Implementation of hatchery reform in the context of recovery planning using the AHA/ISIT tool

Prepared for:

Washington Department of Fish and Wildlife as a training aid for users of the AHA/ISIT tool (July 2017) by the Hatchery Scientific Review Group. Updated version of this document will be developed, as required, by the HSRG.

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INTRODUCTION

- The aim of this report is to present an approach for implementing hatchery reform concepts within the context of a recovery plan using the analytical tools, All-H Analyzer-Life Cycle Model and In Season Implementation Tool (ISIT).
- The audience: Hatchery, harvest, and habitat managers.
- The problem: Ensuring that recovery of naturally spawning populations is achieved and maintained over time while also meeting harvest goals.
- The challenge: How can hatchery, harvest and habitat management best be applied over time to maintain a trajectory toward success? Here, "best" means that progress toward recovery of the natural population is maximized while retaining harvest opportunities.

The approach is presented in four parts:

I. Foundation—concepts, principles and definitions
II. Management process and tools to guide decision making
III. Example programs
IV. Reference materials and detailed AHA and ISIT User Guides

The goal of this report is to provide managers with a) background information (terminology and logical framework) needed to use AHA and ISIT as planning and in-season management tools, and b) detailed information to help managers go through the steps of setting up and using AHA and ISIT.

I. FOUNDATION

The HSRG recommends that hatchery programs be designed and operated consistent with three overarching principles:

- Principle 1 – Develop clear, specific, quantifiable harvest and conservation goals for natural and hatchery populations within an "All H" management context.
- Principle 2 – Design and operate hatchery programs in a scientifically defensible manner.
- Principle 3 – Monitor, evaluate and adaptively manage hatchery programs.

Hatchery production may present both benefits and risks to natural population recovery. Hatchery programs are classified in terms of their purpose (conservation, harvest, or both) and broodstock management strategy (integrated, segregated, or stepping stone).

Once the natural population goals have been established, the scientific rationale for a hatchery program must be described in a working hypothesis that explains the expected benefits and risks from the hatchery program. The purpose, operation, and management of each hatchery program must be scientifically defensible. Assumptions under which the hatchery program will be operated must be consistent with the best available information.

Steps to establishing the resource goals for the natural population and the scientific rationale for a hatchery program: (See Chapter IV, Appendix A for more discussion)

A. Determine the biological significance of the population (either the natural population, hatchery population or both) within its Evolutionarily Significant Unit (ESU), which affects recovery goals and priorities for the population. Biological significance is captured in the Population Designation (Primary, Contributing, or Stabilizing; LCFRB 2004).

B. Establish viability goals for the population and determine its current viability status. Population viability is expressed in terms of productivity and abundance, and should also incorporate spatial structure and diversity (i.e., VSP parameters; McElhany et al. 2000). Establish explicit long-term goals for harvest (numbers of fish in specific fisheries). It is useful to track the progression of a population toward its viability goals in four recovery phases: Preservation, Recolonization, Local Adaptation, and Fully Recovered (HSRG 2015). When a population is fully recovered, viability and harvest goals are met.

C. Determine whether a hatchery program is needed to meet goals for conservation and/or harvest. If it is determined that a hatchery program is needed, its purpose and expected benefits and risks should be explicitly stated. The level of hatchery production should be based on an assessment of the expected number of returning adults and the long-term effects on harvest and conservation goals. This assessment should be based on an explicit, working hypothesis. An explicit working hypothesis is necessary to achieve scientific defensibility and to account for trade-offs between benefits and risks.

D. If hatchery production is needed to achieve conservation or harvest goals, select the broodstock strategy for the hatchery program (integrated, segregated, or stepping stone). Hatchery program performance is tracked using a set of standard metrics (pHOS, PNI, and pNOB).

A. BIOLOGICAL SIGNIFICANCE → POPULATION DESIGNATIONS

The effects of hatcheries on natural populations may vary between populations depending on their biological significance to the recovery and sustainability of the ESU. The HSRG has adopted a system of population designations to "customize" recommendations for populations based on biological significance.

Population designations (Primary, Contributing, or Stabilizing) are a measure of the biological significance of a population to the recovery of the ESU. Viability requirements for recovery are highest for Primary and lowest for Stabilizing populations.

Different definitions of biological significance are used by managers throughout the Pacific Northwest. In an effort to provide some consistency, the HSRG uses the designations for biological significance and population viability defined by the Lower Columbia River Fish Recovery Board to describe salmon and steelhead populations (LCFRB 2004).

- **Primary:** populations must achieve at least high viability.
    - High priority for recovery—once recovered, highest viability standards apply.
    - Also, identified as 'biologically significant', 'core', 'key', or 'highly viable' populations. Important to recovery of the ESU.
    - Historically were a large segment (in terms of abundance) of the population structure or contain a unique genetic component of the ESU. Must be at low risk of extinction.
- **Contributing:** populations must achieve at least medium viability.
    - Second to Primary populations in importance to recovery of the ESU—high viability standards apply.
    - Are expected to have some significance, are viable but less abundant than Primary. These populations contribute to diversity of the ESU.
- **Stabilizing:** populations must maintain at least current viability.
    - Important to the ESU—viability should not decline.

- A defined population, but may not have ever been a large segment of the population structure of the ESU.

Why are Population Designations important to hatchery reform?

- Not all populations are created equal – there are different levels of risk tolerance
- Evaluation – provide a consistent basis for comparing populations in terms of their role in sustaining the ESU and species
- Balance—helps to ensure an ESU has diversity, spatial structure, and resiliency.
- Provides flexibility in meeting conservation and harvest goals across a large geographic area

The designation of a population as Primary, Contributing or Stabilizing is a science informed policy decision. If a designation has not been established, managers may make assumptions about biological significance based on the status (current/historical/potential) of each population and/or goal statements found in various planning documents (i.e., Recovery Plans, Management Plans, etc.).

B. POPULATION VIABILITY STATUS → RECOVERY PHASES

Benefits and risks associated with hatchery programs depend on the viability status of the population. The HSRG has adopted a phased approach to population recovery (Preservation→ Recolonization → Local Adaptation → Full Recovery) and has developed management guidelines specific to each of the four phases.

The recovery phases are defined in terms of population viability status and management priorities:

- Phase 1 – Preservation—population is severely depressed; priority is to maintain native and/or unique genetic stock or establish a founder stock if native stock has been extirpated.
- Phase 2 – Recolonization— population abundance is increasing, habitat improving; priority is to populate vacant or restored natural habitat.
- Phase 3 – Local Adaptation—natural production is sustainable; priority is to improve fitness of the population by ensuring that the natural environment has a stronger influence on the adaptation than the hatchery environment.
- Phase 4 – Population is restored/recovered; priority is to maintain sustainable natural production that meets restoration goals. If hatchery augmentation is required to meet harvest goals, hatchery must be operated consistent with conservation goals.

The conservation role of a hatchery is different during each phase. For example, during the Preservation and Recolonization phases, hatcheries can help maintain or increase abundance, diversity and distribution. During the local adaptation and restoration phases, hatcheries may serve as demographic safety nets against future sudden or gradual declines in natural productivity.

Hatcheries may also be operated for harvest augmentation purposes during each of the four phases. During the Preservation and Recolonization phases, hatchery production may exceed the conservation requirements to also meet some harvest needs. During the local adaptation phase, hatcheries can be operated for harvest augmentation purposes so long as guidelines for genetic and ecological interactions are met (i.e., pHOS and PNI constraints apply-see Section D).

The target population moves from one phase to the next based on indicators that specified conditions have been met to successfully implement the succeeding phase. These observable indicators are referred to as phase triggers.

Considerations for defining phase triggers:

1) Triggers should be biologically based (observable indicators such as abundance or productivity), rather than arbitrary timelines.
2) Triggers should allow movement both up and down the Phases.
3) The higher the trigger threshold, the longer local adaptation benefits (e.g., increased productivity) are deferred.
4) Indicators of habitat condition should be included to ensure sustainability. For example, specific habitat improvement milestones (e.g., percent increase in spawning or rearing habitat quality or quantity).

The phase triggers may, for example, be based on observed variables such as running averages of natural origin recruitment (NORs), estimated trends in recruits per spawner, or measures of habitat quality or quantity that give assurances that the biological target has been reached. The lower the triggers are set, the sooner the next phase will be implemented, but the risk of entering the next phase too soon is that the population may revert back to the previous phase. Tradeoffs between high and low trigger thresholds should be evaluated so that informed policy decisions can be made.

This framework is applicable to many situations throughout the Pacific Northwest. In constructing and implementing this framework, triggers should be primarily biological, but also need to consider cultural goals for returning salmon and steelhead to Native American and First Nation salmon cultures.

See Appendix B for a more detailed discussion about recovery phases.

C. HATCHERY PROGRAM PURPOSE → CONSERVATION, HARVEST, OR BOTH

The effect of a hatchery program is an increased abundance of adults. The purpose of increasing abundance should be clearly stated (conservation, harvest, or both) and specific, quantifiable goals should be established (e.g., number of natural-origin spawners, number of fish harvested). A conservation program is one that contributes to population goals for biological significance (Primary or Contributing population) and viability (productivity, abundance, diversity and spatial structure). A harvest program is one that contributes to specific fisheries at specified rates or harvest numbers, and is compatible with identified conservation objectives for all populations.

Other purposes of hatchery programs include scientific research, education, and providing cultural benefits, particularly for American Indian tribes. Each of these identified purposes is briefly described below.

- **Conservation**

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

- **Harvest**

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

- **Education and Research**

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

In the past, the purpose of many hatchery programs was described as the release of specific numbers of juveniles, without identifying whether those releases (and more importantly, the adults produced) were intended to achieve conservation goals, harvest goals, or both. Unless the purpose of a hatchery program is clear, it is not possible to effectively design, operate or evaluate the program. Even when “mitigation” is the stated justification for a hatchery the underlying purpose will be either harvest, conservation, or both.

To be successful, hatcheries should be used as part of a comprehensive strategy where habitat, hatchery and harvest management are coordinated to best meet resource management goals that are defined for each population in the watershed. Hatcheries are by their very nature a compromise—a balancing of benefits and risks to the target population, other populations, and the natural and human environment affected by the hatchery program. Use of a hatchery program is appropriate when benefits significantly outweigh the risks and when the benefit/risk mix from the program is more favorable than the benefits and risks associated with non-hatchery strategies for meeting the same goals.

D. GENETIC RISK → BROODSTOCK MANAGEMENT

The HSRG, and others, have concluded that there are two ways to reduce the potential adverse effects of hatchery fish on natural populations: a) reduce the number of hatchery fish that compete or interbreed with wild fish, and/or b) make sure that hatchery fish that do interbreed are similar (genetically) to their locally adapted wild counterparts (HSRG 2009). Consequently, two hatchery broodstock strategies have been identified: segregated (or isolated) and integrated.

Broodstock management is presented in two sections: 1) a description of each strategy, and 2) a description of the metrics used to evaluate hatchery program performance (pHOS, pNOB and PNI).

i. Broodstock Management Strategies

An integrated hatchery program is one in which natural origin fish are used in the hatchery broodstock (NOB). The HSRG described an integrated hatchery program as one where 1) the naturally spawning and hatchery produced fish are considered components of a single population, and 2) the adaptation of the combined population is driven more by the conditions of the natural environment than the hatchery. They are designed to minimize the genetic divergence of a hatchery broodstock from a naturally spawning population, maintain the genetic characteristics of a local, natural population among hatchery-origin fish and minimize the genetic effects of domestication. This is expected to reduce the genetic risks that hatchery-origin fish may pose to the naturally spawning population.

