CONSIDERING ALTERNATIVE ARTIFICIAL PROPAGATION PROGRAMS: IMPLICATIONS FOR THE VIABILITY OF LISTED ANADROMOUS SALMONIDS IN THE INTERIOR COLUMBIA RIVER

Interior Columbia Technical Recovery Team

Michelle McClure
Fred Utter
Casey Baldwin
Richard Carmichael
Peter Hassemer
Philip Howell
Paul Spruell
Thomas Cooney
Howard Schaller
Charles Petrosky

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ABSTRACT

Artificial propagation of imperiled and commercially exploited anadromous salmonid species for conservation and harvest is widespread. However, while these programs can mitigate demographic extinction risk and provide fish for harvest, they also have the potential to affect the long-term viability and evolutionary trajectory of wild populations. In this paper, we describe the potential benefits and risks of artificial propagation programs in achieving the Interior Columbia Technical Recovery Team's viability criteria for listed anadromous salmonid populations and provide two case studies illustrating the potential effects of a range of artificial propagation strategies on the viability of a large population and of a Major Population Group or meta-population. Overall, the immediate short-term risk of extinction must be balanced against the longer-term risks to diversity and productivity that are posed by an artificial propagation program. Hatchery management practices and the duration of hatchery actions aimed at recovery of wild populations should be designed to avoid long-term impacts to viability. In some cases, strategies that isolate hatchery production from wild production and that do not compromise the viability of populations or meta-populations have the potential to provide opportunities to support other societal goals such as harvest.

INTRODUCTION

The relative merits and risks associated with artificially propagated salmonids (see definitions in Table 1) have been the subject of much discussion among fisheries professionals. Artificial propagation clearly has the potential to increase abundance of fishes (Brannon et al. 2004); however, several detrimental effects that releases of hatchery fish may have on native populations have been well documented, including competition, reduced fitness and reduction of effective population size (Araki et al. in press) . As a result, many practices such as extensive out-of-basin transfers of these species are much less common than they were historically (Brannon et al. 2004). However, substantial legacy effects on some populations persist from past practices; and a good deal of uncertainty remains regarding the degree to which improved hatchery practices can overcome these risks.

As salmon conservation and planning moves forward, both the ultimate goals and the risks and benefits of existing and future artificial propagation programs must be considered as those programs are developed and implemented. These programs can certainly have their place in conservation and recovery efforts. For example, if not for captive broodstock programs, Redfish Lake Sockeye salmon (*Oncorhynchus nerka*) would likely be extinct. Similarly, endangered Sacramento River winter-run Chinook salmon (*O. tshawytscha*) may have also benefited from captive release programs (Hedrick et al. 2000). In addition, artificial propagation programs that do not contribute directly to recovery of wild populations may be desired to support harvest. A key element of recovery planning will be to incorporate artificial propagation programs in a manner that is consistent with long-term recovery goals and viability criteria.

This paper provides an overview of the potential effects on long-term risk to populations posed by a range of artificial propagation programs. Following a brief description of the general biological risks and benefits of artificial propagation to wild populations, we provide an overview of the biological viability criteria developed by the Interior Columbia River Technical Recovery Team (ICTRT) for populations and ESUs and consider the implications of artificial propagation on achieving those criteria. We then predict relatively specifically the impact of a range of potential artificial propagation programs on population and meta-population viability with two specific case studies from the Columbia River basin. Finally, we offer some general conclusions and discussion regarding artificially propagated fish and salmon conservation in the interior Columbia Basin.

BIOLOGICAL RISKS AND BENEFITS OF ARTIFICIAL PROPAGATION

Since the last half of the 20th century there has been increasing scientific discussion regarding potential effects of hatchery programs (NRC 1996, Lichatowich et al. 2006). These include both direct and indirect ecological effects as well as a variety of potential genetic changes that could influence the continued persistence and viability of naturally reproducing populations.

