets and distributed frozen by the Oregon Food Bank. Projections for the 2002 contribution from Oregon hatcheries were similar to Washington's—approximately 140,000 fish to be processed into 500,000 pounds of food (Bill Otto, Oregon Department of Fish and Wildlife, personal communication).

MARINE CARRYING CAPACITY

The present hatchery system for Pacific salmon was developed to produce increasingly higher numbers of fish in a constant oceanic ecosystem, believed to be near limitless in its capacity to accommodate hatchery salmon. Until recently, these oceanic systems were believed to be stable, internally regulated, and to behave in a deterministic manner. The more current view is of an open system in near constant flux - a system without long-term stability, and one that is often under the influence of stochastic factors, many originating outside the ecosystem itself. The modern view of the ecosystem is one characterized by ecological uncertainty (Mahnken et al. 1998).

Based on the assumption that ocean carrying capacity was unlimited, or had not yet been reached, the goal of increasing the size of a fishery was simply achieved by building more hatcheries and releasing more fish. As a result, for more than 20 years there has been massive growth in salmon hatchery releases in the Pacific Northwest (Mahnken et al. 1998), with more smolts entering the ocean from the Pacific Northwest hatchery system than at any time in the past. An example of this general increases in hatchery output is the Columbia River Basin. The Northwest Power Planning Council (NWPPC 1986) estimated that annual natural abundance before 1850 was 264 million smolts. Since the late 1980s, public hatcheries in the Columbia River Basin have reared between 200 - 300 million juveniles annually for release (Chapman 1986, Schiewe et al. 1989). In 1992, for example, based on releases of nearly 203 million hatchery fish and an estimated 145 million wild fish, almost 350 million smolts were in the Basin that year, or 32 % above the historic high of 1850. Such vast numbers of out-migrants clearly place a heavy demand on the food production capabilities of any ecosystem, whether in the natal streams and rivers, the coastal estuaries, or in the ocean itself. Furthermore, in the intense competition for food, which must occur, the dramatic increases in numbers of hatchery fish have obviously affected the chances for survival of the smaller numbers of native stocks.

Studies on abundance of stocks in widely separate geographic areas over time have indicated oceanic conditions are primarily responsible for changes in annual returns of adult salmon (Cooper and Johnson 1992, Beamish and Bouillon 1993, Lichatowich 1993, Olsen and Richards 1994). The way in which these physical, chemical, and biological processes conditions can impact fish populations and production trends are reasonably well known.

Based on analysis of climatic trends and the productivity of salmon fisheries in the North Pacific, Beamish and Bouillon (1993) noted that the strategy of releasing large numbers of artificially reared smolts during a period of decreasing marine survival was not appropriate. Concerns over the limits of ocean carrying capacity, and other factors, are conspiring to force a re evaluation of industrial hatchery production of North Pacific salmonids (Mahnken et al. 1998). Concerns include (i) high harvest rates of wild fish in fisheries targeted on the more abundant hatchery stocks, (ii) over-production of hatchery chum salmon in Japan, and both pink and chum salmon in Alaska, (iii) declining fish size, and (iv) altered return timing and age at maturity, and (v) widely varying ocean survivals. Concern for declining size and increasing age at maturity observed in North Pacific stocks of five salmon species suggests that large-scale hatchery production may be resulting in density-dependent growth reduction (Kaeriyama and Urawa 1992, Rogers and Ruggerone 1993, Bigler and Helle 1994).

Although ocean harvest rates are generally scaled back when the abundance or productivity of wild stocks is low and regime shifts become evident, hatchery production is not. Rather, the tendency in the 1970-90 period has been to increase hatchery production in the Pacific Northwest as ocean productivity decreased (Mahnken et al, 1998). Given that the carrying capacity of the ocean has a primary impact on salmon returns, it is eminently sensible that hatchery releases should be reduced during periods of poor ocean survival to protect wild fish. Scientific ignorance of oceanic regime shifts, and their impact on the variability of fish abundance and survival, has acted against wild fish populations through poorly informed or ill-considered hatchery production and harvest policies.

Regime shifts, or major changes in ocean productivity, occur only infrequently but are becoming increasingly predictable. By interpreting physical, chemical, and biological signals of changing oceanic productivity, certain impacts can now be anticipated. Fishery managers now know they should decrease harvest rates during periods of lower productivity, that is, they should scale fisheries to the natural spatial and temporal patterns of abundance of wild fish populations. Likewise, hatchery production should be curtailed during periods of increased density dependant mortality to protect wild stocks and to reduce monetary waste. Modern hatcheries should program their production to accommodate the natural spatial and temporal patterns of abundance in wild fish populations.

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OUTPLANTING AND NET PEN RELEASE OF HATCHERY-ORIGIN FISH

A large system of fish hatcheries exists in the Pacific Northwest for propagating Pacific salmon and steelhead (Oncorhynchus spp). A significant proportion of those released fish support commercial, Tribal, and recreational fisheries to specifically mitigate for fish and habitat losses associated with land- and water-use development. For example, approximately 85% of all returning adult salmon and steelhead in the Columbia River are of hatchery origin.

The vast majority of salmon hatcheries in the Pacific Northwest operate largely as adult spawning and juvenile rearing facilities through the smolt stage of development. Upstream-migrating adults are trapped and/or are diverted into adult holding ponds and then spawned when they reach sexual maturity. The fertilized eggs are incubated and hatched, and the resulting progeny are reared to the smolt stage prior to release into a freshwater stream. Age at release varies considerably among the various species of Pacific salmon (including steelhead), ranging from a few days or weeks after yolk absorption for pink and chum salmon (*O. gorbuscha* and *O. keta*, respectively) to approximately 15–20 months post-fertilization for steelhead, coho salmon (*O. kisutch*), and spring Chinook salmon (*O. tshawytscha)*.

The standard method of propagation is to release juveniles into the stream areas where returning adults can be recaptured for broodstock. The homing and recapture of returning adults may be further maximized if smolt releases and adult trapping occur "on-station" at the hatchery. Fish returning elsewhere where they cannot be trapped are known as "strays". The recapture and removal of unharvested, hatchery-origin adults reduces potential genetic and ecological risks to naturally spawning populations when the purpose of those hatchery-origin fish is strictly harvest.

On the other hand, smolts are often released from a site where adult collection facilities do not exist. In many situations, smolts are transported by hatchery truck—oftentimes into other watersheds and sometimes over relatively large distances (e.g. >100 km)—and then released. In general, salmon and steelhead return as adults to the areas where they are released, not where they are reared (reviewed by Quinn 1993).

Releasing smolts into streams geographically removed from a hatchery or adult collection facility is commonly called "outplanting." Steelhead programs in Washington state, for example, have often used outplanting to support recreational fisheries in a large number of small streams where no hatchery or adult collection facilities exist. More recently, saltwater net pens have been used increasingly to acclimate and release salmon smolts in marine areas where a targeted marine fishery on returning adults is desired. In these latter net pen releases, juvenile salmon are transferred to brackish or salt water (i.e., at a nearshore, estuarine location) at the early stages of smoltification and then fed in the net pens for one to three months prior to release. Significant harvests on returning adults can then occur in the near shore marine areas in the general vicinities of the net pens.

A common feature of outplanting and net pen programs is the release of smolts where no facilities exist to trap returning adults that escape target fisheries. In these latter situations, non-harvested adults may spawn unintentionally in streams far-removed from the source hatchery or geographic location where their parents were trapped for broodstock. Outplanting juvenile and/or adult salmonids also occurs in restoration and recovery programs where natural spawning by hatchery-origin adults is explicitly desired; however, these latter programs are not the subject of the discussion here.

Homing to natal streams is an important biological characteristic of salmonid fishes, allowing evolution of local adaptations in life history and other fitness traits (Quinn 1993; Altukhov and Salmenkova 1994; Quinn et al. 2001). Stock-specific, genetically-based adaptations include size and age at sexual maturity, adult return and spawn timing, pre-hatch developmental rate, length of freshwater residence prior to outmigration, and marine migration patterns (e.g., Smoker et al. 1998). Despite the biological importance of homing, natural straying also plays an important role related to colonization of new habitats and maintaining connectivity between geographically adjacent populations (Shapovolov and Taft 1954; Milner 1997; Quinn 1997).

Many studies have shown that salmon and steelhead seek alternative spawning habitats if no appropriate habitat is immediately available (Pascual and Quinn 1994). Such behavior is most apparent when natal streams are blocked by catastrophic, environmental events. For example, siltation resulting from the 1980 eruption of Mount St. Helens resulted in significant numbers of Chinook salmon and steelhead straying from the Cowlitz River to the Kalama and Lewis rivers (Leider 1989; Quinn et al. 1991).

Tagging and genetic studies have shown that outplanting and net pen programs promote stray rates that far exceed natural levels (Candy and Beacham 2000; Mackey et al. 2001). The absence of freshwater imprinting by fish released from saltwater net pens can lead to unpredictable straying by large numbers of unharvested adults to streams where natural spawning is not desired. Similarly, significant numbers of adults returning to outplanted streams typically escape targeted fisheries and potentially spawn with natural-origin fish. Consequently, outplanting and net pen releases can pose significant genetic risks to natural populations by promoting high stray rates to freshwater areas where interbreeding with naturally spawning populations is not desired.

Outplanted smolts may also outmigrate from freshwater at a much slower rate compared to smolts resulting from on-station releases (Hawkins and Tipping 1999; Pearsons and Fritts 1999). Such delayed outmigraton rates may result in increased predation on, and competition with, wild fish. Although side-by-side comparisons have not been done, outmigration rates of outplanted steelhead smolts have been documented at 2.9 km/day (Tipping and Byrne 1996) and 1.6 km/day (Tipping et al.1995), whereas on-station releases have documented 33 km/day (Dawley et al.1977; Harza 1998). This travel time difference could substantially increase smolt predation opportunities on wild salmonid fry. Also, the desired benefit of changing adult distributions within a river for supporting fisheries may be minimally affected by outplanting smolts in rivers downstream of a hatchery. Tipping and Hillson (2002) found that on the Lewis River—where steelhead smolts were reared near the upstream anadromous terminus—adult returns of winter steelhead were only slightly changed by downstream smolt release location, and summer steelhead were unaffected.

Outplanting and net pen releases from segregated hatchery programs[58] are especially problematic because of the potentially high level of genetic divergence between the hatchery stock and natural populations where straying and natural spawning may occur. Although the natural spawning success of hatchery-origin fish may be less than that of natural-origin fish when they occur in the same stream, those same data indicate that significant numbers of hatchery-origin fish from non-native or long-standing "domesticated" populations do indeed spawn successfully and can contribute significant numbers of progeny to naturally spawning populations (Chilcote et al. 1986; Campton et al. 1991; Mackey et al. 2001; Kostow et al. 2003; McLean et al. 2003). Kostow et al. (2003) presented data supporting a conclusion that hatchery summer steelhead adults and their offspring may have contributed to wild winter steelhead population declines through competition for spawning and rearing habitats.

Many studies have further indicated a genetic component to homing such that non-native fish, or their hybrid progeny, stray at higher rates than identically-reared native fish (Bams 1976; McIsaac and Quinn 1988; Pascual et al. 1995; Candy and Beacham 2000). This latter characteristic further confounds the genetic risks associated with straying of returning, outplanted fish by potentially increasing stray rates among natural-origin fish representing the progeny of hatchery-origin adults that reproduced successfully in nature. Consequently, based on the available scientific and fishery research data, both published and unpublished, the HSRG concludes that outplanting and net pen releases of hatchery-origin smolts pose significant, and potentially unacceptable, genetic risks to naturally spawning populations.

The HSRG has concluded that the simplest way to reduce risks associated with outplanting and net pen releases is to reduce the number and/or size of existing programs. However, the HSRG also recognizes that many of these programs support important tribal, commercial and/or recreational fisheries. As a result, significant trade-offs may exist between the fishery benefits of such programs and the risks they pose to naturally spawning populations. Consequently, the HSRG recommends that the biological risks of outplanting and saltwater net pen programs also be reduced by implementing the following actions:

- Mark all net pen released and outplanted fish each year, and tag a significant proportion of released fish with coded-wire tags, to assess the direct contribution of those fish to targeted fisheries and to assess stray rates and biological risks to natural populations. Systematically tagging a portion of the released fish each year, coupled with marking all outplanted and net pen released fish, will allow the co-managers to assess the degree to which these programs meet harvest goals while posing risks to natural populations.

- Conduct intensive harvest of hatchery-origin fish and/or use adult traps to reduce potential natural spawning of unharvested, hatchery-origin fish.

- Restrict releases of hatchery-origin fish to areas where adult collection facilities exist or can be easily developed. In some cases, adult traps can be added to existing smolt release ponds. In other cases, release sites can be restricted to streams with existing adult

[58] *See Emerging Issues section on Integrated versus Segregated hatchery programs.*

collection facilities. The wild steelhead management zones recommendations for steelhead would also help meet this recommendation (see below).

- Use locally-adapted and genetically integrated[59] hatchery stocks for net pen releases and outplanting wherever possible. That is, minimize—or eliminate—the use of "out-of-region" stocks and fish from genetically segregated hatchery stocks for these high-risk programs. Fish outplanted or net-pen reared for harvest-driven programs should be obtained from genetically integrated hatchery stocks and/or stocks native to the region or watershed where the net pen or outplanting programs occur. One possible exception to this latter recommendation would be hatchery populations that have been selectively bred, or otherwise manipulated genetically or phenotypically, for reproductive traits (e.g. spawn timing) that result in low probabilities of successful natural reproduction in the specific streams or geographic area where smolts are released. For example, hatchery-propagated populations of steelhead have often been selectively bred for early run and spawn timing, and these fish may have low reproductive success in watersheds driven hydrodynamically by snow-melt. However, these latter assumptions must be carefully tested and evaluated for such actions to be considered scientifically defensible.

- Implement the HSRG's recommendation for wild steelhead management zones to substantially reduce outplanting and thereby reduce risks to naturally spawning populations.[60] Similar region-wide guidelines and changes are needed to reduce biological risks of net pen releases and other outplanting programs, especially where no adult collection facilities are present for trapping non-harvested adults.

- Evaluate the benefits and risks of each program every two to three years. Programs imposing significant risks relative to benefits should be reduced or terminated.

- Monitor and evaluate high-risk programs annually to ensure that adverse effects to wild populations are minimal, that straying risks are appropriately managed, and that off-station releases are appropriately located such that non-harvested, hatchery-origin adults do not spawn in undesirable locations.

- Develop system-wide risk management guidelines and protocols for outplanting and net pen programs.

The HSRG believes these recommendations should be implemented as soon as possible as a first step alternative to terminating outplanting and saltwater net pen programs that are conferring significant fishery benefits. Many of the HSRG's specific recommendations within each region reflect the more generalized recommendations presented above.

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[59] *See Emerging Issues section on integrated versus segregated hatchery programs.*

[60] *See HSRG Hatchery Reform Recommendations, February 2003, System-wide Recommendations.*

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ASSESSING THE POTENTIAL FOR PREDATION ON WILD SALMONID FRY BY HATCHERY-REARED SALMONIDS IN WASHINGTON[61]

Juvenile salmonids are subject to predation by a variety of avian, mammalian, and piscine predators, and predation has been implicated as an important source of mortality in a number of salmon populations (Fresh 1997; Mather 1998). Recently, concern has been expressed about the potential for hatchery-reared salmon and steelhead to prey on wild juvenile Pacific salmonids (*Oncorhynchus spp.*) and the impact that this predation may have on threatened or endangered salmonid populations (Lichatowich 1999; Levin et al. 2001).

The potential for predation of wild salmonids by hatchery-reared smolts will depend on the sizes, numbers, and spatial distribution of predators and prey, the functional and numerical responses of the predators, and the amount of time that predators and prey are in proximity. Here we review the evidence for predation on wild salmonids by hatchery-reared fish and propose a strategy to estimate risks to wild salmonid populations from predation by hatchery-reared salmonids.

Evidence for Intrageneric Predation by *Oncorhynchus* Spp.

Freshwater

Predation on wild salmonid fry by salmonids is probably most likely in the freshwater environment, where potential salmonid predators are concentrated and exposed to large numbers of prey in a relatively small area. There is abundant evidence that salmonid smolts may prey on wild Pacific salmon fry in streams. Ricker (1941) reported that coho salmon were an important predator of sockeye fry in Cultus Lake, British Columbia (BC). Hunter (1959) reported that coho salmon smolts preyed on chum and pink salmon fry in Hooknose Creek, BC, and used his and other data from BC to estimate that each coho smolt might have consumed 1.5–2.0 fry per day. McCart (1967) reported that coho salmon smolts, rainbow trout, and cutthroat trout were important predators of sockeye salmon fry in the Babine River, BC, with coho smolts consuming an estimated mean of 3.7 sockeye per fish. Parker (1971) suggested that the primary source of mortality of chum and pink salmon fry was predation by coho salmon, but presented no data to support this. Fresh and Schroder (1987) reported that coho salmon consumed a large number of chum salmon fry in Big Beef Creek, Washington (WA), as did resident rainbow and cutthroat trout. Hargreaves and LeBrasseur (1986) found that coho salmon smolts selectively preyed on 48–50 mm chum salmon fry. Ruggerone and Rogers (1992) estimated that 59% of the sockeye fry population in the Chignik Lakes, Alaska (AK), was consumed by juvenile coho. Seiler et al.

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[61] *This paper was drafted for the HSRG by Stephen C. Riley, Julie A. Scheurer, and Conrad V. W. Mahnken, NOAA Fisheries, Northwest Fisheries Science Center, Manchester Research Station, PO Box 130, Manchester, WA 98353; and H. Lee Blankenship, Northwest Marine Technology, 955 Malin Lane SW, Suite B, Tumwater, WA 98501; March 2003.*

(2002) found salmonid prey in the stomachs of juvenile steelhead, coho, Chinook and cutthroat trout that were captured in a screw trap on the Green River, WA.

There are several studies that have reported predation by hatchery salmonids on wild salmonid fry. Sholes and Hallock (1979) estimated that millions of wild Chinook were consumed by hatchery-reared Chinook and steelhead in the Feather River, California (CA), and Cannamela (1993) estimated that hatchery-reared steelhead smolts consumed up to 24,000 wild Chinook fry in the Salmon River, Idaho (ID), over the course of 50 days; these estimates were based on extrapolation from small sample sizes. Menchen (1981) found that steelhead smolts released into Battle Creek, CA, were significant predators on naturally-produced Chinook fry. Beauchamp (1995) reported that wild steelhead smolts were the primary predator of sockeye salmon fry in the Cedar River, although hatchery-reared steelhead smolts, which were released during the latter half of the sockeye migration, did not appear to prey on sockeye fry. Hawkins and Tipping (1999) observed a small proportion of hatchery reared coho, steelhead, and cutthroat smolts preying on wild Chinook smolts. Beauchamp (1990) found that rainbow trout stocked into Lake Washington did not become primarily piscivorous until they reached approximately 250 mm, and did not consume many salmonids at any size, although sockeye salmon fry were available in the lake.

Because hatchery-reared salmonids may not feed as well as wild conspecifics (Sosiak et al. 1979; Bachman 1984; Olla et al. 1998), one might expect that they would be less efficient as predators, although wild and hatchery-reared brown trout in a Norwegian reservoir were observed to have similar rates of piscivory (L'Abée-Lund et al. 2002). Moreover, any reduced feeding might be offset by the generally larger size of hatchery-reared smolts. Although there is evidence that predation of salmonid fry by migrating smolts may be common in streams, the estimation of risk to wild salmonid fry from predation by hatchery-reared smolts in WA streams is hindered by a lack of published data on the comparative feeding habits of hatchery and wild smolts. Recent sampling by the Washington Department of Fish and Wildlife (WDFW) indicates that migrating smolts of hatchery and wild coho and steelhead may prey on chum salmon fry in Washington rivers (H. J. Fuss, WDFW, Olympia, personal communication).

The high potential for encounters between hatchery-reared predators and wild salmonid prey in freshwater environments may be tempered by the fact that hatchery-reared smolts generally spend very little time in rivers before migrating to sea. Although we are unaware of any published data on residence times of hatchery-reared smolts in freshwater, it is widely believed that the majority of these fish migrate out of rivers very quickly. Recent work in Willapa Bay tributaries suggests that over 95% of steelhead, coho and Chinook smolts leave the immediate area of release within several hours (Riley et al. 2001; 2002).

Although most hatchery-reared smolts may migrate out of rivers relatively quickly, some steelhead smolts released from hatcheries have been observed to remain in rivers for months or years after release; these fish are known as 'residual' steelhead. Recent snorkeling in WA coastal streams has reported counts of residual steelhead between 1.25–37.7 fish per km several months after release, and stomach sampling on one stream revealed that five of 44 (11%) residual steelhead sampled contained salmonid remains, and a further 11% contained unidentifiable fish remains (Riley et al. 2001). McMichael and Pearsons (2001) found that residual hatchery-reared steelhead migrated up to 12.8 km upstream of their release point and outnumbered wild salmonid yearlings in several stream reaches. Martin et al. (1993) reported that residual hatchery-reared steelhead preyed on wild Chinook fry in the Tucannon River. Predation by residual steelhead on wild salmonids may represent an important impact on wild salmon populations and deserves further study.

Estuarine and Nearshore Marine Environments

Juvenile salmon and steelhead may spend considerable time in estuaries and nearshore environments before moving into offshore marine habitats (Healey 1980; Simenstad et al. 1982; McCabe et al. 1986; Pearcy 1992). The amount of time spent in estuaries by different salmonid species varies from several days to several months among estuaries and among years, and is probably related to environmental conditions (e.g., temperature, prey availability, stream flow) and the physical characteristics of individual estuaries (Simenstad et al. 1982). There is evidence that all five species of Pacific salmon may co-occur in habitats within the Campbell River estuary, BC (Korman et al. 1997), indicating that the potential for intrageneric predation exists in these habitats, although Macdonald et al. (1987) found that larger fish tended to occupy deeper water in these habitats.

Compared to freshwater studies, there is little evidence that wild salmonids are preyed on by other salmonids in estuarine or nearshore environments. Diets of juvenile Pacific salmon in the nearshore marine environment are often dominated by invertebrates (Manzer 1969; Feller and Kaczynski 1973; Craddock et al. 1976; Kjelson et al. 1982; Shreffler et al. 1992; Simenstad et al. 1992; Perry et al. 1996; Miller and Simenstad 1997; Moulton 1997; Gray et al. 2002), but may contain fish after the fish grow larger and move offshore (Healey 1991b; Tadokoro et al. 1996; Landingham et al. 1998), although salmonids have rarely been identified as prey. Emmett (1997) and Simenstad et al. (1992) suggested that the primary fish predators of juvenile salmon in estuaries were cutthroat trout and steelhead smolts, but did not cite any data to support this, and McCabe et al. (1983) suggest that intrageneric predation on salmonids was rare in the Columbia River estuary. Durkin (1982) reported that the diet of coho salmon smolts (128–138 mm) in the Columbia River estuary was composed almost entirely of invertebrates, and found no evidence that salmonids were utilized as prey. Murphy et al. (1988) found no evidence that coho salmon smolts preyed on chum or pink fry in a southeast AK estuary. Macdonald et al. (1987) did not report any salmonids in the diets of coho or Chinook smolts in the Campbell River estuary. Similarly, no salmonids were identified in the stomachs of juvenile Chinook salmon captured in nearshore habitats in Puget Sound (Miller et al. 1977; Fresh and Schroder 1984; Buckley 1999). Recent sampling in Puget Sound, however, has revealed that cutthroat trout may be significant predators of wild salmonid fry in nearshore areas (D. Beauchamp, UW, personal communication).

The results of numerous investigations suggest that intrageneric predation of wild juvenile salmonids is not common in estuarine or nearshore marine environments, but this may reflect difficulties in sampling and the relative paucity of work that has been conducted in these environments compared to freshwater. Because predation of juvenile salmonids by marine fishes may be significant in these environments (e.g., Beamish et al. 1992), the relative risk of predation by hatchery-reared salmonids may be low. However, we are not aware of any studies that have been specifically designed to look for predation by hatchery-reared salmonids in estuarine or nearshore habitats. Hatchery-reared Chinook salmon smolts may spend less time (Levings et al. 1986) and use different habitats (Levings et al. 1986; Macdonald et al. 1987) in the Campbell River estuary than wild smolts, which may affect their predation potential compared to wild fish. More research on the feeding habits of hatchery-reared salmonids in nearshore and estuarine environments is necessary if predation risk to wild salmonids is to be estimated.

Offshore Marine Environment

There is little evidence of intrageneric predation among salmonid species in the offshore marine environment. Although fish may make up a significant component of the diets of juvenile Chinook and coho in offshore marine environments, salmonid remains have rarely been identified as prey (Manzer 1969; Peterson et al. 1982; Brodeur 1989; Brodeur and Pearcy 1990; Pearcy et al. 1990; Brodeur et al. 1992; Landingham et al. 1998; Buckley 1999; Hunt et al.1999). In a sample of stomach contents collected between 1996 and 2002 from 86,266 ocean age-0 salmon (12,005 of which were hatchery-origin) from Puget Sound and the waters off Vancouver Island, only one fish was observed to have salmonid remains in its stomach (Ruston Sweeting, Canadian Department of Fisheries and Oceans, Pacific Biological Station, Nanaimo, BC, unpublished data). Although many of these studies used small sample sizes and were not designed to look for evidence of intrageneric predation, the fact that virtually all of the data collected indicate that salmonids do not feed on other salmonids offshore indicates that offshore predation by salmonids is probably not an important source of mortality to Washington salmon and steelhead stocks.

Offshore predation on wild salmonids by hatchery-reared smolts may be rare because encounter rates between the two may be low. Larger fish may move offshore earlier than smaller fish (Pearcy 1992), and the two may not co-occur in the marine environment when wild fry are small enough to be preyed upon by hatchery smolts. Future studies of salmonid diets in the offshore environment should estimate the density of potential predators and prey to evaluate how likely they are to encounter each other.

Relative Size of Predators and Prey

There is evidence that salmonids are capable of preying on fish that are up to approximately 50% of their body length, but the majority of prey is probably much smaller. Keeley and Grant (2001) provide linear regression relationships for salmonid body size and prey size based on a variety of salmonid diet studies. Their results for salmonids feeding on fish in streams suggest that the mean prey size for 100–200 mm salmonids is between 13–15% of predator body size. There was very little variability among salmonid species in these predator/prey size relationships. Damsgard (1995) developed a maximum prey size relationship for salmonids (based on mouth size) which suggests that salmonids are physically capable of consuming prey that are 49–51% of their body length.

In a laboratory experiment, Pearsons and Fritts (1999) found that hatchery-reared coho salmon consumed Chinook salmon that were up to 46% of their body length. Several other studies suggest that small juvenile salmonids will prey on fish up to about 40–45% of their body length (Martin et al. 1993; McConnaughey 1998), although Hargreaves and LeBrasseur (1986) found that yearling coho salmon very occasionally preyed on juvenile chum that were up to 75% of their body length. A recent study of Arctic char feeding on conspecifics suggests that the maximum relative prey size was approximately 47% of predator length (Finstad et al. 2001). It is therefore reasonable to assume that salmonid predators are capable of consuming prey up to approximately 50% of their body length.

The relative sizes of downstream-migrating smolts or fry of different species of salmonids in Washington suggest that several possible predator/prey combinations are likely to occur. Virtually all *Oncorhynchus* species could be potential prey for larger salmonids in freshwater when they are small, but those that migrate to sea at a small size are probably most vulnerable because they become concentrated in the downstream reaches of rivers. The relative vulnerability of wild juvenile salmonids to predation in freshwater depends on the release location of hatchery fish; if fish are released near the mouth of the river, then migrating fry are probably most vulnerable to predation. Hatchery fish that are released further upstream may encounter concentrations of all species of salmonid fry that occur in a given river.

Pink and chum salmon typically migrate at the smallest size of all species of Pacific salmonids (Heard 1991; Salo 1991; Hard et al. 1996; Johnson et al. 1997), often less than 50 mm in length. Ocean-type Chinook migrate as fry or smolts at sizes ranging from 30–100 mm (Myers et al. 1998, Healey 1991a). Smolts from WA sockeye salmon populations usually migrate to sea as 90–150 mm yearlings, but fry may be vulnerable to predation during earlier migrations to lake habitat and within lakes (Gustafson et al. 1997). These species are probably most likely to be preyed upon by hatchery-reared salmonids in WA.

