HATCHERY SCIENTIFIC REVIEW GROUP
Puget Sound and Coastal Washington Hatchery Reform Project

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

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EXECUTIVE SUMMARY

The Hatchery Scientific Review Group (Scientific Group) is the independent scientific panel established by Congress to ensure that salmon and steelhead hatchery reform programs in Puget Sound and Coastal Washington be scientifically founded and evaluated; that independent scientists interact with agency and tribal scientists to provide direction and operational guidelines; and that the system as a whole be evaluated for compliance with scientific recommendations. The objective of the Scientific Group is to assemble, organize and apply the best available scientific information to provide guidance to policy makers who are implementing hatchery reform.

The purpose of hatchery reform is to ensure that salmon and steelhead hatcheries meet their twin goals: (1) to help recover and conserve naturally spawning populations, and (2) to support sustainable fisheries.

A key early objective of the Scientific Group was to develop a scientific framework to organize the best available scientific information pertinent to hatcheries in Puget Sound and Coastal Washington. This scientific framework is not the Scientific Group's end product, but rather an important first step that provides the scientific foundation and justification for specific recommendations and guidelines that will follow in an action plan.

The Framework identifies four primary conditions for success of hatcheries: (1) Healthy and Viable Hatchery Populations, (2) Effects of Hatchery Programs on Wild and Native Populations and the Environment, (3) Appropriate Contribution of Hatcheries to Conservation and/or Harvest, and (4) Accountability for Performance.

The Scientific Group will periodically update this scientific framework as knowledge is gained, for example, through new research and monitoring results.

Healthy and Viable Hatchery Populations

The fundamental scientific principles established for managing and evaluating wild salmonid populations apply equally to hatchery populations. In this context, hatcheries can be successful only if they propagate healthy and viable populations. The principal measures of population viability are productivity, abundance, diversity, and population structure. Population viability is determined by genetic, biological, and hatchery/environmental conditions.

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.

Biological Conditions. The survival and reproductive success of juvenile hatchery fish depend upon their physiological, morphological, behavioral, and health characteristics at the time of their release and is shaped by their genetic makeup and the environmental conditions they are exposed to in the hatchery. One template for achieving healthy and viable hatchery populations is the biological characteristics of local, wild fish populations. Therefore, in order to achieve productivity similar to wild fish, hatchery environments should produce fish that reflect the natural life history patterns of locally adapted stocks in physiology morphology, behavior, and fish health.

Hatchery and Environmental Conditions. The health and viability of hatchery populations are determined 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 environment into which the fish are released**.** Providing proper hatchery and environmental conditions optimizes potential fish production.

Effects of Hatchery Programs on Wild and Native Populations and the Environment

Hatchery programs affect wild populations and their environment in three general ways: 1) effects of hatchery physical structures, 2) ecological interactions, and 3) genetic mechanisms. The effects of hatchery programs on natural production may be positive or negative, depending on the genetic integrity of existing wild populations and the quality and quantity of the habitat.

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.

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. Ecological interactions caused by the release of hatchery-reared juveniles may include: predation, competition, disease transmission, and ecological function.

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.

Contribution to Conservation and/or Harvest

Hatchery programs are ultimately successful only if they are the best tools for addressing their intended goals. In the context of the twin goals for hatchery reform, we must ask: *under what circumstances is the use of hatcheries appropriate to help recover and conserve naturally spawning populations* and *under what conditions are they appropriate for harvest augmentation?* To be successful, hatcheries should be part of an integrated strategy where harvest, habitat and hatchery management are coordinated to best meet resource goals. This chapter outlines some of the issues involved and conditions required for hatcheries to be an appropriate contributor to meeting conservation and/or harvest goals.

Contribution to Conservation. Conservation hatcheries[6] 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: (1) maintain gene banks to avoid extinction, (2) minimize the risk of demographic loss from unpredictable environmental events, (3) supplement under-recruited wild populations that are below their natural carrying capacity; and (4) introduce and maintain naturally spawning stocks into barren habitat. The conservation hatchery concept implies that following recovery of target populations and receiving habitat, these programs will be terminated.

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 Scientific Group'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.

Contribution to Education. Hatcheries are in a unique position to provide educational opportunities because they are involved in the aspects of the salmon lifecycle that occur largely out of sight of a general public. As a location where citizens can see and work with salmon from their egg to adult stages, each area of the Puget Sound and Coastal Washington region has a potential educational center in its hatchery. Hatcheries are of particular value to their communities as a venue for community involvement and education, a place where the public can obtain data and information about salmon biology, fisheries, and ecology. Hatcheries should be used to educate the public about the role of hatcheries in meeting goals for salmon restoration and harvest in each region. Hatcheries also provide the controlled environments researchers need to develop and test innovative methods that may be of use in salmon restoration efforts.

Accountability for Performance

The Scientific Group calls for an implementation system that ensures accountability for decisions made and actions taken related to hatcheries, and an ability to use adaptive management[7] to change the system in response to new information. To achieve the promise of hatchery reform, accountability for decisions and actions is required at all levels of hatchery management and operation. The repositioning of hatchery programs in Puget Sound and Coastal Washington will be built around accountability for performance, to ensure that hatcheries are successfully operated to accomplish the goals of hatchery reform. The Scientific Group views education and effective communication with the public as vital to accountability and the success of hatchery reform.

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

[7] *Adaptive management, as it is used in this framework, is the policy of actively pursuing and incorporating new information, knowledge, and experience at all levels of decision making*

Clear Statement of the Benefits to Be Achieved. In reviewing hatchery operations, two goals should be kept in mind: 1) hatcheries should aid in the recovery of naturally spawning populations; and/or 2) hatcheries should provide sustainable fisheries. Siting, stock status, founding broodstock, potential production, local habitat conditions, and harvest opportunities or constraints may dictate whether a particular hatchery should focus on one or both of the above goals. Artificial production programs must also be consistent with a wide range of legal mandates relating to fish production throughout Puget Sound and Coastal Washington. These include (for example): 1) treaty fishing rights of Indian Tribes; 2) the responsibility of the State of Washington to preserve, protect, and enhance fish populations; 3) the requirements of the Endangered Species Act; 4) implementation of the U.S./Canada salmon Treaty; and 5) numerous mitigation obligations in law and agreements.

Known Measures of Success. In evaluating hatchery success, managers need to answer three basic questions:

1. What occurs inside the hatchery? Are the conditions required to produce healthy and viable hatchery fish being met?
2. What happens to the hatchery fish outside the hatchery?
3. What are the effects of the hatchery on the environment and naturally produced fish outside the hatchery?

In order to answer these general questions, specific performance indicators need to be identified. Success should be measured in terms of specified goals (validation monitoring) and performance benchmarks (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.

Accurate Assessment and Management of Costs. This refers to a careful review of a hatchery program, to ensure that efforts are focused on meeting specified goals. The most cost effective alternative to meet those goals should be adopted, to provide efficient use of funds. Before effective changes can be made to a hatchery program, a clear understanding of the problem(s) must be established.

Identification of Least Cost Option to Provide Benefits. Least cost option is a management approach for comparing available alternatives to reaching an objective. It ensures that among alternatives producing equal benefits, the least costly is identified. All reasonable alternatives should be considered.

Protocols for Collecting and Disseminating Important Management Information. 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 information 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.

INTRODUCTION

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 wild salmon populations. Hatcheries have generally been successful at fulfilling this purpose. They are important to the North Pacific recreational and commercial fishing economy and to meeting Treaty harvest obligations.

However, hatcheries have also been identified as one of the factors responsible for the decline of wild salmon populations. Some facilities have negatively affected wild fish, inhibited freshwater migrations of adult and juvenile fish, and lowered water quality. Ecological and genetic interactions between wild and hatchery fish may have harmed the natural populations. The once common, and sometimes successful, practice of transferring hatchery fish for release in other basins has the potential to diminish or eliminate important native populations.

In addition, harvest restrictions to protect weak populations, including compliance with the federal Endangered Species Act (ESA), limit the ability to harvest available surpluses from many successful hatchery programs. Hatchery management decisions have often been piecemeal, rather than system-wide. Hatchery and harvest strategies have not been sufficiently coordinated to best meet both harvest and conservation goals.

The listing of several Puget Sound and Coastal populations under the ESA has highlighted activities that may harm wild salmon, including hatchery programs. The federal, state and tribal managers of Washington's salmon and steelhead hatchery programs must demonstrate that their hatcheries do not present unacceptable risks to listed species.

Hatchery Reform in the Puget Sound and Coastal Washington

In fiscal year 2000, the U.S. Congress funded the Puget Sound and Coastal Washington Hatchery Reform Project.