Ecological Effects

Artificial propagation programs typically have the explicit goal of increasing the abundance of fish within a system. This augmentation can be advantageous when abundance in the natural population is exceptionally low, as immediate risks of extinction can be mitigated. Such demographic increase is a primary reason for the use of artificial propagation in many conservation programs. Increases in abundance are also the goal of most harvest augmentation programs, which have as their main purpose the provision of additional fish for harvest, usually as mitigation for habitat losses resulting from human actions such as the construction of impassable barriers.

However, this increased abundance has the potential to have additional indirect and direct ecological consequences (NRC 1996) affecting conspecifics or other species (Fausch 1988, Fresh 1997). For example, the increased number of juveniles and smolts has been implicated in generating feeding and territorial competition between hatchery and wild smolts. For instance, some authors have found increased dispersal or emigration of wild salmonids (McGinnity et al. 1997, Weiss and Schmutz 1999), and others have found some displacement of wild juveniles from their foraging habitats (McMichael et al. 1999) after the introduction of hatchery fish. However, this effect may be dependent on a variety of factors, as at least one study (Riley et al. 2004) found little competitive effect from relatively small releases of Chinook and coho salmon hatchery releases. Competition for food may extend to ocean areas as well (Cooney and Brodeur 1998, Heard 1998). In fact, recent work suggests that large releases of hatchery steelhead (*O. mykiss*) smolts into the Snake River may reduce smolt-to-adult return rates in wild Chinook salmon (Levin and Williams 2002). Non-endemic hatchery production can also exert a negative effect on wild smolt and adult production, probably through such density-dependent mechanisms as competition for food and territories among juveniles (Kostow and Zhou 2006).

Finally, the intermingling of wild and hatchery fish can complicate management of mixed-stock fisheries (Fraidenberg and Lincoln 1985). While this is a harvest management issue, hatchery production and harvest management can be tightly inter-linked; we therefore include this as a potential impact of artificial propagation programs.

Genetic Effects

In addition to potential ecological effects, hatchery fish may also affect the genetic structure of populations or ESUs (Currens and Busack 2004). In at least one case, the effect can be positive. This is when a sub-population, population or ESU is at extremely low numbers, and the artificial propagation program serves to preserve genetic variation that would otherwise likely be lost (Eldridge and Killebrew in press). A variety of other factors, however, have the potential to disrupt natural patterns of genetic (and thus potentially adaptive) variation (Hindar et al. 1991). The degree of threat posed by hatchery fish depends on several factors including the source of the hatchery fish, the proportion of hatchery fish being contributing to a population, and the duration of the hatchery program. Currently, these factors together are often referred to as the "Proportion Natural Influence" or PNI. While the intensity of threat depends on the specific situation and practices, genetic problems related to artificial propagation can be grouped into for categories as follows:

Domestication. Domestication is an essentially unavoidable consequence of artificial propagation (Busack and Currens 1995) as a result of unintentional or natural selection that occurs in artificial environments, selection resulting from non-random choice of broodstock and the relaxation of selection on early life stages (Waples 1999). In addition, managers can intentionally or artificially select for particular traits. In segregated hatchery programs, this is not necessarily detrimental, as it can allow a stock to flourish in the program. However, in integrated programs, or in situations where a segregated hatchery program produces many strays, it can result in lowered fitness for the wild population.

It has been hypothesized that domestication may be moderated through rearing regimes that simulate natural conditions (Maynard et al. 2004) or through integrated breeding programs that maximize wild-adapted genotypes (Mobrand et al. 2005). However, since neither strategy is capable of completely eliminating domestication, any intentional or inadvertent (e.g., through straying) interbreeding of hatchery fish with natural populations has the potential to reduce the adaptation of the resultant progeny to natural conditions.

Outbreeding depression. Introgressive hybridization of non-local hatchery fish with native wild populations promotes outbreeding depression both from differential adaptations such as domestication, and genomic incompatibilities (i.e., diverged coadaptive gene complexes) of the two groups (Gharrett and Smoker 1993, Utter 2001). Despite a broad consensus for the use of local populations in hatchery supplementation programs (NRC 1996, Independent Scientific Advisory Board 2001, Mobrand et al. 2005), out-of-ESU outplantings persist (e.g., Utter and Epifanio 2002). Increased straying, which is typical of such releases (Quinn 2005), elevates the risk of introgression beyond the area of release.