Hatchery-reared chum, pink, sockeye, and ocean-type (underyearling) Chinook are unlikely to prey on wild salmonids due to their relatively small size at release and their non-piscivorous feeding habits. Yearling coho, Chinook, and steelhead smolts are typically released from WA hatcheries at sizes ranging from 115–140, 150–180, and 180–240 mm, respectively (H. Fuss, WDFW, personal communication); these species have the greatest likelihood of preying on wild salmonid fry due to their large size. Although some hatchery-reared smolts, particularly steelhead, are large enough to feed on wild yearling salmonids, it is less likely that they would do so because yearlings would be far less abundant than fry. Hatchery-reared steelhead might be expected to prey on the largest size-range of prey due to their larger size; at 50% of body size, coho, Chinook and steelhead smolts could consume prey up to 70, 90 and 120 mm in length, respectively (Figure 1). Hatchery-reared coho, however, are probably the most likely species to have significant effects on wild salmonid populations in WA due to the large numbers released: WDFW released approximately 32.7 million coho in 2000, compared with 10 million steelhead and 3.5 million yearling Chinook (H. Fuss, WDFW, personal communication).

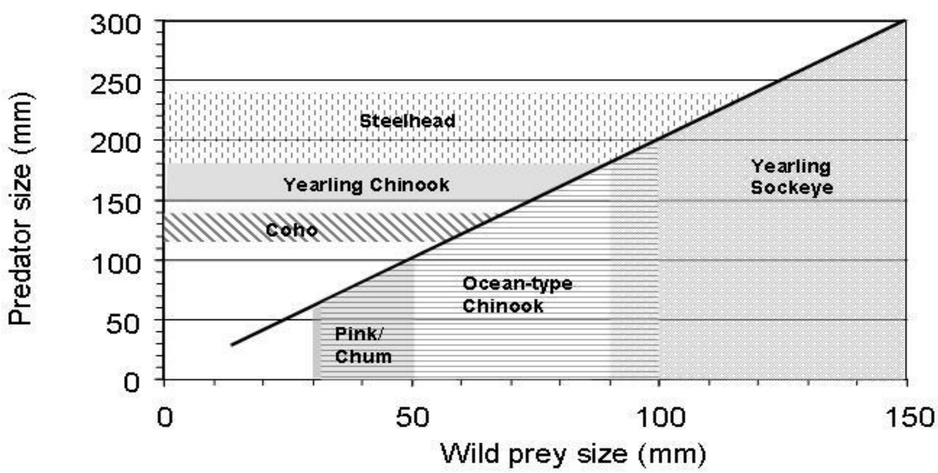

Figure 1. Relative sizes of hatchery-reared salmonid predators (at release) and their potential migratory salmonid prey in Washington, assuming that predators may consume fish up to 50% of their body size.

Spatial and Temporal Overlap of Potential Predators and Prey

Predators and prey must show significant overlap in time and space in order for predation to have an impact on prey populations. Estimation of the risk to wild salmonid populations in WA from hatchery-reared salmonid predation is complicated because both predators and prey may be migratory and the spatial and temporal overlap between predators and potential prey may vary among locations and years. The likelihood that hatchery-released juvenile salmonids will prey on wild salmonids will depend on, among other factors, the spatial and temporal distribution of wild salmonids relative to hatchery-reared predators.

Spatial Overlap

Hatchery-reared yearling coho, Chinook and steelhead are released from a number of hatcheries throughout WA. For example, yearling Chinook are released from hatcheries on 15 rivers in coastal (Sol Duc, Dungeness), Puget Sound (Skagit, Nooksack, Skykomish, Green, Deschutes), and Columbia River (Cowlitz, Kalama, Lewis, Klickitat, Tucannon, Yakima, Wenatchee, Methow) regions (H. Fuss, WDFW, personal communication). The distribution of potential wild salmonid prey within WA varies widely by species. For example, sockeye salmon populations occur in only six drainages in WA (Gustafson et al. 1997), pink salmon occur in eleven (Hard et al. 1996), while coho occur in most drainages capable of supporting salmon. An initial step that should be taken, as we suggest below, is to tabulate the distribution of hatchery-reared yearling salmonid smolts and their potential salmonid prey to identify basins where predation by hatchery-reared fish might be expected to be most important.

The previous section suggests that predation on wild salmonid fry by hatchery-reared salmon and steelhead is most likely to occur in freshwater, although the potential for predation in estuarine and nearshore environments deserves more study. Relatively little is known about the distribution and habitat use of wild and hatchery-reared salmonids in estuarine and nearshore environments, which makes it difficult to determine the potential for spatial overlap of hatchery predators and wild prey. For example, the likelihood that hatchery-reared salmonids might migrate within the nearshore environment (e.g., among estuaries) is unknown. Further research on salmonid use of nearshore and estuarine environments is necessary to determine the potential for predation of wild salmonids by hatchery-reared fish.

Temporal Overlap

Chum salmon fry emerge from the gravel between late-January and June and usually begin migrating downstream immediately after emergence (Johnson et al. 1997), although some reside in freshwater for up to one month before migrating (Simenstad et al. 1982). Peak chum migrations usually occur between March and April in WA streams (Healey 1982). In WA, juvenile migrations are usually short, ranging from just a few hours to a few days, because chum salmon generally spawn in the lower reaches of rivers. Simenstad et al. (1982) found that the average residence time per estuary was ten weeks and 24.5 days for individuals. Chum salmon juveniles spend more time rearing in estuaries than most other anadromous salmonid species.

Pink salmon have the shortest freshwater residence phase of all *Oncorhynchus* species. Most adult returns occur in odd years in WA (except for an even-year run in the Snohomish River), so juveniles are primarily present in freshwater in even years (Hard et al. 1996). Juvenile pink salmon begin migrating immediately upon emerging from the gravel (Simenstad et al. 1992). Emergence and migration typically occur between March and April in WA, but may extend into May. The duration of residence in the estuary ranges from a few days to three months, but is generally short (Healey 1982). Later emerging fry tend to move directly into salt water without pausing long in the estuary (Hurley and Woodall 1968).

During the period of emergence and migration to the nursery lake, sockeye fry are highly vulnerable to predation by other fish and birds (Gustafson et al. 1997). Fry emerge in the Cedar River, WA between January and early June, with peak emergence from early-March through mid-May (Stober and Hämäläinen 1979, 1980; Seiler and Kishimoto 1996). Most sockeye in WA smolt and migrate seaward after one year of lake residence (Gustafson et al. 1997).

Ocean-type Chinook salmon migrate seaward as subyearlings during one of three distinct phases, here referred to as immediate, fry, and fingerling migrants. The immediate phase fish migrate soon after yolk resorption (Lister et al. 1971, Healey 1991a). Most Chinook salmon migrate as fry between March and June after rearing for 60-150 days in freshwater. Fingerling migrants stay in the river until late summer of their first year (Myers et al. 1998). Juvenile fall Chinook salmon are therefore likely to be present in freshwater anytime between emergence in late-January or February through September. Ocean-type Chinook juveniles make greater use of estuaries for rearing than their spring-type counterparts, and earlier migrating smolts spend proportionately more time rearing in the estuary environment. Levings et al. (1986) reported that individual wild Chinook fry resided in the Campbell River, BC estuary for 40 to 60 days. Estuary residence times in southern BC (e.g. Campbell River estuary) may be shorter than elsewhere due to the abundant sheltered coastal habitat available in that region. Simenstad et al. (1992) found individuals residing in large WA estuaries for up to 189 days. McCabe et al. (1986) reported subyearling Chinook present in the Columbia River estuary year-round, but most numerous from May through September. Fall Chinook are present in the estuary environment throughout the spring, summer and fall (Healey 1982).

In summary, chum and Chinook salmon have the longest estuary residencies whereas pink and sockeye typically spend less time rearing in this environment (Healey 1982; Simenstad et al. 1992). Pink and chum salmon typically migrate to the estuary soon after emergence, whereas Chinook and sockeye spend a few months to a year rearing in freshwater before migration. The active rather than passive migration, nocturnal movement, and schooling behaviors of pink, sockeye and to a lesser extent chum salmon are behavioral adaptations to reduce predation risk during migration (Burgner 1991).

We have identified hatchery-reared yearling coho, fall and spring Chinook, and steelhead smolts as potential predators of wild salmonid fry, and a comparison of their release dates with the stream and estuary residencies of wild fry may identify periods when intrageneric predation could occur. In Puget Sound, hatchery-reared yearling coho smolts are released from late-April through June (Fuss and Ashbrook 1995). Yearling fall Chinook are released between March and May; yearling spring Chinook are released in April and May. Yearling summer Chinook smolts are released from late-March through early-April. Hatchery steelhead generally smolt after one year and are released from April through June. As we suggest below, determining the potential temporal overlap between hatchery-reared smolts and their potential prey in rivers where hatchery smolts are released is an important first step in determining the likelihood of predation by hatchery-reared smolts.

Predator Functional and Numerical Responses

The functional response of a predator is the relationship between the consumption rate of a predator and the abundance of prey. For example, predator consumption may be limited unless sufficient numbers of prey are available, and predators may be ‘swamped’ at high prey densities. There is relatively little information on the functional response of salmonid predators to congeneric prey, although Fresh and Schroder (1987) found that consumption of chum fry by fish predators (primarily rainbow trout and coho) leveled off at higher densities of prey, suggesting that relative predator consumption was limited at higher prey densities. Peterman and Gatto (1996), however, suggested that predators on salmonid fry were not likely to be swamped by all but the largest prey populations.

The functional response of hatchery-reared salmonids may depend on a number of factors, including prey behavior (e.g., schooling, sheltering), habitat use of predators and prey, physiological condition of predators (e.g., smolt status), habitat availability, temperature, discharge, and turbidity. For example, chum salmon do not form tight schools and typically migrate at night (Mason 1974; Salo 1991), while pink salmon fry migrate in tight schools near the water surface. This may mean that chum fry may be more widely dispersed than pinks, which may make them less vulnerable to predation by larger fishes.

The numerical response describes how predators respond in terms of numbers to prey abundance. For example, some predators have been shown to aggregate in areas where salmonid prey are abundant (Larsson 1985; Beamish et al. 1992). We are aware of no published studies that describe the migratory behavior of hatchery-reared salmonids with respect to the abundance of potential prey. For example, if hatchery-reared smolts delay migration in order to feed on wild fry in freshwater or estuarine environments, the impact of predation on wild salmon populations might be greater.

A Strategy to Estimate Risks to Wild Salmon and Steelhead Populations from Hatchery-Reared Salmonid Predation

1. Describe Spatial and Temporal Overlap of Predators and Prey

Based on WDFW and other agency stocking programs, the spatial distribution, migration timing, and size of yearling hatchery-reared salmonids should be tabulated for freshwater, estuarine, and offshore habitat. The spatial distribution, migration timing and size of potential prey in basins where hatchery predators are present should similarly be tabulated. This information will allow the identification of areas where predation on wild fry by hatchery-reared fish is likely to be important.

2. Conduct Research to Estimate Predation Rates on Wild Salmonids

Within areas identified in step 1, field research should be conducted to determine the importance of predation by hatchery-reared salmonids on wild salmonid fry in freshwater and estuarine environments. The data collected should include, but not be limited to, predation rates by hatchery fish, density and habitat use of hatchery and wild fish, residence time of wild and hatchery-reared fish in freshwater and estuarine environments, the proportion of wild fry consumed by predators, and the relative importance of predation by hatchery fish versus other predators.

Laboratory research could be combined with field work to examine questions about how predator and prey behavior and habitat use may affect predation rates, how environmental factors (temperature, flow, turbidity) may affect predation, and the functional response of predators to multiple prey types. The ultimate goal of this research would be to obtain estimates of predation rates of hatchery-reared fish on wild salmonid fry and to determine how these are likely to vary in order to develop models to estimate risk to wild salmonid populations from predation by hatchery fish.

3. Develop Models to Estimate the Risk of Predation by Hatchery-Reared Smolts.

The risk to wild salmon and steelhead populations associated with predation by hatchery-reared fish should be estimated by developing models based on data collected from specific locations where predation is determined to be likely. These models could then be applied to other areas to determine the likelihood that predation by hatchery-reared smolts effects wild salmonid populations throughout the state.

Models have previously been developed to estimate the impacts of predators on migrating salmonids (e.g., Petersen and DeAngelis 1992). Recent research indicates that the scale at which modeling is conducted may have significant effects on results, and that modeling should be undertaken at the smallest temporal and spatial scales that are relevant (Petersen and DeAngelis 2000; DeAngelis and Petersen 2001). The type of models that are to be developed should be determined before data collection begins in order to ensure that data are collected at the appropriate scale to provide relevant results.

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USING ACCLIMATION PONDS IN THE REARING OF SALMON[62]

Introduction

Acclimation ponds are frequently used in Pacific Northwest anadromous salmonid hatchery programs to redistribute adult salmon and steelhead returns. A literature review indicates that coho salmon, spring Chinook salmon and steelhead home to acclimation locations, but not fall Chinook salmon released as sub-yearlings (Slatick et al 1988; Vander Haegen and Doty 1995; Castle et al. 2002). Because returning adult fish often spawn near acclimation ponds, some conservation programs use acclimation ponds to increase spawning in under seeded areas. In harvest programs, homing to acclimation ponds can help managers by allowing returning adult fish to be removed before the fish spawn, important in the genetic management of wild fish.

Many acclimation ponds provide a more natural rearing environment, including aquatic macrophytes and dirt bottoms, and produce fish with increased post-release survivals (Tipping 1998; Tipping 2001). Acclimation ponds also allow smolt release directly at the site, which may decrease smolt travel times compared to trucked releases (Dawley et al.1977; Harza 1998; Tipping et al.1995; Tipping and Byrne 1996), and reduce the time that hatchery smolts prey on or compete with wild fish.

Homing to Acclimation Ponds

The homing ability of salmon and steelhead to natal areas has long been recognized. This ability has been shown to be heavily influenced by olfactory responses to chemical characteristics of natal waters (Brannon et al. 1984) and may also be genetically influenced (McIsaac and Quinn 1988). Imprinting appears to occur when fish undergo smoltification and emigration (Dittman et al. 1996).

The practice of outplanting smolts from hatcheries is being increasingly scrutinized due to the potential genetic damage to wild fish caused by straying of returning hatchery adults. Homing to acclimation ponds provides managers with the opportunity to remove adult hatchery fish before they spawn naturally.

Coho

Slatick et al. (1988) reported that most Columbia River coho salmon imprinted for 48 hours demonstrated a positive homing response to their point of release, be it a hatchery or upper or lower river release site. Vander Haegen and Doty (1995) analyzed the homing of coho salmon from Washington state hatcheries and found that similar rates of straying were observed for

[62] *This paper was drafted for the HSRG by Jack Tipping, Washington Department of Fish and Wildlife, July 2003.*

hatchery coho released on-station and wild coho. However, the stray rate increased for coho transported and released in-basin.

Fall Chinook

Slatick et al. (1988) found that fish released from Columbia River hatcheries generally homed back to those hatcheries. However, homing of adults to a mid-river site where juveniles had been imprinted for 9–44 days was considered poor. The majority of these fish strayed to the hatchery of origin and elsewhere. Quinn et al. (1991) reported that straying of fall Chinook in the lower Columbia River ranged from 8–19.3%. Vander Haegen and Doty (1995) reported that in-basin and out-of-basin releases resulted in more adult strays than on-station releases.

Spring Chinook

Castle et al. (2002) found that subyearling spring Chinook homed to the North Fork Nooksack River at a slightly higher rate than transported fish when acclimated to a pond on a North Fork tributary (Deadhorse Creek) (Table 1).

Table 1.Adult return distribution of spring Chinook salmon on the Nooksack River with and without use of an acclimation pond on a tributary of the North Fork Nooksack Rive (note that the hatchery is located relatively low on the North Fork).

		Recovery Location			
Year	Release strategy	North Fork	Middle Fork	Hatchery	South Fork
1996	Acclimated	61.1%	1.0%	36.3%	1.5%
	Unacclimated	54.4%	2.0%	41.1%	2.5%
1997	Acclimated	80.2%	0.0%	12.5%	7.3%
	Unacclimated	68.7%	12.1%	16.6%	2.6%
Mean	Acclimated	70.7%	0.5%	24.4%	4.4%
	Unacclimated	61.6%	7.1%	28.9%	2.6%

Steelhead

Kenaston et al. (2001) found no difference in homing rates between steelhead that were acclimated for 30 days in portable raceways and those trucked from a hatchery and directly released. They concluded that acclimation of juvenile steelhead is not necessary to achieve a high rate of homing to a release site. Slatick et al. (1988) reported that for the Columbia River, indigenous stocks of adult steelhead showed a high fidelity of return rates to the release site, but non-indigenous stocks did not. On rivers with an upstream hatchery, adult return distribution may be minimally affected by downstream smolt releases. Slaney et al. (1993) found small but significant release-site fidelity differences, but also observed substantial dispersal of lower-river-released fish to the upper river near the rearing hatchery. Tipping and Hillson (2002) found that adult return distributions from downstream smolt releases were only slightly changed for winter steelhead, while summer steelhead were unaffected.

Survival

The act of acclimating salmonids does not appear to enhance fish survival. Survival enhancements from acclimation ponds are probably due to the more natural rearing environment and/or trucking stress mollification. Kenaston et al. (2001) acclimated steelhead in portable raceways, similar to hatchery concrete raceways, and found no post-release survival enhancement over fish that were directly released into the same waters. Further, Kenaston et al. (2001) mentioned an ongoing evaluation of acclimated steelhead groups that showed no clear survival advantage. Using similar rearing raceways for acclimated and non-acclimated spring Chinook yearlings, Appleby et al. (2002) reported similar post-release survival for both groups. Acclimated subyearling spring Chinook in an asphalt bottom pond had lower survival than unacclimated fish on the Nooksack River (Castle et al. 2002).

Acclimation ponds with a more natural rearing environment have been shown to improve post-release survival of fish. Adult survival of hatchery sea-run cutthroat trout was doubled for fish reared in an acclimation-type semi-natural rearing pond versus a concrete raceway (Tipping 1998; Tipping 2001). The improved survivals may be associated with reduced rearing densities (Banks 1994; Ewing and Ewing 1995); possible cryptic coloration differences for pond-reared fish that helps them avoid predation (Donnelly and Whoriskey 1991; Maynard et al. 1996); increased exposure to natural feed that may help in post-release foraging ability (Savino et al. 1993; Maynard et al. 1996); and the acclimation process allowing trucking stress to be mollified prior to release (Specker and Schreck 1980; Schreck et al. 1989). Trucking stress was shown to reduce post-release survival in coho salmon by 20% (Johnson et al. 1990). However, for steelhead, no survival enhancement was observed for trucked smolts that were allowed to rest before release, suggesting that an acclimation pond for stress mollification would not benefit survival (Tipping 1998). In addition, steelhead and sea-run cutthroat reared in acclimation ponds have lower condition factors (measure of plumpness) than fish from raceways. This lower condition factor has been associated with improved survivals (Ewing et al. 1984; Tipping et al. 1995).

Duration of exposure to natural-type acclimation ponds appears to influence post-release survivals. Survival of sea-run cutthroat increased an average of 31% for fish placed in an acclimation pond for four to seven months prior to release, compared to fish exposed for one month prior to release (Tipping 2001). Importantly, fish exposed for even one month prior to release had 2.0 times better survival than fish reared in raceways; fish reared for four to seven months in acclimation ponds had 2.6 times better survival than fish reared in raceways.

Due to the large size and surface water source of many acclimation ponds, water temperatures within may fluctuate. Wagner (1974) found that hatchery steelhead smolts exposed to a variable temperature cycle emigrated in larger numbers than did those under constant temperature. Bjorn and Ringe (1984) reported that steelhead transferred to a pond with cold water (four to ten degrees centigrade) for two to three months prior to release had higher survivals than fish held in 15°C water until release. Wedemeyer (1982) showed that gill ATPase activity in coho salmon and steelhead could be markedly increased with a sudden temperature change. Temperature fluctuations were used to accelerate smolt development and downstream movement in yearling Chinook salmon (Muir et al. 1994). However, yearling spring Chinook that were acclimatized in the same rearing vessels from 10°C well water to four to ten degree centigrade surface water for three or six weeks prior to release had no survival enhancement (Appleby et al. 2002).

Smolt Travel Times

Although side-by-side comparison data are lacking, there is some evidence that outplanted smolts may have longer travel times compared to smolts from on-station releases. Mean travel time for ten groups of trucked steelhead smolts in one study was 2.9 km/day (Tipping and Byrne 1996), 1.6 km/day in another study (Tipping et al.1995) and 7.1 km/day in another instance (Pat Hulett, WDFW, personal communication). Meanwhile, travel times of steelhead released directly from a hatchery was 33 km/day in two studies (Dawley et al.1977; Harza 1998). Smolt emigration time is important because faster emigration reduces the time that hatchery smolts can compete and prey (Hawkins and Tipping 1999) on wild fish.

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C. Operational Guidelines

OVERVIEW

The Hatchery Scientific Review Group's Operational Guidelines are intended to describe operational practices that are most likely to meet conditions for success, as defined in the *Scientific Framework for the Artificial Propagation of Salmon and Steelhead.* They were developed primarily for use by the Hatchery Scientific Review Group (HSRG) in its regional hatchery reviews, but can also be useful in future reviews of these and other programs. The guidelines were then turned into a series of questions for each operational phase that can be asked about every hatchery program. A positive response to a question implies consistency with the conditions for success from the scientific framework. A negative response to a question identifies a potential risk to meeting the conditions for success.

Since objectives, as well as habitat and stock status, vary among hatchery programs, conditions for success may also vary among programs. No program is expected to meet all guidelines described in his document. Hatcheries are by their very nature a compromise, where risks must be balanced against benefits. For example, to meet survival objectives, some genetic or ecological risks may be acceptable. To meet objectives for proper ecological function, certain risks to fish health goals may be acceptable. The purpose of these guidelines is to assure that potential risks and benefits are clearly identified and managed.

BROODSTOCK CHOICE

Framework Section	Operational Guidelines for Choice of Broodstock		Applicability	
	QUESTIONS	GUIDELINES	Program Type (S = Segregated, I = Integrated, B = Both)	Program Purpose (C = Conservation, H = Harvest, B = Both)
3.1, 4.2, 5.1	Does the broodstock chosen represent natural populations native or adapted to the watersheds in which hatchery fish will be released?	The broodstock chosen should represent the natural populations native or adapted to the watersheds in which hatchery fish will be released.	B	B - SH
3.1, 4.2, 5.1	Have eggs or adults been introduced from outside the watershed since the inception of the hatchery program?	Program should avoid the use of stocks from outside the watershed.	B	B
5.2	Does the broodstock chosen minimize negative ecological interactions?	A broodstock should be chosen that will minimize negative ecological interactions.	S	H
4.2	Does the broodstock chosen have a history of no pathogens?	The broodstock chosen should have a history of no pathogens.	S	H
4.4.1	Does the broodstock chosen or developed have the desired life history traits to meet harvest goals?	The broodstock chosen or developed should have the desired life history traits to meet harvest goals.	S	H

BROODSTOCK COLLECTION

Framework Section	Operational Guidelines for Collection of Broodstock		Applicability	
	QUESTIONS	GUIDELINES	Program Type (S = Segregated, I = Integrated, B = Both)	Program Purpose (C = Conservation, H = Harvest, B = Both)
3.1, 4.1	Are adults randomly selected among all returning adults?	Broodstock should be selected at random from all returning adults.	B	B
3.1, 4.1	Are representative samples of donor and hatchery populations collected with respect to size, age, sex ratio, run and spawn timing, and other traits important to long-term fitness?	Representative samples of donor and hatchery populations should be collected with respect to size, age, sex ratio, run and spawn timing, and other traits important to long-term fitness.	B	B - SH
4.1, 5.1	Were sufficient numbers of donors collected from the natural stock to minimize founder effects when the program was initiated?	When initiating a hatchery program, sufficient numbers of donors should be collected from the natural stock to minimize founder effects.	B	B - SH
3.2, 4.1	Are sufficient broodstock collected to maintain an effective population size of 1000 fish per generation?	Sufficient broodstock should be collected to maintain an effective population size of 1000 fish per generation.	B	B
3.1, 4.1, 5.1	Is the composition of hatchery and wild fish in the broodstock known and controlled?	The composition of the broodstock should be monitored and controlled.	I	B
3.1, 4.1	If goal is to minimize genetic divergence, is 10 - 20% of the broodstock derived from wild fish each year?	If goal is to minimize genetic divergence, 10-20% of the broodstock should be derived from wild fish each year.	I	B
3.2	Is the necessary security of the stocks maintained?	Necessary security of the stocks should be maintained.	B	B
3.2	If the wild population has 150 fish or more, is collection of wild broodstock limited to 30% of the population?	If the wild population has 150 fish or more, limit collection of wild broodstock to 30% of the population.	I	C
3.2, 4.1	Does prespawning mortality exceed 10%?	Prespawning mortality should not exceed 10%.	B	B
3.1, 4.1, 4.2.4	Does the program avoid stock transfers and subsequent releases of eggs or fish from outside the watershed?	Program should avoid stock transfers and subsequent releases of eggs or fish from outside the watershed.	B	B
3.1, 4.1, 5.1	Do you have guidelines for acceptable contribution of hatchery origin fish to natural spawning?	Hatchery programs should adopt explicit guidelines for acceptable contribution of hatchery fish to all potentially affected natural spawning populations.	B	B
3.1, 4.1, 5.1	Is the proportion of naturally spawning fish that are of hatchery origin known?	The annual contribution of hatchery fish to natural spawing should be directly or indirectly estimated.		
3.1, 4.1, 5.1	Are guidelines for hatchery contribution to to natural spawning met for all affected naturally spawning populations?	Guidelines for hatchery contribution to to natural spawning should be met.	B	B

Framework Section	Operational Guidelines for Collection of Broodstock (Cont'd.)		Applicability	
	QUESTIONS	**GUIDELINES**	**Program Type** (S = Segregated, I = Integrated, B = Both)	**Program Purpose** (C = Conservation, H = Harvest, B = Both)
3.1, 4.1	Is the duration of the program clearly defined?	The duration of the program should be clearly defined.	I	C
4.2	Is the broodstock maintained on natural water temperature profiles to provide optimum maturation and gamete development?	The broodstock should be maintained on natural water temperature profiles to provide optimum maturation and gamete development.	B	B - SH
2.1, 2.1, 5.2	Does the number of broodstock collected maintain program size within carrying capacity of the natural environment?	The number of broodstock collected should maintain program size within carrying capacity of the natural environment.	B	B
2.3, 5.2	Are adult fish or carcasses provided for upstream planting?	Consideration should be given to provide adult fish or carcasses for upstream planting.	B	B
4.2.4	If broodstock choice is from another drainage, are eggs preferentially transferred? Are fish or eggs held in quarantine as described in the Salmonid Disease Control Policy of the Fisheries Co-Managers of Washington State (disease control policy).	If broodstock choice is from another drainage, are eggs should be preferentially transferred. Fish or eggs should be held in quarantine as described in the Salmonid Disease Control Policy of the Fisheries Co-Managers of Washington State (disease control policy).	B	B
4.2.4	Are broodstock maintained on pathogen-free and/or fish-free water supply?	Broodstock should be maintained on pathogen-free and/or fish-free water supply.	B	B
4.2.4	Does attending fish pathologist monitor and recommend treatments to maximize survival as needed?	Attending fish pathologist should monitor and recommend treatments to maximize survival as needed.	B	B
5.2	Are pre-spawning mortalities disposed of in a manner that prevents pathogen transmission to the receiving watershed?	Pre-spawning mortalities should be disposed of in a manner that prevents pathogen transmission to the receiving watershed.	B	B

SPAWNING

Framework Section	Operational Guidelines for Spawning		Applicability	
	QUESTIONS	GUIDELINES	**Program Type** (S = Segregated, I = Integrated, B = Both)	**Program Purpose** (C = Conservation, H = Harvest, B = Both)
3.1, 4.1	Are males and females available for spawning on a given day randomly mated?	Males and females available for spawning on a given day should be randomly mated.	B	B - SH
3.1, 3.2, 4.1	Do fish selected for broodstock have an equal opportunity to make a genetic contribution to the progeny gene pool?	Fish selected for broodstock should have an equal opportunity to make a genetic contribution to the progeny gene pool.	B	B - SH
4.2.4	Is pathogen sampling at spawning sufficient to provide quantitative and qualitative information for needed pathogen control measures that may be necessary for resultant transfers or rearing of progeny?	Pathogen sampling at spawning sould be sufficient to provide quantitative and qualitative information for needed pathogen control measures that may be necessary for resultant transfers or rearing of progeny.	B	B
4.2.4	Are eggs water-hardened in iodophor solution as described in the disease control policy?	Eggs should be water-hardened in iodophor solution as described in the disease control policy.	B	B
4.2.4	Are disinfection procedures implemented that prevent pathogen transmission between stocks of fish on site?	Disinfection procedures should be implemented that prevent pathogen transmission between stocks of fish on site.	B	B
5.2	Is spawning waste collected and disinfected prior to discharge to receiving water?	Spawning waste should be collected and disinfected prior to discharge to receiving water.	B	B
5.2	Are carcasses disposed of in a manner that prevents pathogen transmission to the receiving watershed?	Carcasses should be disposed of in a manner that prevents pathogen transmission to the receiving watershed.	B	B