A segregated program is one where only hatchery fish are used as broodstock. The intent of a segregated hatchery program is to maintain a genetically distinct hatchery population. The only way to reduce risk (genetic and ecological) to natural populations from segregated programs is to minimize the contribution of hatchery fish to natural spawning (HOS).

The integrated and segregated strategies both have strengths and weaknesses, so the decision about which strategy to follow must be determined on a case-by-case basis. While the primary purpose of many integrated hatchery programs is to contribute to harvest, they may also contribute to conservation by providing a demographic safety net for the natural population. But they can pose a risk to natural populations if the size of the hatchery program exceeds the size of the associated natural spawning population. And of course, the size of the integrated program is dependent on the number and availability of natural origin spawners for use in the hatchery brood. On the other hand, segregated hatchery programs, which are most often used to provide harvest, can pose significant genetic and ecological risks to natural populations if they reproduce naturally with wild fish and so the number of hatchery fish from these programs must be severely limited in the natural environment. Regardless of the type of program, there are only three methods of reducing pHOS, either through selective harvest, physical removal at a barrier or lowered production.

The ideal integrated or segregated hatchery program is nearly impossible to achieve in practice. Because hatchery fish have lower reproductive fitness (even when they come from well-integrated programs), they represent a fitness risk to a natural population (where one is present) when they spawn in the natural environment. Yet as noted above, hatchery fish on the spawning grounds may confer a net conservation benefit when the demographic extinction risk is high. During the Local Adaptation or Fully Recovered phases, there is no implied intent to allow hatchery fish to spawn naturally, regardless of broodstock management strategy.

A stepping-stone program is a segregated hatchery program that draws its broodstock from an integrated hatchery program. It retains some genetic continuity between hatchery fish and naturally spawning fish when natural origin brood is in short supply. A stepping-stone program can transition to a fully integrated one as the abundance of natural origin fish increases in the recovery process. Stepping stone programs can and should be designed and operated consistent with HSRG guidelines for hatchery influence.

The HSRG established recommendations for hatchery contribution to natural spawning based on the biological significance and recovery phase of the natural populations for both integrated and segregated programs. The biological principle behind broodstock recommendations for integrated, segregated and stepping stone programs is to promote local adaptation, productivity and fitness in the natural population(s) effected by the hatchery program. Recent studies suggest that segregated programs should be used with greater caution than originally suggested by the HSRG (HSRG 2014, HSRG 2015).

The relative reproductive success of hatchery fish spawning in the wild and long-term fitness effects on natural populations should continue to be a research priority.

ii. Metrics to Assess Hatchery Program Performance

The principle behind the HSRG broodstock management guidelines is local adaptation. This is the notion that for natural populations to persist over time, the individuals that complete their lifecycle in the wild should be dominant in the spawning population. The proportionate natural influence (PNI) measures the degree of dominance of natural origin individuals in the population over time. If a population tends towards a PNI of 0.5, their influence is barely dominant. If PNI is 2/3 (i.e., 0.67), then their influence is roughly twice that of hatchery produced fish.

The Ford (2002) model has given rise to the definitions and methods to calculate PNI recommended by the HSRG. PNI is useful for several reasons – it has intuitive appeal, monitoring data are usually available to calculate PNI, and setting a PNI goal helps managers set a trajectory toward greater local adaptation.

Other models have been developed (e.g. Baskett and Waples) that refine our ability to predict fitness effects and establish broodstock management guidelines in the future. The HSRG is encouraged by the efforts among geneticists to help convert the most recent genetic tools and information into useful management guidelines.

Definitions of Metrics (See Appendix D for more discussion)

pNOB = % Natural Origin fish in the hatchery broodstock-this is an estimate of the level of gene flow from the natural to the hatchery population.

pHOS = % Hatchery Origin fish on the spawning grounds-this is an estimate of the level of gene flow from the hatchery to the natural population.

PNI = Proportionate Natural Influence, calculated as a function of the composition of spawners in the hatchery and in the natural populations over generations.

While pHOS and PNI are imperfect measures, they are practical and useful. They are the only broadly available measurements that consistently account for gene flow and contribution of HORs. Carcass and/or spawning ground surveys are routinely conducted in many basins in the Pacific Northwest.

To address the fitness risks posed by hatchery fish, the HSRG adopted a set of recommendations for hatchery influence on natural populations. These recommendations, which vary depending on the biological significance of the population, are intended to support recovery of natural populations while retaining overall harvest benefits. They are also designed to be simple to implement and monitor. The HSRG also proposes methods for achieving those recommendations. It is important to note that while PNI levels are “not specified” for the Preservation and Recolonization phases, the HSRG encourages the use of natural origin brood (pNOB) to the extent possible during those Phases.

How HSRG Recommendations apply during Phases of Recovery

1) Preservation- No pHOS or PNI recommendations
2) Recolonization- No pHOS or PNI recommendations
3) Local Adaptation- All recommended guidelines for pHOS and PNI apply
4) Full Restoration- All recommended guidelines for pHOS and PNI apply

Guidelines for pHOS and PNI during the Local Adaptation and Full Restoration Phases

Primary populations—
- Integrated hatchery programs--PNI $\geq$ 0.67; pHOS $\leq$30%
- Segregated hatchery programs—pHOS < 5%

Contributing populations—
- Integrated hatchery programs--PNI > 0.50; pHOS $\leq$30%
- Segregated hatchery programs—pHOS < 10%

Stabilizing populations—
- Integrated hatchery programs—current condition
- Segregated hatchery programs—current condition

II. MANAGEMENT PROCESS AND TOOLS (AHA AND ISIT)

This section introduces the management process and two tools, AHA and ISIT, used to implement the process. All-H management can be divided into the 1) <u>Conservation Framework</u>, which involves setting resource goals, establishing a population designation and recovery phase, and identifying biological targets for each phase, and 2) <u>Decision Making Framework</u>, which involves identifying key assumptions about the population, establishing the Hatchery Reform Strategy, setting Annual Management Targets, tracking the population's long term trajectory, and prioritizing recovery actions (Figure 1).

The steps in the management process can be divided into two types of tasks.

1. **Planning (one time or periodic) tasks:**
    a. Complete Conservation Framework items listed in (A) below
    b. Establish Hatchery Reform Strategy (item B-2 below)

2. **Annual tasks:**
    a. Update Status and Trends data
    b. Review Key Assumptions
    c. Calculate Annual Management Targets
    d. Review progress toward meeting program goals

A. CONSERVATION FRAMEWORK

The purpose of the conservation framework is to ensure that hatchery programs are managed consistent with long-term resource goals for each population. The AHA and ISIT tools are set up to allow managers to enter each of the following items, which are determined during the planning process for a hatchery program:

i. Identify Population Designation

Primary, Contributing, or Stabilizing.

ii. Identify Current Population Phase

Preservation, Recolonization, Local Adaptation, or Full Recovery. Based on the current conservation/viability status of the population.

iii. Identify Management Priorities

Identify management priorities for both the natural and hatchery population.

1) **Biological Targets for the Natural Population during each Phase**
   Biological targets are specific metrics that must be met to implement the next recovery phase. They may be expressed in terms of Viable Salmonid Population (VSP) parameters (abundance, productivity, diversity, and spatial structure) and habitat conditions (quality and/or quantity). They are typically calculated as a five-year running average.

2) **Harvest Goals**
   Harvest goals may be expressed in terms of harvest rate, season length or total number of fish harvested. Any goal needs to be convertible to a total number of adults. This is critical as once a desired number of adults has been established, the size of the hatchery program (juvenile numbers) can be calculated.

3) **Other Resource Goals**
   State any cultural or other resource goals.

iv. Identify Purpose of Hatchery Program

Determine if a hatchery program is needed to meet management priorities, and if so, for what purpose (conservation, harvest or both).

v. Establish Criteria for Phase Shifts (triggers)

As part of the planning process, triggers for each Phase shift need to be established. Phase shifts generally occur based on 5-year running averages. For example, if a Biological Target for Recolonization is an average abundance greater than 500 NORs, then the trigger to shift to the Local Adaptation phase might be 600 NORs. This means that the shift would occur once the 5-year running average reaches 600 NORs, indicating that the long-term abundance is now likely to exceed 500 NORs.

The distinction between Biological Targets, triggers, and management priorities is important. For example, the Biological Target for Recolonization should be the conditions required for successful implementation of the Local Adaptation phase. In other words, the Biological Targets for the Recolonization phase are its ‘end point’. Biological Targets should be distinguished from priorities. For example, management priorities during Recolonization might be to populate habitat, increase abundance, and improve habitat to meet the Biological Targets, which are expressed in terms of VSP parameters.

Key (minimum) considerations for transitioning between Phases:

- Preservation to Recolonization: Population must exhibit the ability to be successful at all life stages (spawner to spawner) in the natural environment.

- Recolonization to Local Adaptation: This transition should occur when the reintroduced fish are self-sustaining, spatially distributed to avoid potential catastrophic losses, and have large enough effective population sizes to maintain genetic variation for natural selection to act on. Potential metrics and examples of thresholds are in Table 1. Program-specific triggers will vary based on the distinct characteristics of the species, habitat, and goals of the program.

Table 1. Example metrics and triggers for moving from Recolonization to the Local Adaptation phase.

Viability Attribute	Example Metrics for Biological Targets	Example of Phase Triggers
Abundance	Mean natural origin spawner abundance of 500 adults	Observed natural origin abundance > 600 (5-year running average).
Productivity	Intrinsic productivity of 2.5	R/S greater than 1 when spawner abundance is greater than 500
Spatial Distribution	50% of habitat occupied	Surveys indicate < 50% of spawning/rearing habitat is vacant
Diversity	Genetic effective population size (N_e) > 200	Observed N_e > 200
Habitat	Available spawning or rearing habitat	10% increase in available habitat

B. DECISION MAKING FRAMEWORK

The purpose of the decision-making framework is to ensure that management actions are applied consistently within an All-H context and help move the population toward long-term conservation and harvest goals.

i. Identify Key Assumptions

The scientific foundation of the program includes a set of key assumptions about the population. The key assumptions are applied to standard population dynamics models, which are used to predict the long-term population trajectory. Together, these are often referred to as the working hypothesis for the program. The key assumptions capture our current understanding of the population and how management actions affect outcomes. The identification and documentation of the key assumptions are necessary to ensure accountability.

The key assumptions predict how the population will respond on average and help managers develop long-term strategies to meet harvest and conservation goals. Key assumptions are reviewed annually and are updated as new knowledge and information emerges over time. Changes in key assumptions are likely to affect the Hatchery Reform Strategy and in-season management targets, which are discussed in more detail in the next section.