The purpose of hatchery reform is to ensure that the following two goals are met:

- ⇒ *help to recover and conserve naturally spawning populations, and*
- ⇒ *support sustainable fisheries.*

If successful, the project will not only help the managers comply with ESA directives, but actually provide *benefits* to the process of recovering wild salmon and at the same time support justifiable and sustainable fishing opportunities in a time of ESA restrictions. The appropriation 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 related to hatcheries;*
- ⇒ *Support state and tribal efforts to implement new hatchery reforms; and*
- ⇒ *Provide for the facilitation of a reform strategy by an independent third party to ensure implementation of reform.*

HATCHERY SCIENTIFIC REVIEW GROUP

Puget Sound and Coastal Washington Hatchery Reform Project

The Hatchery Scientific Review Group (Scientific Group) is the independent scientific panel established by Congress to ensure that salmon and steelhead hatchery reform programs in Puget Sound and Coastal Washington be scientifically founded and evaluated, that independent scientists interact with agency and tribal scientists to provide direction and operational guidelines, and that the system as a whole be evaluated for compliance with scientific recommendations. The objective of the Scientific Group is to assemble, organize, and apply the best available scientific information to provide guidance to policy makers who are implementing hatchery reform.

The Scientific Framework

A key early objective of the Scientific Group was to develop a scientific framework to organize the best available scientific information pertinent to hatcheries in Puget Sound and Coastal Washington.

The scientific framework was developed specifically for Puget Sound and Coastal Washington, however it has much broader potential applicability. The Scientific Group has drawn upon information and knowledge acquired by the broad scientific community and expects to make the framework and other work products part of the global information base.

The scientific framework allows the Scientific Group to form and test the hypotheses that will guide research; communicate with other scientists, decision-makers and the public; and create a repository of knowledge upon which to base advice to the managers of Washington’s salmon and steelhead resources. It records issues previously addressed, so that acquired knowledge and experience is retained and accessible. Another key purpose is to identify knowledge gaps and information linkages. The scientific framework will be applied in the context of current and projected habitat conditions, and will take into account harvest goals and implications.

This scientific framework is not the Scientific Group’s end product, but rather an important first step that provides the scientific foundation and justification for specific recommendations and guidelines in an action plan to follow.

Scientific Group Work Plan Through 2001

Over the course of 2001, the Scientific Group will focus on developing an action plan and recommendations for hatchery reform. As a first step, the Scientific Group will review the hatchery system within smaller geographic areas[8] in Puget Sound and Coastal Washington. This regional review will enable the Scientific Group to make recommendations on actions or changes needed for each area. The Scientific Group has concluded that this regional scale is the most appropriate for making decisions that take into account cumulative effects of hatchery production, habitat conditions, and harvest goals. In conducting these regional reviews, the Scientific Group will use a number of existing tools, including state and tribal management information on stock status, recent Hatchery and Genetic Management Plans (HGMPs), the best available habitat and harvest data, and other evaluation tools.

In conjunction with a task team appointed by the state, tribal and federal salmonid managers, the Scientific Group will develop recommendations for operational guidelines that can be used by the managers. These operational guidelines will synthesize current knowledge to improve the quality and

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[8] *Each geographic area or region consists of one or several adjacent watersheds. They do not necessarily coincide with existing management areas.*

effectiveness of hatchery programs and lead to decisions about whether a particular program should be discontinued, modified, or expanded to address particular, regional needs. The operational guidelines will be part of an action plan, components of which are shown in Figure 1.

The action plan will allow the managers to develop decision documents containing these operational guidelines, funding strategies, accountability processes and training for hatchery personnel. The Scientific Group can evaluate these guidelines and strategies for compatibility with the action plan and the twin goals of hatchery reform described above.

Developing a monitoring system will be an important step in evaluating success. The monitoring system should provide an accurate assessment of the benefits, risks, and cost-effectiveness of actions taken.

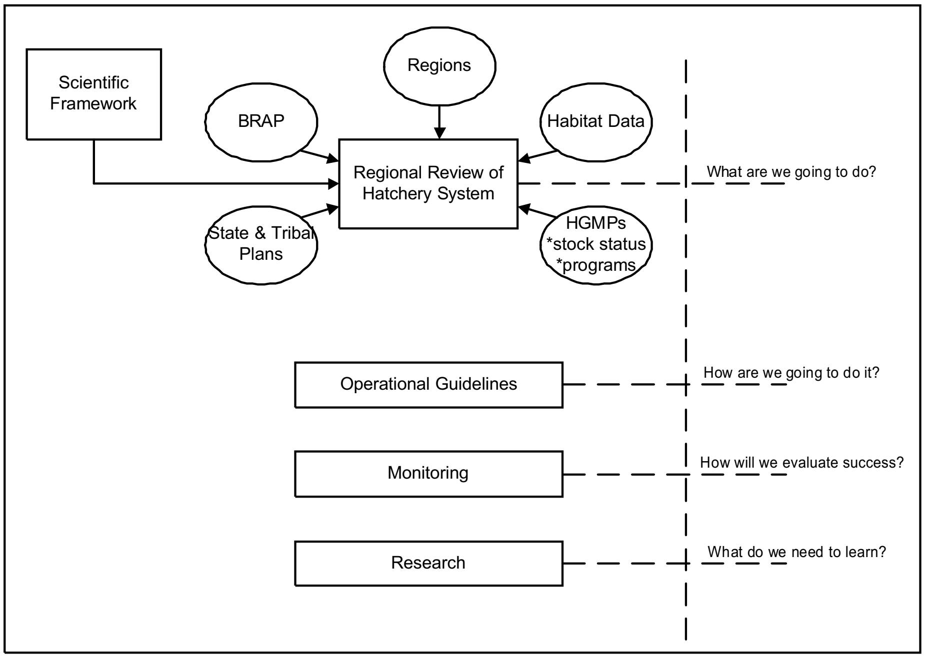

Figure 1. *Initial Steps to Hatchery Reform (through 2001). (BRAP = Benefit Risk Assessment Protocol)*

Longer-Term Actions – Adaptive Management

In addition to these short and medium-term steps, the results of research and the monitoring of current and future operations will be used in the long-term to inform hatchery decisions and guidelines, and to improve the quality of the scientific framework. Adaptive management is the policy of actively pursuing and incorporating new information, knowledge, and experience at all levels of decision making (Figure 2).

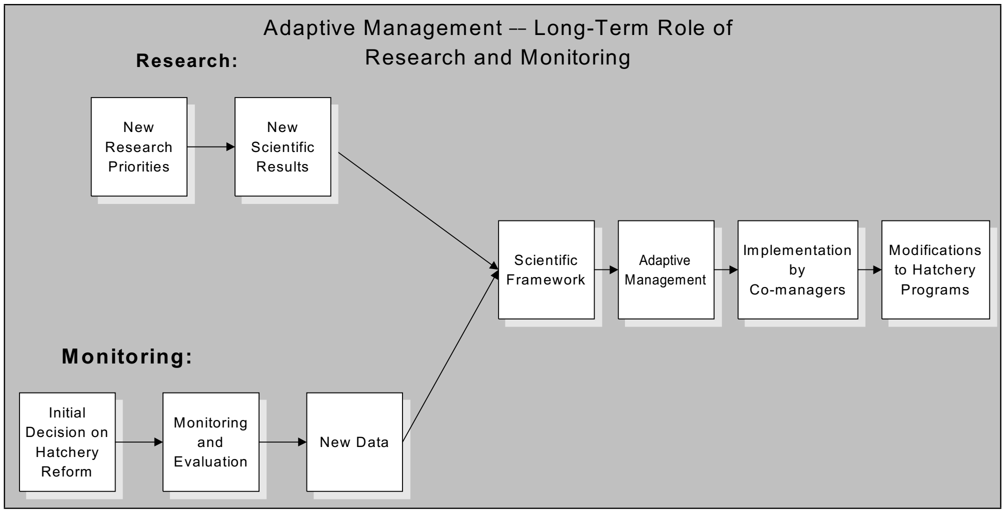

Figure 2. *Adaptive Management – long-term role of research and monitoring*

Bibliography

The bibliography (see end of document) 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*.

Conditions for Success

This scientific framework is organized around the question, *"What does it take for hatcheries to be successful in helping to restore wild salmon and support sustainable fisheries?"* It includes four major conditions identified by the Scientific Group as necessary for hatcheries to succeed in their new goals:

⇒ *Healthy and viable hatchery populations (chapter 1);*

⇒ *Known effects on wild and native populations and the environment (chapter 2);*

⇒ *Appropriate contribution to conservation and/or harvest (chapter 3); and*

⇒ *Accountability for performance in terms of benefits, biological risks and costs (chapter 4).*

Each of these conditions constitutes a chapter within the scientific framework. The Scientific Group will periodically update this scientific framework as knowledge is gained, for example, through new research and monitoring results.