INCUBATION

Framework Section	Operational Guidelines for Incubation		Applicability	
	QUESTIONS	GUIDELINES	Program Type (S = Segregated, I = Integrated, B = Both)	Program Purpose (C = Conservation, H = Harvest, B = Both)
3.1, 3.2, 4.1	Are eggs incubated under conditions that maximize the probability that all segments of the population contribute equally to the release population?	Eggs should be incubated under conditions that maximize the probability that all segments of the population contribute equally to the release population.	I	B
3.1, 3.2, 4.1	Are eggs incubated under environmental conditions that tend to maximize survival of all segments of the population? (e.g. control temperature of incubation water to synchronize ponding of fry)	Eggs should be incubated under environmental conditions that tend to maximize survival of all segments of the population. (e.g. control temperature of incubation water to synchronize ponding of fry)	I	B
3.1, 3.2, 4.1, 4.2	Are eggs incubated under environmental conditions that tend to maximize individual fitness of fry? (e.g. allow volitional ponding of fry, incubate under environmental conditions that simulate the natural rearing environment)	Eggs should be incubated under environmental conditions that tend to maximize individual fitness of fry. (e.g. allow volitional ponding of fry, incubate under environmental conditions that simulate the natural rearing environment)	B	B
3.1, 3.2, 4.1	Does incubation take place in home stream water?	Incubation should be take place in home stream water.	I	C
3.2, 4.1	Are full sib families incubated separately?	For integrated programs, full sib families should be incubated separately.	I	C
4.2, 5.2	Does the program use water sources that result in hatching/emergence timing similar to that of the naturally produced population?	Program should use water sources that result in hatching/emergence timing similar to that of the naturally produced population.	I	B
2.1, 2.2, 5.2	Does the number of eggs incubated maintain program size within the carrying capacity of the natural environment?	The number of eggs incubated should maintain program size within the carrying capacity of the natural environment.	B	B
4.2.4	Does incubation occur on pathogen-free and/or fish-free water supply?	Incubation should occur on pathogen-free and/or fish-free water supply.	B	B
4.2.4	Are species-specific incubation recommendations followed for water quality, flows, temperature, substrate, and density parameters to prevent syndromes such as “gas bubble disease”, “cold water disease”, “blue sac”, etc.)?	Species-specific incubation recommendations should be followed for water quality, flows, temperature, substrate, and density parameters to prevent syndromes such as “gas bubble disease”, “cold water disease”, “blue sac”, etc.).	B	B

Framework Section	Operational Guidelines for Incubation (Cont'd.)		Applicability	
	QUESTIONS	**GUIDELINES**	**Program Type** (S = Segregated, I = Integrated, B = Both)	**Program Purpose** (C = Conservation, H = Harvest, B = Both)
4.2.4	Are incubating eggs treated when recommended by attending fish pathologist?	Incubating eggs should be treated when recommended by attending fish pathologist.	B	B
4.2.4	Following eye-up stage, are eggs inventoried, and dead or undeveloped eggs removed and disinfected, as described in the disease control policy?	Following eye-up stage, eggs should be inventoried, and dead or undeveloped eggs removed and disinfected, as described in the disease control policy.	B	B
4.2.4	Are disinfection procedures implemented that prevent pathogen transmission between stocks of fish on site?	Disinfection procedures should be implemented that prevent pathogen transmission between stocks of fish on site.	B	B
4.2.4	Are eggs monitored when needed to determine fertilization efficiency and embryonic development?	Eggs should be monitored when needed to determine fertilization efficiency and embryonic development.	B	B
4.2.4	Are fry removed from incubation units when 80-90% of observed fry have yolk-sac material that is 80-90% utilized and contained within body cavity ("button-up")	Fry should be removed from incubation units when 80-90% of observed fry have yolk-sac material that is 80-90% utilized and contained within body cavity ("button-up").	B	H
4.2.4	Are appropriate water temperature profiles maintained to provide optimum embryo development?	Appropriate water temperature profiles should be maintained to provide optimum embryo development.	B	B
4.2.4	Are incubator loading and densities maintained at levels that ensure optimum survival of eggs and fry?	Incubator loading and densities should be maintained at levels that ensure optimum survival of eggs and fry.	B	B
4.2, 4.2.4	Is substrate used to promote suitable fry distribution, optimum size, and appropriate emergence timing?	Substrate should be used to promote suitable fry distribution, optimum size, and appropriate emergence timing.	B	B
5.2	Are eggs (dead or culled) discarded in a manner that prevents pathogen transmission to the receiving watershed?	Eggs (dead or culled) should be discarded in a manner that prevents pathogen transmission to the receiving watershed.	B	B

REARING

Framework Section	Operational Guidelines for Rearing		Applicability	
	QUESTIONS	GUIDELINES	**Program Type** (S = Segregated, I = Integrated, B = Both)	**Program Purpose** (C = Conservation, H = Harvest, B = Both)
3.1, 3.2, 4.1	Are fish reared under conditions that maximize the probability that all segments of the population contribute equally to the release population?	Fish should be reared under conditions that maximize the probability that all segments of the population contribute equally to the release population.	I	B
3.1, 3.2, 4.1	Are all fish reared under environmental conditions that tend to maximize survival of all segments of the population?	All fish should be reared under environmental conditions that tend to maximize survival of all segments of the population.	B	*B - SH*
3.1, 4.1	Are families within spawning groups mixed randomly at ponding so that unintentional rearing differences affect families equally?	Families within spawning groups should be mixed randomly at ponding so that unintentional rearing differences affect families equally.	I	B
3.1, 3.2, 4.1	Are excess juveniles culled randomly when necessary?	Excess juveniles should be culled randomly when necessary.	B	*B - SH*
3.1, 3.2, 4.1	Are fish reared in multiple facilities or with redundant systems to reduce the risk of catastrophic loss?	Fish should be reared in multiple facilities or with redundant systems to reduce the risk of catastrophic loss.	B	C
3.1, 4.1	Are fish reared for the shortest period possible?	Fish should be reared for the shortest period possible.	I	C
3.1, 3.2, 4.1	For captive broodstocks, are fish maintained on natural photoperiod to ensure normal maturation and water temperatures below 12^0C to minimize disease?	For captive broodstocks, fish should be maintained on natural photoperiod to ensure normal maturation and water temperatures below 12^0C to minimize disease.	S	C
3.1, 3.2, 4.1	For captive broodstocks, are diets and growth regimes selected that produce potent, fertile gametes and reduce excessive early maturation of fish?	For captive broodstocks, diets and growth regimes should be selected that produce potent, fertile gametes and reduce excessive early maturation of fish.	S	C
3.2, 4.1	Are families reared individually to maintain pedigrees?	Families should be reared individually to maintain pedigrees.	B	C
3.2, 4.1	If required, are larger families culled to minimize family size variation?	If required, larger families should be culled to minimize family size variation.	I	B
2.3, 3.1, 4.1, 5.1, 5.2	Are fish reared under conditions that maximize homing fidelity?	Fish should be reared under conditions that maximize homing fidelity.	B	*B - SC*
4.2, 5.2	Does the program use a diet and growth regime that mimics natural growth patterns?	Program should use a diet and growth regime that mimics natural growth patterns.	B	*B - SH*

Framework Section	Operational Guidelines for Rearing (Cont'd.)		Applicability	
	QUESTIONS	GUIDELINES	**Program Type** (S = Segregated, I = Integrated, B = Both)	**Program Purpose** (C = Conservation, H = Harvest, B = Both)
4.2, 5.2	Are natural rearing conditions simulated for rearing density, temperature, photoperiod, hydraulic characteristics, feeding conditions, and predator avoidance training?	Natural rearing conditions should be simulated for rearing density, temperature, photoperiod, hydraulic characteristics, feeding conditions, and predator avoidance training.	I	B
4.2, 5.2	Are the fish produced qualitatively similar to natural fish in size, morphology, behavior, growth rate, physiological status, health, and other attributes?	Fish produced should be qualitatively similar to natural fish in size, morphology, behavior, growth rate, physiological status, health, and other attributes.	I	B
2.1, 2.2, 5.2	Does the number of fish reared maintain program size within carrying capacity of the natural environment?	The number of fish reared should maintain program size within carrying capacity of the natural environment.	B	B
2.4	Are adequate flows maintained in the by-pass reach?	Adequate flows should be maintained in the by-pass reach.	B	B
2.4	Has a riparian management plan been implemented that incorporates vegetation management, herbicide and pesticide use, and surface water management provisions?	A riparian management plan been should be implemented that incorporates vegetation management, herbicide and pesticide use, and surface water management provisions.	B	B
2.3, 2.4	Does the facility operate within the limitations established in National Pollution Discharge Elimination System permit?	The facility should operate within the limitations established in National Pollution Discharge Elimination System permit.	B	B
2.4	Has an on or off-site habitat mitigation plan been implemented?	An on or off-site habitat mitigation plan should be implemented.	B	B
4.2.4	Does rearing occur on pathogen-free and/or fish free water supply?	Rearing should occur on pathogen-free and/or fish free water supply.	B	B
4.2.4	Are fish health examinations performed at a minimum of once per month and more frequently when required?	Fish health examinations should be performed at a minimum of once per month and more frequently when required.	B	B
4.2.4	Whenever possible, are vaccines used to minimize the use of antimicrobial compounds?	Whenever possible, vaccines should be used to minimize the use of antimicrobial compounds.	B	B
4.2.4	Are fish treated with appropriate chemicals or drugs as recommended by fish pathologist?	Fish should be treated with appropriate chemicals or drugs as recommended by fish pathologist.	B	B
4.2.4	Are disinfection procedures implemented that prevent pathogen transmission between stocks of fish on site?	Disinfection procedures should be implemented that prevent pathogen transmission between stocks of fish on site.	B	B

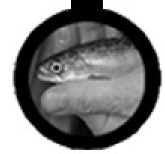
Framework Section	Operational Guidelines for Rearing (Cont'd.)		Applicability	
	QUESTIONS	GUIDELINES	Program Type (S = Segregated, I = Integrated, B = Both)	Program Purpose (C = Conservation, H = Harvest, B = Both)
4.2.4	Are predators excluded from ponds to prevent the spread of pathogens between containers?	Predators should be excluded from ponds to prevent the spread of pathogens between containers.	S	B
4.2.4	In the event of an epizootic, are: Treatment recommendations of attending pathologist followed? Are affected containers isolated? Is effluent sanitized if possible?	In the event of an epizootic: Treatment recommendations of attending pathologist should be followed. Affected containers should be isolated? Effluent should be sanitized if possible.	B	B
2.4, 4.2.4	Are settleable solids, unused feed and feces periodically removed to ensure proper cleanliness of rearing container?	Settleable solids, unused feed and feces should be periodically removed to ensure proper cleanliness of rearing container.	B	B
4.2	Does the operator follow proper feeding rates, conduct periodic feed quality analysis, and store feed under proper conditions to prevent nutritional disorders?	The operator should follow proper feeding rates, conduct periodic feed quality analysis, and store feed under proper conditions to prevent nutritional disorders.	B	B
4.2	Are appropriate physical and chemical characteristics of water inflow and effluent (suspended solids, temperature, dissolved gases, pH, mineral content, and potential toxic metals) maintained to promote growth and survival?	Appropriate physical and chemical characteristics of water inflow and effluent (suspended solids, temperature, dissolved gases, pH, mineral content, and potential toxic metals) should be maintained to promote growth and survival.	B	B
4.2	Are accurate fish inventory data maintained (e.g. Hat-Pro) with a minimum of handling stress?	Accurate fish inventory data should be maintained (e.g. Hat-Pro) with a minimum of handling stress.	B	B
4.2	Are appropriate flow and density indexes maintained for the species and life stage being reared?	Appropriate flow and density indexes should be maintained for the species and life stage being reared.	B	B
4.2	Is the correct amount and type of food provided to achieve the desired growth rate, body composition, and condition factors for the species and life stage being reared?	The correct amount and type of food should be provided to achieve the desired growth rate, body composition, and condition factors for the species and life stage being reared.	B	B
4.2.5, 5.2	Are mortalities removed daily and disposed of in a manner that prevents pathogen transmission to the receiving watershed?	Mortalities should be removed daily and disposed of in a manner that prevents pathogen transmission to the receiving watershed.	B	B
4.4.1	Are facility and species-specific recommendations for water quality, temperature, loading, and density followed to maximize recruitment to fisheries?	Facility and species-specific recommendations for water quality, temperature, loading, and density should be followed to maximize recruitment to fisheries.	S	H

RELEASE AND ADULT MIGRATION

Framework Section	Operational Guidelines for Release and Adult Migration: QUESTIONS	Operational Guidelines for Release and Adult Migration: GUIDELINES	Applicability: Program Type (S = Segregated, I = Integrated, B = Both)	Applicability: Program Purpose (C = Conservation, H = Harvest, B = Both)
2.3, 3.1, 4.1, 5.1, 5.2	Are fish released at life stages and locations that maximize homing fidelity?	Fish should be released at life stages and locations that maximize homing fidelity.	B	*B - SC*
3.1, 4.1, 5.1	Are marking/tagging techniques used to distinguish among segments of the hatchery population and between the hatchery and natural populations?	Marking/tagging techniques should be used to distinguish among segments of the hatchery population and between the hatchery and natural populations.	B	B
4.1, 5.1	Are fish identified with nonlethal detectable identification marks or tags?	Fish should be identified with nonlethal detectable identification marks or tags.	I	C
2.3, 3.1, 4.1, 5.1, 5.2	Is the straying of hatchery fish into the wild controlled?	Straying of hatchery fish into the wild should be controlled.	B	H
2.3, 3.1, 5.1, 5.2	Is the attraction of hatchery fish maximized and that of wild fish minimized?	The attraction of hatchery fish should be maximized and that of wild fish minimized.	S	H
3.2, 5.3	Are hatchery fish identified so the status of the natural population is not masked?	Hatchery fish should be identified so the status of the natural population is not masked.	B	*B - SC*
4.2, 5.2	Are fish released within the size range of naturally produced fish from which the hatchery population is derived?	Fish should be released within the size range of naturally produced fish from which the hatchery population is derived.	I	B
3.1, 4.1, 4.2, 5.2	Are volitional releases during natural out-migration timing practiced?	Volitional releases during natural out-migration timing should be practiced.	I	B
4.2, 5.2	Are fish released at sizes and life history stages similar to those of natural fish of the same species?	Fish should be released at sizes and life history stages similar to those of natural fish of the same species.	I	B
2.3, 5.2	Are fish released in areas or at life history stages where they are unlikely to encounter or prey upon natural fish of the same or other species?	Fish should be released in areas or at life history stages where they are unlikely to encounter or prey upon natural fish of the same or other species.	B	*B - SC*
2.3, 5.2	Are fish released in a manner so they are unlikely to encounter or prey upon natural fish of the same or other species?	Fish should be released in a manner so they are unlikely to encounter or prey upon natural fish of the same or other species.	B	*B - SC*
2.1, 2.2, 2.3, 5.2	Are fish released in numbers that do not exceed the carrying capacity for the natural population?	Fish should be released in numbers that do not exceed the carrying capacity for the natural population.	B	*B - SC*

Framework Section	Operational Guidelines for Release and Adult Migration (Cont'd.)		Applicability	
	QUESTIONS	GUIDELINES	Program Type (S = Segregated, I = Integrated, B = Both)	Program Purpose (C = Conservation, H = Harvest, B = Both)
2.3, 5.2	Are fish released in stream reaches within the historic range of that species?	Fish should be released in stream reaches within the historic range of that species.	B	*B - SC*
3.1, 4.2, 5.2	Are fish released in a manner that simulates natural migratory patterns?	Fish should be released in a manner that simulates natural migratory patterns.	B	*B - SC*
2.3, 3.1, 4.1, 5.1, 5.2	Are fish released in areas with adequate imprinting to the facility or desired stream reach?	Fish should be released in areas with adequate imprinting to the facility or desired stream reach.	B	*B - SC*
2.3, 5.2	Are fish released at locations where they are unlikely to encounter natural fish that are negatively affected by hatchery fish?	Fish should be released at locations where they are unlikely to encounter natural fish that are negatively affected by hatchery fish	B	*B - SC*
2.1, 5.2	Are fish released into properly functioning freshwater, estuarine and marine habitat?	Fish should be released into properly functioning freshwater, estuarine and marine habitat.	B	*B - SC*
2.4	Does the hatchery operate to allow all migrating species of all ages to pass through hatchery related structures to maximize use of natural habitat?	The hatchery should operate to allow all migrating species of all ages to pass through hatchery related structures to maximize use of natural habitat.	B	*B - SC*
2.4	Are adults distributed upstream of hatchery to meet habitat capacity?	Adults should be distributed upstream of hatchery to meet habitat capacity.	I	B
2.4	Is unimpeded passage provided for wild fish through hatchery structures and by-pass reaches?	Unimpeded passage should be provided for wild fish through hatchery structures and by-pass reaches.	B	*B - SC*
4.2.4	Are all fish examined for presence of “reportable pathogens” as defined in the disease control policy at the assumed pathogen prevalence Level (APPL) of 5% no less than 3 weeks prior to release?	All fish should be examined for presence of “reportable pathogens” as defined in the disease control policy at the assumed pathogen prevalence Level (APPL) of 5% no less than 3 weeks prior to release.	B	*B - SC*
4.2.4	Are attending fish pathologist recommendations followed for treatments prior to release?	Attending fish pathologist recommendations should be followed for treatments prior to release.	B	*B - SC*
4.2.4	Are fish released in same drainage as rearing facility?	Fish should be released in same drainage as rearing facility.	B	*B - SC*

Framework Section	Operational Guidelines for Release and Adult Migration (Cont'd.)		Applicability	
	QUESTIONS	GUIDELINES	**Program Type** (S = Segregated, I = Integrated, B = Both)	**Program Purpose** (C = Conservation, H = Harvest, B = Both)
4.2.4	Are transfers out of drainage inspected as above and accompanied by appropriate notifications to responsible/regulatory parties as described in the disease control policy?	Transfers out of drainage should be inspected as above and accompanied by appropriate notifications to responsible/regulatory parties as described in the disease control policy.	B	B
2.1, 3.1, 4.1	Are fish released at times of the year and sizes to allow adoption of multiple life history strategies?	Fish should be released at times of the year and sizes to allow adoption of multiple life history strategies.	B	*B - SC*
4.4.1	Are fish released at a time, size, location, and in a manner that maximizes recruitment to fisheries?	Fish should be released at a time, size, location, and in a manner that maximizes recruitment to fisheries.	S	H



ACCOUNTABILITY

Framework Section	Operational Guidelines for Accountability		Applicability	
	QUESTIONS	GUIDELINES	**Program Type** (S = Segregated, I = Integrated, B = Both)	**Program Purpose** (C = Conservation, H = Harvest, B = Both)
6.1	Are all hatchery personnel aware of the goals for the hatchery with respect to conservation, harvest and other purposes?	All hatchery personnel should be aware of the goals for the hatchery with respect to conservation, harvest and other purposes	B	B
6.1	Are expenditures tracked to assure that funds are expended as intended for the hatchery program?	Expenditures should be tracked to assure that funds are expended as intended for the hatchery program.	B	B
6.1	Are KEY staff aware of the funding available for carrying out the various activities in the production cycle so that it can be done the most cost effective manner?	Key staff should be aware of the funding available for carrying out the various activities in the production cycle so that it can be done the most cost effective manner.	B	B
6.1	Is all new relevant information from research or other sources made available to hatchery staff and others and used for attaining goals?	All new relevant information from research or other sources should be made available to hatchery staff and others and used for attaining goals.	B	B
6.1	Is the most recent information obtained from monitoring and evaluation programs for the production cycle, including performance indicators and progress toward goals, taken into consideration when determining whether hatchery operations should be changed or not?	The most recent information obtained from monitoring and evaluation programs for the production cycle, including performance indicators and progress toward goals, should be taken into consideration when determining whether hatchery operations should be changed or not.	B	B
6.1	Is there a management program in place that assures that information pertaining to items 1-4 is available on a "real-time" basis and that changes warranted by that information are implemented?	There should be a management program in place that assures that information pertaining to items 1-4 is available on a "real-time" basis and that changes warranted by that information are implemented.	B	B
6.1	Are standards specified for in-culture and post release performance of hatchery fish and their offspring?	Standards should be specified for in-culture and post release performance of hatchery fish and their offspring.	B	B
6.1	Are there state or federal laws that constrain the program by specifying objectives, such as numbers and size of smolt produced?	State or federal laws that constrain the program by specifying objectives, such as numbers and size of smolt produced, should be reviewed and conflicts reported.	B	B

EDUCATION

Framework Section	Operational Guidelines for Education		Applicability	
	QUESTIONS	GUIDELINES	Program Type (S = Segregated, I = Integrated, B = Both)	Program Purpose (C = Conservation, H = Harvest, B = Both)
1.13	Is the hatchery facility open to the public during hours of operation?	The hatchery facility should be open to the public during hours of operation.	B	B
1.13	Are the hatchery operations visible to facility visitors?	Hatchery operations should be visible to facility visitors.	B	B
1.13	Are hatchery operations (egg take, incubation, rearing) demonstrated to the public?	Hatchery operations (egg take, incubation, rearing) should be demonstrated to the public.	B	B
1.13	Does the facility have a fish ladder and/or adult holding facilities that are open to the public?	If the facility has a fish ladder and/or adult holding facilities they should be are open to the public.	B	B
1.13	Does the hatchery have signage describing the facility, fish production goals, ties to management goals, ecosystem function?	The hatchery should have signage describing the facility, fish production goals, ties to management goals, ecosystem function.	B	B
1.13	Is there a visible link to riparian zone such as viewing boardwalk or bridge?	There should be a visible link to riparian zone such as viewing boardwalk or bridge.	B	B
1.13	Is the facility used by other fish and wildlife programs?	When beneficial, the facility should be used by other fish and wildlife programs.	B	B
1.13	Does the hatchery schedule tours for groups?	The hatchery should schedule tours for groups.	B	B
1.13	Does the program provide opportunities for student interns?	The program should provide opportunities for student interns.	B	B
1.13	Does the program provide opportunities for citizen volunteer involvement?	The program should provide opportunities for citizen volunteer involvement.	B	B
1.13	Does the agency maintain a web page describing the hatchery program?	The agency should maintain a web page describing the hatchery program.	B	B
1.13	Is a pamphlet or brochure describing agency or hatchery programs available?	A pamphlet or brochure describing agency or hatchery programs should be available.	B	B

Framework Section	Operational Guidelines for Education (Cont'd.)		Applicability	
	QUESTIONS	GUIDELINES	Program Type (S = Segregated, I = Integrated, B = Both)	Program Purpose (C = Conservation, H = Harvest, B = Both)
1.13	Are eggs or fish provided to volunteer groups?	Are eggs or fish provided to volunteer groups?	B	B
1.13	Are eggs or fish provided to educational groups i.e. "Salmon in the Classroom"?	Are eggs or fish provided to educational groups i.e. "Salmon in the Classroom"?	B	H
1.13	Is hatchery staff involved in community/volunteer meetings or outreach programs?	Hatchery staff should be involved in community/volunteer meetings or outreach programs.	B	B
1.13	Does hatchery staff regularly give classroom presentations?	Does hatchery staff regularly give classroom presentations?	B	B
1.13	Does hatchery staff participate in formal professional presentations/seminars?	Hatchery staff should participate in formal professional presentations/seminars.	B	B
1.13	Is the facility used or does staff participate in agency research projects?	Where appropriate and benficial, the facility should be used and staff should participate in agency research projects.	B	B
1.13	Is the facility used or does staff participate in university or other cooperative research projects?	Is the facility used or does staff participate in university or other cooperative research projects?	B	B
1.13	Are data and information pertaining to the program accessible to interested researchers?	Data and information pertaining to the program should be accessible to interested researchers.	B	B

D. Monitoring and Evaluation Criteria

INTRODUCTION

Accountability and adaptive management are two of the cornerstones of hatchery reform. They require collecting and using information that tell us (1) if hatchery programs are successfully contributing to resource goals and (2) if they are not how they should change. A conceptual outline of a monitoring and evaluation strategy to achieve accountability and support adaptive management is contained in Chapter 6 of the Scientific Framework (Appendix A). The purpose of this Appendix is to show how a monitoring plan can be developed that generates the information needed to assess the performance of a hatchery program relative to its goals. The co-managers and the HSRG are currently engaged in an effort to develop a comprehensive, operational monitoring and evaluation plan, therefore this Appendix should be viewed as a preliminary report on a work in progress.

This appendix first identifies and describes the conditions for success based on the concepts in the Scientific Framework. A set of evaluation questions, derived from the operational guidelines (Appendix C), are then identified that relate hatchery operations to the conditions for success. The monitoring criteria that follow identify the data that must be collected to answer the evaluation questions. The answers to the evaluation questions tell us to what extent a hatchery program is meeting specific conditions for success. In other words, the conditions for success represent the scientific rationale for the program: if the program is conducted consistent with the specified guidelines it will be successful (i.e. contribute to resource goals as intended), when guidelines are not met, resource goals may be at risk.

SUMMARY OF CONDITIONS FOR SUCCESS

The following conditions for success are derived from the concepts decribed in the Scientific Framework.

a) Genetic Conditions

The productivity of a hatchery population is determined jointly by the environment and by genetic conditions in both the hatchery population and any naturally spawning populations connected to it. Genetic conditions affect not only productivity; they also determine adaptability to environmental change, and include genetic composition, genetic diversity, and genetic population structure.

b) Biological Conditions

The survival and reproductive success of juvenile hatchery fish depends upon their physiological, morphological, behavioral, and health characteristics at the time of their release. The success is also shaped by their genetic makeup and the environmental conditions they are exposed to in the hatchery. One template for achieving healthy/viable hatchery populations is the biological characteristics of local, wild fish populations. Therefore, in order to achieve productivity similar to wild fish, the hatchery environment should produce fish that reflect the natural life history patterns of locally adapted stocks in: physiology, morphology, and behavior.

c) Fish Health

Fish health, in the fish hatchery context, is a term used when considering the well-being of fish populations in hatcheries. The term does not indicate whether the fish are diseased or free of disease, be it of infectious or non-infectious cause. Health of the fish is important to the productivity and success of the hatchery for a number of reasons. First, losses experienced during rearing of healthy fish are usually much less than those for diseased fish. Second, the cost of trying to correct disease problems in hatcheries can be considerable. Third, rearing healthy fish obviates the need for using anti-microbial compounds. Some of these (e.g., formalin), may be harmful to hatchery personnel if not used strictly according to directions. Others (e.g., antibiotics) can result in the selection/production of antibiotic-resistant fish pathogens (Dixon 1994) and enhance levels of the resistant forms present in the environment (Herwig et al. 1997). Finally, healthy fish are more likely to survive following release from the hatchery than are sick fish.

d) Hatchery and Receiving Environment

The health and viability of hatchery populations are affected by the environment in which the fish are reared and are dependent upon the culture techniques these fish experience. Each hatchery has a unique combination of water sources, rearing facilities, and release parameters. The viability of hatchery populations is also affected by the receiving habitat or environment into which fish are released. Providing proper hatchery and environmental conditions optimizes potential fish production.

e) Hatchery Structures

The physical structures of hatcheries are located in riparian areas. Some hatchery structures have severe adverse effects on wild fish populations by creating obstacles to migration, changes in instream flows, and loss of water quality. Hatchery structures may affect wild fish and the environment in various ways: downstream fish passage (i.e., water intake screens), upstream fish passage, volitional entry into hatchery, water discharge quality, riparian alterations, and human harassment.

f) Ecological Effects

After their release, hatchery fish become components of the ecosystem, affecting it in various ways. While many of these effects are difficult to predict, it is important to evaluate some of these consequences and consider them in the course of planning and evaluating hatchery programs. Released hatchery salmonids can interact with their wild cohorts to reduce survival, growth, migration, and reproduction. Ecological interactions caused by the release of hatchery-reared juveniles include: predation, competition, disease transmission, and ecological function.

g) Genetic Interactions

Hatchery populations directly affect the genetic composition of natural populations through gene flow, the transfer of genes from hatchery populations into naturally spawning populations. Gene flow is influenced by the straying or stocking rate of hatchery populations into natural populations, as well as by the reproductive success of the hatchery fish. The effects of this gene flow are unpredictable and depend on the genetic composition of the hatchery population. Factors affecting genetic interactions include: change of diversity among populations, change of diversity within populations, decrease in fitness of a population, and changes in abundance. Hatchery releases may also have positive demographic effects on natural populations.

h) Contribution to Conservation

Conservation hatcheries can play a vital part in the recovery of threatened and endangered species by maintaining their genetic diversity and natural behavior, and by reducing the short-term risk of extinction. Under proper conditions, conservation hatcheries can maintain severely depleted natural stocks in captive culture in gene banks to avoid extinction. Hatcheries have the capability to maintain large breeding populations of wild stocks to minimize the risk of demographic loss from unpredictable environmental events. Hatcheries, when operating in the conservation mode, can supplement under-recruited wild populations that are below their natural carrying capacity. Finally, in cases where wild stocks have been extirpated, conservation hatcheries have the capability to introduce and maintain naturally spawning stocks until they are self-sustaining. The conservation hatchery concept implies that following the recovery of target populations and receiving habitat, these programs will be terminated. In order to be effective, conservation hatchery programs must be integrated with habitat and harvest management programs that provide for rebuilding of self-sustaining, naturally spawning populations.

i) Contribution to Harvest

The range of harvest issues and integration of harvest with artificial production are very complex. They are best addressed under comprehensive management plans developed by the fisheries co-managers. This section of the framework is meant to identify the general harvest conditions necessary for hatcheries to be successful, rather than to prescribe specific harvest management policies or solutions, which while important, is beyond the scope of the HSRG's assignment. One of the principal goals for hatcheries is to provide for sustainable harvest in subsistence, recreational, ceremonial, and commercial fisheries. In order to meet this goal, harvest methods and policies, as well as the repositioning of hatchery programs must be taken into consideration. Fisheries must have access to harvestable hatchery fish without significant adverse impacts to fish stocks of concern. Harvest access implies that hatcheries and harvest operations must be coordinated. They must also provide for: opportunity to meet harvest goals, protection of hatchery spawning requirements, and protection of co-mingled stocks of concern.