Key assumptions used in the AHA/ISIT tool for each of the 4 Hs include:

a) Hatchery

Data on in-hatchery survival and post release performance of hatchery fish are usually readily available. The SAR values used are survival from release to return (harvest + escapement), usually from Coded-Wire Tags (CWT). The stray rate is the percent of the returning adults that escape fisheries, but do not return to the hatchery. While this may not be directly measurable for some species (coho, steelhead) an informed estimate can be made using catch-record-cards (CRC) data where available. Data for Chinook is usually readily available from carcass surveys.

b) Harvest

The harvest management policy should be specified, especially for terminal fisheries—this may amount to identifying escapement goals for MSY or other fixed rates, or selective harvest policies (e.g., pHOS targets or relative HOR/NOR harvest rates). Current and assumed future harvest rates for pre-terminal (Ocean) and terminal fisheries should be documented. Harvest rates may vary to some degree from year to year but the recent average as well as the target rate should be available.

c) Habitat

Habitat potential is defined by the two parameter Beverton-Holt production function. The productivity parameter is a measure of the rate of reproduction of the population when competition is not a factor in survival (i.e., at very low abundance levels). Productivity is expressed as smolts per spawner and is primarily a measure of habitat quality. The other habitat parameter is capacity. Capacity represents the number of smolts that the habitat can sustain over time. It is a measure of both habitat quality and quantity and accounts for competition for food and space.

d) Hydrosystem and Migration Survival

The overall spawner to spawner production of the natural population also depends on survival during juvenile and adult migration from the spawning grounds to the ocean and back. This includes key assumptions about smolt to adult survival (SAR) and fish passage survival.

ii. Establish Hatchery Reform Strategy

Within each recovery phase, the objective is to manage harvest, hatcheries and natural escapement consistent with the biological targets for that phase. The Hatchery Reform Strategy developed should help managers to “do the best thing” each year in terms of managing harvest, broodstock collection, and spawning escapement to ensure progress toward biological targets over time.

The Hatchery Reform Strategy provides guidance to managers on hatchery and harvest management based on the adult run size forecast. For example, the expected number of NORs is often used to determine the size of the hatchery program.

The Hatchery Reform Strategy is developed as part of the planning process for a hatchery program. They are reviewed periodically to ensure that they are consistent with conservation and harvest goals, but are generally not revised unless the goals have changed.

iii. In-Season Management

The Hatchery Reform Strategy is used to calculate Annual Management Targets for natural escapement, harvest, and hatchery production based on the adult run forecast. Annual Management Targets include the number of hatchery releases, catch (number of fish), pHOS, pNOB, NOS, and so on. Management targets will vary from year to year based on the run forecast.

iv. Long Term Management Strategies

Habitat, hatchery, hydro and harvest management operate on different time scales. The contribution of each over time determines the rate of progress toward biological targets. Strategies and actions during the current recovery phase are specified for:

i. Habitat (e.g., projects and their expected outcomes in terms of productivity and capacity, effects of climate change)
ii. Hatchery (e.g., broodstock management)
iii. Harvest (e.g., selective harvest, weak stock management)

iv. Monitoring and Evaluation (e.g., test key assumptions, measure progress toward biological targets, and track triggers for phase shifts)

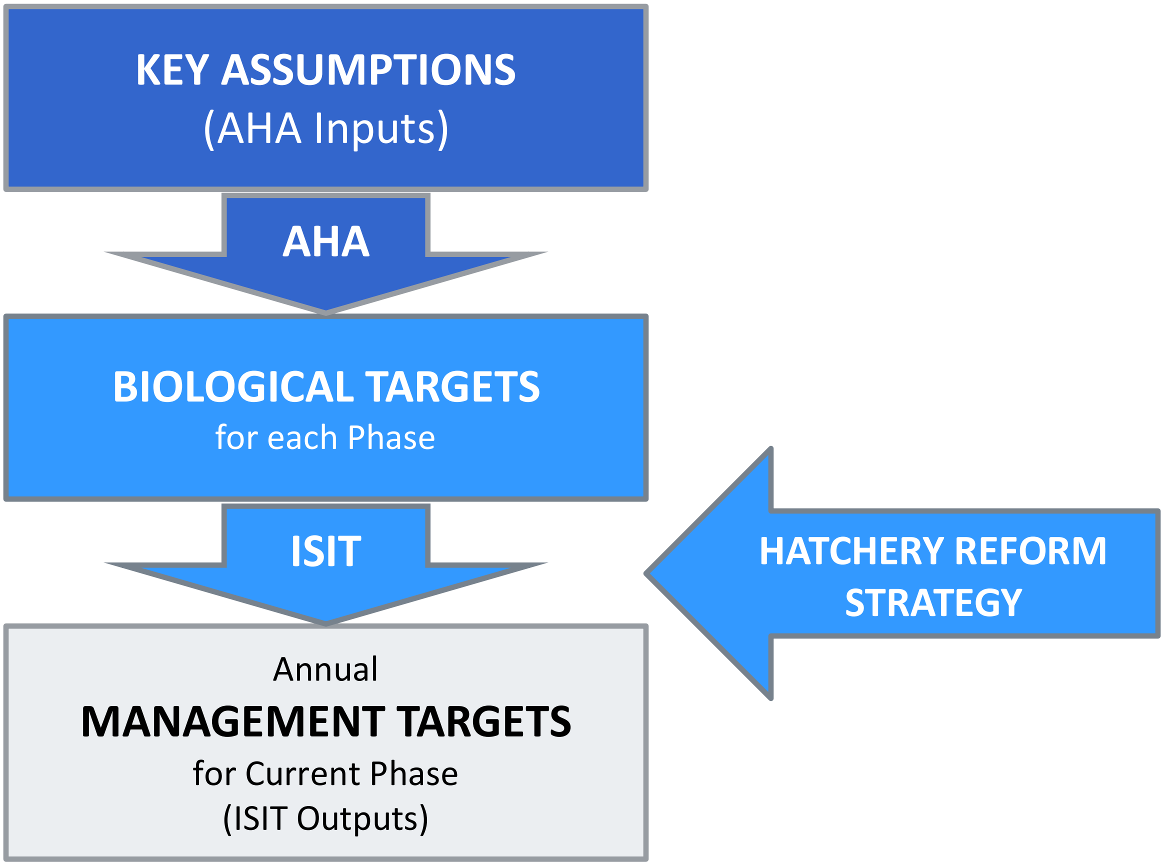


Figure 1.

C. DECISION SUPPORT TOOLS (AHA-LIFE CYCLE MODEL AND ISIT)

Decision support tools help managers make in-season management decisions and project potential future outcomes from specific management actions. Tools are designed to help analyze, implement, and document strategies designed to ensure progress toward long-term resource goals. We describe two recently developed tools that have been applied to several ongoing management projects, the All-H Life Cycle Model (AHA-LCM) and the In-Season Implementation Tool (ISIT). These tools are incorporated into a single Microsoft Excel-based desktop application. We provide a general overview of the tools here and a Quick Start Guide in Section III. In the AHA-LCM tool, there are videos that provide details about how to use the application.

i. AHA - Life Cycle Model

The All-H Analyzer - Life Cycle Model tool captures assumptions about the four “Hs” which comprise the main influences on salmonid populations: habitat, harvest, hatcheries, and passage through hydroelectric dams. The tool produces calculations and summary graphics for salmon and steelhead populations based on assumptions about each of the H’s:

- Habitat conditions
- Harvest rates
- Hydrosystem survival
- Hatchery operations

The purpose of the AHA-Life Cycle Model tool is to allow managers to explore the implications of alternative ways of balancing hatcheries, harvest, habitat, and hydro-system constraints. The tool illustrates the implications of alternative ways of balancing the four “Hs” so that informed decisions can be made. AHA should not be viewed as a “new” tool to predict habitat, harvest or hydroelectric system effects on salmonid populations – it really is a platform for integration of existing analyses. It is a relatively simple aid to regional decision making with which managers can rapidly explore the potential impacts of a variety of detailed scenarios relating to one or more “Hs”.

What is AHA Really?

- AHA is a gene flow calculator.
- Inputs include Key Assumptions about the 4 Hs
- Currency is adult spawning fish (wild and hatchery).
- Calculates the number of natural and hatchery fish produced and where they end up spawning.

- Results incorporates an estimate of fitness loss due to domestication.

Thoughts on Using AHA

- Does not absolutely define effects of actions
- Provides hypotheses for interaction of Hs and population
- M&E required to test hypotheses and adjust actions (fitness assumptions)
- Does not analyze ecological impacts of hatcheries (predation, competition)

The All-H Life Cycle Model contains the ‘AHA’ model that was originally developed as part of the Columbia Basin Hatchery Reviews (HSRG 2009) plus additional features. These include:

- Incorporates the Hatchery Reform Strategy (dynamic management over time rather than a static strategy)
- Incorporates assumptions about population age structure, an annual time step, etc.
- Sensitivity Analysis – compare effects of Key Assumptions on program outcomes
- Spawner-Recruit Analysis – empirical estimate of population productivity and capacity
- Incorporates sources of random variation (harvest variability, PDO, etc.)
- Projects population over time (annual time step, rather than a single long-term average estimate)

ii. In-Season Implementation Tool (ISIT)

The In-Season Implementation Tool (ISIT) is designed to help managers make annual decisions about hatchery and harvest management. For example, annual decisions may be made about the number, size, and age of hatchery releases, the percentage of natural-origin broodstock (pNOB), weir management policies, and harvest policies. The ISIT helps managers make decisions that move the population toward the biological targets established for the current recovery phase. The ISIT is both a database and a calculator. It is designed to document the population’s history and current status and provide guidance on annual management decisions.

Components of the ISIT include:

- Status and Trends data
- Key Assumptions about the H’s
- Hatchery Reform Strategy
- Annual Management Targets

Status and Trends data includes natural spawning escapement estimates (NOS and HOS), hatchery broodstock and release numbers, and harvest data. These data are updated in ISIT on an annual basis. Key Assumptions about habitat (productivity and capacity), fish passage (adult and juvenile passage survival), in-hatchery survival and fecundity, and SARs are also documented in the ISIT. These assumptions are updated when new data are available. Hatchery and survival (SAR) assumptions are typically updated annually, but habitat and fish passage assumptions are updated less frequently.

The Hatchery Reform Strategy provides guidance to managers on hatchery and harvest management based on a) Status and Trend data to establish the current recovery phase and b) the adult run size forecast to set Annual Management Targets. For example, the expected number of NORs may affect the size of the hatchery program and/or pNOB as well as natural escapement targets and terminal harvest rates for the coming year.

Each year, the ISIT is updated with the most up-to-date Status and Trends data and an Annual Program Review (APR) is held to perform the following tasks:

- Review Status and Trends data
- Confirm and adjust Key Assumptions
- Assess program performance in meeting the Biological Targets
- Establish Annual Management Targets (harvest, escapement, hatchery production) by applying the Hatchery Reform Strategy to the run forecast.
- Review projected program performance

The APR is an opportunity for stakeholders to review program performance and discuss potential management actions for the upcoming year and beyond. We have developed ISITs for Okanogan summer/fall Chinook and for eleven Cowlitz Basin Chinook, coho, and steelhead populations.

III. QUICK START GUIDE

This guide is intended to provide the user with help completing the key tasks in preparation for using the ISIT/AHA tool. Throughout the ISIT tool, “yellow” cells are for user input, “orange” cells have a drop-down menu, and “green” cells have formulas and should not be edited.