HATCHERY SCIENTIFIC REVIEW GROUP
Puget Sound and Coastal Washington Hatchery Reform Project

CHAPTER 1. HEALTH AND VIABILITY OF HATCHERY POPULATIONS

Healthy and viable populations are defined as those that 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. 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. The conditions necessary to achieve healthy and viable populations are discussed in the following subsections:

⇒ *Genetic conditions (subsection 1.1),*

⇒ *Biological conditions (subsection 1.2), and*

⇒ *Environmental conditions (subsection 1.3).*

1.1 Genetic Conditions

The productivity of a hatchery population—as part of a geographic complex of naturally spawning and hatchery populations—is determined jointly by the environment and by genetic conditions in both the hatchery population and any naturally spawning populations connected to it. Hatchery populations vary in amount of connection, through interbreeding, with naturally spawning populations. They range from segregated (never interbreeding) to integrated (regularly interbreeding). Genetic conditions affect not only productivity; they also determine adaptability to environmental change. Conditions that sustain productivity include:

⇒ *Genetic composition (1.1.1),*

⇒ *Genetic diversity (1.1.2), and*

⇒ *Genetic population structure (1.1.3).*

1.1.1 Genetic Composition

Genetic composition refers to the suite of genes and genotypes present in a population. The fitness of a population, in terms of viability and productivity, depends on its genetic composition. The integrity of a population's genetic system is maintained by a balance between natural selection and other factors that can change genetic composition over time (e.g., migration, genetic drift, mating structure, etc.). The population's suite of genes and genotypes remains an integrated, adaptive system as long as this balance is in dynamic equilibrium; that is, if gene flow (interbreeding from another population), environmental change, or anthropogenic factors do not overwhelm genetically based, local adaptations. The genetic composition of hatchery populations may be particularly susceptible to artificial perturbation via domestication (genetic adaptation to an artificial hatchery environment) or stock transfers (e.g. Gharrett et al. 1999; review by Campton 1995).

The genetic composition of a population can be measured by quantitative or molecular methods. Measurements of phenotypic traits among members of different families can be used to estimate quantitative genetic parameters of those traits in a population. Fitness-related traits of particular relevance to anadromous salmonids and hatchery populations include:

⇒ *Fecundity, egg size, hatchability;*

⇒ *Size/age at sexual maturity (Smoker et al. 1994; Silverstein and Hershberger 1992; Hankin, et al. 1993; Su et al. 1996);*

⇒ *Disease resistance (Winter et al. 1980; Beacham & Evelyn 1992; Ibarra et al. 1994);*

⇒ *Body shape, (Swain et al. 1991; Hard et al. 1999);*

⇒ *Seasonal timing of major life history transitions; e.g. upstream migration of adults, spawn timing, embryonic development and emergence timing of alevins (Su et al. 1997; Hebert et al. 1998; Smoker et al. 1998; McGregor et al. 1998; Su et al. 1999);*

⇒ *Homing behavior (Bams 1976; McIsaac and Quinn 1988; Smoker and Thrower 1995);*

⇒ *Other behaviors, including feeding, aggression, and mate selection (Riddell and Swain 1991; Berejikian 1995).*

Detection of individual genes at the molecular level, or their biochemical products, can also be used to estimate population genetic parameters (e.g., gene and genotype frequencies, genetic diversity within and among populations, etc.). These latter methods are particularly useful for understanding the ancestral history of a population, but they usually provide little insight regarding the adaptive significance of the observed genetic variation.

The genetic composition of a population is the product of its:

⇒ *Founding broodstock*

⇒ *Local adaptation,*

⇒ *Domestication, and*

⇒ *Gene flow resulting from stock transfers or natural straying.*

Founding Broodstock

The founding broodstock of a hatchery population is simply all the adult fish that were used to initiate the hatchery population. The genetic composition of the founding broodstock is the basis for the future genetic composition, phenotypic fitness, and productivity of the hatchery population. Understanding the genetic composition of a hatchery population thus requires detailed records of the founding broodstock (e.g. population sources, number of male and female parents, mating protocols, etc.). 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.

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, 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. Those 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 at the same temperature. Also, 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 range of phenotypic responses, probably reflecting local adaptations, which have been shown experimentally to have significant genetic components.

Local adaptation can be maintained in a hatchery population by controlling domestication selection, deriving broodstock from local sources, controlling the transfer and mixing of hatchery population broodstock with members of other populations, and conserving genetic diversity.

Domestication

Domestication is the process of a population changing genetically, over time, in response 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. absence of mate selection, absence of spawning site selection, absence of fry habitat selection); 2) natural selection in the hatchery or domestic environment (e.g. faster growth by more aggressive, more active parr); and 3) direct artificial selection or selective breeding imposed by hatchery personnel on hatchery broodstocks such as avoidance of small young males (jacks), disproportionate choice of early-migrating adults as spawners, disproportionate choice of large (old) parents, etc.

Domestication may increase the overall fitness of hatchery populations in a combined artificial (hatchery) and natural (stream and ocean) environment and may be advantageous in hatchery populations whose only purpose is to provide sustainable fisheries rather than to supplement naturally spawning populations. However, domestication is assumed to represent some level of local adaptation to hatchery conditions and can thus reduce population fitness under natural conditions (Nickelson et al. 1986; Reisenbichler and Rubin 1999).

Domestication can be inferred from observations of morphology, physiology, and behavior in cultured populations, as compared to naturally spawned populations. Studies of several species of salmonids have demonstrated greater activity, surface orientation, and aggression among domesticated fish, presumably a consequence of high density rearing and pulsed, surface feeding. Some of these studies have observed less survivability among domesticated (more active, aggressive) fish in natural habitats (review in Campton 1995). Further experimental work has shown that domesticated (more active, more aggressive) salmonids can displace locally adapted fish from their native habitat (e.g. Berejikian et al. 1996)[9].

Stock Transfers

Backfilling egg or spawner shortages at one hatchery from surpluses at another hatchery has been a common hatchery practice. In many instances, this transfer of fish or gametes has taken place over hundreds of miles and even between ecological provinces (e.g. Puget Sound and the Columbia River). However, 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 broodstock. The end result of such natural selection is the development and maintenance of local adaptations.

Local hatchery broodstocks (as appropriately defined by each program and including, in some programs, aggregate broodstocks of a local regional hatchery complex) should not be subsidized with fish or gametes from hatcheries in other regions or watersheds, even when the donor and recipient hatchery stocks share a common ancestry. Separate watersheds and geographic locations can be expected to have imposed different selection pressures for time of return, spawn timing, age and size at sexual maturity, and many other life history traits directly related to fitness. Consequently, the transfer of fish or eggs between hatcheries and localities would most likely be antagonistic to the establishment and maintenance of local adaptations in hatchery broodstocks (see section 1.1.3 for natural straying).

1.1.2 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 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 different environmental conditions.

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9. Solutions that may be appropriate in particular programs for managing the deleterious effects of domestication include managed gene flow from wild populations to the hatchery population, modified hatchery environments that more closely resemble natural conditions (e.g. cover, substrate, structures, etc.), protocols for selecting and mating spawners designed to minimize genetic change between adults and their progeny, matching hatchery life cycles to local natural life cycles (e.g. subyearling fall chinook rather than yearling smolts), and limits on the duration of supplementation programs.

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.

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 Ne in distinct, or semi-isolated, populations have been proposed:

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

⇒ *Ne > 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)*

⇒ *Ne > 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 Ne needs to be large enough to minimize genetic drift and the potential loss of alleles that may confer a slight, selective advantage under existing and future environmental conditions.*

Conditions that sustain or promote genetic diversity are:

⇒ *Sufficient number of spawners,*

⇒ *Appropriate selection of spawners, and*

⇒ *Appropriate mating protocols.*

Sufficient Number of Spawners

Hatchery goals should be established in terms of the minimum number of spawners per year necessary to propagate a population in accordance with the minimum effective population size criteria outlined above. Although effective population size is defined in terms of numbers of reproducing adults per generation, hatchery programs should establish a minimum *effective number of spawners* (or breeders) *per year* according to the following relationship: Ne = (t)(Nb) where Nb = the harmonic mean of the effective number of breeders per year, t = the generation time of the species, and Ne is the desired effective population size (Waples 1990 a, b). Generation time is, by definition, the average age of spawners when they reproduce. This quantity clearly varies among species of Pacific salmon.

An absolute minimum Ne > 1,000 is a reasonable goal for most hatchery populations of Pacific salmon. This minimum translates into a minimum Nb of 500 adults/year for pink salmon (t = two years) and approximately 250 adults/year for chinook salmon. However, those numbers should be multiplied by a factor of two to five for hatchery populations in which long-term conservation of genetic resources is a primary goal of the hatchery program.

Ne can be estimated directly if the following quantities are known: (a) the number of males and female spawners per year and (b) the approximate number of viable progeny per parent. These numbers can be obtained in most hatchery programs if males and females are mated pairwise and/or if fertilized eggs constituting family groups (full or half siblings) are incubated separately and the number of eggs and percent hatch are recorded. In the absence of such parental information (e.g. in naturally spawning populations), indirect estimates with relatively large standard errors can be obtained by molecular genetic methods (Waples 1989; Waples and Teel 1990; Bartley et al. 1992).

One situation of particular importance occurs when a naturally spawning population (or stock) is depressed and decreasing in size with a near-term risk of going below a minimum desired Ne. In such situations, hatchery propagation, coupled with supplementation, may be viewed as a way to prevent Ne from decreasing below a minimum desired threshold for the stock as a whole.