EVALUATION QUESTIONS

Like the operational guidelines (Appendix C), the evaluation questions that follow are organized by operational phases of a hatchery program. The relative importance of the questions and monitoring criteria depends on the context (in terms of habitat and stock status), the goals (for conservation and harvest), and uncertainties associated with each program. Thus the order of the questions and the associated monitoring criteria do not reflect their priority order.

BROODSTOCK CHOICE

a) Genetic Conditions

Evaluation questions applicable to both **integrated** and **segregated** programs and to both **conservation** and **harvest** programs

- What is the origin of the broodstock (SASI stock, GDU membership; include both major and minor sources)?
- What is the stock-specific replacement rate (R/S)?
- (Estimate recruitment in adult equivalents by brood year.)
- Do the morphological, behavioral & physiological traits of the adults returning to the hatchery match those of the local stock?
- What are the history of translocations to other facilities and the history of outplantings within and out of the watershed?
- What is the genetic relationship of the extirpated stock to the donor stock?
- Are the life history patterns of the extirpated stock similar to those of the donor stock? Are the freshwater and marine environments of the donor and receiving watersheds similar?

Evaluation questions applicable to **integrated** programs and to both **conservation** and **harvest** programs

- Are allele frequencies being monitored for changes between broodstock and progenitor wild populations?
- What are the morphological, behavioral & physiological traits of local stocks?

c) Fish Health

Evaluation questions applicable to both **integrated** and **segregated** programs and to both **conservation** and **harvest** programs

- What is the disease history of the broodstock over the last decade?
- What are the most serious pathogens in terms of pre-spawning mortality?

e) Ecological Effects

Evaluation questions applicable to **segregated** programs and to **harvest** programs

- Has the hatchery stock been isolated from the wild population through such purposeful mechanisms as run timing differences, or weirs, or is the hatchery stock of local origin?

i) Contribution to Harvest

Evaluation questions applicable to both **integrated** and **segregated** programs and to **harvest** programs

- What are the morphological, behavioral & physiological traits of local stocks?
- Do the morphological, behavioral & physiological traits of the adults returning to the hatchery match those of the local stock?
- What desirable harvest traits does the broodstock possess (size at maturity, distribution in the marine environment, return time, percent jacks, etc.)?

Monitoring Criteria for Broodstock Choice by Species/Race/Stock:

For **all** programs determine and/or record:

1. Broodstock origin (GDU,ESU,SASSI) for introductions; provide rationale (similarity to native stock) - annually
2. Composition (NOR vs. HOR) - annually
3. Population characteristics (run timing, sex/age, fecundity, egg size, length) - annually
4. Tag recoveries in fisheries and escapement (to reconstruct recruitment and estimate productivity) - annually
5. Disease history for each broodstock - annually

In addition for **integrated** programs determine and/or record:

1. Population characteristics of natural spawners (as above plus morphology-body shape, coloration) - every generation
2. Gene (allele) frequencies in hatchery and natural stocks - 3 BY/decade (1 BY/generation, each cohort every other generation)

BROODSTOCK COLLECTION

a) Genetic Conditions

Evaluation questions applicable to both **integrated** and **segregated** programs and to both **conservation** and **harvest** programs

- What are the location, time, and method of broodstock capture?
- What are the historical trends for size and age at maturity, and return and spawn timing, and other critical life history traits?
- What are the morphological characteristics unique to the local and hatchery stocks (size and age at maturity, body form, secondary sexual characteristics, etc.)?
- What is the hatchery entry date, over time for the population?
- What is the number of NORs and HORs used for broodstock by sex by date?
- What safeguards are employed to maintain the biosecurity of the broodstock(s)?
- What are the history of translocations to other facilities and the history of outplantings within and out of the watershed?
- What strategies are employed if the hatchery broodstock goal is not met?

Evaluation questions applicable to **integrated** programs and to both **conservation** and **harvest** programs

- What is the number of NORs and HORs used for broodstock by sex by date?

b) Biological Conditions

Evaluation questions applicable to both **integrated** and **segregated** programs and to both **conservation** and **harvest** programs

- Is there sufficient water of proper temperature to ensure good maturation and gamete development?
- Are the flows sufficient to attract and separate adults into the hatchery?
- Are there hatchery barriers to upstream passage or that would impede entry to hatchery?

c) Fish Health

Evaluation questions applicable to both **integrated** and **segregated** programs and to both **conservation** and **harvest** programs

- What is the disease history of the broodstock over the last decade?
- What are the most serious pathogens in terms of pre-spawning mortality?
- How are the eggs of non-local species quarantined?

- How are pre-spawning mortalities collected and disposed of?
- What is the cause of pre-spawning mortality? If infectious invoke pathogen treatment protocols.
- How are pre-spawning mortalities collected and disposed of?
- If maintained on-site, are the carcasses maintained under quarantine conditions?
- Describe disinfection procedures for adult holding containers, equipment and personnel during and following spawning?

d) Hatchery and Receiving Environment

Evaluation questions applicable to both **integrated** and **segregated** programs and to both **conservation** and **harvest** programs

- What are the adult holding densities?
- What is the diurnal temperature cycle in the holding ponds?
- What is the average pre-spawning mortality over the preceding decade?
- How does the current year pre-spawning mortality compare?
- How frequently are the spawners handled to determine ripeness?
- Is the holding pond deep enough and flow adequate to minimize stress, and is human activity minimized?
- Are night lights extinguished during adult holding?

f) Ecological Effects

Evaluation questions applicable to both **integrated** and **segregated** programs and to both **conservation** and **harvest** programs

- Is sufficient escapement on natural/hatchery spawners allowed to maximize the natural productivity of the watershed?
- Is the watershed deficient in nutrients?
- Are hatchery carcasses sufficient to reach nutrient requirements of watershed?

g) Genetic Interactions

Evaluation questions applicable to both **integrated** and **segregated** programs and to both **conservation** and **harvest** programs

- What are the history of translocations to other facilities and the history of outplantings within and out of the watershed?

Evaluation questions applicable to **integrated** programs and to **conservation** programs

- What is the number of NORs and HORs used for broodstock by sex by date?

- What is the size of the naturally spawning population?
- What is the composition of the natural spawning escapement in terms of NORs and HORs?
- What is the duration of the program?

h) Contribution to Conservation

Evaluation questions applicable to both **integrated** and **segregated** programs and to **conservation** programs

- What is the relative probability of survival of the hatchery and wild components?

Evaluation questions applicable to **integrated** programs and to both **conservation** and **harvest** programs

- What is the composition of the natural spawning escapement in terms of NORs and HORs?

Monitoring Criteria for <u>Broodstock Collection</u> by Species/Race/stock:

For **all** programs determine and/or record:

1. Number, composition (HOR, NOR), life stage (eggs, juveniles, or adults), and method of broodstock collection (Rationale for number and method of collection)- annually
2. Number of fish entering hatchery and number passed upstream of hatchery - weekly during run
3. Disposition of all broodstock transferred out of hatchery - annually
4. Incidents of broodstock losses and their causes - each event
5. Water temperature and flow in holding ponds - Daily
6. Holding pond volume, temperature (daily), dissolved oxygen level (weekly) and flow (weekly)
7. Natural spawners (HOR and NOR) in watershed - annually
8. Incidence and prevalence of pathogen in the broodstock - annually
9. Methods used to quarantine and/or disinfect ponds, equipment and personnel - annually
10. Type and duration of disease treatment of adults - annually

In addition for **integrated** programs determine and/or record:

1. Indicators of biological significance and viability of natural population - annually
2. Quantity and quality of habitat (factors affecting whether to alter or terminate program) - annually
3. Water temperature in stream – continuously

SPAWNING

a) Genetic Conditions

Evaluation questions applicable to both **integrated** and **segregated** programs and to both **conservation** and **harvest** programs

- What are the spawner selection protocols (e.g. random, size, ripeness, wild or hatchery origin)?
- How are the gametes handled (pooling of milt and/or eggs?
- What is the mating scheme (e.g. 1:1, factorial, multiple pooling)?

Evaluation questions applicable to **integrated** programs and to both **conservation** and **harvest** programs

- Was a representative subsample of the population used for spawning?

b) Biological Conditions

Evaluation questions applicable to both **integrated** and **segregated** programs and to both **conservation** and **harvest** programs

- What are the sex, age, and size composition of the spawning population?
- What are the procedures for sexing and determining ripeness?
- What is the age-specific fecundity of hatchery and wild fish (number eggs/female, distribution of fecundities, mean egg size, etc.)?
- What is the relative reproductive success of hatchery-origin/wild-origin spawners?

c) Fish Health

Evaluation questions applicable to both **integrated** and **segregated** programs and to both **conservation** and **harvest** programs

- What procedures are used for water hardening of eggs in iodophor solution (iodophor concentration, duration, etc.)?

f) Ecological Effects

Evaluation questions applicable to both **integrated** and **segregated** programs and to both **conservation** and **harvest** programs

- Are adult fish or carcasses provided for upstream planting?
- Are carcasses disposed of in a manner that prevents pathogen transmission to the receiving watershed?
- Is spawning waste collected and disinfected prior to discharge to receiving water?

Monitoring Criteria for Spawning by Species/Race/Stock:

For **all** programs determine and/or record:

1. Number of NORs and HORs spawned by sex, fecundity, length, date and age - annually
2. Spawner selection protocol (e.g. random,,,) wrt size, run timing, HOR/NOR - annually
3. Number of NORs and HORs NOT spawned by sex, fecundity, length, date and age - annually
4. Mating scheme (e.g. 1:1, factorial, pooled gametes) - annually
5. Number of carcasses distributed to watershed - annually
6. Method of carcass disposition - annually
7. Incidence and prevalence of pathogens - annually
8. Type and duration of disease treatment of eggs - annually
9. Disinfection methods for ponds, equipment and personnel - annually

In addition for **captive brood** programs determine and/or record:

1. Genotype of selected mated pairs - annually

In addition for **integrated** programs determine and/or record:

1. Genotype of selected mated pairs (where needed to separate stock components) - annually

INCUBATION

a) Genetic Conditions

Evaluation questions applicable to both **integrated** and **segregated** programs and to both **conservation** and **harvest** programs

- How are the gametes handled (pooling of milt and/or eggs?
- What is the mating scheme (e.g. 1:1, factorial, multiple pooling)?
- How are the gametes handled (pooling of milt and/or eggs?
- What is the mating scheme (e.g. 1:1, factorial, multiple pooling)?
- Evaluation questions applicable to integrated and to conservation programs
- What is the incubation water source? (Essential IC, annually)

Evaluation questions applicable to both **integrated** and **segregated** programs and to **conservation** programs

- How are families incubated?

b) Biological Conditions

Evaluation questions applicable to both **integrated** and **segregated** programs and to both **conservation** and **harvest** programs

- How does fertility, eyeing, hatch time, emergence timing and egg survival of hatchery fish compare to their naturally spawning counterparts?

c) Fish Health

Evaluation questions applicable to both **integrated** and **segregated** programs and to both **conservation** and **harvest** programs

- What is the source of water in the incubation containers (well water, surface water, etc.)?
- Are other salmonids of the same or other species present in the source water?
- What diseases are indigenous to the source water?
- What are the egg densities?
- What is the diurnal temperature cycle in the incubators?

d) Hatchery and Receiving Environment

Evaluation questions applicable to both **integrated** and **segregated** programs and to both **conservation** and **harvest** programs

- What is the percent egg mortality per day?
- What are the cause(s) of egg losses (poor fertilization, disease, environmental, etc)?
- What is the diurnal temperature cycle in the incubators?
- What type of substrate used in incubators?

f) Ecological Effects

Evaluation questions applicable to both **integrated** and **segregated** programs and to both **conservation** and **harvest** programs

- Will the juveniles resulting from the egg take equal or exceed the habitat carrying capacity (quantity and quality of rearing habitat and accessibility)?
- What are the progeny to parent ratios of the hatchery and naturally spawning populations?
- How are dead eggs collected and disposed of?
- If maintained on-site, are the eggs sequestered under quarantine conditions?

Monitoring Criteria for Incubation by Species/Race/Stock:

For **all** programs determine and/or record:

1. Incubation water source, flow, temperatures, and water quality by lots (to estimate developmental rates) - daily
2. Spawning dates, hatching dates, ponding dates by lots (to estimate developmental rates) - annually
3. Counts of fertilized eggs, eyed eggs, dead eggs, and ponded fry (to estimate survival by lots) - annually
4. Incubator type, substrate used, number of eggs per incubator - by lot
5. Size of fry and % yolk absorption at ponding - by lot
6. Method of disposal of eggs - by lot
7. Presence of pathogens in water - when water source changes
8. Egg treatments (by event); disinfection procedures for incubating eggs, incubators, equipment, effluent water, and personnel - by lot

In addition for **integrated** and **conservation** programs determine and/or record:

1. How families (or family groups) of eggs are incubated - annually
2. Hatching dates, developmental rates for natural population - annually

REARING

a) Genetic Conditions

Evaluation questions applicable to both **integrated** and **segregated** programs and to both **conservation** and **harvest** programs

- What hatchery rearing protocols are used?
- What is the mean size (length & weight) and length frequency distribution at release?
- Are families reared individually?
- What protocols are used to randomize distribution of family groups?
- What culling procedures are used?

Evaluation questions applicable to both **integrated** and **segregated** programs and to **conservation** programs

- What biosecurity procedures are used to minimize the risk of catastrophic loss during juvenile rearing?
- Are families reared individually?
- What protocols are used to randomize distribution of family groups?
- Evaluation questions applicable to integrated programs and to conservation programs
- What protocols are used to randomize distribution of family groups?
- How long are fish reared in hatchery environment?

b) Biological Conditions

Evaluation questions applicable to both **integrated** and **segregated** programs and to both conservation and harvest programs

- Are growth patterns of hatchery fish similar to natural counterparts?
- Does the rate of development compare favorably with natural fish in the receiving environment?

Evaluation questions applicable to **integrated** programs and to both **conservation** and **harvest** programs

- How does the hatchery water temperature cycle vary from ambient stream conditions?
- Are the fish reared and incubated on ground water?
- Are hatchery work/security lights used at night to extend the normal photoperiod?
- What is the feeding regimen (times per day, amounts in %bow/day, etc.)?

- Is environmental enrichment (cover, structure, substrate, etc.) employed and are the fish conditioned to avoid predators?

c) Fish Health

Evaluation questions applicable to both **integrated** and **segregated** programs and to both **conservation** and **harvest** programs

- What is the source of water in the rearing containers (well water, surface water, etc.)?
- Are other salmonids of the same or other species present in the source water?
- What diseases are indigenous to the source water?
- Based on water flow, numbers and biomass of fish, what are the loading and densities?
- What are the diurnal and seasonal temperature cycles in the raceways/ponds?
- What is the date and developmental stage of fish at time at the time of vaccination?
- What type, dosage and method of delivery of drugs and therapeutants used to treat diseases?

d) Hatchery and Receiving Environment

Evaluation questions applicable to both **integrated** and **segregated** programs and to both **conservation** and **harvest** programs

- Are settleable solids, unused feed and feces periodically removed to ensure proper cleanliness of rearing container?
- Does the operator follow proper feeding rates, conduct periodic feed quality analysis, and store feed under proper conditions to prevent nutritional disorders?
- Are appropriate physical and chemical characteristics of water inflow and effluent (suspended solids, temperature, dissolved gases, pH, mineral content, and potential toxic metals) maintained to promote growth and survival?
- Are accurate fish inventory data maintained (e.g. Hat-Pro) with a minimum of handling stress?
- Are appropriate flow and density indexes maintained for the species and life stage being reared?
- Is the correct amount and type of food provided to achieve the desired growth rate, body composition, and condition factors for the species and life stage being reared?

e) Hatchery Structures

Evaluation questions applicable to both **integrated** and **segregated** programs and to both **conservation** and **harvest** programs

- What is the extent of the riparian zone in the immediate vicinity of the hatchery?
- What is the quality of the riparian habitat impacted by hatchery structures?

- How much riparian habitat has been lost or impacted by hatchery structures and what actions have been taken to mitigate for this loss?
- Is the hatchery in compliance with limitations established in National Pollution Discharge Elimination System permit for hatchery wastewater discharge?
- Does the hatchery and effluent water meet water quality standards for normal growth & survival of the cultured species?
- What are the objectives of the mitigation plan?
- Is there a monitoring component to the mitigation plan?

f) Ecological Effects

Evaluation questions applicable to both **integrated** and **segregated** programs and to both **conservation** and **harvest** programs

- Will the resulting juveniles equal or exceed the habitat carrying capacity (quantity and quality of rearing habitat and accessibility)?
- How are dead fish collected from the raceways/ponds and disposed of?
- If maintained on-site, are the dead fish sequestered under quarantine conditions?

g) Genetic Interactions

Evaluation questions applicable to both **integrated** and **segregated** programs and to both **conservation** and **harvest** programs

- What is the source of rearing water?
- What is the range in size and smoltification at release?
- Is the rate of development just prior to release adequate to maximize homing fidelity?
- Are acclimation ponds used?

i) Contribution to Harvest

Evaluation questions applicable to both **integrated** and **segregated** programs and to **harvest** programs

- Are facility and species-specific recommendations for water quality, temperature, loading, and density followed to maximize recruitment to fisheries?

Monitoring Criteria for Rearing by Species/Race/Stock:

RELEASE

a) Genetic Conditions

Evaluation questions applicable to **integrated** programs and to both **conservation** and **harvest** programs

- When does natural out migration occur?

b) Biological Conditions

Evaluation questions applicable to both **integrated** and **segregated** programs and to both **conservation** and **harvest** programs

- How do the size and growth parameters the cultured fish compare to the natural fish?
- What are the fish's energy stores (whole body proximates, liver glycogen, hepatosomatic index)?
- What is the developmental stage of the released fish (fry, pre-smolt, smolt, precocity)?
- Does the rate of smolt development compare favorably with natural fish in the receiving environment?
- What is the age at release?
- What is their swimming efficiency (stamina, stride efficiency)?

Evaluation questions applicable to **integrated** programs and to both **conservation** and **harvest** programs

- When does natural out migration occur?
- When and how are hatchery fish liberated?

d) Hatchery and Receiving Environment

Evaluation questions applicable to both **integrated** and **segregated** programs and to both **conservation** and **harvest** programs

- What is the origin of the broodstock (SASI stock, GDU membership; include both major and minor sources)?
- What is the distribution of release sites both in and out of the basin? What is the disease history of the juveniles over the last decade?
- What are the most serious pathogens in terms of pre-release mortality?
- Are the fish certified and appropriate responsible parties notified?

Evaluation questions applicable to both **integrated** and **segregated** programs and to **harvest** programs

- What are the number and size of fish released by location, time & date?
- How many fish were marked/tagged?
- What is the tag type & tag code(s) (cwt, PIT, otolith, etc.)?
- What is the percent of marked and tagged fish in the fishery?
- What is the contribution to the fishery?

f) Ecological Effects

Evaluation questions applicable to both **integrated** and **segregated** programs and to both **conservation** and **harvest** programs

- What pathogens are present and what is their prevalence in the populations?
- Were diseases present?
- What drugs and chemotherapeutants were used and what were the treatment protocols?
- Did the drugs/chemotherapeutants used to trace the disease(s) conform to recommendations of the attending fish pathologist?
- How were the fish released (mass, volitional, staggered)?
- What are the similarities/dissimilarities between wild and hatchery fish regards size, timing, and duration of release period?
- Is there sufficient attraction water at the hatchery or stream reach to adequately imprint the migrants?
- Are natural fish entering the hatchery facility?
- What numbers, species and life stages of natural fish bypass hatchery structures?
- What is the magnitude of fish release (numbers, size, biomass, etc.)?
- Do these cultured fish exceed the carrying capacity of the receiving stream, and is there excess carrying capacity?
- Are receiving habitats in properly functioning condition?
- How do the size and growth parameters the cultured fish compare to the natural fish?
- What are the fish's energy stores (whole body proximates, liver glycogen, hepatosomatic index)? What is the developmental stage of the released fish (fry, pre-smolt, smolt, precocity)?
- Does the rate of smolt development compare favorably with natural fish in the receiving environment?
- What is the age at release?
- What is their swimming efficiency (stamina, stride efficiency)?
- If planted out (trucking, barging, release site, etc.), where are the fish released in the target watershed, and what is the distribution and density of natural fish within that watershed?
- Are fish released into properly functioning habitat?
- If planted out (trucking, barging, release site, etc.), where are the fish released in the target watershed, and what is the distribution and density of natural fish within that watershed?

- Are acclimation ponds used?
- If released at the hatchery, what is the manner of release (volitional, staggered, forced, etc)?
- What is the magnitude of fish release (numbers, size, biomass, etc.)?
- Do these cultured fish exceed the carrying capacity of the receiving stream, and is there excess carrying capacity?
- If planted out (trucking, barging, release site, etc.), where are the fish released in the target watershed?
- Are acclimation ponds used?
- If released at the hatchery, what is the manner of release (volitional, staggered, forced, etc)?
- Is there sufficient attraction water at the hatchery or stream reach to adequately imprint the migrants?
- If planted out (trucking, barging, release site, etc.), where are the fish released in the target watershed, and what is the distribution and density of natural fish within that watershed?
- Are fish released into properly functioning habitat?
- What is the magnitude of fish release (numbers, size, biomass, etc.)?
- Do these cultured fish exceed the carrying capacity of the receiving stream, and is there excess carrying capacity?
- What is the magnitude of fish release (numbers, size, biomass, etc.)? Do these cultured fish exceed the carrying capacity of the receiving stream, and is there excess carrying capacity?
- How do the size and growth parameters the cultured fish compare to the natural fish?
- What are the fish's energy stores (whole body proximates, liver glycogen, hepatosomatic index)?
- What is the developmental stage of the released fish (fry, pre-smolt, smolt, precocity)? Does the rate of smolt development compare favorably with natural fish in the receiving environment?
- What is the age at release?
- What is their swimming efficiency (stamina, stride efficiency)?
- What is the prevalence of disease in co-mingling wild and hatchery fish?
- How do the hatchery fish interact with their natural counterpart (territoriality, displacement, foraging ability, etc.)?
- How are the fish likely to be impacted by water quality and the riparian zone?
- Is there a management plan for vegetation, herbicide and pesticide use, and surface water allocation?

g) Genetic Interactions

Evaluation questions applicable to both **integrated** and **segregated** programs and to both **conservation** and **harvest** programs

- How are fish released?
- What treatments are used to encourage homing fidelity?

i) Contribution to Harvest

Evaluation questions applicable to both **integrated** and **segregated** programs and to **harvest** programs

- What is the contribution to the fishery?
- (How many fish were marked/tagged?
- What is the tag type & tag code(s) (cwt, PIT, otolith, etc.)?)

Monitoring Criteria for Release by Species/Race/Stock:

For **all** programs determine and/or record:

1. Release method, locations, life stage, length and weight (for individuals in random 100 fish sample), and result of required pre-release fish health tests, smoltification - by event
2. Numbers and types of marks and tags used (to distinguish among segments of the hatchery populations and between hatchery and natural populations) - by lot
3. Approximate numbers of precocious males - by lot
4. Health status prior to release or transfer, and disposition of diseased fish -by lot
5. Disease treatments prior to release (type, date and duration) - by lot
6. Distribution of naturally-produced and hatchery juvenile fish in the receiving habitat - periodically
7. Quantity and quality of the receiving marine and freshwater habitat - annually.
8. Distribution of other potentially affected species
9. Behavioral characteristics of released fish and their interaction with naturally produced fish through feeding behavior, aggressive behavior, group size, territory size, and habitat use

In addition for **integrated** programs, determine and record:

1. Natural outmigration timing (date and duration) - annually
2. For naturally produced fish, length, weight (for 100 fish) - annually
3. For naturally produced fish, timing of smoltification (silvering, migratory behavior) - annually
4. For naturally produced fish, nutritional condition (proximate composition, liver glycogen) - annually

ADULT RETURN

e) Hatchery Structures

Evaluation questions applicable to both **integrated** and **segregated** programs and to both **conservation** and **harvest** programs

- Is there unimpeded passage for wild fish through hatchery structures and bypass reaches?
- What species of salmonids and non-salmonids use the migratory corridor past the hatchery?
- Are there hatchery structural barriers to upstream passage or entry to hatchery?
- Is there adequate stream flow below the hatchery water intake and in the by-pass reach to allow passage of adults upstream?
- Are there thermal or odorant barriers that impede or block upstream migration?
- Is there sufficient upstream spawning habitat to attract adults to the upstream reaches?

Evaluation questions applicable to **integrated** and to **conservation** programs

- What is stream carrying capacity?
- Do adults adequately utilize habitat capacity?

g) Genetic Interactions

Evaluation questions applicable to both **integrated** and **segregated** programs and to both **conservation** and **harvest** programs

- What is the extent of straying of hatchery fish into natural spawning areas
- What measures are used to control straying and/or natural spawning of hatchery fish?
- What is the extent of straying of naturally produced fish into the hatchery?
- What measures are used to control attraction of wild fish into the hatchery?

Monitoring Criteria for Adult Return by Species/Race/Stock:

For **all** programs determine and/or record:

1. Potential barriers to upstream migration of adults and movement of adults into and past the hatchery - annually
2. The number of HORs from any hatchery program found in spawning areas, and the number of NORs attracted into the hatchery - annually
3. Straying rates of individual hatchery populations - periodically
4. Reproductive success of HORs from a particular hatchery program in nature - periodically
5. Abundance and distribution of hatchery- and natural-origin spawners - annually

E. Regional Information Key Questions Form

This form is provided to regional participants not affiliated with the management agencies, to guide them in assembling information for the HSRG's regional briefing book.

The HSRG feels it is essential to receive input or knowledge from those who are most familiar with the region and its hatchery system. Having been identified as one of these persons, you are requested to provide written information for a Regional Briefing Book to be provided to the HSRG. The HSRG is requesting information on: 1) regional management goals for conservation, harvest, and other priorities; 2) stock status (biological significance and viability of salmonid populations within the region); 3) habitat; and 4) hatchery programs.

The HSRG and regional managers have divided natural and artificially propagated anadromous salmonids in the region into appropriate individual stocks (see attached list), reflecting management units. It is at this level that the HSRG requests you to provide information. The HSRG will provide their evaluations and recommendations based on the stock management goals provided by this same grouping.

Below are a series of questions the HSRG would like you to address. Address any or all questions for which you have pertinent information. Please provide this information in memo form, with author, affiliation, date, and sources noted. Please provide soft copy in Microsoft Word or Rich Text Format to Michael Kern, mkern@lltk.org.