A. Step 1. ISIT Set-up

i. **Resource Goals for the natural population**. Determine which goals for harvest (catch in specific fisheries) and conservation (Abundance, Productivity, Spatial Structure and Diversity) are desirable. See Section 1 above for discussion. Once these have been determined, they can be entered by clicking the gray button titled “Set Biological Targets” under Step 1**.** These goals can be thought of as the “triggers” for the ”Full Recovery Phase” (see vi, below).

ii. **Population Designations for the natural population:** Primary, Contributing, or Stabilizing (select one). This can be entered on the “Step 1 ISIT Set-Up” tab, using the drop-down menu. See discussion in Section II-A above.

iii. **Population Viability Status of the natural population**. Recovery Phases: 1) Preservation, 2) Recolonization, 3) Local Adaptation, 4) Full Recovery. Choose one. This can be entered on the “Step 1 ISIT Set-Up” tab, using the drop- down menu. See Section II-B above for discussion. For this example, we have selected “Local Adaptation” based on the status of the natural population. However, if you are unsure of the current Phase designation, go ahead and select one. Once you have entered data on the Status and Trends page and established triggers for each Phase on the Hatchery Strategy page, the model will identify the current phase for you on the Hatchery Strategy page.

Managers should complete the following entries for all 4 Phases. However, at a minimum, managers should complete the following for the current Phase and one Phase higher and lower than the Current phase. Once established, this information will provide guidance in the future in case of unexpected eventualities (decrease in run size or loss of habitat) as well as strong scientific defensibility for current and or future hatchery programs.

iv. **Priorities.** Usually specific to each Phase, but may include both conservation and harvest objectives. See Section B for discussion. These are entered by clicking the gray button entitled “Set Biological Targets” and panning to the left. Priorities can be phase specific with some overlap (as in “providing harvest”). For the “local adaptation phase”, increasing fitness of the natural population would be a logical priority.

v. **Biological targets for each Phase**. Usually using VSP parameters (Abundance, Productivity, Spatial Distribution, Diversity, Habitat conditions). These are entered by clicking the gray button entitled “Set Biological Targets”. These should be the conditions required for successful implementation of the next Phase (the “end point” of the current Phase).

vi. **Phase shift (triggers).** Similar to Biological targets, but these are the actual measurements that will be used to provide certainty of achieving the targets. For example: if a Biological Target for one Phase is an average abundance greater than 500 NORs, then the trigger to shift to the next Phase might be 600 NORs as measured by spawner escapement estimates using a 5-year running average. This means that the shift would occur once the 5-year running average reaches 600 NORs, indicating that the long-term abundance is now likely to exceed 500 NORs (assuming the other triggers for Phase shift have been achieved as well). These are entered under Step 4 item C.

B. **Step 2. AHA and Key Assumptions**. This step is used to set up AHA. Key assumptions for each of the 4 H’s need to be entered, including Hatchery data (both in-hatchery and out-of-hatchery survival by life stage), Harvest data (harvest rates by fishery), Habitat potential (defined by productivity and capacity), and Hydro-system mortalities (both juvenile and adult). Some key assumptions will not change between Phases (in-hatchery survival), while others (Harvest, Habitat) will likely change as the population transitions between Phases.

C. **Step 3. Status and Trends.** Enter the most recent data for each field. This can also be a place to keep historical data for this population. NOT all fields are required, but field headings in red font are required. Missing data should be entered as zeros. Data for the most recent years are used to set the initial conditions for the life cycle model. The life cycle model begins with the current status of natural and hatchery populations and then projects forward to predict a range of future outcomes.

D. **Step 4. Life Cycle model.**

   i. **Hatchery Reform strategies and actions.** These provide guidance to managers on hatchery and harvest actions for the coming year based on the adult run size forecast and are Phase specific. They can include things such as: minimum NOR escapement, Max % NORs that can be used for broodstock, size of hatchery program (for those hatcheries that use a sliding scale program), and PNI and pHOS goals. While they are reviewed periodically, they are not generally revised unless the goals have changed. These are entered by clicking on item C under Step 4, “Refine Hatchery Reform Strategy”. The Hatchery Reform Strategies are used to calculate “Annual Management Targets” for natural escapement, harvest, and hatchery production based on the current adult run forecast. These targets can include: pHOS, pNOB, NOS, catch by fishery etc. These targets may vary each year based on the run forecast. This step is designed to allow you to “do the best you can do” given the current run forecast in achieving your Biological Targets.

E. **Step 5. Annual Management Targets.** Annual Management Targets include the number of hatchery releases, catch (number of fish), pHOS, pNOB, NOS, and so on. Management targets will vary from year to year based on the run forecast. These are based on the Hatchery Reform Strategy developed earlier. The annual forecast is entered in Step 5 and provide a “plan for this year”. In cases where run forecasts are updated periodically, these new values should be entered as the season progresses.

IV. REFERENCE MATERIAL

A. MEASURES OF VIABILITY → VIABLE SALMONID POPULATION (VSP) PARAMETERS

The Viable Salmonid Population (VSP) parameters include abundance, productivity, spatial structure, and diversity. These parameters describe characteristics of salmonid populations that are useful in evaluating population viability. See NOAA Technical Memorandum NMFS-NWFSC-42, *Viable salmonid populations and the recovery of evolutionarily significant units* (McElhany et al. 2000).

- **Abundance and productivity.** Abundance refers to the number of adult fish on the spawning grounds. Productivity is the population's growth rate, which indicates whether the population can sustain itself or rebound from low abundance. Productivity can be measured as spawner-to-spawner ratios (i.e., returns per spawner or recruits per spawner), annual population growth rate, or trends in abundance. Abundance and productivity are closely linked, and a population needs both: abundance to maintain genetic health and respond to normal environmental variation, and productivity to bounce back if population numbers drop for some reason.
- **Spatial structure.** Spatial structure refers to both the geographic distribution of individuals in the population and the processes or conditions that generate that distribution. Factors affecting spatial structure include the amount of habitat available, how connected the habitat is, and how much neighboring populations mix with each other. Spatial structure is important because a species that is not geographically spread out is at risk of extinction from a single catastrophic event, such as a landslide.
- **Diversity**. Diversity refers to the variety of life history, behavioral, and physiological traits within and among populations. Most traits vary as a result of a combination of genetic and environmental factors. Diversity is important because it gives populations an edge in surviving (and eventually adapting to) environmental change (Lower Columbia River Salmon and Steelhead ESA Recovery Plan — June 2013).

B. POPULATION VIABILITY STATUS → RECOVERY PHASES

Benefits and risks associated with hatchery programs depend on the viability status of the population. HSRG has adopted a phased approach and developed guidelines specific to each phase of recovery.

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

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

These stages are: 1) Preservation, 2) Recolonization, 3) Local Adaptation, and 4) Full Restoration (HSRG 2014).

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

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

i. Classification of Conservation Programs

Across the spectrum of ecological conditions in which salmon recovery occurs, we recognize four phases of restoration and rebuilding, ranging from preventing extinction to full restoration (Table 2). Transition between phases is determined by changes in habitat and ecosystem conditions that lead in turn to changes in population status and the biological objectives necessary to continue to full restoration. In many cases, the change from one phase to another will not mean that previous objectives are no longer important but rather that the need for these objectives has lessened and new objectives are a greater priority. For example, as major threats of population extinction are removed, the objective of reintroducing fish to newly accessible or restored habitat may become the primary objective of the conservation hatchery program. However, the shift to a different phase does not mean the hatchery program should no longer provide any buffer against extinction. To avoid potential confusion, transparent identification of priority objectives is essential.

a) Conservation Programs for Preservation

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

Requirements for Success

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

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

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

Considerations for identifying triggers

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

Table 2. Biological phases of restoration and objectives for different ecosystem conditions.

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

b) Conservation Programs for Recolonization

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

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

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

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

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

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

Requirements for success

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

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

Design and operation of the program needs to be scientifically defensible.

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

The program is supported by other management actions that address the key, known limitations on productivity of reintroduced and recolonizing salmon.

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

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

The broodstock chosen has life history and morphological characteristics that are suitable for the environmental characteristics of the area where the reintroduction will occur.
Where the reintroduction is to expand the range of an existing population, fish from the existing population with genetic background that minimizes exposure to hatchery environments are most likely to succeed. Where reintroduction is intended to re-establish a distinct population, indigenous populations that are geographically close to the reintroduction area are initial candidates because they are likely to share the same genetic legacy as the population that occurred there originally and they may be adapted to similar environmental conditions.

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

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

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

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

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

Considerations for identifying triggers

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

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

Viability Attribute	Example Metrics for Biological Targets	Example of Phase Triggers
Abundance	Mean natural origin spawner abundance of 500 adults	Spawner abundance: mean abundance > 600 (5 year running average).
Productivity	Intrinsic productivity of 2.5	R/S greater than 1 when spawner abundance is greater than 500
Spatial Distribution	50% of habitat occupied	< 50% of spawning/rearing habitat is vacant
Diversity	Genetic effective population size (N_e)> 200	> 200
Habitat	Available spawning or rearing habitat	10% increase in available habitat

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

c) Conservation Programs for Local Adaptation

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

ii. Conservation Programs and Harvest

The treaty and reserved rights of Native Americans and their cultural and spiritual connection to salmon require that tribal harvest be included when defining and achieving sustainability. A population cannot be considered fully recovered unless tribal harvest is accommodated.

Hatchery programs can provide harvest opportunities even during the early biological recovery phases (preservation and recolonization) so long as the programs are designed and operated to not conflict with the biological necessities of recovery. For example, during the century long preservation phase in the Elwha River, the hatchery was the genetic preserve for the native Chinook population, while also providing harvest. As this recovery program moves through the recovery phases after dam removal and as habitat improves, the hatchery program will serve to speed up recolonization while also continuing to provide compatible harvest for indigenous peoples.

iii. Summary and Conclusions

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

C. GENETIC RISK → BROODSTOCK MANAGEMENT

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

i. Integrated, Segregated and Stepping Stone Programs

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

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

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

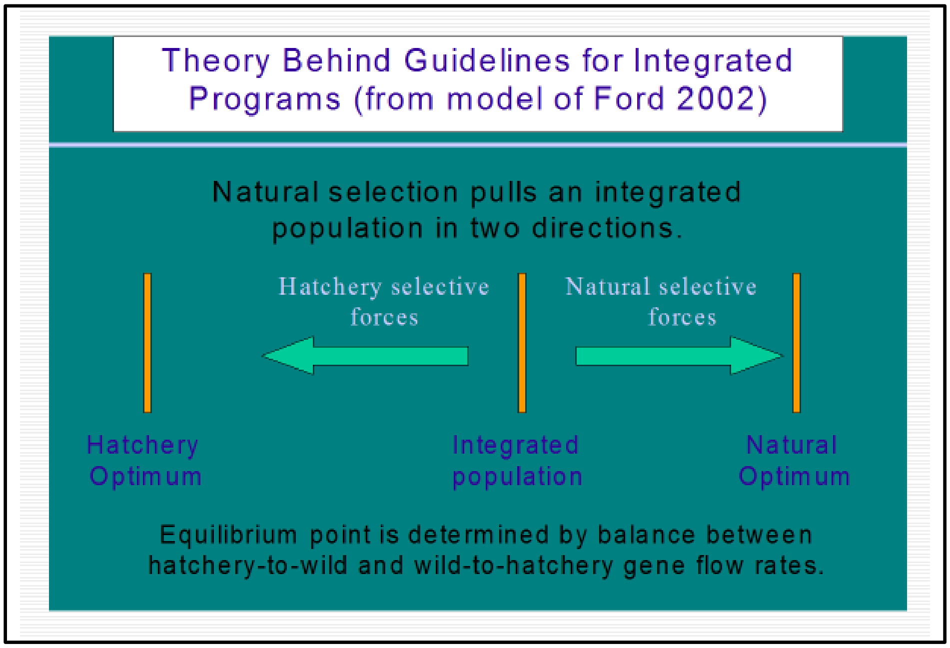
Segregated programs have been studied in several systems. Seamons et al. (2012) evaluated a segregated steelhead program at Forks Creek, Washington, where the Chambers (via Bogachiel Hatchery) stock was introduced. Segregation relied on divergent life history strategies based on spawn timing. They found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

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

In some situations, it is not feasible to meet harvest objectives using either integrated or segregated hatchery programs. This occurs when pHOS cannot be reduced sufficiently to meet the standards of a segregated program or when natural production (abundance) is insufficient to support an integrated program large enough to meet harvest objectives. If revising harvest objectives and reducing hatchery production is not an option, a compromise approach is a stepping-stone program.