Appropriate Selection of Spawners

Viable, healthy hatchery populations will, by definition, return more adults to the facility than are necessary for propagating the population. Thus, hatchery personnel often must decide which fish to spawn and which to exclude from spawning. These decisions are extremely important because they can impose a form of artificial selection on the hatchery broodstock and change the genetic composition of a population between generations. Moreover, these changes are cumulative over multiple generations. Hatchery programs must, therefore, have specific broodstock management guidelines that explicitly state the intended purpose and goal of the program and the spawner selection process.

The potential effects of selecting spawners from a pool of adults available for reproduction can be quantified by the *selection differential*[10]. Selection differentials can be estimated if the traits under study are measured in sufficient numbers of actual and potential parents. However, a response to selection of parents (i.e., with a selection differential significantly different from zero) will occur only if the trait in question is heritable.

For hatchery populations of anadromous salmonids, selection of spawners can be either random or directed.

Random Selection—The goal of random selection is to avoid changing the genetic composition or gene frequencies of a population. The genetic composition of the progeny population should equal the genetic composition of the parent population (all adults available for spawning), with the understanding that not all adults may be spawned. A common goal of many, if not most, hatchery programs is to minimize or prevent genetic change over time (i.e. between generations within a hatchery population). In such programs, adult spawners should represent a large, random sample of all adults available for spawning.

Directed Selection—One goal of some hatchery programs may be to develop an artificially propagated population that is phenotypically and genetically distinct from the founding population or from the natural populations with which it may interact. In such situations, adult spawners may be artificially selected for a particular trait, with the intent of changing the phenotypic distribution of that trait in the hatchery population over time. These types of hatchery programs are clearly not

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[10] *A selection differential is defined as the difference in mean value of a trait between the parents that reproduce—where individual parental values are weighted by their respective number of progeny—and all the adults available for reproduction in a population (Falconer and MacKay 1996).*

appropriate if conservation is a purpose or goal. Moreover, these types of programs may introduce unacceptable risks to natural populations (Section 2.3).

Appropriate Mating Protocols

The mating of hatchery fish should strive to achieve two principal objectives: 1) maximize the effective number of breeders and 2) prevent natural selection for reproductive fitness in the artificial spawning environment. These objectives can be achieved if steps are taken to ensure that every selected adult has an equal probability of producing progeny. To achieve this, male and female hatchery fish can be mated in one of three, principal ways: pairwise (1 male:1 female), nested (e.g. 1 male:3 female), or factorial (e.g. 2 x 2 spawning matrix).

Pairwise mating of males and females is a production-oriented method that strives for equal genetic contribution by each parent to the progeny gene pool. This relatively straightforward method is recommended for large broodstock programs where the number of males and females available for spawning each exceeds one-half of the desired effective number of breeders.

One variation of pairwise mating is *overlapping* pairwise mating. Under this protocol, milt from each of two males is added to the eggs of two females in an overlapping fashion. Approximately 30 seconds after the milt and eggs from one male and one female are combined, the milt from a second male is added as “back-up” to the first male, in case the first male has poor sperm quality. This second male then becomes the primary or first male for the next female spawner. The process is repeated until all males and females are spawned.

A nested design, or modified nested design, may be required if a shortage of one sex (or skewed sex ratio) precludes pairwise mating from achieving the desired effective number of breeders. In such situations, some individuals from the least abundant sex are mated with more than one individual from the more abundant sex. The general guideline is that the number of male and female spawners should be maximized, and individuals of the more abundant sex should not be excluded from spawning because of a lower number of adults of the other sex. Surpluses of one sex can compensate genetically for shortages of the other sex for achieving the desired effective number of breeders. However, as the sex ratio becomes more skewed, the total number of spawners necessary for achieving the desired effective number of breeders will increase proportionately.

Factorial mating, commonly referred to as *matrix spawning*, will maximize the number of family groups and potential genotypic combinations of the progeny. However, this type of mating is somewhat labor intensive and impractical for large hatchery programs. Consequently, it is usually reserved for comparatively small broodstocks in conservation programs, where maximizing genotypic diversity among progeny is a primary goal. In such situations, factorial mating can increase the effective population size by reducing the variance in family size that results from variation in egg quality or sperm potency among individual parents.

Regardless of which mating protocol is used, milt from multiple males should not be combined in a single container of eggs, except as outlined above under *overlapping pairwise mating.* Mixing milt from two or more males can substantially reduce the genetic contribution of one or more males, due to sperm competition (Gharrett and Shirley 1985; Withler 1988; Withler and Beacham 1994). Not only does this have the potential to substantially reduce the effective number of breeders, it can also impose an unknown amount of *domestication (natural) selection.* This can significantly change the genetic composition of a hatchery population in unknown and potentially undesirable ways, particularly if the variation in sperm potency is correlated genetically with other fitness traits (e.g. age or size at maturity, disease resistance, etc.).

1.1.3 Genetic Population 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.

Hatchery populations that are designed and managed as integrated or supplementation projects also benefit from population structure. These projects are part of larger metapopulations connected to adjacent populations through natural gene flow.

Factors that influence population structure include:

⇒ *Spatial variability among populations,*

⇒ *Temporal variability, and*

⇒ *Gene flow between wild and hatchery populations.*

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 1.1.2). 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 across year classes

The degree of temporal structure across years varies substantially among species and depends on the number of brood years spawning together and their relative abundances. It decreases as the variance in age at maturity increases. Temporal structuring for year class is absolute in pink salmon, with a strict, two-year life cycle. It is less strict 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. There is generally even less temporal structure in sockeye salmon, chinook salmon, chum salmon, and steelhead trout, and very little temporal structure may be evident in species that undergo a degree of repeat spawning at variable ages.

Populations showing temporal stability in abundance have a low or minimal variance in the effective number of breeders per year. The number of breeders each year, in turn, contributes to the effective population size of the entire population. 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) where generation time is defined as the average age of parents when their offspring are produced.

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. Divergence among run timing can contribute significantly to the overall among-population diversity. For example, 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[11].

Gene Flow Between Wild and Hatchery Populations

Straying of wild salmonids allows for colonization of new or emerging habitats and maintenance of genetic variability within populations. Therefore, some low level of gene flow among wild and hatchery populations may be expected, similar to that observed among wild populations. Natural levels of gene flow likely vary among populations and species, but observed local adaptation presumably results from the scarcity of strays or their poor reproductive performance rate relative to locally adapted salmon. This observation is consistent with the generally poor survival of transplanted salmon relative to wild populations (Quinn 1997).

The amount of gene flow between wild and hatchery populations will vary with the design and purpose of the hatchery (Candy and Beacham 2000). The relationship of hatchery populations to the naturally spawning populations and supporting ecosystems ranges widely, from projects genetically integrated with the gene pool of a naturally spawning population, to those genetically segregated from the naturally spawning populations, to the full spectrum of relationships in between.

One goal of integrated projects is to minimize genetic divergence between hatchery and wild populations. Gene flow from natural spawners to hatchery spawners is desired in this case. The hatchery population can potentially serve as a genetic repository, or gene bank, for the naturally spawning population and contribute to the structure of the natural populations.

An extended version of an integrated program is one where gene flow from hatchery spawners to natural spawners is desired. These programs are commonly called *supplementation* programs. A primary goal of supplementation is for hatchery-origin adults to spawn naturally and contribute genetically and demographically to a naturally spawning population. The ability of hatchery-origin adults to accomplish this goal is currently the subject of much debate, largely because appropriate experiments to evaluate reproductive success genetically, with appropriate broodstocks and natural population controls, are difficult to accomplish.

Segregated projects, by definition, are designed to minimize interactions with the natural populations. Segregated hatchery populations may be genotypically and phenotypically similar to the wild populations or, either by design or stochastic properties, show genotypic and phenotypic divergence. The hatchery site or release point is a critical factor for these projects. It must be at a location that substantially reduces the likelihood, or possibility, of interactions with naturally spawning

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[11] Temporal structuring for year class is absolute in pink salmon, with a strict, two-year life cycle. It is less strict 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. There is less temporal structure yet in sockeye salmon, chinook salmon, chum salmon, and steelhead trout. There is very little temporal structure in cutthroat trout and other species that undergo a degree of repeat spawning at variable ages.

populations while providing adequate opportunities for the hatchery fish to properly imprint and return to the release point. Gene flow between divergent hatchery and wild populations can increase the potential risks of outbreeding depression and breakdown of local adaptations to natural populations (Section 2.3).

1.2 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 and 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 (1.2.1),*
- ⇒ *Morphology (1.2.2),*
- ⇒ *Behavior (1.2.3), and*
- ⇒ *Fish health (1.2.4).*

The following sections describe the normative life history patterns as a template for hatchery populations.

1.2.1 Physiology

Physiological fitness is the ability of fish to grow, smoltify and resist disease in the hatchery environment. 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, temperature, feed availability, day length (photoperiod), size attained, and fish health. These factors may produce life history patterns that vary within and between populations.