1. *Do you feel that the conservation, harvest, and other goals for the region's hatchery system are appropriate, given current habitat conditions and other factors? If not, what adjustments or suggestions do you have to resolve the conflict?*

2. *Are monitoring and evaluation programs adequate to determine if goals are being met?*

3. *Do you see the quality of the habitat in this region changing for the worse or better in the next ten to twelve years? Fifty years? What are the long-term goals for habitat in this region?*

4. *Using the definitions given below, what would your overall rating be for the habitat available to each sub-regional species? Please provide using the table format below, one table per sub-regional species. The general habitat ratings are defined as:*
   a. *<u>High (H) = Healthy</u>: Productivity of the target species is high and the population is capable of growth and supporting significant terminal harvest.*
   b. *<u>Medium (M) = Limiting</u>: The target species is productive enough for the population to sustain itself at a low level terminal harvest.*
   c. *<u>Low (L) = Inadequate</u>: The target species is unproductive and the population will go extinct, even without terminal harvest.*

Sub-Region Species:

	Spawning Habitat		*Freshwater Rearing Habitat*		*Migration Habitat*		*Estuarine Habitat*
	Hatchery	*Wild*	*Hatchery*	*Wild*	*Hatchery*	*Wild*	
Rating (H/M/L)							

5. *Are there exceptions or "islands" of greater or lesser productivity in this sub-region that the HSRG should be aware of in reviewing the hatchery programs?*

6. *Are there habitat improvement projects that could elevate the rating for this sub-region or that could elevate the productivity of "islands" of inferior production within this sub-region? If so, what are they and are they in the proposed or planning stages?*

7. *How would you rate the stock status (biological significance and population viability) of each sub-regional species (high, medium or low)? Please provide using the table format below, one set of ratings per sub-regional species. For biological significance, please take into account factors such as whether the species is native to the watershed; whether it exhibits any unique or distinctive biological attributes that are not shared with other stocks within the GDU; and the history of introductions, hatchery fish releases, and hatchery fish strays from other watersheds. For population viability, high = healthy, medium = at risk, low = critical.*

	Sub-Region Species:		*Sub-Region Species:*		*Sub-Region Species:*		*Sub-Region Species:*	
	Biol. Sig.	*Viability*	*Biol. Sig.*	*Viability*	*Biol. Sig.*	*Viability*	*Biol. Sig.*	*Viability*
Rating (H/M/L)								

8. *How well are current hatchery programs contributing towards meeting regional goals? In the future, could hatchery programs make better or different contributions toward meeting these goals?*

9. *Are regional hatchery facilities designed and operated to optimize benefits to and reduce negative interactions with naturally produced stocks?*

10. *In your opinion, what is the most valuable use of these facilities for the future?*

F. Regional Information Instruction Form

This form is provided to regional participants from the management agencies, to guide them in assembling information for the HSRG's regional briefing book.

Purpose

This document provides information to the co-managers regarding the Hatchery Reform Project and the Regional Review Process. This document asks the co-managers questions about hatchery-related regional issues. Replies to these questions will be compiled in a briefing book. This book will enable the scientists participating in the Hatchery Reform Project to make recommendations for hatchery facilities and programs within Washington's Puget Sound and coastal regions.

Benefits

The managers will receive as a result of this review of the hatchery system: 1) independent appraisal of the regional hatcheries; 2) documentation of their existing and potential benefits to both salmonid conservation and sustainable fisheries; 3) documentation and tools for evaluating potential risks of hatchery programs; and 4) recommendations for improvement. These will be in the form of a written report. Implementation of these recommendations will be made possible through Washington state and US Congressional legislative appropriations and private sector resources. To date, Congress has provided $12.6 million for this effort.

The regional review process involves the following steps:

1. Managers identify regional and other agency support staff to participate in regional review. The facilitation team creates and maintains a regional participant contact list.
2. Managers and others (such as funding entities) meet with the HSRG and the facilitation team to introduce the regional review process and to discuss issues and concerns specific to this region.
3. Managers receive this form; other interested parties receive the HSRG Key Questions form.
4. Agency staff meet internally and with other regional participants to discuss the best method to assemble the information requested on this form.
5. Managers submit the requested information to the facilitation team who compile it into the Regional Briefing Book.
6. The facilitation team visits and photographs the region and its facilities prior to the regional review.
7. The facilitation team works with regional participants to design a regional tour for the beginning of the regional review.
8. HSRG and facilitation team tour the region's hatchery and other relevant sites, meeting with managers along the way. This regional tour is first day or more of the review.
9. Managers meet with the HSRG to discuss the regional habitat and goals as they relate to hatchery programs. This is primarily to clarify information and gather new data as needed.

10. The HSRG finishes their review and gives regional managers their preliminary recommendations verbally in an informal meeting (last day of the schedule review).
11. Regional managers meet to consider the HSRG's preliminary recommendations and provide feedback prior to the report writing process.
12. HSRG drafts its report to include recommendations for all regions reviewed.
13. The draft report is provided to the management agencies to allow them an opportunity to include a response to each set of recommendations, including their implementation plans.
14. Regional review report is provided to the managers, US Congress, Washington state legislature and other appropriate parties.
15. Available funding is prioritized for implementation of recommendations.

Regional Information Briefing Book – What We Need From You

The HSRG feels it is essential to receive answers to their questions from the regional managers and staff that are most familiar with the region and its hatchery system. Your peers have identified you as a regional expert. The HSRG requests your written responses to the questions on this form for a Regional Briefing Book. We encourage working together to avoid duplication of efforts and use existing documents such as HGMPs, planning documents, etc. as source material (cut and paste as needed). The HSRG recognizes that some information may be incomplete, anecdotal, or not well documented – *it is still important and should be included***.** If you have little or no information for a particular question, please give the information you do have. The HSRG may recognize a lack of information, and the corresponding need to learn more as a part of their recommendations.

This Regional Briefing Book will be provided to the HSRG and regional participants *in advance* of the review for your region. You will be provided with due dates and information on where to send the material. Please provide the information as soft copy in Microsoft Word or Rich Text Format with author(s), affiliation(s), sources, and date noted. You will also be requested to meet with the HSRG to participate in the review.

The HSRG is requesting information on:

A. Habitat
B. Salmon and steelhead stock status – both hatchery and wild
C. Management goals for harvest, conservation and other priorities
D. Current hatchery programs.

The HSRG and regional managers will work with you to divide natural and artificially propagated anadromous salmonids into appropriate individual stocks. The grouping should reflect management units. The HSRG will provide their evaluations and recommendations based on the stock management goals provided by this same grouping.

Questions: WDFW or NWIFC hatchery reform staff members or the facilitation team staff (Kathleen Hopper at 206-382-9555 ext. 24, Michael Kern at 206-382-9555 ext. 25, or Michael Schmidt at 206-382-9555 ext. 26) can be contacted for more information.

A. General Description of the Region

This description is a general overview of the region for the members of the HSRG who are unfamiliar with your area. Use existing material if it is available (such as Watershed Lead Entity documents).

Provide a general narrative description of the regional landscape. This description should include, if available: watershed topography, rivers and significant tributaries, land ownership, and land use. Feel free to use maps. We ask that this description be as concise as possible.

B. Status of the Habitat by Stock

Appropriate habitat or other agency policy staff should answer the following questions for each hatchery and naturally spawning stock:

1. Please fill out the table below for each stock using the general definitions provided:

Stock Name:

	Spawning Habitat		***Freshwater Rearing Habitat***		***Migration Habitat***		***Estuarine Habitat***
	Hatchery	***Wild***	***Hatchery***	***Wild***	***Hatchery***	***Wild***	
Rating (H/M/L)							

Three categories of habitat are defined in terms of conditions that support the target stocks, with the assumption that these conditions would also provide for the needs of other native stocks of salmonids (assume that pre-terminal harvest is part of the environment during the fish's whole life cycle).

These habitat ratings are:

a. *High (H) = Healthy: Productivity of the target stocks is high and the population is capable of growth and supporting significant terminal harvest.*
b. *Medium (M) = Limiting: The target stocks is productive enough for the population to sustain itself at a low level terminal harvest.*
c. *Low (L) = Inadequate: The target stocks is unproductive and the population will go extinct, even without terminal harvest.*

2. Are there exceptions or "islands" of habitat that are in better or worse condition and do not correspond with the rating given in question?

3. What habitat improvement projects could elevate the rating for this sub-region or the "islands" of inferior production? If so, please list them and indicate if they are in the proposed or planning stages.

4. Do you see the quality of the habitat in this region become better or worse in the next ten to twelve years? Fifty years? What are the long-term goals for habitat in this sub-region?

5. What other habitat information should the HSRG consider (for example, salmonid or non-salmonid stocks not native to the watershed)? Please describe.

C. Status of the Salmonid Stocks

Appropriate management or other agency policy staff should answer the following questions for each hatchery and naturally spawning stock:

I. Trends
Please answer the following for each stock.

1. *Fill out a table as completely as possible that resembles the template below. We will generate a general trend for this stock with this information.*

Fill Out This Template			
Year	Survival	Catch	Escapement
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19___			
19___			
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20___			
20___			

2. *What is the age class structure of this stock (by sex) and do historical data exist on potential changes over time? For example, five year-old adults may have constituted 20% of returning adults 30 years ago, but those fish may now be rare.*

3. *Do you know if hatchery origin fish comprise a portion of natural spawning fish? If so, please give your estimation of the number of hatchery spawners and a timeline. These numbers can be estimated through escapement or carcass counts.*

4. *For hatchery stocks - what proportion of hatchery eggs, fry or adults are from wild fish or another hatchery?*

5. *Is this stock a coded wire tag index stock? If not, which index stock is it most closely aligned with? Provide any additional relevant information from previous coded wire tag groups.*

II. Biological Significance

Please answer the following for each stock:

1. *Within each watershed, what is the history of introductions (e.g. stock transfers), hatchery fish releases, and hatchery fish strays from other watersheds?*
    a. *Are naturally spawning populations considered "native" with little or no history of stock transfers, introductions, or artificial propagation within the watershed? or*
    b. *Have little or no stock transfers occurred, but the species has been artificially propagated within the watershed to some extent (how extensive has artificial propagation been?)? or*
    c. *Have significant stock transfers into the watershed occurred historically, with the potential for significant interbreeding between native and introduced fish? or*
    d. *Was the species extirpated from the watershed historically, but stock introductions reestablished the species within the watershed? or*
    e. *Is the species not native to the watershed, but currently exists as a naturalized population resulting from past stock transfers?*

2. *Biological Attributes - Does the stock exhibit any unique or distinctive biological attributes within the watershed with respect to life history characteristics (e.g. age/size at maturity, run timing, freshwater migration distance, morphology, physiology, disease resistance, genetics, etc.?) Use the following questions to guide your answer:*
    a. *Are the distinctive traits potentially irreplaceable or not typical of other stocks within the same GDU? Or*
    b. *Does the stock have no unique, biological attributes but share some unique attributes with other stocks in the same GDU? Or*
    c. *Are all known biological attributes shared with other GDUs?*

3. *Population Subdivisions - How diverse is the metapopulation structure within the watershed? Use the following questions to guide your answer:*
    a. *How many distinct spawning aggregations (e.g., tributary creeks) exist within the stock under consideration?*
    b. *What genetic data exist for this stock? Please provide agency reports or publication citations that contain these data, or provide summary tables of population allele frequencies if such reports or publications do not exist.*
    c. *What is the total number of stocks within the same GDU as the stock under consideration?*
    d. *What it the mean and range of viabilities (i.e. status) of the other stocks within the same GDU?*

D. Co-Manager Goals for Salmonid Stocks

Appropriate management or other agency policy staff should answer the following questions for each hatchery and naturally spawning stock:

1. *For each hatchery stock program, is the program goal conservation, harvest or both?*

2. *Please list your harvest management goals for each of the following time frames: present day, short-term (10 years in the future) and long-term (50 years in the future.)* Use the following definitions for harvest goals:
   High – harvest opportunity each year, spread over seasons
   Medium – opportunity most years, for some seasons
   Low – occasional opportunity, single run
   0 – no harvest opportunity

Goals	Present	Short-Term	Long-Term
Harvest Opportunity			

3. *What are your conservation goals? The answer to this question is typically qualitative. The answer should include local as well as regional (i.e., ESU) and/or statewide goals for each stock.*

4. *For hatchery programs, please summarize the production goals:*
   a. *How many fish at what size are planned for release? Transferred off-station?*
   b. *Where are eggs taken and incubated? Where are fish reared and released?*
   c. *Does this program stay relatively constant or does it change regularly? If it changes, what is the process for this change?*
   d. *Is the duration of this program clearly defined?*

5. *Are there other goals for this stock that are important to the co-managers? Some examples include: use of a stock as an indicator for survival or fishery contribution, cultural importance to tribal members, educational programs, mitigation for lost habitat or access to spawning area, scientific research, etc.*

6. *Do you have a monitoring and evaluation program that is adequate to determine if the goals are being met? If so, please describe.*

7. *Are the current goals being achieved? What are the levels of achievements being realized for each of these goals?*

8. *Is there a conflict between the present goals based upon current management practices or habitat conditions? If so, what adjustments or suggestions do you recommend (example: hatchery coho production vs. natural chum production)?*

9. *Are regional decisions based upon adaptive management? How do you incorporate new information to adjust existing programs and goals?*

E. Current Regional Hatchery Programs

Appropriate hatchery or hatchery support staff should answer these questions with regard to current hatchery programs.

The first set of questions deals with the general features of each hatchery facility that could affect all stocks and activities on station. There should be one set of answers per facility. (Questions 1 through 9, 20)

The second set of questions is for each stock that you rear or handle on site. (Questions 10 through 19) You can "lump" stocks if the same answer applies. For example, if all your eggs on site are incubated in a similar manner, state that the answer will, **"Apply To All Stocks**."

For hatchery stocks that are reared and/or transferred between sites, provide a summary set of answers for that stock, rather than splitting up the answers between facilities (include a chart or other graphic to express what stage of culture takes place at what site). If a stock released at your site is reared for part of the time outside of the region, please include this same information for that facility.

One answer per facility – questions 1-9

1. *Describe the property location and ownership. Give the funding and operating organization names, approximate size of the property (acres), number of buildings, any unique attributes of the site worth noting.*

2. *What is the primary goal of the facility? (Examples: conservation of Shirley creek summer chum because of degraded habitat, harvest augmentation of Michael River coho salmon primarily for north Puget Sound commercial fisheries, community education)*

3. *What stocks of fish are handled and/or reared at this facility?*

4. *Describe the water supply, including the following components:*
    a. *Each water source: Available flow – stable, increasing, decreasing? Spring, well, surface? Normal year's temperature regime? Pumped or gravity flow? Water chemistry profile, if available?*
    b. *If surface water, is it fish- or specific-pathogen free? Do you experience problems with "dirty water" that limits your ability to reach your goals?*
    c. *Surface water intake structures on station – are they screened or sited in a way that excludes fish or other animals from entering the water supply?*
    d. *If you use surface water, is there adequate water in the by-pass reach throughout the year?*
    e. *Are there unique physical characteristics of the water supply on site or nearby that you feel should be noted?*

5. *Describe the fish health/pathogen history, including the following components:*
    a. *How often does a fish health professional visit your site?*

b. *What is the most significant fish health problem at your facility (this could be a fish pathogen, inability to correct a situation, poor water, etc.)?*
c. *Have you had any significant epizootics on your facility? Please explain. Were you able to isolate the affected containers? Sanitize the effluent?*
d. *Do you have a history of viral isolations at your facility in the past five years? This excludes epizootics as described above.*
e. *Do you disinfect equipment between rearing units or banks of ponds? What method do you use?*
f. *Are you able to keep distinct lots or stocks of fish physically separated? Please answer for each of these life stages – adults, eggs, and juveniles.*

6. *Describe the waste removal/pollution abatement system including the following components:*
   a. *What is the general frequency of pond cleaning?*
   b. *How is pond waste disposed of (vacuum, brush, dry and remove, etc.)?*
   c. *Describe pollution abatement pond or settling pond, if one exists.*
   d. *Status of permits for discharging pollutants?*
   e. *Any particular challenges you would like to share on this subject?*

7. *Other general questions:*
   a. *What are your predator control methods/facilities (nets, wires, etc)? Do you have unresolved predator problems?*
   b. *Describe how you inventory your fish (frequency, size of weight sample, etc.).*
   c. *How do you keep your inventory and other data? (Hatpro, spreadsheets of your own, agency forms, etc.)*
   d. *How do you decide which food to use (mandatory contract, fish health recommendations, etc.)?*
   e. *How do you store your feed?*
   f. *Does your facility have any habitat improvements on site (wetlands, riparian improvements, etc.)?*

8. *Education – please give details regarding the following:*
   a. *Is your facility open to the public?*
   b. *Do you have signs, pamphlets, or other materials for the public to self-tour?*
   c. *Do hatchery staff or others schedule and conduct tours of the facility?*
   d. *Are there citizen involvement opportunities such as volunteer programs, student interns, etc?*
   e. *Are hatchery operations visible to facility visitors?*
   f. *Do other fish and wildlife programs use the facility?*
   g. *Do you have regular involvement with community or school groups?*
   h. *Do you give fish or eggs to educational groups? If so, please estimate the amount of time this activity takes.*

9. *General Administration*
   a. *Does key staff have a good understanding of the facility goals, budget, and expenditures? If not, what tools do you need for correcting this?*

b. *Is new relevant information from research and other sources made available to hatchery staff and used for attaining goals?*
c. *As fish culture and other related scientific understanding evolves, are you able to make changes to your programs? If not, what ideas do you have for changing this?*
d. *Are there state or federal laws that constrain the program, such as numbers and size of smolts produced?*

One answer per hatchery stock (Questions 10-19) .The production goals for these stocks are summarized under "Co-Manager Goals for Salmonid Stocks", question 4.

10. *Describe the broodstock as follows: (These may be a repeat of some questions asked under stock status - you may refer to those answers or cut and paste.)*
    a. *How was the broodstock chosen?*
    b. *Do you consider it an integrated (goal is to maintain a single gene pool and prevent divergence) or segregated (isolated in the hatchery ,managed to restrict gene flow) population?*
    c. *Does this broodstock have a history of reportable pathogens?*
    d. *Are you are able to collect representative samples each year of the population, with respect to size, age, sex ratio, and run and spawn timing? If not, please explain the limitation.*
    e. *What has your run size been for the last five years?*
    f. *What is the sex ratio at spawning?*
    g. *Do you have any information on the sex ratio by age? If so, please provide.*

11. *Describe the broodstock collection process, including the following components. Differentiate by Natural Origin Recruit (NOR) and Hatchery Origin Recruit (HOR) if they are collected in a different manner:*
    a. *Describe/give the location of adult collection relative to the physical plant where fish are held or spawned?*
    b. *Describe how fish are collected (ladder, sorter, trap, in river, etc.)*
    c. *Do you have the ability to handle or sort individual fish? If so, please describe your process.*
    d. *If you transport adults from one site to another, describe method of transport. Have you had problems with mortality from handling because of this?*
    e. *If the fish enter the adult holding structure on their own, describe the process for handling and counting. Include details on how and when you pass fish upstream, and about your ability to do so.*
    f. *In what type of container do you hold these adults? Is it covered? Do you use overhead sprinklers? Do you have a problem with predation?*
    g. *Which water supply is used for this purpose?*
    h. *Are you able to hold these fish within recommended guidelines for temperature, water flow, and density?*

i. Do you have adequate security?
j. How do you deal with numbers of fish in excess of your egg take needs? Do you feel you have the tools you need for this?

12. Please describe how you handle adults:
    a. What is the method for choosing and mating your broodstock (include how many adults of each sex are used per mating)?
        1. What are the spawner selection protocols (e.g. random, size, ripeness, wild or hatchery origin?)?
        2. Record how the gametes are handled (pooling of milt and/or eggs? If so, how?). What is the mating scheme (e.g. 1:1, factorial, multiple pooling?)
    b. Do you use anesthesia?
    c. Describe the pathogen-sampling regime.
    d. Describe mark sampling program, if any.
    e. Is there any other biological sampling done on adults?
    f. How do you dispose of spawning waste?
    g. How do you dispose of pre-spawning mortalities?
    h. How do you dispose of spawned adults?

13. Please describe your method for putting down green eggs:
    a. Do you have adequate "clean" and "dirty" areas for handling eggs?
    b. Describe your water hardening procedure.
    c. Describe your green egg enumeration process.
    d. Where are these eggs incubated (What type of incubator, water supply used)?
    e. Do you incubate in single-family units? If you had the capacity, would that be desirable?
    f. How many eggs per incubation unit?
    g. What is the typical flow used?

14. Please describe your methods for handling and putting down eyed eggs:
    a. How do you monitor egg development? (Temperature units, visual check, fish pathologist check, etc.)
    b. Have you had any chronic (or difficult to control) losses of eggs to the eyed stage? If so, please explain.
    c. How do you dispose of dead eggs?
    d. Do you disinfect eyed eggs prior to putting down to hatch?
    e. What type of container do you use for hatching?
    f. Do you use any type of substrate?
    g. What is your loading density? (eggs per unit)

15. Other incubation questions:
    a. Is your water temperature regime similar to that in the natural environment?
    b. Are eggs incubated under environmental conditions that tend to maximize individual fitness of fry? (e.g. allow volitional ponding of fry, incubate under environmental conditions that simulate the natural rearing environment)

c. *Do you heat or cool your water during incubation? If so, please explain what you do and the purpose of the temperature manipulation.*
d. *Do you cull eggs during incubation for any purpose? (ELISA results, spawn timing, etc.)*
e. *Are excess eggs/fry culled randomly when necessary?*
f. *How do you deal with eggs in excess of your egg take needs?*
g. *Do fry have the ability to emerge volitionally?*
h. *If you have to remove fry from rearing units, how do you determine appropriate stage of development (Temperature units, visual check, pathologist check, etc.)?*

16. *Rearing conditions:*
    a. *Explain what type of container this stock is rearing in from first ponding to release (size and types of each kind of rearing unit).*
    b. *What water supply is used for rearing this stock (from first ponding to release)?*
    c. *Are the rearing units covered?*
    d. *Do you attempt to provide any type of "natural rearing" for this stock (cover, substrate, food, etc.)? Please describe.*
    e. *How do you decide which fish to combine in a rearing unit (individual families, results of ELISA, size of fish, etc.)?*
    f. *What do you use for keeping fish within recommended density and/or poundage targets (Flow Index, Density Index, pounds/gallon/minute, etc.)?*
    g. *Are you typically able to stay at or below this guideline? If not, what are your limiting factors?*
    h. *Are fish produced similar to natural fish in size, growth rate, morphology, behavior physiological status, health, etc.?*

17. *Stock-specific fish health questions*
    a. *Do you use any prophylactic treatments? If so, describe drug/chemical used, targeted pathogen, life stage treated, and method of delivery.*
    b. *Do you vaccinate this stock? If so, for what pathogen and with what vaccine?*
    c. *Are you able to remove and enumerate mortalities easily? If not, what are your limitations?*
    d. *Is this stock sampled for pathogens at spawning?*
    e. *Do you or your fish health specialist perform any fish health assessments on this stock? If so, what sort and at what frequency?*
    f. *What is your most challenging fish health problem with this stock? If you could, what would you do to resolve the problem?*

18. *Marking*
    a. *Is this stock marked or tagged in any way prior to release? Please describe (numbers, replications, quality control).*
    b. *What is the purpose of this mark or tag?*
    c. *How many years has it been identified in this way?*
    d. *Are there historic marks or tags we should know about?*
    e. *Please provide all tag recovery information for this program.*

19. *Release/transfer of fish*
    a. *How is time of release decided?*
    b. *How do you measure the size of fish at release (fish per pound, average length, other)?*
    c. *What is the typical size range in millimeters of these fish at release? If you do not know the size range, what is average weight?*
    d. *What other smolt quality monitoring do you perform, if any (fish pathologist checks, on-going research projects, smoltification indicators, etc.)?*
    e. *Are fish released with adequate imprinting to facility or desired stream reach?*
    f. *Describe your on-station release procedure for this stock (volitional vs. forced, time of day, typical date, length of time of release, etc.).*
    g. *If you truck this stock off station, where do they go (acclimation pond, stream plant, transfer to another facility, etc.)?*
    h. *Are you or others able to monitor the fish after they enter the river (snorkeling, smolt trapping downstream, etc.)?*
    i. *Do you have any idea if these fish have interactions with other salmonids in the receiving environment? If so, what do you know?*

20. *Migration of returning adults*
    a. *Is the straying of hatchery fish into the wild controlled?*
    b. *Is the attraction of wild fish into the hatchery minimized?*

One answer per facility – question 2

21. *Wish list and other comments*
    a. *What is the most-needed piece or pieces of equipment for your facility and why?*
    b. *What capital improvements are most needed at your facility and why?*
    c. *What do you think would be the most valuable use of your facility?*
    d. *Is there anything else that we have not covered that you would like to add?*

THANK YOU

G. Benefit/Risk Tool

OVERVIEW

The Hatchery Scientific Review Group's (HSRG) Benefit/Risk Tool was adapted and simplified from a tool developed by the co-managers.[63] It allows the HSRG and the managers to evaluate the relative benefits and risks associated with specific actions and choices in hatchery management, in a scientifically sound, methodical manner. It is the vehicle by which scientists and managers can compare the best available science contained in the scientific framework[64] and the best operational practices in the operational guidelines[65] to current hatchery program purposes and operations. As such, its use in evaluating hatchery programs is key to meeting the HSRG's principle that hatcheries be operated in a scientifically defensible manner.[66]

The tool has been used by the HSRG during the regional reviews and contains three worksheets. "Generic" (not specific to a region) versions of these worksheets are presented on the following pages, after a description of each worksheet and how it is used.

The HSRG understands that the terms "risk" and "benefit" are sometimes used to convey a specific legal or policy status, condition or decision about the results of a particular action, policy or program. For the purposes of the HSRG's review and recommendations, these terms are not being used in this manner, but rather in the general sense of whether a hatchery program, or some aspect of that program, is likely to be affecting one or more regional salmonid stocks in a positive and/or negative way. The intent is to provide policy makers with a sense of the trade-offs involved in different options or courses of action.

Part One

The Part One worksheet is titled *Summary of Goals for Affected Stocks and Habitat; Description of Current Hatchery Programs*. It is where the HSRG records the results of working with the regional participants to develop a common understanding of the current status of each regional hatchery program's purpose, type and release strategies. The participants also use this worksheet to rate current, short-term and long-term goals for each regional stock, in terms of biological significance, population viability, habitat and harvest opportunity. Each category is rated as being high, medium or low. The following definitions are used for these ratings.

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63. *Draft Benefit-Risk Assessment Procedure (BRAP) for Washington State Department of Fish and Wildlife Artificial Propagation Programs, November 17, 2000.*

[64] *See Appendix A, Scientific Framework for the Artificial Propagation of Salmon and Steelhead.*

[65] *See Appendix C, Operational Guidelines.*

[66] *See Applied Hatchery Reform,, Principles and System-Wide Recommendations.*

Definition of Population Biological Significance

Rating criteria and scores for evaluating the biological significance of salmon and steelhead populations as part of assessing the benefits and risks of hatchery programs in Puget Sound and coastal Washington:

A. Stock origin (possible scores = 1-5)

   a. Native (Score = 5)

   b. Admixture

      i. >50% native genes (Score = 4)

      ii. <50% native genes (Score = 3)

   c. Reintroduced: species occurred historically in watershed, was extirpated, but stock transfers re-established species in watershed (Score = 2)

   d. Introduced: species was historically absent from watershed/habitat (Score = 1)

   [What data/information do we need to obtain a stock origin score?, What/who are the sources for that info?]

B. Biological attributes (Life history, physiological, morphological and behavior characters; disease resistance, etc.): How unique are these characters and to what extent are they irreplaceable (possible scores = 1-5)

   a. Population has unique, irreplaceable biological attributes that are not shared with other SASI stocks within the GDU (Score = 5)

   b. Has no unique biological attributes, but shares some unique attributes with other SASI stocks within the GDU that are not shared with other GDUs (Score = 3)

   c. Key biological attributes are shared with other GDUs (Score = 1).

   [What data/information do we need to obtain a biological attributes score? What/who are the sources for that info?]

C. Level of population subdivision or metapopulation structure (scores = 1-7)

   a. Number of distinct spawning aggregations (e.g. tributaries) within the SASI stock under consideration:

      i. <5: Score = 2

      ii. >5: Score = 1

   b. Total number of SASI stocks within the same GDU:

      i. < 3: Score = 2

      ii. > 3: Score = 1

   c. Viability of other SASI stocks within the same GDU:

i. Mean viability = “High”, Score = 1

ii. Mean viability = “Medium”, Score = 2

iii. Mean viability = “Low or no other SASI stocks within GDU, Score = 3.