A stepping-stone program consists of an integrated program that produces broodstock for a segregated program (Figure 2). This maintains genetic continuity between the hatchery population and natural-origin fish returning to the system. Adults produced by the integrated program need to be distinguishable from adults produced by the segregated (stepping-stone program, i.e., coded wire tag only/adipose fin clip only, respectively). If sufficient numbers of adults return from the integrated program to meet escapement needs, integrated broodstock needs, and the second stage stepping-stone broodstock needs, the smolts may be adipose fin clipped as well to allow for additional harvest. Managers should monitor this closely and revert to coded wire tags only if insufficient adults return to meet all needs. Unharvested “harvest component” fish (segregated program) would not be used for broodstock, nor released upstream of the weir, nor returned to a population downstream of the weir. Unharvested adults could be used for stream nutrification as appropriate. Stepping-stone programs may be used as a transition to an integrated program while natural habitat conditions improve.

The HSRG developed quantitative recommendations for the proportion of natural-origin spawners consisting of hatchery-origin fish (pHOS), the proportion of hatchery broodstock derived from natural-origin fish (pNOB), and the proportionate natural influence (PNI) on an integrated population, calculated as a function of pHOS and pNOB.



Theory Behind Guidelines for Integrated Programs (from model of Ford 2002)

Natural selection pulls an integrated population in two directions.

Hatchery selective forces

Natural selective forces

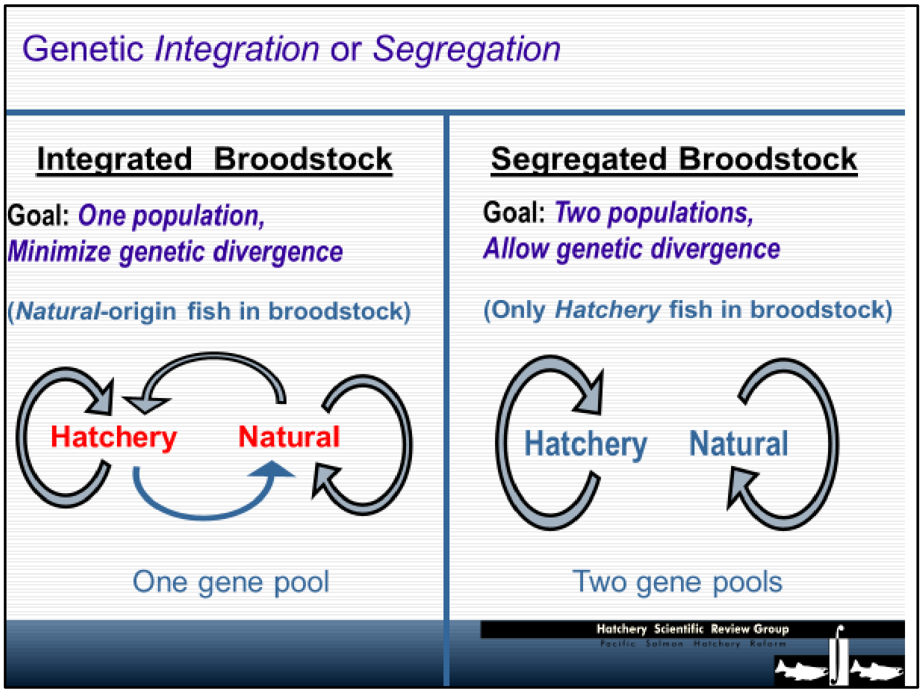
Hatchery Optimum

Integrated population

Natural Optimum

Equilibrium point is determined by balance between hatchery-to-wild and wild-to-hatchery gene flow rates.

Figure 2. For any phenotypic trait we may examine, it is easy to imagine there is a “hatchery” optimum and a “wild” optimum and that they differ. Natural selection pulls an integrated population in two directions, due to selection in each environment. The equilibrium point (or PNI) identifies how close to the wild optimum the population ends up and is controlled by gene flow between the hatchery and wild population.



Genetic *Integration* or *Segregation*

Integrated Broodstock

Goal: *One population, Minimize genetic divergence*

(*Natural*-origin fish in broodstock)

Hatchery

Natural

One gene pool

Segregated Broodstock

Goal: *Two populations, Allow genetic divergence*

(Only *Hatchery* fish in broodstock)

Hatchery

Natural

Two gene pools

Figure 3. Example of gene flow in Integrated and Segregated programs.

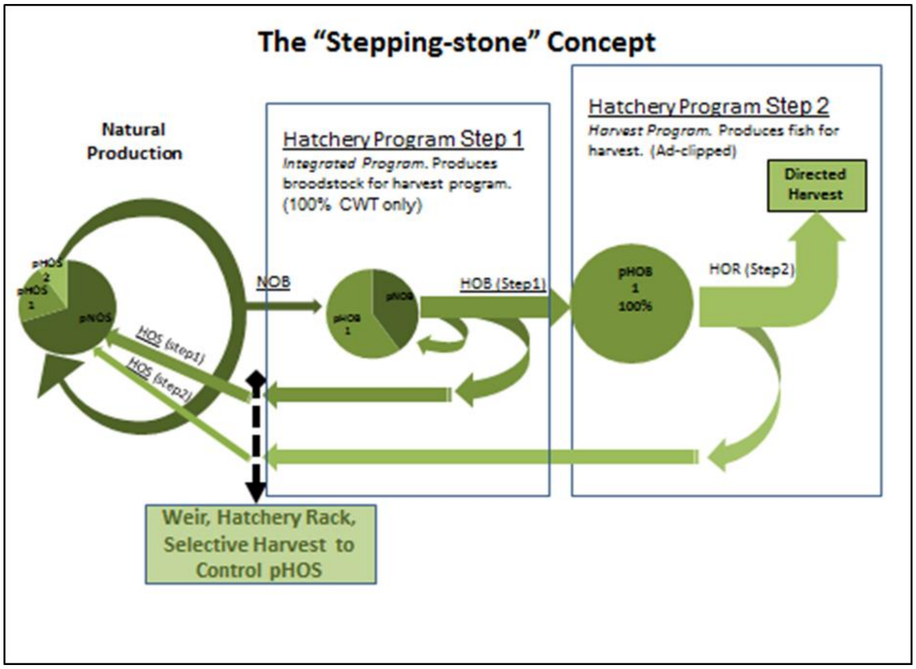


Figure 4. A "stepping-stone program" consists of two interdependent hatchery programs: an integrated broodstock generator and a segregated harvest program. As with a simple integrated program, the intent is for the combined hatchery and natural population to adapt to the conditions in the natural environment.

ii. Operational guidelines

Integrated Programs

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

population or use of a “stepping stone” program may be necessary before complete genetic integration is possible.

Segregated Programs:

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

See HSRG (2004) for additional discussion.

iii. Summary – Broodstock Management Strategies

Integrated Hatchery Programs

- Goal: Natural selection in the wild drives the fitness of the population as a whole.
- Integrated programs are intended to artificially increase the demographic abundance of a naturally spawning population.
- Requires a self-sustaining natural population to provide fish for broodstock (dependent on Habitat and Harvest).

May be appropriate when:

- Hatchery programs have (a) conservation goals or (b) when the proportion of hatchery fish on the spawning grounds cannot be reduced sufficiently to meet guidelines for a segregated program.

Segregated Hatchery Programs

- Goal: Create a new, hatchery-adapted population genetically distinct from the natural population.
- Hatchery fish may pose significant genetic and ecological risks to naturally spawning populations.

May be appropriate when:

- Very low probability of hatchery fish spawning with natural populations.
- Mitigation programs where spawning habitat no longer exists (e.g., mitigation for a hydro project).
- Where smolt release and adult recollection facilities are physically separated from natural spawning areas.

Stepping Stone Hatchery Programs

- Goal: Increase hatchery production while maintaining genetic continuity with the natural population.
- Retains some genetic continuity between hatchery fish and naturally spawning fish when natural origin brood is in short supply.
- Provide a transition to a fully integrated program

May be appropriate when:

- Limited size of the integrated program doesn’t meet harvest objectives
- Fish from each program can be visually identified by separate marks

The designation of a population as Primary, Contributing or Stabilizing is a science-informed policy decision. Recommendations developed by the HSRG for broodstock management are as follows (see Table 4):

HSRG criteria for hatchery influence on Primary populations:
The proportion of effective hatchery-origin spawners (pHOS) should be less than 5% of the naturally spawning population, unless the hatchery population is integrated with the natural population. For integrated populations, the proportion of natural-origin adults in the broodstock (pNOB) should exceed pHOS by at least a factor of two, corresponding to a PNI (proportionate natural influence) value of 0.67 or greater and pHOS less than 30%.

HSRG criteria for hatchery influence on Contributing populations:
The proportion of effective hatchery-origin spawners (pHOS) should be less than 10% of the naturally spawning population, unless the hatchery population is integrated with the natural population. For integrated populations, the proportion of natural-origin adults in the broodstock (pNOB) should exceed pHOS, corresponding to a PNI value of 0.50 or greater and pHOS less than 30%.

HSRG criteria for hatchery influence on Stabilizing populations:
The current operating conditions are considered adequate to meet conservation goals. However, this implies that existing conditions should be maintained. In order to meet these recommendations, the number of hatchery fish on the spawning grounds must be monitored and controlled. This can be accomplished by selectively removing hatchery fish (e.g., via harvest or weirs) or by reducing or totally eliminating hatchery production. HSRG (2009) modeling results showed that in most cases, both conservation goals and harvest goals can be met with an appropriate combination of reduced/relocated hatchery production, selective harvest of hatchery fish, and/or selective removal of hatchery adults with tributary traps or weirs. Marking or tagging all hatchery fish so that they are easily distinguished (in real time) from natural-origin fish is a basic requirement for selective harvest, as well as for monitoring escapement and achieving desired levels of pHOS, pNOB and PNI.

Table 4. Summary of HSRG Broodstock management recommendations.