Anadromous salmonids undertake a major metamorphosis, 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;). These processes are under hormonal control and mediated primarily by photoperiod. The same hormones that control growth rate (growth hormone, insulin-like growth factor-I) also stimulate the development of seawater tolerance in salmonids (see Sakamoto and Hirano 1993 for review). The sharp increase in growth of wild fish concomitant with smoltification is similar to the rapid growth of high quality smolts in hatcheries (Beckman et al. 1996). Enhanced seawater tolerance is also a characteristic attribute of successful smoltification (Hoar 1988).

In addition, 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.

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 gill Na-K ATPase enzyme activity, blood concentrations of thyroid hormones, growth hormone, insulin, insulin-like growth factor, and body lipid levels, among others. Physiological fitness can also be measured during the parr-smolt transformation by examining the pattern of juvenile growth. In reproductive adults, physiological fitness can be measured in terms of their morphology (e.g. size and age at maturity; see section 1.2.2.), development of secondary sexual characteristics, and endocrine cycles[12].

1.2.2 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 early, 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).

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 silvery smolt is produced.

Size at Maturity—Large body size has been shown to confer a competitive advantage to males competing for temporary access to females (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,

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[12] Example: Cyclic water temperatures during fresh water rearing, photoperiod control, dietary salt supplementation, environmental enrichment of rearing containers, emulating a natural growth cycle, and low rearing density have all been reported to stimulate physiological fitness through the production of better quality smolts.

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 correlated with male sockeye salmon breeding success. They also demonstrated that coho salmon males with longer snouts (kypes) attained greater access to spawning opportunities and greater estimated fertilization success than those with shorter snouts. Caudal peduncle depth has been correlated with female breeding success (Fleming and Gross 1994). 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).

1.2.3 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 the smolt to school and migrate to the sea. Imprinting and subsequent homing behavior result 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.

1.2.4 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[13]. 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, Wederneyer 1996). Use of such publications will greatly assist in ensuring that disease problems are avoided in salmonid hatcheries.

Disease Control/Prevention Approaches include the following:

- ⇒ *Use water supply suitable for salmonid culture (pathogen-free, if possible);*
- ⇒ *Select, if feasible, pathogen-free stocks for hatchery purposes (it is preferable to start with eggs rather than fish because eggs carry fewer types of pathogens than fish));*
- ⇒ *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 (e.g., frequent fish handling, holding of fish in high activity areas, overcrowding) likely to result in chronic stress);*

Use locally adapted stocks that are likely to have developed reasonable resistance to any pathogens likely to be present in the water supply (see section 2.2.4 on the role of genetics in disease resistance).

1.3 Hatchery and Environmental Conditions

The health and viability of hatchery populations are affected by the environment in which the fish are reared (1.3.1) and are dependent upon the culture techniques these fish experience (1.3.2). 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 (1.3.3)**.** Providing proper hatchery and environmental conditions optimizes potential fish production.

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[13] 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).

Hatchery population performance is affected by:

- ⇒ *The hatchery environment (1.3.1),*
- ⇒ *Culture techniques (1.3.2), and*
- ⇒ *The receiving habitat (1.3.3).*

1.3.1 Hatchery Environment

The hatchery environment refers to the physical habitat in which fish are reared prior to release. Important factors include:

- ⇒ *Water quality, and*
- ⇒ *Waste management*

Both of these factors can be measured to determine the quality of the hatchery environment.

Water Quality

Water quality is a result of physical and chemical characteristics such as suspended solids, temperature, dissolved gases, pH, mineral content, and potential toxic metals. Water quality determines, to a great extent, the success or failure of a fish culture operation.

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.

Other factors also influence hatchery fish performance. Several gases have implications for effective hatchery management, including oxygen and nitrogen. 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). 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, PCBs and herbicides interfere with a variety of metabolic processes essential to growth, reproduction, and smoltification (Pennell and Barton 1996).

Waste Management

Fish waste management is the removal of metabolic products and unused food. Rearing vessel construction and configuration can effect rate of accumulation and dictate pond management. As water passes through a hatchery, fish remove oxygen, excrete carbon dioxide, urea, and ammonia, and deposit feces. Uneaten food can accumulate in the pond and can be a source of disease, reduced growth, and reduced survival (Warren 1991; Piper et al. 1992; Wedemeyer 1996).

The consumption of oxygen and accumulation of metabolic products are primary factors limiting the carrying capacity of rearing units. Both factors are proportional to the amount of daily feeding.

Minimum dissolved oxygen criteria exist, but many times these are a compromise between efficient use of the water supply and fish health and growth. 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, where water is being reused through a culture system. The toxicity of these metabolites is pH dependent and varies with species of fish.

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. 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.

Accumulated levels of waste can be measured and predicted based upon rearing facility construction, configuration, and fish densities. Removal of accumulated waste material is often accomplished with pump or Venturi vacuum systems.

1.3.2 Culture Techniques

Fish culture techniques are the husbandry practices and scientific principles used in artificial rearing. These techniques include:

⇒ *Rearing space and fish density,*
⇒ *Water flow and pond loading,*
⇒ *Type of release,*
⇒ *Time and fish size at release,*
⇒ *Nutrition and diet management, and*
⇒ *Promoting life history diversity.*

These parameters can directly affect physiological, morphological and behavioral fitness (see 1.2).

Rearing Space and Density

Rearing space is the volume of water provided to rear fish. It is consists of containers of various shapes and sizes that hold water. Rearing density is the ratio of pounds of fish being reared to rearing space. It can be expressed as a Density Index, which provides for the direct comparison of fish densities at different fish sizes. To maximize production, space parameters need to be tailored to the species and life stage being reared (Pennell and Barton 1996; Piper et al. 1992). Higher than optimal rearing densities may cause increased stress, disease and fin erosion, along with decreased growth rates and survival (Ewing and Ewing 1995; Wedemeyer 1996).

Water Flow and Pond Loading

Water flow is the quantity of water available to rear fish. It limits the production capacity of a hatchery facility. Pond loading is the ratio of pounds of fish being reared to water flow. It can be expressed as a Flow Index, which provides for the direct comparison of fish at different sizes to water flow (Piper et al. 1992).

Type of Release

The type of release is the mechanism by which the fish leave the hatchery. The release may be volitional (there are no barriers preventing fish from leaving the rearing facility) or forced (fish are planted en masse on or off station into a natural habitat). The method of release is 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).

Time and Fish Size at Release

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 early, and most importantly recruit into the fishery or spawning population (see 1.2.1, 1.2.2, and 1.2.3). 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).

In intra-specific contests over food and space, all else being equal, the largest fish usually win and are able to establish prime territory (see section 1.2.2). In addition, some male juveniles grow rapidly in the year before they smolt and exhibit a precocious male reproductive tactic. Instead of out-migrating, they remain in freshwater to spawn in the coming fall. As residents of the same streams and rivers as wild fish in the ecosystem, they become potential competitors and predators.

Nutrition and Diet Management

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 diet management.

Life History Diversity

To cope with environmental variability and fluctuations, hatchery populations should exhibit life history diversity characteristics similar to natural populations. Some of these characteristics include: growth rate, size of fish, age structure, size at maturity, smolt migration timing, and spatial-temporal migration patterns.

Diversity in morphology and behavior, such as cryptic coloration and natural behavior to avoid predation, can also be important to maintaining the long-term success of hatchery populations. Hatchery practices that maintain morphologic and behavioral diversity include maintenance of rearing densities that minimize behavioral changes, rearing in enhanced environments (i.e., hatchery environments that mimic, to some degree, features present in natural environments), and feeding and release practices that promote the survival of the full range of fish sizes under propagation.

1.3.3 Receiving Habitat

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 of receiving environment,*
- ⇒ *Complexity and connectivity of receiving habitat, and*
- ⇒ *Quantity of receiving habitat.*

Quality of the Receiving Environment

The quality of the receiving environment refers to the condition of the habitat available to the hatchery population after release from the hatchery. The quality of the receiving environment can affect productivity, abundance, and diversity of salmon populations (Allen 1969; 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)

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 2.2.5).

Quantity of Receiving Habitat

The abundance potential of a hatchery population is in part a function of the quantity of food and space in the receiving natural habitat (Hall and Field-Dodgeson 1981; Nickelson 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).

CHAPTER 2. EFFECTS OF HATCHERY PROGRAMS ON WILD AND NATIVE POPULATIONS AND THE ENVIRONMENT.

2.1 Hatchery Structures

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 wild fish populations by creating (for example) obstacles to migration, changes in instream flows, and loss of water quality. Most effects of hatchery structures are quantifiable. Water quality of hatchery effluent and changes in instream flows are relatively easy to measure. Impassible barriers to migration are identifiable and delays in migration can be estimated. Hatchery structures may affect wild fish and the environment in various ways:

⇒ *Downstream fish passage (water intake screens) (2.1.1),*

⇒ *Upstream fish passage (2.1.2),*

⇒ *Volitional entry into hatchery (2.1.3),*

⇒ *Instream flow (2.1.4),*

⇒ *Water [discharge] quality (2.1.5),*

⇒ *Riparian alterations (2.1.6), and*

⇒ *Human harassment (2.1.7).*

2.1.1 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. Improperly sized screens can allow wild 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.