[What data/information do we need to obtain a biological attributes score? What/who are the sources for that info?]

Sum of scores and biological significance ratings (A + B + C):

5-8 = **Low**

9-13 = **Medium**

14-17 = **High**

Definition of Population Viability

Rating criteria and scores for evaluating the viability of salmon and steelhead populations as part of assessing the benefits and risks of hatchery programs in Puget Sound and coastal Washington:

Ne: Effective population size (estimated from known estimated numbers of spawners per year and generation time) Worksheet to be developed. (possible scores = 1-5)

N_e <100	Score = 1
100< N_e < 500	Score = 2
500 < N_e <2,500	Score = 3
2,500 < N_e <5,000	Score = 4
N_e > 5,000	Score = 5

Mean numbers of recruits per spawners (R/S) over preceding 10 years

a. R/S > 5	Score = 5
b. 3 < R/S < 5	Score = 4
c. 2 < R/S < 3	Score = 3
d. 1 < R/S < 2	Score = 2
e. R/S < 1	Score = 1

Proportion of natural spawners comprised of hatchery-origin fish (possible score = 1-4)

< 1 %	Score = 4
1 – 5 %	Score = 3

5-30% Score = 2

>30% Score = 1

For hatchery populations, this latter criterion would be chanced to Proportion of eggs, fry or adults from wild fish or another hatchery:

f. <1% Score = 4

g. 1-5 % Score = 3

h. 5-30 % Score = 2

i. > 30% Score = 1

Sum of scores and population viability ratings:

3-6 **Critical**

7-10 **At Risk**

11-13 **Healthy**

Definition of Population Habitat Conditions

Three categories of environment, habitat (e.g., watershed), are defined in terms of conditions that support the target species (i.e., Chinook salmon) with the assumption that these conditions would also provide for the needs of other native species of salmonids (these definitions implicitly assume that any pre-terminal harvest is part of the environment during the fish's whole life cycle).

1. **High** = Healthy: Productivity of the target species is high, everywhere and at all times, and the population is capable of growth and terminal harvest.
2. **Medium** = Limiting: The target species is productive enough for the population to sustain itself at a low level of harvest.
3. **Low** = Inadequate: The target species is unproductive and the population will go extinct, even without terminal harvest.

Habitats are characterized by Quality (HQ1), Quantity (HQ2), and Diversity (HD). An illustration of how these categories might be quantified suggests that a characterization of "Healthy" would require that HQ1 and HQ2 would combine such that the productivity of the population (recruits per spawner uninhibited by density, or some other measure) is greater than 5 and that the population has an abundance potential of 5,000 spawners. A categorization of "healthy" would require that HD is sufficient to support a variety of life history patterns (e.g., diverse smolt ages, emigration timing, a range of run timings, a range of spawning locations.)

A characterization of "Limiting" would require that HQ1 and HQ2 would combine such that the productivity of the population is at least 2, the population has an abundance potential of at least

500 spawners, and HD is restricted, supporting only a uniform age and size of smolts, a short duration of run timing, and a limited location for spawning.

Definition of Harvest Goals

High – harvest opportunity each year, spread over seasons

Medium – opportunity most year, for some seasons

Low – occasional opportunity, single run

0 – no harvest opportunity

Definition of Other Goals:

Educational

Cultural (ceremonial, first fish...)

Employment

Research

Program Purpose and Type

The **purpose** of the hatchery program is defined as either *conservation*, *harvest*, *both* and/or another purpose (such as *education*, *research* or *cultural/ ceremonial*).

The **type** of program is also included. Hatchery programs are classified as *integrated* if the goal is to minimize potential genetic divergence between the hatchery broodstock and the naturally-spawning population in the watershed where fish are released and returning adults trapped for broodstock. *Segregated* programs are classified as those in which the goal is to maintain the hatchery population as a distinct, or genetically segregated population.

Part Two

The Part Two worksheet is entitled *How Current Program Operations Compare to HSRG Operational Guidelines*. It is where the HSRG records the results of working with regional hatchery managers to understand current operations at the region's hatcheries. The HSRG then evaluates how these current operations compare to the "best practices" outlined in the HSRG's operational guidelines. The four areas considered in this evaluation are: 1) Culture Methods, 2) Accountability/Education, 3) Physical/Morphological/Ecological, and 4) Genetics/Conservation.

Part Three

The Part Three worksheet is entitled *Benefit/Risk Analysis; Recommendations and Alternatives*. Using the Part Three worksheet, the HSRG assesses the benefits and risks derived from each regional hatchery program on both the target stock and every other regional stock. This analysis leads to the group's scientific conclusions, which are recorded on the second half of the worksheet.

"GENERIC" BENEFIT/RISK TOOL WORKSHEETS

[See following pages]

Benefit-Risk Tool - Part 1. Summary of Goals for Affected Stocks and Habitat and Description of Current Hatchery Program for Region X

Stock	Goals				Current Hatchery Program		
	Category	Now	Short-Term	Long-Term	**Program Type** (S = Segregated, I = Integrated, B = Both)	**Program Purpose** (C = Conservation, H = Harvest, B = Both)	**Program Description**
Sub-region							
Stock A	BioSig						
	Viabil						
	Habitat						
	Harvest						
Stock B	BioSig						
	Viabil						
	Habitat						
	Harvest						
Stock C	BioSig						
	Viabil						
	Habitat						
	Harvest						
etc.	BioSig						
	Viabil						
	Habitat						
	Harvest						

Benefit-Risk Tool - Part 2: Operational Guidelines Questions Related to Genetics and Conservation for Region X.

Question applies to:			Operations questions derived from conditions for success in HSRG Framework Sections 1.1, 2.3 and 3.1 (**Genetics and Conservation**)	Answers to Operations Questions: (Y = Yes, N = No, I = Insuf. Info, NA = Not Applicable)					
Program Type (S = Segregated, I = Integrated, B = Both)	**Program Purpose** (C = Conservation, H = Harvest, B = Both)	**Not Applicable To:** (SH =Segregated/ Harvest, SC = Segregated/ Conservation)		**Program A**		**Program B**		**etc.**	
				Type	**Purpose**	**Type**	**Purpose**	**Type**	**Purpose**
Broodstock Choice									
B	B		1. Is the hatchery stock native to the watersheds in which it is released?						
I	B		3. Have eggs or adults been introduced from outside the watershed since inception of the hatchery program?						
Broodstock Collection									
B	B		4. Are adults randomly selected among all returning adults?						
B	B		5. Were sufficient numbers of donorscollected from the natural stock to minimize founder effects when the program was initiated?						
B	B		6. Are sufficient broodstock collected to maintain an effective population size of 1000 fish per generation? (How many males and females do you typically spawn?)						
I	B		7. If goal is to minimize genetic divergence, are at least 10% of the broodstock derived from wild fish each year? (How many wild fish do you incorporate into your broodstock each year?)						
I	C		8. If the wild population has 150 fish or more, is collection of wild broodstock limited to 30% of the population?						
B	B		9. Has any backfilling of egg shortages occurred in the recent past?						
B	B		10. Does pre-spawning mortality exceed 10%?						
B	B		11a) Do you have guidelines for acceptable contribution of hatchery origin fish to natural spawning? What do you do with surplus adults?						
B	B		11b) Are guidelines for hatchery contribution to natural spawning met for all affected naturally spawning populations? What do you do with surplus adults?						
I	C		13 b) Is a composite of naturally spawned and hatchery-bred fish spawning in the wild?						
I	B		13 d) Is the proportion of naturally spawning fish that are of hatchery origin known? If so, is it controlled?						
I	B		13 e) Is the composition of hatchery and wild fish in the broodstock known and controlled?						
B	B		14. Is the necessary security of the stocks maintained?						
I	C		16. Is the duration of the program clearly defined?						

Benefit-Risk Tool - Part 2: Operational Guidelines Questions Related to Genetics and Conservation for Region X.

Question applies to: Program Type (S = Segregated, I = Integrated, B = Both)	Program Purpose (C = Conservation, H = Harvest, B = Both)	Not Applicable To: (SH =Segregated/ Harvest, SC = Segregated/ Conservation)	Operations questions derived from conditions for success in HSRG Framework Sections 1.1, 2.3 and 3.1 (**Genetics and Conservation**)	Answers to Operations Questions: (Y = Yes, N = No, I = Insuf. Info, NA = Not Applicable) Program A Type	Program A Purpose	Program B Type	Program B Purpose	etc. Type	etc. Purpose
Spawning									
B	B		17. Are males and females available for spawning on a given day randomly mated?						
B	B		18. Do fish selected for broodstock have an equal opportunity to make a genetic contribution to the progeny gene pool? (How are eggs fertilized? Pairwise? Overlapping pairwise?, modified matrix? Etc.)						
I	B		19. Does the hatchery program include any natural spawning?						
Incubation									
I	B		20. Are full sib families incubated separately? (Are eggs from a single female incubated separately?)						
I	B		23. Are water sources used that match the hatching/emergence timing of naturally produced populations?						
Rearing									
I	B		28. Are fish reared under conditions that maximize the probability that all segments of the population contribute equally to the release population? (Is size grading practiced? If so, are slower growing fish culled?)						
B	B		29. Are all fish reared under environmental conditions that tend to maximize survival of all segments of the population? (Is growth modulation practiced?)						
B	B		31. Are excess juveniles culled randomly when necessary?						
I	B		33. Are the fish produced similar to natural fish in size, growth rate, morphology, behavior, physiological status, health, etc?						
B	B		34. Are fish reared under conditions that maximize homing fidelity?						
B	C		35. Are fish reared in multiple facilities or with redundant systems to reduce the risk of catastrophic loss?						
I	C		37. Are fish reared for the shortest period possible?						
B	C		40. Are families reared individually to maintain pedigrees?						
I	B		41. If required, are larger families culled to minimize family size variation?						

Benefit-Risk Tool - Part 2: Operational Guidelines Questions Related to Genetics and Conservation for Region X.

Question applies to:			Operations questions derived from conditions for success in HSRG Framework Sections 1.1, 2.3 and 3.1 (**Genetics and Conservation**)	Answers to Operations Questions: (Y = Yes, N = No, I = Insuf. Info, NA = Not Applicable)					
Program Type (S = Segregated, I = Integrated, B = Both)	**Program Purpose** (C = Conservation, H = Harvest, B = Both)	**Not Applicable To:** (SH =Segregated/ Harvest, SC = Segregated/ Conservation)		**Program A**		**Program B**		**etc.**	
				Type	**Purpose**	**Type**	**Purpose**	**Type**	**Purpose**
Release									
B	B		42. Are fish released at life stages and locations that maximize homing fidelity?						
I	B		43. For a given release date and location, are fish similar to the natural population in size, morphology, behavior, physiological status, health?						
I	B		44. Is volitional release practiced during the natural out-migration timing?						
B	B		45. Are marking/tagging techniques used to distinguish among segments of the hatchery population and between the hatchery and natural populations?						
I	C		46. Are fish identified with nonlethal detectable identification marks or tags?						
Adult migration									
B	H		47. Is the straying of hatchery fish into the wild controlled?						
S	H		48. Is the attraction of wild fish into the hatchery minimized?						
B	B		49. Are hatchery fish identified so the status of the natural population is not masked?						

Benefit-Risk Tool - Part 2: Operational Guidelines Questions Related to Physiology, Morphology, and Ecology for Region X.

Question applies to: Program Type (S = Segregated, I = Integrated, B = Both)	Program Purpose (C = Conservation, H = Harvest, B = Both)	Not Applicable To: (SH =Segregated/ Harvest, SC = Segregated/ Conservation)	Operations questions derived from conditions for success in HSRG Framework Sections 1.2.1-1.2.3, 2.1, 2.2, 2.2.4 (**Physiology, Morphology, and Ecology**)	Answers to Operations Questions: (Y = Yes, N = No, I = Insuf. Info, NA = Not Applicable) Program A Type	Program A Purpose	Program B Type	Program B Purpose	etc. Type	etc. Purpose
Broodstock Choice									
B	B	SH	1. Is the broodstock local or locally adapting?						
I	B		2. Does the broodstock chosen for initiating hatchery programs represent populations native or adapted to the watersheds in which they will be released?						
S	H		3. Does the broodstock chosen minimize negative ecological interactions?						
Broodstock Collection									
B	B	SH	4. Are representative samples of the adult population collected with respect to size, age, sex ratio or other traits important to long term fitness?						
B	B	SH	5. Are broodstock maintained on natural water temperature profiles to provide optimum maturation and gamete development?						
B	B		6. Does the number of broodstock collected maintain program size within carrying capacity of the natural environment?						
B	B		7. Are adult fish or carcasses provided for upstream planting?						
Spawning									
			None						
Incubation									
I	B		8. Does the program use water sources to match hatching/emergence timing of naturally produced population?						
B	B		9. Does the number of eggs incubated maintain program size within the carrying capacity of the natural environment?						
Rearing									
B	B	SH	10. Does the program use a diet and growth regime that mimics natural growth patterns?						
I	B		11. Are natural rearing conditions simulated for temperature, photoperiod, hydraulic characteristics, feeding conditions, and predator avoidance?						
B	B		12. Are adequate flows maintained in the by-pass reach?						
B	B		13. Has a riparian management plan been implemented that incorporates vegetation management, herbicide and pesticide use, and surface water management provisions?						
B	B		14. Does the facility operate within the limitations established in National Pollution Discharge Elimination System permit?						
B	B		15. Has and on or off-site habitat mitigation plan been implemented?						
B	B		16. Does the number of fish reared maintain program size within carrying capacity of the natural environment?						
I	B		17. Are the fish produced qualitatively similar to natural fish in size, morphology, behavior, physiological status, health, and other attributes?						
I	B		18. Are natural juvenile rearing conditions simulated for rearing density, temperature, hydraulic characteristics, habitat complexity, feeding conditions, and predator avoidance behavior?						
B	B	SC	19. Are fish reared under conditions that maximize homing fidelity?						

Benefit-Risk Tool - Part 2: Operational Guidelines Questions Related to Physiology, Morphology, and Ecology for Region X.

Question applies to:			Operations questions derived from conditions for success in HSRG Framework Sections 1.2.1-1.2.3, 2.1, 2.2, 2.2.4 (**Physiology, Morphology, and Ecology**)	Answers to Operations Questions: (Y = Yes, N = No, I = Insuf. Info, NA = Not Applicable)					
Program Type (S = Segregated, I = Integrated, B = Both)	**Program Purpose** (C = Conservation, H = Harvest, B = Both)	**Not Applicable To:** (SH =Segregated/ Harvest, SC = Segregated/ Conservation)		**Program A**		**Program B**		**etc.**	
				Type	**Purpose**	**Type**	**Purpose**	**Type**	**Purpose**
Release									
I	B		20. Are fish released within the size range of naturally produced fish from which the hatchery population is derived?						
I	B		21. Are volitional releases during natural out-migration timing practiced?						
Type 1 Interactions – Hatchery/natural fish -- Predation (Inter and intra-specific)									
I	B	SC	22 a. Are fish released at sizes and life history stages similar to those of natural fish of the same species?						
B	B	SC	22 b. Are fish released in areas or at life history stages where they are unlikely to encounter or prey upon natural fish of the same or other species?						
B	B	SC	22 c. Are fish released in a manner so they are unlikely to encounter or prey upon natural fish of the same or other species?						
B	B	SC	22 d. Are fish released in numbers that do not exceed the carrying capacity for the natural population?						
B	B	SC	22 e. Are fish released in stream reaches within the historic range of that species?						
B	B	SC	22 f. Are fish released in a manner that simulates natural migratory patterns?						
B	B	SC	22 g. Are fish released in areas with adequate imprinting to the facility or desired stream reach?						
B	B	SC	23 a. Are fish released at locations where they are unlikely to encounter natural fish that are negatively affected by hatchery fish?						
B	B	SC	23 b. Are fish released in numbers that do not exceed the carrying capacity of the natural environment?						
B	B	SC	23 c. Are fish released at sizes and life history stages similar to those of natural fish of the same species?						
Type 2 Interactions – Adult Returns & offspring of hatchery fish/natural fish									
B	B	SC	24 a. Are fish released in areas with adequate imprinting to facility or desired stream reach?						
I	B		24 b. Are fish released in numbers that do not exceed the carrying capacity of the natural environment?						
B	B	SC	24 c. Are fish released into properly functioning freshwater, estuarine and marine habitat?						
Adult migration									
B	B	SC	25. Is unimpeded passage provided for wild fish through hatchery structures and by-pass reaches?						
B	B	SC	26. Does the hatchery operate to allow all migrating species of all ages to pass through hatchery related structures to maximize use of natural habitat?						
I	B		27. Are adults distributed upstream of hatchery to meet habitat capacity?						

Benefit-Risk Tool - Part 2: Operational Guidelines Questions Related to Culture Methods for Region X.

Question applies to:			Operations questions derived from conditions for success in HSRG Framework Sections 1.2.4, 1.3, and 3.2 (**Culture Methods**)	Answers to Operations Questions: (Y = Yes, N = No, I = Insuf. Info, NA = Not Applicable)					
Program Type (S = Segregated, I = Integrated, B = Both)	**Program Purpose** (C = Conservation, H = Harvest, B = Both)	**Not Applicable To:** (SH =Segregated/ Harvest, SC = Segregated/ Conservation)		**Program A**		**Program B**		**etc.**	
				Type	**Purpose**	**Type**	**Purpose**	**Type**	**Purpose**
Broodstock Choice									
S	H		1. Does the broodstock chosen have a history of no pathogens?						
B	B		2. Is the broodstock indigenous to the watershed?						
S	H		3. Does the broodstock chosen or developed have the desired life history traits to meet harvest goals?						
Broodstock Collection									
B	B		4. If broodstock choice is from another drainage, are eggs preferentially transferred? Are fish or eggs held in quarantine as described in the Salmonid Disease Control Policy of the Fisheries Co-Managers of Washington State (disease control policy).						
B	B		5. Are broodstock maintained on pathogen-free and/or fish-free water supply?						
B	B		6. Does attending fish pathologist monitor and recommend treatments to maximize survival as needed?						
B	B		7. Are pre-spawning mortalities disposed of in a manner that prevents pathogen transmission to the receiving watershed?						
B	B		8. Are disinfection procedures implemented that prevent pathogen transmission between stocks of fish on site?						
B	B		9. Are species-specific holding recommendations followed for water quality, flows, temperature, and density?						
B	B		10. Is the broodstock collected and held in a manner that minimizes prespawning mortality?						
Spawning									
B	B	SC	11. Is a minimum effecitive population size of 1000 fish per generation maintained?						
B	B		12. Is pathogen sampling at spawning sufficient to provide quantitative and qualitative information for needed pathogen control measures that may be necessary for resultant transfers or rearing of progeny?						
B	B		13. Are eggs water-harden in iodophor solution as described in the disease control policy?						
B	B		14. Are carcasses disposed of in a manner that prevents pathogen transmission to the receiving watershed?						
B	B		15. Is spawning waste collected and disinfected prior to discharge to receiving water?						
B	B		16. Are disinfection procedures implemented that prevent pathogen transmission between stocks of fish on site?						

Benefit-Risk Tool - Part 2: Operational Guidelines Questions Related to Culture Methods for Region X.

Question applies to:			Operations questions derived from conditions for success in HSRG Framework Sections 1.2.4, 1.3, and 3.2 (**Culture Methods**)	Answers to Operations Questions: (Y = Yes, N = No, I = Insuf. Info, NA = Not Applicable)					
Program Type (S = Segregated, I = Integrated, B = Both)	**Program Purpose** (C = Conservation, H = Harvest, B = Both)	**Not Applicable To:** (SH =Segregated/ Harvest, SC = Segregated/ Conservation)		**Program A**		**Program B**		**etc.**	
				Type	**Purpose**	**Type**	**Purpose**	**Type**	**Purpose**
Incubation									
B	B		17. Does incubation occur on pathogen-free and/or fish-free water supply?						
B	B		18. Are species-specific incubation recommendations followed for water quality, flows, temperature, substrate, or density parameters to prevent syndromes such as "gas bubble disease", "cold water disease", "blue sac", etc.)?						
B	B		19. Are eggs monitored when needed to determine fertilization efficiency and embryonic development?						
B	B		20. Are incubating eggs treated when recommended by attending fish pathologist?						
B	B		21. Following eye-up stage, are eggs inventoried, dead or undeveloped eggs removed, and disinfected as described in the disease control policy?						
B	B		22. Are eggs (dead or culled) discarded in a manner that prevents pathogen transmission to the receiving watershed?						
B	H		23. Are fry removed from incubation units when 80-90% of observed fry have yolk-sac material that is 80-90% utilized and contained within body cavity ("button-up")						
B	B		24. Are disinfection procedures implemented that prevent pathogen transmission between stocks of fish on site?						
B	B		25. Are appropriate water temperature profiles maintained to provide optimum embryo development?						
B	B		26. Are incubator loading and densities maintained at levels that ensure optimum survival of eggs and fry?						
B	B		27. Is substrate used to promote suitable fry distribution, optimum size, and appropriate emergence timing?						

Benefit-Risk Tool - Part 2: Operational Guidelines Questions Related to Culture Methods for Region X.

Question applies to:			Operations questions derived from conditions for success in HSRG Framework Sections 1.2.4, 1.3, and 3.2 (**Culture Methods**)	Answers to Operations Questions: (Y = Yes, N = No, I = Insuf. Info, NA = Not Applicable)					
Program Type (S = Segregated, I = Integrated, B = Both)	**Program Purpose** (C = Conservation, H = Harvest, B = Both)	**Not Applicable To:** (SH =Segregated/ Harvest, SC = Segregated/ Conservation)		**Program A**		**Program B**		**etc.**	
				Type	**Purpose**	**Type**	**Purpose**	**Type**	**Purpose**
Rearing									
B	B		28. Does rearing occur on pathogen-free and/or fish free water supply?						
B	B		29. Are species-specific recommendations followed for water quality, flows, temperature, or density parameters to reduce adverse stress and related pathogens and/or disease syndromes?						
S	H		30. Are facility and species-specific recommendations for water quality, temperature, loading, and density followed to maximize recruitment to fisheries?						
B	B		31. Are settleable solids, unused feed and feces periodically removed to ensure proper cleanliness of rearing container?						
B	B		32. Are mortalities removed daily and disposed of in a manner that prevents pathogen transmission to the receiving watershed?						
B	B		33. Are fish health examinations performed at a minimum of once per month and more frequently when required?						
B	B		34. Whenever possible, are vaccines used to minimize the use of antimicrobial compounds?						
B	B		35. Are fish treated with appropriate chemicals or drugs as recommended by fish pathologist?						
B	B		36. Does the operator follow proper feeding rates, conduct periodic feed quality analysis, and store feed under proper conditions to prevent nutritional disorders?						
B	B		37. Are disinfection procedures implemented that prevent pathogen transmission between stocks of fish on site?						
S	B		38. Are predators excluded from ponds to prevent the spread of pathogens between containers?						
B	B		39. In the event of an epizootic, are: Treatment recommendations of attending pathologist followed? Are affected containers isolated? Is effluent sanitized if possible?						
B	B		40. Are appropriate physical and chemical characteristics of water inflow and effluent (suspended solids, temperature, dissolved gases, pH, mineral content, and potential toxic metals) maintained to promote growth and survival?						
B	B		41. Are accurate fish inventory data maintained (e.g. Hat-Pro) with a minimum of handling stress?						
B	B		42. Are appropriate flow and density indexes maintained for the species and life stage being reared?						
B	B		43. Is the correct amount and type of food provided to achieve the desired growth rate, body composition, and condition factors for the species and life stage being reared?						
I	B		44. Do the hatchery populations exhibit growth rates, body composition and condition factors similar to natural populations?						

Benefit-Risk Tool - Part 2: Operational Guidelines Questions Related to Culture Methods for Region X.

Question applies to:			Operations questions derived from conditions for success in HSRG Framework Sections 1.2.4, 1.3, and 3.2 (**Culture Methods**)	Answers to Operations Questions: (Y = Yes, N = No, I = Insuf. Info, NA = Not Applicable)					
Program Type (S = Segregated, I = Integrated, B = Both)	**Program Purpose** (C = Conservation, H = Harvest, B = Both)	**Not Applicable To:** (SH =Segregated/ Harvest, SC = Segregated/ Conservation)		**Program A**		**Program B**		**etc.**	
				Type	**Purpose**	**Type**	**Purpose**	**Type**	**Purpose**
Release									
B	B	SC	45. Are all fish examined for presence of "reportable pathogens" as defined in the disease control policy at the assumed pathogen prevalence Level (APPL) of 5% no less than 3 weeks prior to release?						
B	B	SC	46. Are attending fish pathologist recommendations followed for treatments prior to release?						
B	B	SC	47. Are fish released in same drainage as rearing facility?						
B	B		48. Are transfers out of drainage inspected as above and accompanied by appropriate notifications to responsible/regulatory parties as described in the disease control policy?						
B	B	SC	49. Are fish released at times of the year and sizes to allow adoption of multiple life history strategies?						
S	H		50. Are fish released at a time, size, location, and in a manner that maximizes recruitment to fisheries?						
B	B	SC	51. Are releases consistent with the ability of the habitat (freshwater, estuarine, and marine near-shore and off-shore) to support the number and life stage being released?						
Post Release and Adult migration									
B	B	SC	52. Are fish released into properly functioning habitats?						
B	B	SC	53. Are the number of fish released compatible with habitat carrying capacity?						
B	H		54. Is sufficient water flow provided to attract and separate adults into hatchery?						

Benefit-Risk Tool - Part 2: Operational Guidelines Questions Related to Accountability and Education for Region X.

Question applies to: Program Type (S = Segregated, I = Integrated, B = Both)	Program Purpose (C = Conservation, H = Harvest, B = Both)	Not Applicable To: (SH =Segregated/ Harvest, SC = Segregated/ Conservation)	Operations questions derived from conditions for success in HSRG Framework Sections 3.3, and 4 (**Accountability and Education**)	Answers to Operations Questions: (Y = Yes, N = No, I = Insuf. Info, NA = Not Applicable) Program A Type	Program A Purpose	Program B Type	Program B Purpose	etc. Type	etc. Purpose
Accountability									
B	B		1. Are all hatchery personnel aware of the goals for the hatchery with respect to conservation, harvest and other purposes?						
B	B		2. Are expenditures tracked to assure that funds are expended as intended for the hatchery program?						
B	B		3. Are KEY staff aware of the funding available for carrying out the various activities in the production cycle so that it can be done the most cost effective manner?						
B	B		4. Is all new relevant information from research or other sources made available to hatchery staff and others and used for attaining goals?						
B	B		5. Is the most recent information obtained from monitoring and evaluation programs for the production cycle, including performance indicators and progress toward goals, taken into consideration when determining whether hatchery operations should be changed or not?						
B	B		6. Is there a management program in place that assures that information pertaining to items 1-4 is available on a "real-time" basis and that changes warranted by that information are implemented?						
B	B		7. Are standards specified for in-culture and post release performance of hatchery fish and their offspring?						
B	B?		8. Are there state or federal laws that constrain the program by specifying objectives, such as numbers and size of smolt produced?						
Education									
Hatchery Operations									
B	B		9. Is the hatchery facility open to the public during hours of operation?						
B	B		10. Are the hatchery operations visible to facility visitors?						
B	B		11. Are hatchery operations (egg take, incubation, rearing) demonstrated to the public?						
B	B		12. Does the facility have a fish ladder and/or adult holding facilities that are open to the public?						
Hatchery Physical Plant									
B	B		13. Does the hatchery have signage describing the facility, fish production goals, ties to management goals, ecosystem function?						
B	B		14. Is there a visible link to riparian zone such as viewing boardwalk or bridge?						
B	B		15. Is the facility used by other fish and wildlife programs?						
B	B		16. Does the hatchery schedule tours for groups?						
Educational Outreach Programs									
B	B		17. Does the program provide opportunities for student interns?						
B	B		18. Does the program provide opportunities for citizen volunteer involvement?						
B	B		19. Does the agency maintain a web page describing the hatchery program?						
B	B		20. Is a pamphlet or brochure describing agency or hatchery programs available?						
Hatchery Program									
B	B		21. Are eggs or fish provided to volunteer groups?						
B	H?		22. Are eggs or fish provided to educational groups i.e. "Salmon in the Classroom"?						
Hatchery Staff									
B	B		23. Is hatchery staff involved in community/volunteer meetings or outreach programs?						
B	B		24. Does hatchery staff regularly give classroom presentations?						
B	B		25. Does hatchery staff participate in formal professional presentations/seminars?						
Formal Research									
B	B		26. Is the facility used or does staff participate in agency research projects?						
B	B		27. Is the facility used or does staff participate in university or other cooperative research projects?						
B	B		28. Are data and information pertaining to the program accessible to interested researchers?						