Natural Population		Hatchery Program Purpose			
Designation	**Status**	**Seg.Harv**	**Int. Harv**	**Cons+Harv**	**Cons. Only**
Primary	Fully Restored	**pHOS<5%**	**PNI>0.67**	**PNI>0.67**	
	Local Adapt.	**pHOS<5%**	**PNI>0.67**	**PNI>0.67**	**PNI>0.67**
	Re-coloniz.	**pHOS<5%**	Not Specified	Not Specified	Not Specified
	Preservation	**pHOS<5%**	Not Specified	Not Specified	Not Specified
Contrib	Fully Restored	**pHOS<10%**	**PNI>0.50**	**PNI>0.50**	
	Local Adapt.	**pHOS<10%**	**PNI>0.50**	**PNI>0.50**	**PNI>0.50**
	Re-coloniz.	**pHOS<10%**	Not Specified	Not Specified	Not Specified
	Preservation	**pHOS<10%**	Not Specified	Not Specified	Not Specified
Stabil.	Fully Restored	Current conditions	Current conditions	Current conditions	
	Local Adapt.	Current conditions	Current conditions	Current conditions	Current conditions
	Re-coloniz.	Current conditions	Current conditions	Current conditions	Current conditions
	Preservation	Current conditions	Current conditions	Current conditions	Current conditions

D. METRICS

Background: HSRG has recommended standards for limiting hatchery influence on naturally spawning salmon and steelhead populations. The standards are expressed in terms of PNI and pHOS. The standards vary based on the biological significance and recovery status of the affected natural population. In the HSRG framework, the pHOS and PNI variables are related to fitness of the populations via the Ford (2002) model. The purpose of this section is to develop guidelines for the estimation of pHOS (census to effective) and PNI as used in this context.

i. Definitions of metrics

Proportionate Natural Influence (PNI)

pNOB = % Natural Origin fish in the hatchery broodstock- this is an estimate of the level of gene flow from the wild to hatchery

pHOS = % Hatchery Origin fish on the spawning grounds-this is an estimate of the level of gene flow from the hatchery to the wild.

PNI = Proportionate Natural Influence, calculated as a function of the composition of spawners in the hatchery and in the wild over generations.

Percent Hatchery Origin Spawners (pHOS)

pHOS census = % Hatchery Origin fish on the spawning grounds. Rough estimate of gene flow.

pHOS effective = estimated % genetic contribution of first generation hatchery fish, spawning in nature, to adult offspring in the next generation. Better estimate of gene flow.

The HSRG has recommended adjusting census estimates of pHOS to account for first generation differences between the genetic contributions of natural origin and hatchery origin fish spawning in the wild (known as effective pHOS). The HSRG originally referred to this *correction factor* as the relative reproductive success (RRS) of first generation hatchery fish. To avoid confusion, the HSRG has abandoned the use of the term RRS in this context.

Use of a correction factor in calculation of pHOS and PNI. Currently, the AHA model has set default values of 0.8 for Coho and Chinook populations, 0.9 for pink, chum and sockeye (fry release programs) populations and specific steelhead values (Table 5), Before accepting these default values, consider the following factors:

ii. Comments regarding the estimation of effective pHOS

a) Since the Ford (2002) model accounts for long-term genetic effects, to avoid double counting the correction factor should apply to first generation phenotypic effects.

b) The "correction factor" may be appropriate to account for non-genetic, spatial or temporal differences in spawn timing between fish raised in the hatchery and those raised in the wild.

c) Whatever correction factor is applied should be biologically justified. Factors that vary among populations include stratification, i.e. uneven distribution of hatchery fish among spawning aggregates within a population and run timing (see item d following).

d) The specific case of early winter (Chambers Creek) or hatchery summer (Skamania) steelhead spawning with native late winter or summer steelhead are common cases where run timing differences are large enough that reducing census pHOS, and thus assumed gene flow could be applied. Lacking any recent evidence, the current HSRG advice on discounting census pHOS to calculate effective pHOS for these programs remains the best we can offer (Table 5). Also, see comments about PEHC below.

e) What matters is gene flow, i.e. the genetic contribution of first generation hatchery fish to natural origin adult offspring. When pHOS is used as a surrogate for gene flow, how should it be calculated?

  - Stratified estimates of pHOS based on sex, age, and spatial composition may be appropriate where such data are available. For example, reach specific habitat potential, proportion of total available habitat used by hatchery fish and/or distribution of NORs among reaches might be considered to weight uneven spatial distribution of HORs and thus discount census pHOS.
  - An example for developing the correction factor is provided in sub-section iv below.
  - Consider using Proportion Effective Hatchery Contribution (PEHC) (Warheit 2014) to estimate gene flow. PEHC is calculated using genetic data of offspring to estimate parentage (opposite approach to using pHOS, which estimates composition of offspring based on spawner composition). PEHC and pHOS values are correlated in populations that have been analyzed using both metrics. PEHC is useful for segregated hatchery programs, but the technology doesn't apply to integrated programs.
  - While pHOS and PNI are imperfect measures, they are practical and useful. They are the only broadly available measurements that consistently account for gene flow and contribution of HORs. Carcass and/or spawning ground surveys are routinely conducted in many basins in the Pacific Northwest.

As a generalized statement, as census pHOS is most likely an over estimate of actual gene flow, if a program is meeting the HSRG recommendations based on census pHOS it is most likely meeting "gene flow" recommendations.

In summary, the reduction for spawning effectiveness is already accounted for in the Ford (2002) model. If a further discount is justified, for example due to differences in spawn timing/location of NORs and HORs, the additional discount or weighting scheme should be carefully considered on a population specific basis. Gene flow in a population is not a single year event in most cases. PNI is a long-term outcome (many generations) of a broodstock management strategy.

Table 5. Steelhead Correction Factors (partly based on Kalama River studies) (Leider et al. 1984).

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

Strength of selection settings ($\omega^2 \gg \sigma^2$).

Discussion Points:

a) Individual based modeling (M. Falcy, ODFW pers. comm.) revealed that PNI is very sensitive to strength of selection. Should the assumptions about heritability and strength of selection used in the AHA model be revised in light of recent work by Blouin and others?
b) Lower PNI is less important if selection is very weak. Need to focus on modeling situations where selection is strong.
c) Baskett and Waples (2013) relaxed assumptions about heritability and explored questions about where in the life cycle selection occurs. Although there are opportunities to improve existing models, we lack sufficient data to apply most models to actual populations.

PNI calculation

a) The PNI has been generalized to multiple populations (Busack 2015, unpublished). This is useful in developing "stepping stone" programs (i.e., determining the relative size of integrated and segregated programs and the impact on PNI from hatchery fish from each program). The calculation, which is incorporated in the current AHA/ISIT tools, is more involved than the previous HSRG version.

b) Importantly, PNI is an indicator of the long-term trajectory of a population and not an annual outcome.

iii. Extending the Ford model to Three or More Populations (Craig Busack)

The commonly cited HSRG guidelines for integrated hatchery programs are based on a model developed by Mike Ford (NMFS-NWFSC) and published in Conservation Biology in 2002 (Ford 2002). The purpose of this paper is to explain how the model can be extended to additional populations, and demonstrate the value of this approach.

The Ford model assumes a normally distributed trait with heritability h^2, variance σ^2 and phenotypic means $\bar{z}_w$ and $\bar{z}_c$ in the natural (wild) and hatchery (captive) environments, respectively. The trait is under Gaussian stabilizing selection with fitness functions having optima θ_w and θ_c, and selection strengths ω_w and ω_c in the natural and hatchery environments, respectively. The recursion equations for changes (Ford's equations 5 and 6) in the mean trait values in the two environments are:

$$\bar{z}_w' = p_w\left[\bar{z}_w + \left(\frac{\bar{z}_w\omega_w^2 + \theta_w\sigma^2}{\omega_w^2 + \sigma^2} - \bar{z}_w\right)h^2\right] + (1 - p_w)\left[\bar{z}_c + \left(\frac{\bar{z}_c\omega_w^2 + \theta_w\sigma^2}{\omega_w^2 + \sigma^2} - \bar{z}_c\right)h^2\right] \qquad (1)$$

$$\bar{z}_c' = p_c\left[\bar{z}_c + \left(\frac{\bar{z}_c\omega_c^2 + \theta_c\sigma^2}{\omega_c^2 + \sigma^2} - \bar{z}_c\right)h^2\right] + (1 - p_c)\left[\bar{z}_w + \left(\frac{\bar{z}_w\omega_c^2 + \theta_c\sigma^2}{\omega_c^2 + \sigma^2} - \bar{z}_w\right)h^2\right] \qquad (2)$$

where p_w is the proportion of individuals spawning naturally that are natural-origin fish, and p_c is the proportion of individuals in the hatchery broodstock that are hatchery-origin fish. Although equilibrium values for natural-origin and hatchery-origin fish could be generated by iterating these equations until the solutions did not change, Ford also developed equations for the equilibrium trait values. For natural-origin fish, for example, the equilibrium point is given by:

$$\hat{z}_w = \frac{\sigma^2((1 + p_c(h^2 - 1))\theta_w + (h^2 - 1)(p_w - 1)\theta_c + \theta_c(\omega_w^2 - \omega_w^2 p_w) - \theta_w\omega_c^2(p_c - 1)}{\sigma^2(2 - p_w - p_c + h^2(p_w + p_c - 1)) + \omega_w^2(1 - p_w) + \omega_c^2(1 - p_c)} \qquad (3)$$

These equations could in theory be used for an actual trait, provided the heritability, selection strength, and optima were known, but it is debatable that these are known for any trait in salmon or steelhead. The equations' purpose in the paper was to demonstrate the relative importance of the various parameters in the equation in determining genetic change, and for the range of parameter values that Ford explored, the most important by far were the gene flow rates from natural to hatchery and vice versa. The HSRG concluded that a useful statistic would be *proportionate natural influence* or *PNI*, the position of the natural population equilibrium point relative to the two optima. Substituting the expressions pNOB and pHOS for Ford's $(1-p_c)$ and $(1-p_w)$, respectively, the HSRG also presented a simple equation that approximates PNI:

$PNI \approx pNOB/(pNOB + pHOS)$. Although the PNI approximation equation is commonly used as a performance metric, it is important to keep in mind that it is not an instantaneous measure of population condition, but an approximation of the equilibrium point at which the population would arrive after many generations.

In extending the Ford equations to additional populations it is useful to use an alternative form of his equations, one based on Lande's (1976) equation:

$$\bar{x}' = \left(1 - \frac{h^2\sigma^2}{\omega^2 + \sigma^2}\right)\bar{x} \qquad (4),$$

where $\bar{x}$ is the deviation of the population trait mean from the optimum. Ford's equation 1 can then be rewritten as:

$$(\bar{z}_w{}' - \theta_w) = \left(1 - \frac{h_w^2\sigma^2}{\omega_w^2 + \sigma^2}\right)\left(p_w(\bar{z}_w - \theta_w) + (1 - p_w)(\bar{z}_c - \theta_w)\right) \qquad (5)$$

Although the particular situation Ford was considering was gene flow between a hatchery population and a natural population, there is nothing in the equations that strictly applies to either a hatchery or a natural population. The equations simply describe the effect of gene flow between two populations[1]. Equations 1 and 2 can be rewritten as:

$$(\bar{z}_1{}' - \theta_1) = \left(1 - \frac{h^2\sigma^2}{\omega_1^2 + \sigma^2}\right)\left(p_{11}(\bar{z}_1 - \theta_1) + p_{21}(\bar{z}_2 - \theta_1)\right) \qquad (6)$$

---

[1] Throughout this document the term population is used simply to denote a group of fish spawning together, not a population defined for recovery purposes.

$$(\bar{z}_2{}' - \theta_2) = \left(1 - \frac{h^2\sigma^2}{\omega_2^2 + \sigma^2}\right)\left(p_{12}(\bar{z}_1 - \theta_2) + p_{22}(\bar{z}_2 - \theta_2)\right) \qquad (7),$$

where p_{ij} is the proportion of spawners in population *j* that originated from population *i*.