2.1.2 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. Hatchery fish require sufficient and unique flows for attraction and separation into the hatchery, but wild fish need to be able to pass through hatchery structures, such as intake dams or adult weirs, in a timely manner. Passage of wild salmon is important to maximize use of natural habitat. Allowing separation of hatchery and wild adults to their respective natal rearing areas is also important to minimize negative ecological and genetic interactions (see 2.2 and 2.3).

Physical structures (adult weirs, water intake dams) block natural passage of salmonids to spawning or rearing areas. When adults are passed upstream of impassable barriers, it is important to minimize physical handling stress and the length of time they are delayed from migrating (see 3.1.2).

Structures that are impassible can be measured by direct observation. Hatchery operating procedures often require adults to be periodically passed upstream of impassible hatchery structures. The length of delay in migration can be measured in these cases.

2.1.3 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.

If attraction is sufficient to selectively influence the return of only hatchery fish, negative genetic and ecological interactions between wild and hatchery adults can be reduced (see 3.1.2).

2.1.4 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, the section of stream between the intake and discharge should be reduced so that upstream migration by adult salmonids is not prevented or delayed during the usually dry fall season.

2.1.5 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. Unregulated discharge and poor water quality can alter the native flora and fauna below the point of discharge. The Unites 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.

2.1.6 Modification of Riparian Areas

The physical structures of hatcheries are located in riparian areas, where original habitat has been removed and 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.

2.1.7 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.

2.2 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 (2.2.1),*

⇒ *Competition (2.2.2),*

⇒ *Disease transmission (2.2.3), and*

⇒ *Ecological function (2.2.4).*

Recent literature reviews have summarized current knowledge on these topics (Fresh 1997; Flagg et al. 2000). Detailed information supporting the following summary can be found in these reviews.

2.2.1 Predation

The effects of released hatchery-reared salmon on predator-prey interactions involving wild salmonid populations can be divided into two major categories: 1) salmon released from hatcheries may prey on wild fish; 2) releases of hatchery fish may influence the behavior and dynamics of predator populations, indirectly affecting wild fish (Flagg et al. 2000).

There is evidence that released hatchery fish prey on wild fish in streams and lakes (Fresh 1997; Flagg et al. 2000). Quantifying the magnitude of predation impacts is problematic because of the numerous biotic and abiotic factors affecting predator-prey interactions. Estimated predation impacts of released hatchery fish have ranged from no wild fish consumed to upwards of 20% of age-zero juveniles in the affected wild population (Cannamella 1993). USFWS (1992) summarized existing information for the Columbia/Snake River system and concluded that the number of fry/fingerlings eaten by hatchery-produced steelhead was, "… low or negligible, either because of low rates of predation, the lack of coexistence, or both; and too many assumptions would have to be made to confidently estimate the actual number of chinook salmon fry and fingerlings consumed (or to calculate their resulting adult equivalents)." Information summarized since the completion of that report (e.g., Whitesell et al. 1993; Jonasson et al. 1994, 1995) supports these conclusions.

In addition to direct predation by hatchery fish on wild fish, hatchery releases can alter the behavior and dynamics of predator populations, which may indirectly impact wild salmonids. The rapid numerical response (predator abundance) and functional response (number of prey eaten per predator per unit time) to large-scale hatchery releases could have either a positive or negative impact on wild fish. For example, concentrating predators near hatcheries could expose wild fish in those areas to greater predation pressure. On the other hand, predators migrating towards large numbers of hatchery fish concentrated near release sites would temporarily reduce predator abundance in other areas of the migratory corridor, which may reduce predation on wild fish in those areas. In fact, releases of hatchery-reared salmon have been demonstrated to attract predators to areas near release sites (Collis et al. 1995). The increased predator abundance and increased predation rates on recently released hatchery salmon have not been demonstrated to either increase or decrease predation on wild salmonids near or away from hatchery release locations.

Theoretically, predation on wild fish may be reduced if the numbers of hatchery-produced fish released exceeds the capacity of the predator population to consume the additional prey ("swamping"). Numerous studies have investigated the "functional response" of predators to salmonid prey (Peterman and Gatto 1978; Ruggerone and Rogers 1984; Fresh and Schroeder 1987; Peterson and DeAngelis 1992). Numerous factors can affect the functional response relationships including temperature, turbidity, prey abundance, and prey size (Ruggerone and Rogers 1984). An upper limit (asymptote) to the predation rate by a predator population has been demonstrated (Petersen and DeAngelis 1992). Therefore, the release of large numbers of hatchery fish could reduce predation on wild fish if the abundance of local predator population remains stable or decreases (Collis et al. 1995). Thus, without complementary information on both the functional and numerical response of predators to prey, predictions as to how increases or decreases in hatchery fish abundance will affect predation on intermixed wild fish would be unfounded.

Increases in predator population abundance directly caused by long-term hatchery production would likely increase predation on wild fish. Increases in predator populations have been correlated with annually increasing numbers of released hatchery fish (Kirn et al. 1986, Beamesderfer and Rieman 1991). However, no causal relationship between increases in the number of hatchery-released fish and long-term increases in population abundance of predators, has been established.

2.2.2 Competition

Competition between released hatchery salmonids and wild salmonids is among the principal concerns with artificial propagation programs. Several studies have documented the decline of wild salmon populations concomitant with large-scale release of hatchery-produced juveniles (e.g., Nickleson et al. 1986; Flagg et al. 1995; Perry 1995). Although competition was implicated as the mechanism causing the decline in wild populations in these studies, empirical evidence for such an effect was lacking.

Clearly, inter- and intra-specific competition can occur between released hatchery fish and wild fish. Intraspecific competition is generally believed to be more intense than interspecific competition because of greater spatial (i.e., microhabitat), temporal, and body size overlap within species than between species (Bisson et al. 1988).

Factors such as prior residence (Rhodes and Quinn 1998), large body size (Abbott et al. 1985), and aggressiveness (Swain and Riddell 1990) interact to determine the outcome of agonistic encounters (i.e., dominance) among individuals. Wild fish have the advantage of prior residence, but are typically smaller than released hatchery fish. Levels of aggression have a genetic basis (Riddell and Swain 1991), but are also determined by environmental (rearing) conditions. Thus, hatchery-produced salmonids may be more or less aggressive than wild fish, depending on the species, selection regimes, and rearing environments (Swain and Riddell 1990; Berejikian et al. 1996; Berejikian et al. 2000).

Some research studies have investigated the effects of pre-smolt hatchery releases on competitive interactions in streams. For example, following release of over 90,000 yearling hatchery reared coho salmon into the Noyo River in California Nielsen (1994) observed: (i) an increase in the total number of agonistic interactions in the stream; (ii) alteration in the feeding behavior of wild fish; and (iii) over 83% of marked wild fish were displaced from their foraging habitats. Berejikian (1995) observed that although hatchery-reared steelhead fry were less competitive in individual territorial contests with wild fry, wild fish were displaced from preferred microhabitats by the hatchery-reared fish.

The negative effects of competitive interactions between hatchery-produced and wild salmonids in streams are less likely to be disruptive (see Bachman 1984) to wild fish provided that released hatchery-reared fish are: i) derived from locally adapted wild broodstock (Busack and Currens 1995; Kapuscinski 1996); ii) restocked at densities within the carrying capacity of the target stream (Reisenbichler 1997); and iii) within the size range of wild fish to minimize size-related effects on competition (Abbott et al. 1985; Holtby et al. 1993; Berejikian et al. 1996).

2.2.3 Disease Transmission

Disease transmission is one of several possible outcomes of the transfer of an infectious agent between fish. Another possible outcome is that the pathogen will cause only a transient infection (i.e., an infection that the fish will be able to eliminate quite rapidly). Still another possible outcome is that a persistent infection will occur but the fish will remain healthy (i.e., show no signs of disease). Fish that carry infections without showing signs of disease are often referred to as “carriers.” Carriers doubtless often survive just as well as uninfected, healthy fish but there is always the risk that they will succumb to the infection if stressed—and in the process serve as potential sources of the infection for their uninfected cohorts.

The transmission of the pathogen can be vertical (from mother fish to offspring, via the egg), horizontal (via fish-to-fish contact or via water), or even indirect (from fish to one or more alternate hosts and then back to fish). With microbial pathogens such as viruses, bacteria, and fungi the primary method of transmission is horizontal. With a few microbial agents (e.g., the kidney disease bacterium, *Renibacterium salmoninarum*; Evelyn et al. 1986a and 1986b), transmission is also known to occur vertically.

Disease transmission is important because survival of diseased fish is decreased (sometimes dramatically). Also, the costs of trying to correct disease problems in hatcheries are great. Finally, with wild fish, it is virtually impossible to correct an existing problem unless it is due to an adverse habitat or water quality condition that can be reversed.

Disease transmission results in an increased prevalence of disease in an affected population. It is thus relatively easy to measure. In hatcheries, which are potential sources of infection for wild fish that share the same drainage, the presence of re-occurring disease outbreaks is a sign that something is wrong and needs correcting. It may, for example, be that the water quality is not optimal, fish rearing densities are too high, fish handling techniques are inappropriate, the fish feed needs amending, or the fish stock selected for propagation is inappropriate for drainage system involved.