Benefit-Risk Tool - Part 3. Benefit/Risk Analysis; Recommendations and Alternatives for Program Y

Potentially Affected Stocks	Benefits/Risks Evaluated: Program Y, Region X For each potentially affected stock, identify a) significant benefits to, and b) major conflicts with...	
	Benefits	**Risks**
Sub-region		
Stock A		
Stock B		
Stock C		
etc.		

Life Stage	Hatchery Program Recommendations: Program Y, Region X	
	Operations	**Monitoring**
Broodstock Choice		
Broodstock Collection		
Spawning		
Incubation		
Rearing		
Release		
Post Release		
Adult Migration		

General Comments - Alternative Programs for Consideration – Different Facility and Production Solutions, etc,	
Program and Facilities	**Monitoring**
Operations	**Accountability**

H. Research Grants

Funded Grants - 2000 Project Descriptions

Category A: Sustainable Fisheries

Development of Field Methods to Determine the Effects of Hatchery Release Methods on Residualism and Interactions Between Hatchery and Wild Juvenile Salmonids in Relation to Stream Carrying Capacity

Project Sponsor: NMFS and WDFW

Principal Investigators: Stephen Riley, NMFS; Howard Fuss, WDFW

HSRG + Sponsor Share = Total Cost: $91,941 + $102,067 = $194,008

Associate Investigators: Todd Pearsons, Geraldine VanderHaegen, WDFW; Barry Berejikian, Walt Dickoff, NMFS

Project Summary: The objective of this project is to develop a cost-effective method to evaluate the effects of hatchery releases on wild juvenile salmonids. We propose to develop field methods designed to determine how hatchery releases affect the abundance, behavior, habitat use, growth, stomach fullness, and condition of wild juvenile salmonids. Field methods will be applied in areas upstream and downstream of hatchery release sites before and after releases, and will involve three levels of effort: a) underwater observation of numbers and behavior of wild and hatchery juveniles; b) estimation of territory size and habitat use of wild juveniles; and c) estimation of the growth, stomach content volume, and physiological status of wild and hatchery juveniles captured by electrofishing or angling. Comparisons between upstream and downstream sites will be used to determine the degree to which wild fish are affected by hatchery releases and the extent of redistribution of hatchery residuals. We will also use these data to estimate the sample size necessary to obtain adequate statistical power of all comparison, and the costs associated with each component of the study will be determined. Similar procedures could be used to evaluate hatchery releases in a variety of streams coast wide. Underwater observations will also be used to assess the level of residualism related to certain hatchery practices such as flush and volitional releases and outplanting. Ultimately, these methods could be routinely applied as part of hatchery evaluations that are likely to be required under the ESA.

Test Commercial Selective Harvest Gears

Project Sponsor: Willapa Alliance

Principal Co-Investigators: Mark Heckert,

HSRG + Sponsor Share = Total Cost:

Willapa Alliance; Geraldine VanderHaegen, WDFW

\$49,260 + \$53,374 = \$102,634

Associate Investigators: WDFW regional staff

Project Summary: On the Naselle River, Willapa Bay, the Willapa Alliance and WDFW propose to test two commercial live capture gears to selectively remove adult hatchery fish from commingled wild stocks. Removing returning adult hatchery salmon will reduce the number of hatchery adults on the spawning grounds, and thereby reduce gene flow and ecological interactions between hatchery and natural spawners. We will also install an adult trap at Naselle Hatchery to collect hatchery broodstock. We will use a series of mark and recapture experiments to estimate long-term survival of released fish, the proportion of hatchery fish that could be removed with these gears and to collect data characterizing the run. If successful, the project will assist Naselle Hatchery in meeting its Chinook egg take goals, will remove hatchery fish from the spawning grounds, and will provide fishing opportunity for commercial fishermen and will evaluate the impacts of selective commercial fishing gear on released fish. This method of removing hatchery adults would be applicable throughout Washington. Our progress and results will be shared at community meetings, by mailings, through annual reports and by publication in a peer-reviewed journal. During the fishing season our progress will be posted daily on the internet.

Impacts of Size Selective Gillnet Fisheries on Puget Sound Coho Salmon Populations

Project Sponsor: WDFW

Principal Investigators: Curtis Knudsen, Craig Busack, WDFW

HSRG + Sponsor Share = Total Cost:
\$11,427 + \$3,720 = \$15,147

Project Summary: We will document historical trends in size selectivity of terminal Puget Sound and coastal gillnet fisheries by comparing coded-wire tagged recoveries from the fishery to recoveries from the terminal spawning areas (trap or hatchery). Utilizing the coded-wire tag database allows us to focus on specific marked populations of coho caught within terminal area fisheries rather than having to deal with aggregations of mixed populations making estimates of size selectivity much more accurate. Reduced body size impacts a population’s productivity and the reproductive fitness of returning adults. We will describe the demographic and genetic impacts to these populations caused by reduced body size selective fisheries. The rates of decline in populations experiencing different intensities of size selection will be compared to determine if they are correlated with the magnitude of size selectivity and fishing intensity and what the background level of size decline may be from other sources such as reduced ocean productivity. Understanding the consequences of size selective fisheries will allow management decisions to be made that take into account the impacts on hatchery and wild population’s productivity and reproductive fitness.

Category B: Recover and Conserve Natural Spawning Populations

Genetic Characterization of Lake Ozette Sockeye Salmon

Project Sponsor: Makah Fisheries Management

Principal Investigators: Ken Currens, NWIFC; Jim Shaklee, WDFW; Michael Crewson, Makah Tribe

HSRG + Sponsor Share = Total Cost: $22,000 + $45,920 = $67,920

Associate Investigator: Jeffrey Grimm, WDFW

Project Summary: This project provides baseline genetic and demographic information for testing 1) whether sockeye salmon and be successfully reintroduced into tributaries of Lake Ozette, where they were extinct, and 2) whether distribution and abundance of beach spawning populations can be rebuilt through supplementation. Genetic profiles of Lake Ozette sockeye salmon, which are protected under the ESA, and kokanee salmon, which are not, are necessary to guide brood stock selection and to monitor hybridization and gene flow. Profiles will be developed from 6-8 microsatellite DNA loci. The ability to mark and identify hatchery is also essential to monitor recovery efforts, but most hatchery-produced sockeye salmon will be released before external marking are possible. Consequently, this project tests eolith marking as a tool. The combination of genetic data and otolith marking will allow the co-managers to develop effective strategies to monitor abundance, distribution, and interactions among natural and hatchery populations. Project results will be summarized in a final technical report to the funding agency, co-managers, and National Marine Fisheries Service (NMFS) and will be incorporated into the Hatchery Genetic Management Plan and recovery plan for Lake Ozette sockeye salmon.

White River Acclimation Pond Evaluation

Project Sponsor: WDFW

Principal Investigators: Chuck Baranski, WDFW; Blake Smith, Puyallup Tribe; Richard Johnson, Muckleshoot Tribe

HSRG + Sponsor Share = Total Cost: $40,508 + $154,368 = $194,876

Associate Investigator: Curt Knudsen, WDFW

Project Summary: One strategy employed to increase natural spring Chinook spawning in the upper White River is to release smolts from three upriver acclimation sites (Huckleberry Cr., Cripple Cr., Clearwater R.). Survival from smolt to spawner and the distribution of pond-origin spawners have not been adequately evaluated. If survivals are low or if returning adults are widely distributed in the Puyallup basin (particularly into fall Chinook production areas), alternative strategies will need to be developed. Standard CWT tagging is not a suitable took in this case because all nose tagged fish are removed from the upriver population. This proposal would utilize "body tagging" as a means of identifying and evaluating these smolt releases. The SSSCTC proposes that WDFW "body tag" (no marks) a total of 400,000 White River Chinook fry at Hupp Springs and White River hatcheries prior to their transfer to the acclimation sites. Tag retention will be estimated at release. Survival and spawning distribution will be quantified by sampling unmarked Chinook returns to White River Hatchery (Muckleshoot Tribe), the Buckley trap and haul facility (Muckleshoot and Puyallup Fisheries staff), Voights Creek Hatchery (WDFW) and Puyallup basin natural spawning grounds (WDFW, Muckleshoot and Puyallup staffs). SSSCTC proposes to tag a complete brood cycle (5 years). Results will be presented annually in the *Northwest Fishery Resource Bulletin's* Project Report Series.

Differences in Natural Production between Hatchery and Wild Coho Salmon: A Proposal to Measure the Influence of the Degree of Hatchery Ancestry on Natural Production Success

Project Sponsor: WDFW and NMFS

Principal Investigators: Howard Fuss, Patrick Hulett, Cameron Sharpe, WDFW; Ken Currens, NWIFC; Michael Ford, Jeffrey Hard, NMFS

HSRG + Sponsor Share = Total Cost
$146,973 + $96,496 = $243,469

Project Summary: Natural production of coho will be evaluated to measure (and identify causal factors for) differences in reproductive competence between hatchery and wild fish. Analyses of morphological (size/age/fecundity/body shape), behavioral (run-time/spawning/rearing), and genetic (msDNA) data will be used to carry out two phases of work. Phase 1 (from 2000 to 2005) will examine reproductive success of hatchery and wild coho spawning together. Phase 2 (from 2006 to 2011) will examine reproductive success of the adult offspring of the Phase 1 fish. Those fish are wild but individually will have varying degrees of hatchery ancestry. Phase 1 will directly measure the ability of hatchery coho to reproduce in the natural environment relative to wild fish of similar genetic backgrounds n the same basin. Phase 2 will allow a determination of the genetic basis for differences in reproductive success between hatchery and wild fish. To facilitate this research it is essential to modify the existing barrier at Minter creek Hatchery in south Puget Sound to control access of salmonids to Minter Creek spawning grounds. The project will be conducted as a partnership between WDFW, NMFS, and the NWIFC. In addition to annual progress reports, final reports or peer-reviewed publications will be produced at the end of each major research phase. The work will increase understanding of differences in reproductive fitness between hatchery and wild fish and, further, will demonstrate how a large hatchery program can be managed without conflicting with natural production objectives in the same watershed.

Snow Creek Coho Recovery Program

Project Sponsor: WDFW

Principal Investigators: Steve Schroder, Thom Johnson, WDFW

HSRG + Sponsor Share = Total Cost
$10,000 + $46,208 = $56,208

Collaborators: Wild Olympic Salmon, North Olympic Salmon Coalition

Project Summary: In the mid-nineteen seventies, as many as 1,400 adult coho and thousand of coho smolts were observed in Snow Creek, a Discovery Bay stream. However, drastic reductions in adult (often<100 and as few as three) and smolt abundance have occurred since 1991. Beginning in the fall of 1998, WDFW and local volunteer groups began an effort to recover this stock. Every returning adult was captured at a permanent weir located near the mouth of the stream. The fish were artificially spawned and their eggs were incubated at the Hurd Creek Hatchery. Eggs from each female were split into three portions, and each group received a unique thermal otolith mark for later identification. Eggs from two of the groups were placed into remote site incubators that were established in Snow Creek and its main tributary, Andres Creek. The remaining eggs were left in the hatchery and the fish produced form them were cultured for either seven or ten months. The reared fish received CWTs. Those fed for seven months had tags placed in their snouts while those reared for ten months had tags placed in their adipose fins. The fish reared for seven months were released into Crocker Lake in November. The second group of reared fish will be place into Crocker Lake in late February. They are expected to over-winter in the lake and emigrate out of system in the spring of 2000. This approach will be continued annually until 2006 and if abundance increases, coho will be allowed to spawn naturally in the system to produce another type of treatment. The objectives of this study are to assess how many smolts are produced from each type of release, to see if size and out-migration timing differ because of treatment origin, to compare the marine survival of smolts originating from each type of release, to determine how differing rearing treatments may have affected adult attributes (e.g. incidence of precocious maturity, size, fecundity, egg size, reproductive effort) and to examine how annual variation in environmental condition may affect fish from each treatment. Results will be presented in the peer-reviewed literature, and annual reports describing project accomplishment will be produced. Data obtained from this work will be used to refine coho recovery efforts throughout Puget Sound and the Washington coast.

Hamma Hamma River Steelhead Supplementation Evaluation

Project Sponsor: NMFS

Principal Investigators: Barry Berejikian, NMFS; Thom Johnson, WDFW; Rick Endicott, LLTK; Al Adams, HCSEG

HSRG + Sponsor Share = Total Cost
$34,000 + $58,562 = $92,562

Associate Investigators: Chris Weller, PNPTC; Kathy Hopper, LLTK; Steve Schroder, WDFW

Collaborators: Point No-Point Treaty Council

Project Summary: Conservation hatcheries are playing an increasing role in recovery efforts for imperiled salmonid populations in the Pacific Northwest. This research will be carried out through a cooperative partnership between non-profit organizations (Hood Canal Salmon Enhancement Group and Long Live the Kings), Washington Department of Fish and Wildlife, National Marine Fisheries Service, and the Point No Point Treaty council, established to apply conservation hatchery strategies to salmon recovery in Hood Canal. The project will evaluate the contribution of a steelhead (*Oncorhynchus mykiss*) supplementation program, implementing conservation hatchery protocols, to changes in the abundance of steelhead in the Hamma Hamma River, WA, and will determine the program's impact by comparing changes in steelhead abundance to other Hood Canal Rivers. Recent research suggests that culturing salmonids under more natural conditions, or implementing alternative release strategies may reduce genetic divergence and harmful effects on target wild populations. The project has an excellent opportunity to succeed in empirically testing the merits of using artificial propagation for conservation purposes. Results of the project will be reported annually to the funding agency and published in peer-reviewed scientific literature.

Category C: Improve Quality and Cost-Effectiveness of Hatchery Programs

Development of Engineered Streams for Salmon Production

Project Sponsor: University of Idaho

Principal Investigators: Ernest Brannon, WSU/UI; Bill Kinsel, WSU; Howard Fuss, WDFW

HSRG + Sponsor Share = Total Cost
$48,301 + $20,290 = $68,591

Project Summary: Development of an engineered stream is proposed as a new concept in hatchery supplementation. In collaboration with WDFW development of engineered streams is proposed by UI/WSU as a long-range alternative to hatcheries for supplementation of weak or failing wild salmonids populations. The objectives are to provide natural-type engineered streams for coho salmon production that result in wild smolt quality and to monitor performance as a demonstration project for the new hatchery concept. The approach is to develop artificial streams for use as salmon habitat with engineering specification based on biological criteria of the species targeted, while maintaining genetic specificity, diversity, and natural smolt quality. The artificial stream will substitute for, or be used in conjunction with, standard hatcheries. Natural feed with supplemental artificial feed will be the source of food. The site selected is Hatchery Creek located immediately behind the WDFW hatchery on the Dungeness River. The present upper creek channel will be enhanced with habitat structures, pools and riffles, and cover to mimic natural coho habitat. Coho stock will be introduced from the Dungeness by planting eyed eggs to provide the determined ultimate density of fish/m^2. Performance will be based on monitoring of fish condition at migration, residence time, and biomass sustained. Quality will be based on residence time and fish condition monitored over the residence period. Post-migration monitoring will involve adult return success based on thermal marks compared to hatchery fish. Results will be published and implemented through application at other sites.

Increase Post-Release Survival by Rearing Coho with NATURES Semi-Natural Raceway Habitat

Project Sponsor: NMFS

Principal Investigators: Desmond Maynard, Thomas Flagg, John Colt, NMFS; Geraldine VanderHaegen, WDFW

HSRG + Sponsor Share = Total Cost
$80,000 + $75,115 = $155,115

Project Summary: It has been repeatedly demonstrated that rearing Chinook salmon in NATURES semi-natural raceway habitat increases their instream survival. Here, WDFW and NMFS are proposing research to determine if NATURES rearing also increases the number of coho salmon recruiting to the fishery and spawning population. The research will be conducted with salmon grown in standard concrete raceways at Puget Sound hatcheries. At each hatchery, there will be control and semi-natural habitat raceways. The experimental habitat will be created by fitting the raceways with: 1) gravel pavers, 2) fir tree instream structure, and 3) camouflage net overhead covers. Salmon will be reared in the raceways for at least 90 days before release. Fish growth, color development, and health will be routinely monitored and compared. Experimental and control fish will be coded-wire-tagged to measure their contribution to the fishery and spawning population. NATURES semi-natural raceway habitat rearing is expected to increase the relative number of fish recruiting to the fishery and spawning population by 25%. Resource managers can use this increased survival to: 1) increase the number of recruits per smolt released, 2) reduce the number of broodstock salmon culture programs must use to produce a given number of recruits to the next generation, and 3) enhance the operational efficiency of mitigation and salmon enhancement programs. We will submit all of our results to peer-reviewed journals for publication.

Using Semi-Natural Rearing Habitat to Improve Smolt-Adult Survival of Chinook Salmon

Project Sponsor: WDFW

Principal Investigators: Geraldine Vander-Haegen, WDFW; John Barr, Bill St. Jean, Nisqually Tribe

HSRG + Sponsor Share = Total Cost
$19,092 + $20,150 = $39,242

Collaborator: Northwest Indian Fisheries Commission

Project Summary: WDFW and the Nisqually Tribe are cooperating to test the hypothesis that the addition of artificial structures to a large rearing pond will increase the smolt-to-adult survival of Chinook salmon. At Clear Creek Hatchery on the Nisqually River (Pierce County), floating and bottom structures will be installed into a large Chinook rearing pond. A second pond identical to the first will be used as a control. Fish in both ponds will be reared identically except for the addition of the artificial structures. Growth and health of fish form each pond will be compared during rearing. Fish from each pond will be coded-wire-tagged and recoveries of tagged adults in fisheries and at the hatchery will be used to compare survival of each group of fish. If the addition of artificial structures to the Clear Creek rearing ponds increases the smolt-to-adult survival, more hatchery adults will be available for harvest, and the techniques will be directly applicable to the Nisqually Tribe's supplementation plan for recovering Chinook. The increased smolt-to-adult survival may reduce the number of wild broodstock need to produce a given number of recruits in the next generation and reduce the number of fish that must be released to provide the desired number of adults. The study will be repeated over three brood years and the final results will be published in a peer-reviewed journal. Annual report will be made available to all interested parties.

Category D: Protect Genetic Resources

Interactions between Wild and Hatchery Steelhead: Evaluating Key Assumptions

Project Sponsor: University of Washington

Principal Investigators: Thomas Quinn, UW

HSRG + Sponsor Share = Total Cost
\$24,000 + \$34,428 = \$58,428

Associate Investigator: Paul Bentzen, UW
Collaborators: Weyerhaeuser, NMFS, LLTK, Willapa Bay Alliance

Project Summary: Natural resource agencies are challenged to not only maintain the overall abundance of salmon and steelhead but also to maintain their genetic and ecological diversity. Hatchery production, designed to achieve the first objective, sometimes conflicts with the second. To prevent deleterious interactions, steelhead in Washington have been bred to return early in the year with the hope that genetic, ecological and fisheries interactions with wild fish can be minimized. The recent establishment of hatchery steelhead at Forks Creek presents a unique opportunity to examine the assumptions underlying this innovative approach. We request funds to supplement an ongoing study, supported by the Weyerhaeuser Foundation and with cooperation form Long Live the Kings, to sample hatchery and naturally produced steelhead at discrete juvenile and adult life history stages. We will sample all adults spawned at the hatchery, and also naturally-produced fish returning to the river to spawn, as well as naturally produced juveniles in the river, smolts, and hatchery pre-smolts. Analysis of DNA microsatellites form fin-clip samples will reveal the parentage and origin of juveniles and returning adults. From this we will determine the relative production and survival of wild, hatchery, and naturally-spawning hatchery origin steelhead, and the extent of interbreeding between groups. The results will be conveyed to agency management staff, contributing sponsors and regional organization, and the scientific community.

Funded Grants - 2001 Project Descriptions

Category A: Sustainable Fisheries

Development of Field Methods to Determine the Effects of Hatchery Release Methods on Residualism and Interactions between Hatchery and Wild Juvenile Salmonids in Relation to Stream Carrying Capacity

Project Sponsor: WDFW and NMFS

Principal Investigators: Howard Fuss, WDFW; Steve Riley, NMFS

HSRG Share + Sponsor Share = Total Cost: $102,500 + $110,261 = $212,761

Collaborators: University of Washington, Weyerhaeuser Co.

Project Summary: There is currently a great deal of uncertainty regarding the effects of hatchery practices on wild salmonids, and it is important to develop standard methods to estimate the effects of hatchery releases on wild juvenile salmonids, particularly for listed stocks. This study is designed to estimate the effects of hatchery releases on wild juvenile salmonids using underwater observation and sampling for growth and condition. We will evaluate several important fitness parameters, including abundance, behavior, habitats use, growth and physiological condition. We will estimate the sample sizes and effort required to obtain adequate statistical power to determine significant differences between treatment (hatchery fish released) and control (no release) sites, and we will determine the cost effectiveness of all techniques applied. This project will result in the development of a cost-effective method to evaluate the impacts of hatchery releases on wild juvenile salmonids, including estimates of required sample sizes and costs. We will provide estimates of the ecological effects of hatchery releases on selected wild salmonids populations in western Washington, information that is needed to assess risks to ESA-listed wild salmonid stocks that are associated with hatchery operations. Ultimately, if standardized methods are applied widely, the resulting database will be useful in assessing the effects of different hatchery rearing and release practices on wild salmon population.

Test Commercial Selective Harvest Gears

Project Sponsor: WDFW

Principal Investigator: Geraldine Vander-Haegen

HSRG Share + Sponsor Share = Total Cost: $75,000 + $80,870 = $155,870

Co-investigators: Michael Johnson, Pat Verhey

Collaborators: Columbia-Pacific Resource Conservation and Development, Willapa Bay Gillnetters Association, Willapa Bay Regional Fisheries Enhancement Group

Project Summary: On the Willapa River, WDFW and the Pacific Conservation District will evaluate the effectiveness of tangle nets and a floating trap for live capture, selective harvesting of coho. Our objectives are to compare the number and condition of coho caught in the tangle net to the conventional gill net, to enumerate the catch of non-target species in each net, to compare the long-term survival of coho released from each net, to estimate the frequency and short-term survival rate of coho recaptured during the fishery, to compare the fork lengths of fish caught in each net to those spawned at Forks Creek Hatchery, and to evaluate a floating trap for capturing coho. Five fishers will simultaneously fish a net that is half tangle net and half conventional gill net in Sept 2001 and will tag and release coho. Fish recaptured during the test fishery will be held for 24 hours to observe the effects of multiple recaptures. Extensive tag recovery efforts in the sport and commercial fisheries, on the spawning grounds and from area hatcheries will continue through January 2002 to compare the long-term survival of fish released from the tangle net to those released from the gill net. A floating trap will also be deployed to target coho. We expect to collect information that will allow for science based implementation of commercial selective fisheries to provide access to more hatchery fish and to reduce the number of surplus fish returning to the hatcheries.

Salmon Marine Trophic Demand-Distribution

Project Sponsor: University of Washington

Principal Investigator: David Beauchamp, UW

HSRG Share + Sponsor Share = Total Cost: 60,000 + $31,285 = $91,285

Co-investigators: WDFW, Washington Cooperative Fisheries and Wildlife Research Unit, USGS, King County Department of Natural Resources

Collaborators: WDFW, NMFS

Project Summary: WDFW, USGS/BRD and UW will examine temporal distribution, diet and size patterns of juvenile salmon at selected estuarine and nearshore marine areas on northern and southern Puget Sound associated with significant production of wild and hatchery salmon. Chinook, coho and chum salmon will be targeted by this study, but all salmonids and potential predator and competitor species will be examined in a food web context. By combining field data on diet, distribution and growth from beach seining and fine-mesh purse seining with bioenergetics modeling, we will produce first-cut estimates of temporal feeding rates by juvenile salmon on their major prey, thus evaluating whether food limitation, predation or competition reduce survival or growth of juvenile salmon in these areas. This effort will provide a first look at current distribution and feeding conditions for juvenile salmon, establish the foundation for expanded studies, identify key processes that influence interactions among species and size classes of hatchery and wild salmonids and with other marine species. This project will provide the rationale for prioritizing and focusing subsequent research and management activities by identifying and quantifying processes that limit survival and growth of juvenile salmon during their critical early life stages in Puget Sound. We will coordinate with King County's sampling in central Puget Sound to provide the broadest possible spatial coverage using standardized methods.

Category B: Recover and Conserve Natural Spawning Populations

Snow Creek Coho Recovery Program

Project Sponsor: WDFW

Principal Investigator: Steve Schroder, WDFW

HSRG Share + Sponsor Share = Total Cost: $36,000 + $16,290 = $52,290

Collaborators: Wild Olympic Salmon, North Olympic Salmon Coalition, Point-No-Point Treaty Council, Jamestown S'Klallam Tribe

Project Summary: Beginning in 1998, WDFW, Wild Olympic Salmon and the North Olympic Salmon Coalition began an effort to recover a threatened coho population native to Snow Creek, a Northeast Olympic Peninsula stream. Since then, every adult coho returning to Snow Creek has been captured at a permanent weir. The fish are artificially spawned and their eggs are incubated at the nearby Hurd Creek Hatchery. Offspring from each fish are placed into three alternative recovery strategies. One involves placing eyed-eggs into remote site incubators located throughout the Snow Creek Basin. In the other two, fish are reared for either seven- or ten-months before being liberated as pre-smolts into Crocker Lake, a 25-hectare body of water that is used as a rearing and over-wintering location by Snow Creek coho. Fish placed into each treatment group have their otoliths thermally marked and the reared fish are also tagged. The otolith marks and tags are used to determine: 1) how many smolts are produced from each treatment, 2) if treatment origin affects size and out-migration timing of smolts, and 3) whether a recovery strategy affects overall survival, size, age, fecundity, egg size, and reproductive effort at maturation. This approach will be continued annually until 2006 and if abundance allows, coho will be allowed to reproduce naturally to create a fourth treatment type. Results from this study will be used to help refine coho recovery efforts throughout Puget Sound and the Washington Coast.

Differences in Natural Production Between Hatchery and Wild Coho Salmon

Project Sponsor: WDFW and NMFS

Principal Investigator: Howard Fuss, WDFW; Michael Ford, NMFS

HSRG Share + Sponsor Share = Total Cost: $100,500 + $76,058 = $176,608

Co-investigators: Jeff Hard, Barry Berejikian, NMFS

Collaborators: WDFW, NWIFC

Project Summary: A key question facing salmon managers is how successful hatchery propagated fish and their offspring are at surviving and reproducing in the wild. This is critical for assessing both risks and benefits of hatchery supplementation.

In this collaborative federal, state and tribal project, we are using state-of-the-art genetic techniques to evaluate the spawning success and survival in the wild of hatchery propagated and naturally-spawning coho salmon. The results of this project will, for the first time, provide information on the rate at which hatchery fish can readapt to the wild environment.

The project works like this: For three years, starting in the fall of 2000, we will intercept all adult coho salmon returning to spawn in Minter Creek, WA. The run consists of naturally produced and hatchery propagated coho salmon. Before being passed upstream to spawn naturally, we measure, photograph and tag each fish; determine its origin (hatchery or natural); and take a small non-lethal fin clip for later DNA analysis. Over the next 6 years, starting this spring, we will sample the progeny of these fish and use microsatellite DNA fingerprinting to determine their parentage. From these data, we will estimate the relative fitness of naturally spawning hatchery- and natural-origin salmon. In the years 2003-2008, we will measure the relative fitness of natural-origin fish with varying hatchery ancestry, providing data on the rate hatchery coho readapt to the wild.

Hamma Hamma River Steelhead Supplementation Evaluation

Project Sponsor: NMFS

Principal Investigator: Barry Berejikian, NMFS

HSRG Share + Sponsor Share = Total Cost: $62,500 + $70,659 = $133,159

Collaborators: Long Live the Kings, Hood Canal Salmon Enhancement, WDFW, Point-No-Point Treaty Council

Project Summary: This project addresses several aspects of the conservation hatchery paradigm including: natural growth profiles, enriched hatchery rearing habitats, release strategies and experimentation to improving captive broodstock technologies. It also evaluates the impacts of a supplementation program on changes in spawner abundance in the Hamma Hamma River where confounding variables (e.g., habitat degradation, harvest) will have minimal influence. The specific research objectives are as follows:

1. Determine whether the supplementation program affects the abundance of naturally spawning steelhead in the Hamma Hamma River.
2. Determine the relative reproductive success of female steelhead from two different reintroduction strategies (smolt vs. adult release).
3. Estimate the relative abundance of steelhead spawners produced from a) wild smolts, b) smolts reared in 'conservancy' ponds and c) smolts reared in hatchery tanks.