Extension to three populations is now straightforward:

$$(\bar{z}_1{}' - \theta_1) = \left(1 - \frac{h^2\sigma^2}{\omega_1^2 + \sigma^2}\right)\left(p_{11}(\bar{z}_1 - \theta_1) + p_{21}(\bar{z}_2 - \theta_1) + p_{31}(\bar{z}_3 - \theta_1)\right) \qquad (8)$$

$$(\bar{z}_2{}' - \theta_2) = \left(1 - \frac{h^2\sigma^2}{\omega_2^2 + \sigma^2}\right)\left(p_{12}(\bar{z}_1 - \theta_2) + p_{22}(\bar{z}_2 - \theta_2) + p_{32}(\bar{z}_3 - \theta_2)\right) \qquad (9)$$

$$(\bar{z}_3{}' - \theta_3) = \left(1 - \frac{h^2\sigma^2}{\omega_3^2 + \sigma^2}\right)\left(p_{13}(\bar{z}_1 - \theta_3) + p_{23}(\bar{z}_2 - \theta_3) + p_{33}(\bar{z}_3 - \theta_3)\right) \qquad (10)$$

Derivation of equilibrium equations from equations 8-10 is also straightforward, but is messy and not necessary at this point, so is left to the adventurous reader.

This three-population extension of the Ford model can be applied to any scenario where three populations are linked, and obviously be extended to include even more populations. It was first developed in planning for a possible Snake River fall Chinook salmon recovery scenario featuring a hatchery, an area with a large number of hatchery-origin spawners, and an area with lower hatchery influence, but appears ideally suited to development of gene flow guidelines for “stepping-stone” situations, where an integrated program operates alongside a genetically linked isolated program, and both have some effect on a natural population through gene flow. A pertinent case in point is that of spring Chinook in the Methow basin, where an integrated supplementation program at the Methow Fish Hatchery (MFH) operates alongside an isolated safety-net program at the Winthrop National Fish Hatchery (WNFH)[2]. Returnees from both programs spawn in the wild, and the WNFH can be genetically linked to the MFH program in that all or nearly all the WNFH broodstock could consist of MFH returnees, with the remainder being WNFH returnees. I will develop this example in detail below.

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[2] Although these are real hatchery programs, the gene flow values used in the example are meant to be illustrative, not necessarily accurate depictions of current or proposed true values for these programs.

Let:

Population 1= natural spawners in Methow basin

Population 2=MFH broodstock

Population 3=WNFH broodstock

Assume that optima for both hatcheries are the same, and are different from the optimum for the natural spawning population. Further assume that selection strength is the same everywhere, and assume a reasonable heritability (e.g., 0.5). All these are routine assumptions that were used in application of the Ford model to develop HSRG guidelines.

Let P be the matrix of spawning proportions (=gene flow surrogates).

P_{11} Proportion of natural spawners that are natural-origin fish	P_{12} Proportion of MFH broodstock that are natural-origin fish	P_{13} Proportion of WNFH broodstock that are natural-origin fish
P_{21} Proportion of natural spawners that are MFH returnees	P_{22} Proportion of MFH broodstock that are MFH returnees	P_{23} Proportion of WNFH broodstock that are MFH returnees
P_{31} Proportion of natural spawners that are WNFH returnees	P_{32} Proportion of MFH broodstock that are WNFH returnees	P_{33} Proportion of WNFH broodstock that are WNFH returnees

Set starting points for z values. These can be arbitrary. But I recommend values between the optima. Then run the equations recursively until the z values equilibrate, and calculate PNI for the natural population as percentage of the distance between the optima[3]. Different combinations of P values can be used to simulate different situations. The lack of equilibrium equations is annoying, but simulating to equilibrium points, which may require hundreds of generations, can be done very easily in a spreadsheet or with a simple R script.

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[3] This PNI value is the true PNI, in contrast to the simple approximation equation for two populations. It may be possible to develop an approximation equation for this situation, but it is unclear how useful this would be.

Tables 6 and 7 demonstrate use of the concept[4]. First assume that 50% of the fish on the spawning grounds are of natural-origin, 30% are MFH returnees, and 20% are WNFH returnees; that the MFH program broodstock is 80% natural-origin fish and 20% MFH returnees; and finally, that the WNFH program broodstock is completely isolated. Without the multi-population stepping stone approach, there is no adequate way to compute PNI. If you chose to ignore the source of the hatchery fish on the spawning grounds and just assume a pHOS of 0.5, calculating PNI using the familiar equation, you would get 0.63, which seems (and is) way too high because so many of the hatchery-origin spawners are not part of the integrated program. Using the stepping stone model, however, you get a PNI value of 0.19, demonstrating the huge load on PNI originating from the fish on the spawning grounds from the isolated program (if all the hatchery-origin spawners were WNFH returnees, the PNI value would be 0.10).

Now consider linking the WNFH program to the MFH program by using surplus MFH returnees as broodstock. Suppose 80% of WNFH broodstock needs can be met this way. The gene-flow matrix is shown in Table 7. This scenario yields a PNI of 0.55, a big improvement over 0.19.

By investigating the consequences of a series of realistic gene flow matrices, gene flow objectives for both programs can be developed that will result in a specified PNI.

Table 6. Spawners/Broodstock.

Sources	Natural Population	PUD Program	WNFH Program
Natural	0.5	0.8	0
PUD Program Returnees	0.3	0.2	0.8
WNFH Program Returnees	0.2	0	0.2

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[4] In the example I used a selection strength of 3 SD and a heritability of 0.5.

Table 7. Spawners/Broodstock.

Sources	Natural Population	MFH Program	WNFH Program
Natural	**0.5**	**0.8**	**0**
MFH Program Returnees	**0.3**	**0.2**	**0**
WNFH Program Returnees	**0.2**	**0**	**1**

Literature Cited

Ford, M. J. 2002. Selection in captivity during supportive breeding may reduce fitness in the wild. Conservation Biology. 16(3): 815-825.

Lande, R. 1976. Natural selection and random genetic drift in phenotypic evolution. Evolution. 30: 314-334.

iv. Example calculation of pHOS from the Chief Joseph Hatchery (CJH) program

The CJH has established biological targets for genetic influence of hatchery fish on natural productivity in terms of pHOS.

Option 1 for estimation of pHOS for Okanogan summer-fall chinook

1) <u>Correction for age composition</u>. Age composition may vary between HORs and NORs, this difference might be corrected for if age and fecundity data are available. Therefore, for each reach calculate pHOS for male and female spawners as follows:

$$pHOS_{Female,r} = \frac{\sum_{a=1}^{6} HOS_{Female,a} \times Fecund_{a,HOS}}{\sum_{a=1}^{6} (HOS_{Female,a} \times Fecund_{a,HOS} + NOS_{Female,a} \times Fecund_{a,NOS})} \quad \text{and,}$$

$$pHOS_{Male,r} = \frac{HOS_{Adult\ Males} + \mathrm{G} * HOS_{Jacks}}{HOS_{Adult\ Males} + \mathrm{G} * HOS_{Jacks} + NOS_{Adult\ Males} + \mathrm{G} * NOS_{Jacks}}$$

2) Correction for sex composition. Males and females contribute 50% of the gametes to each fertilized egg, hence each sex can contribute no more than half of the gametes to the next generation. Therefore, for each reach calculate effective pHOS as follows:

$$pHOS_{Eff,r} = \frac{pHOS_{Female,r} + pHOS_{Male,r}}{2}$$

3) Correction for spatial distribution. Sampling effort and HOR vs. NOR composition may vary by reach. For example, reach S1 tends to have a higher proportion of hatchery origin spawners than other reaches because the Similkameen acclimation and release site is located in the reach. To reduce the bias due to unequal sampling effort and unequal spawner distribution, the effective population pHOS is calculated as a weighted sum of reach estimates, where the weights are the fractions of total redds produced in each reach:

$$pHOS_{Eff} = \sum_{r=1}^{n} pHOS_{Eff,r} \times ReddProp_r \text{, where}$$

$$ReddProp_r = \frac{Redd_r}{Redd_{Total}}$$

4) Calculations are done in the following order: First age correction (1) is done for males and females, then sex correction (2) and finally the spatial bias correction (3).

5) Assumptions when age and/or sex data are missing:

   Age data missing:
   For calculation (1), simply calculate $pHOS_{Female,r}$ and $pHOS_{Male,r}$ for all ages combined and an age weighted fecundity value. Then make calculations (2) and (3) above.

   Age and sex data missing:
   Calculate effective pHOS for each reach as simply:

$$pHOS_{Eff,r} = \frac{HOR_{CF} * HOS}{HOR_{CF} * HOS + NOS}$$

Then make calculation (3) above.

Option 2 for estimating pHOS

Calculate pHOS for each reach then calculate a weighted population pHOS using the estimated NOSs in each reach as weights.

Option 3 for estimating pHOS

Use some measure of habitat quality in each reach to calculate a weighted pHOS. One such measure might be the EDT reach specific productivity estimate.

Option 4 for estimating pHOS

Use census pHOS without weighting, knowing that this will be an overestimate, since HORs spawners tend to congregate in areas close to their release locations.

Option 5 for estimating pHOS

HSRG has suggested that in many cases, a correction factor of 0.8 is a reasonable correction factor for Chinook and coho programs, 0.9 for pink, chum and sockeye (fry release) unless circumstances and/or available data suggest otherwise.

E. GLOSSARY

Adaptive Management	*Adaptive management* is a structured, iterative process of optimal decision-making in the face of uncertain outcomes, with the goal of reducing uncertainty over time. Key elements of adaptive management include an explicit process for testing assumptions (e.g., through a well-designed monitoring and evaluation program) and a systematic feedback process through which new data and information are used to periodically re-evaluate and modify management strategies.
All H Analyzer (AHA)	The *All H Analyzer (AHA)* tool was developed by the HSRG in 2005 as part of the Columbia River Basin Hatchery Review (HSRG 2009). The tool allows managers to compare alternative management strategies for salmon and steelhead populations. AHA predicts population outcomes in terms of natural production and harvest for management policies implemented over a long period of time (HSRG 2014).
All H Management	*All H Management* jointly addresses habitat, hatchery, harvest, and hydropower impacts as part of an integrated management strategy for salmon and steelhead populations (HSRG 2014).
Annual Management Targets	Annual Management Targets include the number of hatchery releases, catch (number of fish), pHOS, pNOB, NOS, and so on. Management targets will vary from year to year based on the run forecast.
Biological Significance	The biological significance of a stock is a function of the origin of the stock and its inherent genetic diversity, biological attributes, uniqueness, and local adaptation, and the genetic structure of the population relative to other conspecific populations. A population can be considered highly significant if it exhibits unique genetic and biological attributes that are not shared with other adjacent stocks. These attributes may include unique life history, physiological, morphological, behavioral, and disease resistance characteristics with a genetic basis (HSRG 2004). Levels of **biological significance** are expressed as **population designations**.
Broodstock Management:	
Integrated Program	In an *integrated program*, hatchery and natural populations are two components of a single population. The intent of an

integrated program is for the natural environment to drive the adaptation of the combined hatchery-natural population. This is accomplished by using natural-origin fish for a portion of the broodstock and by limiting the proportion of hatchery fish spawning in the wild. The intent is to minimize genetic divergence between the hatchery and natural populations. The purpose of an integrated program may be to contribute to conservation and/or harvest goals. A hatchery program is integrated with one specific natural population. It is segregated relative to all others (HSRG 2014).