Hatcheries may acquire infections from their water supplies or from wild or hatchery-derived fish used for their stocking (both well-established facts). Care should be taken, therefore, to operate hatcheries in such a way that they do not serve as sources for amplification of any infectious agents present. If not, infected fish released from the hatchery and large numbers of infectious agents in the hatchery effluent can pose a significant potential threat to wild fish likely to be contacted by the infected hatchery fish or hatchery effluent.

Transplants of infected hatchery fish have been strongly implicated in the spread of at least one important salmonid pathogen (*Myxobolus cerebralis*) in California (Modin 1998), but studies to document the spread of salmonid diseases from hatchery to wild fish via hatchery effluents have apparently not been done. Indeed, a recent unpublished review on this important topic by the Aquaculture Effluents Task Force of the Joint Subcommittee on Aquaculture concluded that “the biological significance of aquatic animal pathogens in effluents is unknown" (copies of the report may be obtained by phoning Dr. Scott LaPatra, 208-543-3456).

Notwithstanding this, it is well recognized that many of the currently important bacterial and viral diseases of salmonids can be spread with water. In addition, the shedding of the bacteria and viruses responsible for these diseases from infected fish has been well documented (see for example Mulcahy et al. 1983 and Zhang and Congleton 1994 for infectious hematopoietic necrosis; McAllister and McAllister 1988 and Maheshkumar et al. 1992 for infectious pancreatic necrosis; McKibben and Pascho 1999 for bacterial kidney disease; and Perez et al 1996 and Rose et al. 1989 for furunculosis). There is every reason to conclude, therefore, that hatchery effluents are potential sources of infection for wild fish.

Thus, even if the pathogen involved is one already present in the particular drainage (as is likely to be the case in Washington state), the prudent course would be to avoid its amplification in the hatchery. Otherwise, wild fish in the drainage could be exposed to doses of the pathogen capable of causing infections culminating in disease, particularly if conditions in the affected drainage were at the time less than optimal for salmonids.

High fish densities in hatcheries and other fish culture situations favor horizontal infections (see, for example, Banks 1994 and Mazur et al 1993 for bacterial kidney disease in chinook salmon). Reducing fish densities in hatcheries will decrease the chances of serious disease problems, thus reducing the infectious potential of hatchery effluents on wild fish.

A number of factors influence whether an infection is transmitted. First, for any particular pathogen there must be a susceptible "host." Second, the host population density must be high enough to favor fish-to-fish transfer of the pathogen or to facilitate contact of the water-borne pathogen with the host (in hatcheries, fish densities used are normally higher than those found in the wild, explaining why hatchery operators prefer to have access to pathogen-free water supplies and pathogen-free "seed stock"). Third, the pathogen concentration should be high enough to make it likely that it will contact the host. Finally, the immune status of the potential host population will influence susceptibility to infection. Immune status is affected by a number of factors—nutrition, water quality, and the degree of stress (particularly chronic stress) imposed on the fish during rearing (Schreck 1996). In addition, the immune status of fish can be affected by genetics. For example, when resistant wild coho were bred with susceptible hatchery coho, resistance in the progeny to the salmon pathogen *Ceratomyxa shasta* was significantly reduced (Hemmingsen et al 1986). Also, a similar loss of resistance to this pathogen was noted in crosses between resistant and susceptible summer steelhead (Wade, 1986).

Disease Control/Prevention Approaches (see Section 1.2.4).

2.2.4 Ecological Function

The productivity of an ecosystem (e.g., a receiving environment) 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.

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 entering salmonids. The structural complexity and species diversity of this habitat determine both the 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). As mentioned above, the growth of riparian vegetation may be enhanced by these nutrients, contributing to stream shading, cover for fish, and stream bank stability. Any structures (such as hatchery weirs) or practices (such as over-fishing and logging) that reduce the nutrient influx from salmon carcasses may reduce the productivity of the system.

Artificial fertilization can be used to enhance salmonid production in nutrient-deficient systems but it can be a costly procedure. 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 a measure for recovering certain natural salmonid stocks on Vancouver Island (McCubbing and Ward 2000). These stocks have been in steady decline due to fish harvesting, inappropriate land-use practices, and unfavorable ocean conditions (Larkin and Slaney 1996).

Community structure of an ecosystem may be affected by hatchery operations. Hatcheries may release such large numbers of fish that the capacity of the ecosystem to handle the released juveniles or returning adults is exceeded. The end result may be increased competition between wild and hatchery fish for rearing or spawning areas and the displacement of wild fish (RASP, 1992).

2.3 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.

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. Only hatchery fish that actually reproduce in the natural population contribute to gene flow, so the reproductive success of the hatchery fish relative to wild fish is a key factor. 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).

Consequences of genetic interactions include:

- ⇒ *Change of diversity among populations (2.3.1),*
- ⇒ *Change of diversity within populations (2.3.2),*
- ⇒ *Decrease in fitness of a population (2.3.3), and*
- ⇒ *Changes in abundance (2.3.4).*

2.3.1 Change of Diversity Among Populations

Hatchery populations can cause a loss or, less commonly, an increase in diversity among 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.

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.

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).

Some 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)[14].

2.3.2 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

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[14] *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).*

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).

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.

2.3.3 Decrease in Fitness of a Population

Decreases in fitness (usually in either fertility or 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).

Decreases in fitness 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.

Reisenbichler and Rubin (1999) provided a comprehensive review of evidence for genetic changes from artificial propagation that affect productivity and viability of wild populations. Based on the evidence presented in the review, they concluded that fitness for natural spawning and rearing can be rapidly and substantially reduced by artificial propagation. Prudent measures include using local broodstocks, minimizing straying of hatchery fish, and maintaining large effective population sizes in hatcheries[15].

2.3.4 Changes in Abundance

Hatchery releases can directly and indirectly affect the abundance of natural populations. These changes can have both positive and negative consequences for the natural populations.

Direct effects include successfully spawning and producing natural-origin smolts and returning adults in the following generation. These changes can have negative consequences if large excesses of hatchery fish stray at high rates into natural populations, disrupt or displace natural spawning (superposition of redds), or attract wild fish into hatchery populations (decoying). However, small natural populations face numerous risks intrinsic to their low numbers, including both directional and random effects (McElhany et al. 1999). Hatchery releases from supplementation projects can serve as demographic buffers and genetic repositories during periods of low natural abundances if the projects are conducted to maintain local genetic and ecological diversity (1.1.3; Hard 1992).

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15. In an extreme example, Gharrett and Smoker (1991) evaluated hybrids of genetically isolated odd- and even-year pink salmon from the same stream by fertilizing eggs with cryopreserved milt. They found increased F1 variation in the hybrids relative to controls. In the next generation, the overall returns of F2 individuals were low, and the F2s had increased bilateral asymmetry. They hypothesized that co-adapted allele complexes were disrupted by outbreeding depression, resulting in low returns and increased bilateral asymmetry in the second generation. Decreased survival of F2 hybrids was confirmed in a later study (Gharrett et al. 1999).

Indirect effects from hatchery releases can also occur if a high abundance of hatchery fish masks the status of the wild populations. Unmarked hatchery fish in high abundance can severely compromise the ability to determine the viability of a natural, population masking the status and productivity of the wild populations.

CHAPTER 3. CONTRIBUTION TO CONSERVATION AND/OR HARVEST

Hatchery programs are ultimately successful only if they are the best tools for addressing their intended goals. In the context of the twin goals for hatchery reform, we must ask: *under what circumstances is the use of hatcheries appropriate to help recover and conserve naturally spawning populations and under what conditions are they appropriate for harvest augmentation?*

To be successful hatcheries should be part of an integrated "all-H" strategy where harvest, habitat and hatchery management are coordinated to best meet resource goals. This chapter outlines some of the issues involved and conditions required for hatcheries to be an appropriate contributor to meeting:

⇒ *Conservation goals (3.1),*

⇒ *Harvest goals (3.2), and*

⇒ *Educational goals (3.3).*

3.1 Contribution to Conservation

Conservation hatcheries[16] 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.

The artificial rearing conditions within a hatchery, it is now recognized, can produce fish distinctly different from 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 and fertilization 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 purposely reduce individual 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 wild fish may be inherent factors that enable these fish to adapt to changing freshwater and marine conditions.

With the emphasis on wild fish required under the Endangered Species Act, there is an opportunity to transfer the role of certain hatcheries from production to wild stock enhancement. The strategic role of a conservation hatchery is to *promote the restoration of wild populations*. These conservation

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

hatcheries will operate on the concept that high quality fish, behaviorally and physiologically similar to wild cohorts, can be produced in conditions that simulate the natural life histories of each particular species under culture. Scientific information now available makes it feasible and practical for hatcheries to propagate juveniles similar in growth, development, and behavior to their wild cohorts. A combination of accepted hatchery production practices and newly developed methods of culture can be used to raise fish for release into natural ecosystems. Methods include, for example, behavioral conditioning, feeding strategies that simulate natural conditions, modification (enrichment) of rearing habitats, maintaining captive broodstocks, and practicing optimal release strategies.