4. Develop rearing protocols to produce steelhead smolts with a two-year freshwater rearing history, such that growth profiles mimic those of wild fish.
5. Compare the reproductive behavior and breeding success of captively reared steelhead grown in high vs. low water velocity environments.

Category C: Improve Quality and Cost-Effectiveness of Hatchery Programs

Development of BKD Vaccine

Project Sponsor: WDFW

Principal Investigator: Jed Varney, WDFW

HSRG Share + Sponsor Share = Total Cost: $40,000 + $81,235 = $121,235

Collaborators: USGS Western Fisheries Research Center, WDFW, NMFS

Project Summary: State, tribal and federal fish health specialists in Washington state believe that bacterial kidney disease (BKD) is a major disease-of-concern for wild and cultured salmonids. Despite significant improvements in fish culture practices and the use of chemotherapeutants such as erythromycin, BKD continues to be a major factor in the propagation of many salmonid stocks in the Pacific Northwest. Because avoidance or treatment is not completely effective, vaccination may represent the most promising control method. This project is a collaborative investigation between the WDFW and researchers at the Western Fisheries Research Center (USGS) in Seattle, WA in which the relative efficacies of one commercial bacteria and five experimental vaccines for BKD, will be compared under laboratory conditions. The final objective of this study is to evaluate the potential for each vaccine to protect juvenile Chinook salmon from infection by the kidney disease bacterium. Groups of vaccinated fish will be exposed under strictly controlled environment conditions to a waterborne BKD challenge specifically designed to resemble what occurs in the natural environment. When complete, this study will provide fish health specialists with an accurate assessment of the feasibility of using any of the six vaccines for the control of BKD in cultured salmonids. If one, or more, vaccines show promise for controlling BKD, they will be evaluated in further laboratory and production-scale trials.

Increase Post Release Survival by Rearing Coho with Natures Semi-Natural Raceway Habitat

Project Sponsor: NMFS and WDFW

Principal Investigator: Desmond Maynard, NMFS

Co-Investigators: Geraldine VanderHaegen, WDFW

HSRG Share + Sponsor Share = Total Cost: $72,380 + $103,885 = $176,265

Project Summary: It has been repeatedly demonstrated that rearing Chinook salmon in NATURES semi-natural raceway habitat increases their instream survival. In the current study, WDFW and NMFS are conducting a 4-year experiment to determine if NATURES rearing also increases the number of coho salmon recruiting to the fishery and spawning population. The research is being conducted with salmon grown in standard concrete raceways at Puget Sound hatcheries. At each hatchery, there are control and semi-natural habitat raceways. The semi-natural habitat was created by fitting the raceways with: (1) gravel pavers (2) fir tree instream structure and (3) camouflage net overhead covers. Fish growth, color development and health are being routinely monitored and compared. Experimental and control fish are coded-wire-tagged to measure their contribution to the fishery and spawning population. NATURES semi-natural raceway habitat rearing is expected to increase the relative number of fish recruiting to the fishery and spawning population by 25%. Managers can use the increased survival offered by NATURES salmon culture practices to restore natural spawning runs, maintain sustainable fisheries, promote economically efficient salmon culture, and reduce ecological interactions with ESA listed wild salmon populations.

Nature vs. Nurture: Do Hatchery Practices Impair Brain Development?

Project Sponsor: NMFS

Principal Investigator: Penny Swanson

HSRG Share + Sponsor Share = Total Cost: $30,000 + $15,800 = $45,800

Project Summary: Fish reared in hatcheries are generally less fit to survive in the wild than naturally-reared fish, but the underlying causes (genetic selection or rearing environment) are not known. Numerous studies have demonstrated behavioral differences between fish reared in conventional hatcheries and wild fish. More recently it has been shown that various regions of the brains of hatchery and wild trout differ considerably in size, but the underlying causes of the brain differences are unknown because fish from this study were from different genetic stocks. The observations on behavior and brain size in salmon and trout are not surprising in view of the recent work in mammals demonstrating that environment can directly impact neural plasticity, development and behavior. In the proposed research, we will determine the effects of rearing environment on brain development in juvenile steelhead reared at the UW, Big Beef Creek Field Station as part of another study funded by Bonneville Power Administration and NMFS. We will compare the size and volume of various brain regions of fish reared in conventional hatchery raceways, raceways enriched with substrate or natural streams. We expect that this technique will be a more direct measure of fitness and could be used as a simple index by which to evaluate wild and hatchery fish, and fish reared in semi-natural rearing systems as proposed for conservation hatcheries.

Development of Engineered Streams for Salmon Production

Project Sponsor: University of Idaho

Principal Investigator: Ernest Brannon, UI

HSRG Share + Sponsor Share = Total Cost: $33,000 + $0 = $33,000

Collaborators: WDFW

Project Summary: This project is a demonstration of a new concept that combines the benefits of hatcheries and natural habitat to improve salmon populations. In collaboration with the WDFW development of engineered streams is proposed by UI/WSU as a long-range alternative to hatcheries for supplementation of weak or failing wild salmonid populations. The objectives are to provide natural-type engineered streams for coho salmon production that result in wild smolt quality and to monitor performance as a demonstration project for the new hatchery concept. The approach is to develop artificial streams for use as salmon habitat with engineering specifications based on the biological criteria of the species targeted, while maintaining genetic specificity, diversity, and natural smolt quality. The artificial stream will substitute for, or be used in conjunction with, standard hatchery raceways. Natural feed with supplemental artificial diets will be the source of food. The site selected is Hatchery Creek located immediately behind the WDFW hatchery on the Dungeness River. A channel was constructed with habitat structures, pools, riffles, and cover to mimic natural coho habitat. Approximately 50,000-eyed eggs will be introduced in the spring of 2001 and fish use of the channel will be quantified through snorkel surveys throughout the summer and fall. Post-migration monitoring will involve adult return success based on thermal marks applied to the eyed eggs.

Category D: Protect Genetic Resources

Residualism in Wild Broodstock Steelhead

Project Sponsor: WDFW

Principal Investigator: Cameron Sharpe, WDFW

HSRG Share + Sponsor Share = Total Cost: $50,000 + $36,893 = $86,893

Co-investigators: Brian Beckman, Pat Hulett, Walt Dickhoff, NMFS

Collaborators: WDFW, NMFS

Project Summary: Some hatchery steelhead and other salmonid smolts become residuals (i.e. fail to out migrate) after release. The problem appears to be particularly acute in hatchery programs that use wild broodstock - a practice that is becoming increasingly popular as a means to limit genetic risk to wild salmonids. Ironically, high rates of residualism increase genetic and ecological risks to wild fish.

Our objectives are to: (1) Develop a method to reduce residualism of hatchery-reared wild-broodstock steelhead, (2) Assess growth, physiological status, and migration/residualism to determine mechanisms promoting residual behavior and (3) Compare growth, physiological status, migration pattern, and residualism among offspring of wild and domesticated broodstock.

The project is a collaboration between WDFW and NMFS. The work will be conducted in the Kalama River and will coordinate closely with the existing federally funded wild steelhead broodstock project in that basin.

The experimental approach will be to control growth patterns to simultaneously reduce the numbers of (1) small fish that residualize because they fail to reach smolt size and (2) large male fish that residualize because they become precociously mature.

Our goal is to develop a practical and effective method to reduce residualism of cultured salmonids. We expect that the results will be "exportable" to steelhead and other salmonid culture programs region wide.

Olfactory Imprinting in Hatchery Salmon

Project Sponsor: National Marine Fisheries Service

Principal Investigator: Andrew Dittman, NMFS

HSRG Share + Sponsor Share = Total Cost: $32,000 + $78,100 = $110,100

Project Summary: Exposure to home-stream water during appropriate juvenile stages is critical for olfactory imprinting in salmon and ultimately for successful completion of the adult homing migration. Inappropriate hatchery rearing conditions and juvenile release practices that interfere with the imprinting process can dramatically increase straying. Straying hatchery fish may in turn have negative ecological and genetic effects on endangered and/or wild populations. The overall goal of this project is to identify the critical developmental periods and environmental conditions required for olfactory imprinting in hatchery-reared Pacific salmon. Experimentally assessing successful imprinting is difficult and currently the only effective measures of imprinting involve expensive large-scale tag-recapture studies or behavioral assessments of captively-reared mature adults. This project has two major components: 1) develop and validate new molecular and electrophysiological tools for assessing imprinting that will not require large-scale adult rearing experiments; 2) determine the critical periods for imprinting for Puget Sound coho salmon by exposing juvenile salmon to imprinting odorants during key developmental periods under different environmental conditions. Ultimately, the imprinting assays developed for this project should be useful for studying homing in all salmonids and the findings of this study will be used to improve hatchery rearing and release strategies to minimize straying.

Interactions between Wild and Hatchery Steelhead: Evaluating Key Assumptions

Project Sponsor: University of Washington

Principal Investigator: Thomas Quinn, UW

HSRG Share + Sponsor Share = Total Cost: $23,700 + $11,156 = $34,856

Collaborators: Weyerhaeuser Company, NMFS, WDFW

Project Summary: Natural resource agencies are challenged to maintain both the abundance of salmonids and their genetic and ecological diversity. Hatchery production, designed to achieve the first objective, sometimes conflicts with the second. In Washington, steelhead have been bred to return early in the year. This selection was initially done to help produce yearling smolts but it now permits selective fisheries on hatchery and wild fish, and provides a measure of genetic separation between the stocks. The extent to which timing differences minimize genetic and ecological interactions between hatchery and wild fish depends on the heritability of spawning date, the reproductive success of the stocks, and the extent of interbreeding. The recently established hatchery steelhead program at Forks Creek Hatchery presents a unique opportunity to examine the assumptions underlying this approach. We request renewal of funds to sample hatchery and naturally produced adults returning to spawn, naturally produced juveniles in the river and smolts, and hatchery pre- smolts. Analysis of DNA microsatellites from fin-clip samples will reveal the parentage and origin of juveniles and returning adults. This will allow us to determine the relative production and survival of wild, hatchery and naturally spawning hatchery origin steelhead, and the extent of interbreeding. The results will be conveyed to agency staff, contributing sponsors and regional organizations and the scientific community.

Funded Grants - 2002 Project Descriptions

Category A: Sustainable Fisheries

Salmon Marine Trophic Demand-Distribution

Project Sponsor: University of Washington

Principal Investigator: David Beauchamp, UW

HSRG Share + Sponsor Share = Total Cost: $69,445 + $33,672 = $103,117

Associate Investigator: Raymond Buckley,

Collaborators: WDFW, UW-Wetland WDFW, Ecosystem Team, USGS, King County Department of Natural Resources, NOAA, NMFS

Project Summary: UW, WDFW, and USGS/BRD will examine temporal distribution, diet and size patterns of juvenile salmon at selected estuarine and nearshore marine areas on northern and southern Puget Sound containing significant numbers of wild and hatchery salmon in a year with high juvenile pink salmon densities. Chinook, coho and chum salmon will be targeted by this study, but all potential predator and competitor species will be examined in a food web context. Diet, growth, and timing of nearshore use will be compared among species, between hatchery and wild salmon, between northern and southern sites, and to historic data. By combining field data on diet, distribution and growth from beach seining and tow netting with bioenergetics modeling, we will estimate temporal feeding rates by juvenile salmon to evaluate whether food limitation, diet, environmental conditions, predation or competition reduce survival or growth of juvenile salmon in these areas. Changes in body size and growth conditions will be related to timing of declines of salmon in nearshore and the offshore transition. This project will provide the foundation for prioritizing and focusing subsequent research and management activities by identifying and quantifying processes that potentially limit survival and growth of juvenile salmon during critical early life in Puget Sound. Activity will be coordinated with King County, Seattle, NMFS, Army Corps to broaden spatial and topical coverage using standardized methods.

Category B: Recover and Conserve Natural Spawning Populations

Differences in Natural Production between Hatchery and Wild Coho Salmon

Project Sponsor: WDFW and NMFS

Principal Investigator: Howard Fuss, WDFW and Michael Ford, NMFS

HSRG Share + Sponsor Share = Total Cost: $107,567 + $74,637 = $182,204

Collaborators: NWIFC

Project Summary: A key question facing salmon managers is how successful hatchery propagated fish and their offspring are at surviving and reproducing in the wild. This is critical for assessing both risks and benefits of hatchery supplementation. In this collaborative federal, state, and tribal project, we are using state of the art genetic techniques to evaluate the spawning success and survival in the wild of hatchery propagated and naturally produced coho salmon. The results of this project will, for the first time, provide information on the rate at which hatchery fish can readapt to the wild environment. The project works like this: For three years, starting in the fall of 2000, we will intercept all adult coho salmon returning to spawn in Minter Creek, WA. The run consists of naturally produced and hatchery propagated coho salmon. Before being passed upstream to spawn naturally, we measure, photograph, and tag each fish; determine its origin (hatchery or natural); and take a small non-lethal fin clip for later DNA analysis. Over the next six years, we will sample the progeny of these fish as fry and as smolt and use microsatellite DNA fingerprinting to determine their parentage. From these data, we will estimate the relative fitness of naturally spawning hatchery and natural-origin salmon. In the years 2003-2008, we will measure the relative fitness of natural-origin fish with varying hatchery ancestry, providing data on the rate hatchery coho readapt to the wild.

Snow Creek Coho Recovery Program

Project Sponsor: WDFW

Principal Investigator: Steve Schroder, WDFW

HSRG Share + Sponsor Share = Total Cost: $28,130 + $10,000 = $38,130

Collaborators: Wild Olympic Salmon, North Olympic Salmon Coalition, Point-No-Point Treaty Council, Jamestown S'Klallam Tribe

Project Summary: Beginning in 1998, WDFW, Wild Olympic Salmon and the North Olympic Salmon Coalition began an effort to recover a threatened coho population native to Snow Creek, a Northeast Olympic Peninsula stream. Since then, every adult coho returning to Snow Creek has been captured at a permanent weir. The fish are artificially spawned and their eggs are incubated at the nearby Hurd Creek Hatchery. Offspring from each fish are placed into three alternative recovery strategies. One involves placing eyed-eggs into remote site incubators located throughout the Snow Creek Basin. In the other two, fish are reared for either seven or ten months before being liberated a pre-smolts into Crocker Lake, a 25-hectare body of water that is used as a rearing and over-wintering location by Snow Creek coho. Fish placed into each treatment group have their otolith thermally marked and the reared fish are also tagged. The otolith marks and tags are used to determine: 1) how many smolt are produced from each treatment, 2) if treatment origin affects size and out-migration timing of smolt, and 3) whether a recovery strategy affects overall survival, size and age at maturation. This approach will be continued annually until 2006 and if abundance allows, such as in 2001, coho will be allowed to reproduce naturally to create a fourth treatment type. Results from this study will be used to help refine coho recovery efforts throughout Puget Sound and the Washington Coast.

Hamma Hamma River Steelhead Supplementation Evaluation

Project Sponsor: NMFS

Principal Investigator: Barry Berejikian, NMFS

HSRG Share + Sponsor Share = Total Cost: $68,554 +$124,440 = $192,994

Collaborators: Long Live the Kings, Hood Canal Salmon Enhancement, WDFW, Point-No-Point Treaty Council

Project Summary: This project addresses several aspects of the conservation hatchery paradigm including: natural growth profiles, enriched hatchery rearing habitats, release strategies, and experimentation to improving captive broodstock technologies. It also evaluates the impacts of a supplementation program on changes in spawner abundance in the Hamma Hamma River where confounding variables (e.g., habitat degradation, harvest) will have minimal influence. The specific research objectives are as follows:

1. Determine whether the supplementation program affects the abundance of naturally spawning steelhead in the Hamma Hamma River.

2. Determine the relative reproductive success of female steelhead from two different reintroduction strategies (smolt vs. adult release).

3. Estimate the relative abundance of steelhead spawners produced from i) wild smolt, ii) smolt reared in 'conservancy' ponds, and iii) smolt reared in hatchery tanks.

4. Develop rearing protocols to produce steelhead smolt with a two-year freshwater rearing history, such that growth profiles mimic those of wild fish.

5. Compare the reproductive behavior and breeding success of captively reared steelhead grown in high vs. low water velocity environments.

Category C: Improve Quality and Cost-Effectiveness of Hatchery Programs

Increase Post-Release Survival by Rearing Coho with NATURES Semi-Natural Raceway Habitat

Project Sponsor: NMFS

Principal Investigator: Des Maynard, NMFS

HSRG Share + Sponsor Share = Total Cost: $84,962 + $84,209 = $169,171

Associate Investigator: Geraldine Vander-Haegen, WDFW

Collaborators: WDFW, Tribes

Project Summary: It has been repeatedly demonstrated that rearing Chinook salmon in NATURES semi-natural raceway habitat increases their instream survival. In the current study, WDFW and NMFS are conducting a 4 (four) year experiment to determine if NATURES rearing also increases the number of coho salmon recruiting to the fishery and spawning population. The research is being conducted with salmon grown in standard concrete raceways at Puget Sound hatcheries. At each hatchery, there are control and semi-natural habitat raceways. The semi-natural habitat was created by fitting the raceways with: 1) gravel pavers, 2) fir tree instream structure, 3) camouflage net overhead covers. Fish growth, color development, and health are being routinely monitored and compared. Experimental and control fish are coded-wire-tagged to measure their contribution to the fishery and spawning population. NATURES semi-natural raceway habitat rearing is expected to increase the relative number of fish recruiting to the fishery and spawning population by 25%. Managers can use the increased survival offered by NATURES salmon culture practices to restore natural spawning runs, maintain sustainable fisheries, promote economically efficient salmon culture, and reduce ecological interactions with ESA listed wild salmon populations.

Development of Engineered Streams for Salmon Production

Project Sponsor: University of Idaho

Principal Investigator: Ernest Brannon, UI

HSRG Share + Sponsor Share = Total Cost: $18,819 + $0 = $18,819

Collaborators: WDFW, NMFS

Project Summary: The project is a demonstration of a new concept that combines the benefits of hatcheries and natural habitat to improve salmon populations. In collaboration with the WDFW development of engineered streams is proposed by UI/WSU as long-range alternative to hatcheries for supplementation of weak or failing wild salmonid populations. The objectives are to provide natural-type engineered streams for coho salmon production that result in wild smolt quality and to monitor performance as a demonstration project for the new hatchery concept. The approach is to develop artificial streams for use as salmon habitat with engineering specifications based on the biological criteria of the species targeted, while maintaining genetic specificity, diversity, and natural smolt quality. The artificial stream will substitute for, or be used in conjunction with, standard hatchery raceways. Natural feed with supplemental artificial diets with be the source of food. The site selected is Hatchery Creek located immediately behind the WDFW hatchery on the Dungeness River. A channel was constructed with habitat structures, pools, riffles, and cover to mimic natural coho habitat. Approximately 25,000-eyed eggs will be introduced in the spring of 2002 and fish use of the channel will be quantified through snorkel survey throughout the summer and fall. Post-migration monitoring will involve adult return success based on the thermal marks applied to the eyed eggs.

Funded Grants - 2003 Project Descriptions

Category A: Sustainable Fisheries

Salmon Marine Trophic Demand-Distribution

Project Sponsor: University of Washington

Principal Investigator: David Beauchamp, UW

HSRG Share + Sponsor Share = Total Cost: $60,871 + $0 = $60,871

Associate Investigator: Raymond Buckley, WDFW

Collaborators: WDFW, UW-Wetland Ecosystem Team, USGS, King County Department of Natural Resources, NOAA Fisheries

Project Summary: Predation rates will be estimated on nearshore-offshore distribution of juvenile hatchery and wild salmon during their early life history in northern and southern Puget Sound. Previous results revealed significant predation by small sea-run cutthroat trout. Larger sea-run cutthroat trout and other salmonids also forage in these habitats, but are not captured effectively with the standard beach seining methods. It is hypothesized that these larger predators represent a larger and prolonged source of mortality for juvenile salmon in Puget Sound, because the per capita consumption rates are higher, they can consume larger prey, and can forage more effectively for juvenile in both nearshore and offshore habitats. Larger seines will be used, tow netting, angling, gillnetting, and hydroacoustics to determine the distribution of predators and juvenile salmon, and to provide samples for diet analysis of predators. Differential predation rates between hatchery and wild origin salmon will be recorded. The transition from nearshore to offshore habitats and offshore distribution of juvenile salmon will determine both their growth potential and exposure to predators. This information will help managers identify the timing and location of critical factors limiting survival of juvenile salmon during residence and migration in Puget Sound. This will be a joint project between University of Washington, United States Geological Service, and WDFW and will coordinate with complementary efforts of Army Corps, NOAA Fisheries, tribes, and city and county agencies.

Category B: Recover and Conserve Natural Spawning Populations

Differences in Natural Production between Hatchery and Wild Coho Salmon: A Proposal to Measure the Influence of the Degree of Hatchery Ancestry on Natural Reproductive Success

Project Sponsor: WDFW and NOAA Fisheries

Principal Investigator: Howard Fuss, WDFW and Michael Ford, NOAA Fisheries

HSRG Share + Sponsor Share = Total Cost: $106,627 + $57,872 = $164,499

Collaborators: NWIFC

Project Summary: A key question facing salmon managers is how successful hatchery propagated fish and their offspring are at surviving and reproducing in the wild. This is critical for assessing both risks and benefits of hatchery supplementation. In this collaborative project National Marine Fisheries Service (NMFS) and Washington Department of Fish and Wildlife (WDFW), are using state-of-the art genetic techniques to evaluate the spawning success and survival in the wild of hatchery propagated and naturally produced coho salmon. The results of this project will, will for the first time, provide information on the rate at which hatchery fish readapt to the wild environment.

Since the fall of 2000, all adult coho salmon returning to spawn in Minter Creek, Washington have been intercepted. The run consists of naturally produced and hatchery propagated coho salmon.

Before being passed upstream to spawn naturally, each adult is measured, photographed, and tagged, its' origin (hatchery or natural) determined, and a small non-lethal fin clip taken for later DNA analysis. Over the subsequent six years, the progeny of these fish are being sampled as fry and as yearling smolts and microsatellite DNA fingerprinting used to determine their parentage. From these data, the relative fitness of naturally spawning hatchery and natural-origin salmon will be estimated. In the years 2003-2008, the relative fitness of natural-origin fish with varying hatchery ancestry will be estimated, providing data on the rate hatchery coho readapt to the wild.

Snow Creek Coho Salmon Recovery Program

Project Sponsor: WDFW

Principal Investigator: Steve Schroder, WDFW

HSRG Share + Sponsor Share = Total Cost: $32,972 + $10,000 = $42,972

Collaborators: Wild Olympic Salmon, North Olympic Salmon Coalition, Point-No-Point Treaty Council, Jamestown S'Klallam Tribe

Project Summary: Beginning in 1998, WDFW, North Olympic Salmon Coalition, and Wild Olympic Salmon began an effort to recover a threatened coho salmon population native to Snow Creek, a Northeast Olympic Peninsula stream. Since then, every adult coho salmon returning to Snow Creek has been captured at a permanent weir. The fish are artificially spawned and their eggs are incubated at nearby Hurd Creek Hatchery. Offspring from each fish are placed into three alternative recovery strategies. One involves placing eyed-eggs into Remote Site Incubators located throughout the Snow Creek Basin. In the other two, fish are reared for either seven or ten months before being liberated as pre-smolts into Crocker Lake, a 25 hectare body of water that is used as a rearing and over-wintering location by Snow Creek coho salmon. Fish placed into each treatment group have their otoliths thermally marked and the reared fish are also tagged. The otolith marks and tags are used to determine: 1) how many smolts are produced from each treatment, 2) if treatment origin affects size and out-migration timing of smolts, and 3) whether a recovery strategy affects overall survival, size, age, fecundity, egg size, and reproductive effort at maturation. This approach will be continued annually until 2006. In 2001 and 2002 adult coho were allowed to reproduce naturally in Snow Creek to create a fourth treatment type. Results from this study will be used to help refine coho recovery throughout Puget Sound and the Washington Coast.

Hamma Hamma River Steelhead Supplementation Evaluation

Project Sponsor: NOAA Fisheries

Principal Investigator: Barry Berejikian, NOAA Fisheries

HSRG Share + Sponsor Share = Total Cost: $68,226 + $105,660 = $173,886

Collaborators: Long Live the Kings,
Hood Canal Salmon Enhancement,
WDFW, Point-No-Point Treaty Council

Project Summary: This project evaluates the impacts of a steelhead supplementation program on changes in spawner abundance in the Hamma Hamma River, where confounding variables (e.g., habitat degradation, harvest) will have minimal influence. Collaborators include Long Live the Kings, Hood Canal Salmon Enhancement Group, NOAA Fisheries. WDFW, and Point No Point Treaty Council The project addresses several aspects of the conservation hatchery paradigm including: natural growth profiles, enriched hatchery rearing habitats, alternative release strategies, and experimentation to improving captive broodstock technologies. The specific research objectives are as follows:

1) Determine whether the supplementation program affects the abundance of naturally spawning steelhead in the Hamma Hamma River; 2) Determine the relative reproductive success of female steelhead from two different reintroduction strategies (smolt vs. adult release); 3) Estimate the relative abundance of steelhead spawners produced from i) wild smolts, ii) smolts reared in 'conservancy' ponds, and iii) smolts reared in hatchery tanks; 4) Develop rearing protocols to produce steelhead smolts with a two-year freshwater rearing history, such that growth profiles mimic those of wild fish; and 5) Compare the reproductive behavior and breeding success of captively reared steelhead grown in high versus low water velocity environments.

Category C: Improve Quality and Cost-Effectiveness of Hatchery Programs

Increase Post-Release Survival by Rearing Coho with NATURES Semi-Natural Raceway Habitat

Project Sponsor: NOAA Fisheries

Principal Investigator: Des Maynard, NOAA Fisheries

HSRG Share + Sponsor Share = Total Cost: $82,172 + $126,580 = $208,752

Associate Investigator: Geraldine Vander-Haegen, WDFW

Collaborators: WDFW, Tribes

Project Summary: It has been repeatedly demonstrated that rearing Chinook salmon in NATURES semi-natural raceway habitat increases their instream survival. In the current study, WDFW and NMFS are conducting a 4 year evaluation to determine if NATURES rearing in a production environment increases the number of coho salmon recruiting to the fishery and spawning population. The research is being conducted with salmon grown in standard concrete raceways at Puget Sound hatcheries. At each hatchery, there are control and semi-natural habitat raceways. The semi-natural habitat was created by fitting the raceways with: 1) gravel pavers, 2) fir tree instream structure, and 3) camouflage net overhead covers. Fish growth, color development, and health are being routinely monitored and compared. Experimental and control fish are coded-wire-tagged to measure their contribution to the fishery and spawning population. NATURES semi-natural raceway habitat rearing is expected to increase the relative number of fish recruiting to the fishery and spawning population by 25%. Managers can use the increased survival offered by NATURES salmon culture practices to restore natural spawning runs, maintain sustainable fisheries, promote economically efficient salmon culture, and reduce ecological interactions with ESA listed wild salmon populations.

Development of Engineered Streams for Salmon Production

Project Sponsor: University of Idaho

Principal Investigator: Ernest Brannon, UI

HSRG Share + Sponsor Share = Total Cost: $30,464 + $0 = $30,464

Collaborators: WDFW, NOAA Fisheries

Project Summary: This project is a demonstration of a new concept that combines the benefits of hatcheries and natural habitat to improve salmon populations. In collaboration with the WDFW development of engineered streams is being investigated by the University of Idaho as a long-range alternative to hatcheries for supplementation of weak or failing wild salmonid populations. The objectives are to provide natural-type engineered streams for coho salmon production that result in wild smolt quality and to monitor performance as a demonstration project for this new hatchery concept. The approach is to develop artificial streams for use as salmon habitat with engineering specifications based on the biological criteria of the species targeted, while maintaining genetic specificity, diversity, and natural smolt quality. The artificial stream will substitute for, or be used in conjunction with, standard hatchery raceways. Natural feed with supplemental artificial diets will be the source of food. The site selected is Hatchery Creek located immediately behind the WDFW hatchery on the Dungeness River. A channel was constructed with habitat structures, pools, riffles, and cover to mimic natural coho habitat. Production levels were comparable to natural habitat at 1.5 smolt/m^2. Based on the previous two years of data, the channel will be modified to increase volitional rearing densities and increase smolt production to levels above natural production while still maintaining wild fish characteristics.