Segregated Program

A *segregated program* establishes a new, hatchery-adapted population that is genetically distinct from all natural populations with which it might interact. Only hatchery-origin fish are used in the broodstock. The intent is to maintain a gene pool that is separated from all natural populations. Genetic and ecological risks to the natural population are minimized by limiting pHOS and strays. The purpose of a segregated program is typically to contribute to harvest goals (HSRG 2014).

Stepping Stone Program

A *stepping stone program* is a two-stage program that may be established when natural production is too low to support an integrated program (or tolerate a segregated one) of sufficient size to meet harvest objectives. Initially, a small integrated program produces broodstock for a larger segregated program, and the segregated program produces fish for harvest. Program fish are differentially marked. Eventually, when sufficient natural-origin broodstock are available, the program may transition into a fully integrated program (HSRG 2014).

Correction Factor

The HSRG recommends using a *correction factor* to adjust census estimates of pHOS to account for first generation differences between the genetic contributions of natural origin and hatchery origin fish spawning in the wild (known as effective pHOS). The HSRG originally referred to this correction factor as the relative reproductive success (RRS) of first generation hatchery fish. To avoid confusion, the HSRG has abandoned the use of the term RRS in this context.

The *correction factor* refers to the difference in the number of progeny produced or genetic contribution to the next generation by hatchery- versus natural-origin spawners. Factors that may influence this contribution include

	domestication selection, choice of hatchery broodstock, and the size, age, and location of hatchery releases (HSRG 2014).
Ecological Interactions	*Ecological interactions* between hatchery and natural fish include competition for feeding and spawning locations, predation of hatchery fish upon natural-origin fish and the potential transfer of disease from hatchery to natural-origin fish (HSRG 2014).
Escapement	The portion of a run that is not harvested or used for hatchery broodstock and returns alive to the spawning grounds. Escapement includes those fish that die on the spawning grounds prior to spawning.
Evolutionarily Significant Unit	An *evolutionarily significant unit* (ESU) is a Pacific salmon population or group of populations that is 1) substantially reproductively isolated from other conspecific populations and 2) represents an important component of the evolutionary legacy of the species (NMFS 2015).
Fitness	*Individual fitness* is the mean number of adult offspring produced by an organism. *Population fitness* is the mean fitness of all individuals within a population.
Hatchery-origin Broodstock	*Hatchery-origin broodstock* (HOB) is the number of hatchery-origin fish used as hatchery broodstock.
Hatchery-origin Recruit	*Hatchery-origin recruits* (HORs) are the sum of hatchery-origin spawners, hatchery-origin broodstock, and hatchery-origin fish intercepted in fisheries.
Hatchery-origin Spawners	*Hatchery-origin spawners* (HOS) are hatchery-origin fish that spawn in the wild.
Hatchery Program	A *hatchery program* is defined by the hatchery purpose (harvest and/or conservation), type of program (integrated, segregated, or stepping stone), the natural population with which it is associated (integrated programs), number of fish released, and type and size of releases (HSRG 2014).
Hatchery Purpose	Hatchery programs are tools for meeting resource goals. Thus, hatchery programs have a purpose not a goal, just like a hammer has a purpose and not a goal.
Conservation Program	A conservation program may be designed to prevent extinction, preserve the population’s genetic diversity, and/or provide a

	demographic safety net. Conservation programs have four phases (see Phases of Recovery below).
Harvest Program	A harvest program is designed primarily to provide recreational, tribal, and/or commercial harvest opportunities. Harvest programs should be designed to meet well-defined goals (e.g., specific harvest levels) without causing adverse impacts to naturally spawning populations.
Hatchery Reform Strategy	Provides guidance to managers on hatchery and harvest management based on a) Status and Trend data to establish the current recovery phase and b) the adult run size forecast to set Annual Management Targets. For example, the expected number of NORs may affect the size of the hatchery program and/or pNOB as well as natural escapement targets and terminal harvest rates for the coming year.
In-season Implementation Tool	The *In-Season Implementation Tool* is designed to help managers make annual decisions about hatchery and harvest management (number, size, and age of hatchery releases, percentage of natural-origin broodstock (pNOB), weir management policies, and harvest policies) that move the population toward the biological targets established for the current recovery phase. The ISIT is both a database and a calculator. It is designed to document the population's history and current status and provide guidance on annual management decisions. Components of the ISIT include: Status and Trends, Key Assumptions, Hatchery Reform Strategy, and Annual Management Targets.
Local Adaptation	*Local adaptation* is the evolutionary product of natural selection in a population that inhabits and reproduces within a specific environment for many generations until the optimum phenotype that confers maximum fitness is reached.
Natural-origin Broodstock	*Natural-origin broodstock* (NOB) is the number of natural-origin fish used as hatchery broodstock.
Natural-origin Recruit	*Natural-origin recruits* (NORs) include the sum of natural-origin spawners, natural-origin broodstock, and natural-origin fish intercepted in fisheries.
Natural-origin Spawners	*Natural-origin spawners* (NOS) are natural-origin fish that spawn in the wild.

pHOS:	
Effective pHOS (pHOS$_{eff}$)	*Effective pHOS* is defined as the mean proportion of natural spawners in a watershed or stream composed of hatchery-origin spawners (HOS), where HOS is discounted by a correction factor (see below). It may also be thought of as the genetic contribution of hatchery-origin adults to the natural population in the next generation as measured at the adult stage. This is first generation gene flow. $pHOS_{eff} = (HOS \times cf)/[(HOS \times cf) + (NOS)]$
Census pHOS (pHOS$_{cen}$)	*Census pHOS* is defined as the mean proportion of natural spawners in a watershed or stream composed of hatchery-origin adults. $pHOS_{cen} = (HOS)/(HOS + NOS)$
Correction Factor (cf)	The *correction factor* discounts the genetic contribution of hatchery-origin adults to the natural population by a factor that accounts for the assumed lower reproductive success of HORs. Value ranging from 0 to 1.0. If the correction factor is 1.0, $pHOS_{eff} = pHOS_{cen}$. See calculations above.
PNI	*Proportionate Natural Influence* (PNI) for a composite hatchery- and natural-origin population is calculated as pNOB/(pNOB + pHOS). It can also be thought of as the percentage of time the genes of a composite population spend in the natural environment.
pNOB	Mean proportion of a hatchery broodstock composed of natural-origin adults. Calculated as NOB/(HOB + NOB).
Population Designation	Three population designations were defined by the Lower Columbia Fish Recovery Board (LCFRB 2004) and reflect the **biological significance** and the expected level of contribution of the population to recovery of the **Evolutionarily Significant Unit (ESU)** or **Distinct Population Segment (DPS)**. The HSRG encourages co-managers to assign a population designation to each natural population associated with a hatchery program. The designation is a science-informed policy decision. The HSRG has recommended standards for hatchery influence (i.e., pHOS and PNI) for each designation.
Primary	A population of high biological significance. Primary populations are critical to recovery of the ESU or DPS. They should meet the highest standards of viability.

Contributing	A population of medium biological significance. Contributing populations are important to the diversity of the ESU or DPS. They should meet high standards of viability.
Stabilizing	A population of lower biological significance than primary or contributing ones. Stabilizing populations should maintain current levels of viability.
Population Goals	The *population goals* for a program should be quantified, where possible, and expressed in terms of values to the community (harvest, conservation, education, research, etc.).
Population Viability	*Population viability* is defined in terms of four parameters: abundance, productivity, population spatial structure, and diversity (McElhany et al. 2000).
Abundance	Size of the population, typically measured in terms of the number of spawning adults.
Productivity	The average number of surviving offspring per parent. Productivity is used as an indicator of a population's ability to sustain itself or its ability to rebound from low numbers. The terms "population growth rate" and "population productivity" are interchangeable when referring to measures of population production over an entire life cycle. Can be expressed as the number of recruits (adults) per spawner or the number of smolts per spawner. If productivity is less than one, the population is failing to replace itself. If this occurs consistently, the population may be at risk of extinction.
Population Structure	The spatial structure of a population refers to the degree to which subpopulations occupy habitat patches connected by low to moderate stray rates (also referred to as "metapopulations"). Population spatial structure depends on habitat quality, spatial configuration of the habitat, and dispersal of individuals.
Diversity	Population diversity includes both genetic and phenotypic (life history, behavioral, and morphological) variation, and contributes to population resilience and the ability to adapt to short-term and long-term changes in the environment. In salmonids, variation is expressed in terms of fecundity, run timing, spawn timing, juvenile behavior, age at smolting, age at maturity, egg size, developmental rate, male and female spawning behavior, etc.

Phases of Recovery	The HSRG defined 4 *phases of recovery* for conservation programs. The phase depends on the 1) program objectives for the population, and 2) ecosystem conditions (HSRG 2014). Moving from one phase to the next occurs when **triggers for phase shifts** are achieved (see below).
Preservation	The primary objective in the *preservation phase* is to prevent extinction and preserve the genetic diversity of the population. Suitable for populations with low abundance where the habitat is unable to support a self-sustaining population.
Re-colonization	The objective in the *re-colonization phase* is to re-populate suitable habitat. Suitable once the population is no longer at risk of extinction and when underutilized habitat is available to re-colonize.
Local Adaptation	In the *local adaptation phase*, the objectives are to meet and exceed the minimum viable spawner abundance for natural-origin spawners, and increase population fitness, reproductive success, and life history diversity through local adaptation (e.g., achieved by reducing hatchery influence by maximizing PNI). This phase is reached when specific population triggers are met and the habitat is capable of supporting abundances that meet these population objectives.
Full Restoration	In the *full restoration phase*, the goal is to maintain a viable population as defined by the viable salmonid population (**VSP**, see below) attributes. This phase is reached when specific population triggers are met and the habitat is fully restored and protected.
Triggers for Phase Shifts	Moving from one phase to the next occurs when specific *triggers for phase shifts* are met. These are biologically based, quantitative goals (e.g., number of NOS) and are typically based on a 5-year average so that phase shifts are based on long-term population trends. Phase shifts can be either up or down depending on the population trend.
Scientifically Defensible	A *scientifically defensible* program is one that explains, in terms of benefits and risks, how the hatchery program expects to achieve its purpose. The benefits of the program must outweigh the risks, and the chosen strategy must be consistent with current scientific knowledge. Where there is uncertainty, hypotheses and assumptions should be documented so that those assumptions can be evaluated and modified as new information becomes available (HSRG 2014).

Selective Harvest	*Selective harvest* programs are designed to target hatchery-origin adults. The purpose of such programs is to reduce the number of hatchery-origin fish on the spawning grounds. Hatchery-origin fish must be differentially marked. Specific gear types are being developed and tested (e.g., tangle nets) for large-scale selective harvest programs on mainstem fisheries such as the lower Columbia River (HSRG 2014).
Stray Rate	The *stray rate* is the proportion of adult spawners that do not return to their natal stream, but enter and spawn in another stream. This includes hatchery-origin recruits (HORs) that do not return to the stream of origin or release. The HSRG recommends taking measures to limit the straying of HORs.
Viable Salmonid Population	A *viable salmonid population* (VSP) is defined as an independent salmonid population that has a negligible risk of extinction due to threats from demographic variation, local environmental variation, and changes in genetic diversity over a 100-year time frame (McElhany et al. 2000). A VSP is defined in terms of four population attributes (abundance, productivity, population structure, and diversity; see **Population viability** above).
Working Hypothesis	Hatchery programs should be based on a *working hypothesis* that takes into account the best available scientific information about the population (smolt-to-adult survival rates, fish passage survival, harvest rates, natural productivity, impacts of hatchery fish on natural populations, etc.).

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