3.2 Contribution to Harvest

The range of harvest issues and the integration of harvest with artificial production are very complex. They are best addressed under comprehensive species management plans being developed by the fisheries co-managers. The focus of the Hatchery Scientific Review Group (Scientific Group) is to address the use of hatcheries to achieve the two goals of hatchery reform: 1) help recover and conserve naturally spawning populations and 2) provide for sustainable fisheries. 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.

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 (3.2.1),*

⇒ *Protection of hatchery spawning requirements (3.2.2), and*

⇒ *Protection of co-mingled stocks of concern (3.2.3).*

3.2.1 Opportunity to Meet Harvest Goals

To meet harvest goals, hatchery populations must be sufficiently productive and abundant (chapter 1). They must also be present in areas and at times where fisheries can be safely conducted to meet subsistence, recreational, ceremonial and commercial fishery goals (Hilborn and Walters 1992).

Without the integration of hatchery programs and harvest opportunity, most hatchery recruits will return to the hatchery or the area of release. Successful hatcheries will experience larger surpluses more frequently than have occurred historically, due to changes in management towards increased protection of stocks of concern. Creative solutions to provide harvest opportunities, both in the operation of hatcheries and in the manner of harvest, will be needed to meet harvest goals while protecting stocks of concern. Even with innovative harvest solutions, surpluses will be inevitable at successful hatcheries.

3.2.2 Protection of Co-Mingled Stocks of Concern

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.

3.2.3 Protection of Hatchery Spawners

Harvest managers must assure that:

⇒ *Sufficient numbers of spawners, and*

⇒ *Diversity of spawners*

remain to provide hatchery brood stock for a sustainable hatchery program.

Number of Hatchery Spawners

Sufficient numbers of spawners must be available to meet production targets and genetic requirements (see chapter 1)

Diversity of Hatchery Spawners

Diversity of spawning escapement is important for long-term reproductive success of hatchery populations. Diversity in terms of age, sex, life history, fish size, and run timing must be provided to assure genetic population diversity (see chapter 1). Harvest should be managed to avoid size, sex, age, and run-timing selectivity. Determination of harvest selectivity has two aspects: 1) what change in composition would result in a significant loss of diversity?, and 2) did the fishery produce such a change? These questions need to be answered.

3.3 Contribution to Education

One of the strongest assets available in the effort to conserve wild salmon and steelhead, and to provide opportunities for harvest, is the fish themselves. Few people who have the opportunity to experience the remarkable salmon story and lifecycle exit that experience unimpressed. Rather, most are moved, engaged and eager to support efforts to preserve these fish and our opportunities to interact with them, as people in this region have done for many thousands of years.

Hatcheries are in a unique position to provide these educational opportunities because they are involved in the aspects of the salmon lifecycle that occur largely out of sight of a general public that usually encounters salmon in the grocery store or on the end of the hook. As a location where citizens of all ages can not only hear about, but actually see and work with salmon from their egg to adult stages, each area of the Puget Sound and Coastal Washington region has a potential educational center in its hatchery. Hatcheries are of particular value to their communities as a venue for community involvement and education, a place where the public can obtain data and information about salmon biology, fisheries, and ecology. Hatcheries should also be used to educate the public about the role of hatcheries in meeting goals for salmon restoration and harvest in each region.

In addition, hatchery personnel represent a wealth of knowledge about salmon and other environmental issues. Their wisdom should be brought to bear for the benefit of the public.

Hatcheries also provide the controlled environments researchers need to develop and test innovative methods that may be of use in salmon restoration efforts.

CHAPTER 4. ACCOUNTABILITY FOR PERFORMANCE

This section includes an implementation system that ensures accountability for decisions made and actions taken in the hatchery system and an ability to use adaptive management[17] to change the system in response to new information. To achieve the promise of hatchery reform, accountability for decisions and actions is required at all levels within the agencies responsible for management and operation of hatcheries, from hatchery technicians to the directors of those agencies. The Scientific Group views education and effective communication within the scientific community and with the public as vital to accountability and the success of hatchery reform.

The repositioning of hatchery programs in Puget Sound and Coastal Washington will be built around accountability for performance to ensure that hatcheries are successfully operated to accomplish the goals of hatchery reform. This will require an accurate and timely management information system that can measure benefits, evaluate actions, and provide information for hatchery management and operations. This information must be useful and accessible at all levels of decision-making. The Scientific Group has identified five areas that the co-managers should consider when reviewing and implementing their hatchery programs. These include:

- ⇒ *A clear statement of value or benefits to be achieved (4.1),*
- ⇒ *Known measures of success, based on chapters 1 through 3 of this framework (4.2),*
- ⇒ *An accurate assessment and management of costs (4.3),*
- ⇒ *Use of the option that provides the most value for the dollars invested (4.4), and*
- ⇒ *Protocols for collecting and disseminating important management information (4.5).*

4.1 Clear Statement of the Benefits to be Achieved

In reviewing hatchery operations, two goals should be kept in mind: 1) hatcheries should aid in the recovery of naturally spawning populations, and/or 2) hatcheries should provide sustainable fisheries. Siting, stock status, founding broodstock, potential production, local habitat conditions, and harvest opportunities or constraints may dictate whether a particular hatchery should focus on one or both of the above goals.

Artificial production programs must also be consistent with a wide range of legal mandates relating to fish production throughout Puget Sound and coastal Washington. These include for example:

- Treaty fishing rights of Indian Tribes under U.S. v. Washington and Hoh v. Baldridge;
- The U.S./Canada Salmon Treaty;
- The responsibility of the State of Washington to preserve, protect, and enhance fish populations;
- The requirements of the Endangered Species Act;
- Numerous mitigation obligations in law and agreement.

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17. Adaptive management, as it is used in this framework, is the policy of actively pursuing and incorporating new information, knowledge, and experience at all levels of decision making

Because of the sometimes-conflicting objectives of these legal mandates, managing hatcheries requires legal, policy, and biological judgment. The role of science is to inform decision makers about the benefits and risks of alternative actions, including the consequences of inaction.

It is important that each hatchery program have clearly stated goals that are sufficient to provide accountability for performance and for evaluating benefits actually derived. This will allow the hatchery to focus its efforts on attaining those goals. In addition, goals are needed so that performance can be measured.

The benefits resulting from a hatchery's operation can be measured. For sustainable fisheries, the measurement can be in terms of the number of fish provided for the commercial, sports, ceremonial and subsistence fisheries. Contributions to the maintenance or recovery of natural populations can also be measured, in principle.

Careful consideration should be given to whether the hatchery will be fulfilling a need and whether the need is likely to be satisfied without adversely affecting other stocks of valuable salmonids.

4.2 Known Measures of Success

If hatcheries are to be considered successful, they must produce fish populations that are productive, abundant, and diverse to ensure that hatchery populations remain healthy and viable in the long term (see chapter 1). In addition, hatcheries must provide for fisheries or contribute to conservation and recovery of natural stocks. Hatchery programs must do so in a way that avoids serious adverse effects and is cost effective (see chapters 2 and 3).

In evaluating hatchery success, managers need to answer three basic questions:

- ⇒ *What occurs inside the hatchery? Are the conditions required to produce healthy and viable hatchery fish (chapter 1) being met?*
- ⇒ *What happens to the hatchery fish outside the hatchery?*
- ⇒ *What are the effects of the hatchery on the environment and naturally produced fish outside the hatchery?*

In order to answer these general questions, specific performance indicators need to be identified. Success should be measured in terms of specified goals (validation monitoring) and performance benchmarks (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 (see section 4.5).

4.3 Accurate Assessment and Management of Costs

Accurate assessment and management of costs refers to a careful review of a hatchery program to ensure that efforts are focused on meeting specified goals. The most cost effective alternative to meet those goals should be adopted to provide efficient use of funds. In achieving goals, it is important to clearly define specific, detailed, and attainable objectives.

Before effective changes can be made to a hatchery program, a clear understanding of the problem(s) must be established. Incorrect assessment of a situation can compound the problem(s), wasting effort and funds, and possibly impairing hatchery operations (Meade 1989).

One tool currently being developed jointly by the co-managers is the hatchery database and management program HatPro. HatPro records include data on broodstock management, egg and fry inventories, rearing-pond management, smolt release, and hatchery water quality. This information will help identify and define potential changes to a hatchery program.

4.4 Identification of Least Cost Option to Provide Benefits

Least cost option is an economic approach for comparing available alternatives to reaching an objective. All reasonable alternatives should be considered. Current and future costs of each must be included in the evaluation (Meade 1989). The approach indicates the most cost-effective option(s), based on quantifiable data and values. It ensures that among alternatives that produce equal benefits the least costly is identified.

4.5 Protocols for Collecting and Disseminating Important Management Information

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.

Data collection protocols should be developed and implemented to assure that the data needed to answer the three questions in section 4.2 above are available. Effective monitoring and evaluation programs, including implementation, effectiveness, and validation monitoring should be developed for hatchery programs. 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.

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.

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