Homogenization. Homogenization both among and within populations may result from artificial propagation programs. Pacific salmonids are renowned for their homing ability, and at least one species exhibits precise philopatry (Bentzen et al. 2001). This tendency to return to natal areas leads to genetic differentiation both within and between populations, often dynamically and at fine-scales (Hendry et al. 1999, Bentzen et al. 2001, Hilborn et al. 2003). This localized complexity buffers the population against ongoing and shifting natural conditions (Reisenbichler et al. 2003). Such complexity necessarily exists at a finer scale than is possible for even a hatchery derived from and maintained by local breeders. Thus, a natural breeding program that includes hatchery supplementation breaks down natural patterns of differentiation between and within populations, and can lead to homogenization across populations or between sub-units of the same population. (Reisenbichler et al. 2003, Mobrand et al. 2005).

Effective population size. Small effective population size (Ne) can lead to inbreeding depression and loss of genetic variation, which are particularly detrimental to viability when the demographic size of the population remains small. Artificial propagation programs have the potential to lower effective population size by reducing the effective number of parents that is represented in the next generation (Ryman and Laikre 1991). This reduction can happen when a relatively small number of parents is disproportionately represented in the next generation, as when in past practices, a small number of males was mated with many females. In addition, the Ne of a post-supplementation program maintained at pre-supplementation numbers inevitably is reduced by the disproportionate representation of the hatchery population imposed through supplementation (Waples and Do 1994). In a recent study (Araki et al. in press), detected no reduction in the number of breeders (Nb) from a new supplementation hatchery. Currently, hatchery reform groups are working on prescribed ratios of hatchery and natural spawners in the hatchery and in the natural environment to reduce risks associated with low Ne and domestication.

Importantly, while there are documented successes of artificial propagation programs in producing high egg-to-smolt survival and positive adult-to-adult replacement rates, there is little information available about the performance and productivity of hatchery-origin fish and their resultant progeny in the natural environment or their cumulative effects on natural population productivity (Araki et al. in press, Waples et al. in press). There is, therefore, great uncertainty about the net long-term effects of artificial propagation programs, particularly long-term programs, on natural populations.

VIABILITY CRITERIA FOR INTERIOR COLUMBIA SALMON AND STEELHEAD

The ICTRT was formed to accumulate, synthesize and interpret information related to the recovery of seven anadromous salmonid Evolutionarily Significant Units within this region listed as threatened or endangered under the Endangered Species Act (ESA). The approach to recovery is based on the concept of a viable salmonid population (VSP) which guides determination of the conservation status of populations and larger-scale groupings within an ESU (McElhany et al. 2000). Under these guidelines, a VSP is an independent population of any anadromous Pacific salmonid that has a negligible risk of extinction due to threats from demographic variation, local environmental variation, and genetic diversity changes over a 100-year time frame.

Hierarchical Subdivisions within ESUs

We have described the biological hierarchy inherent to salmon populations in the interior Columbia Basin (Interior Columbia Technical Recovery Team 2003). We defined populations using genetic, geographic, demographic and ecological information based on a criterion of demographic independence over a 100-year time period. Above the population level, Major Population Groups (MPGs) are groups of geographically proximate populations that are more similar to each other in genetic characteristics and habitat types than they are to other such groups of populations. MPGs are thus a means of identifying genetic diversity and spatial structure across the ESU. ESUs, the units that are listed under the ESA (Waples 1991), can be comprised of one or many Major Population Groups. Below the population level, we used an intrinsic potential analysis (Interior Columbia Technical Recovery Team 2007c) to identify spawning concentrations (Major and Minor Spawning Areas -- MaSA and MiSAs). These areas delineate the spatial distribution of spawning habitats within a population but do not necessarily reflect any demographic or genetic discreteness among spawning areas within populations.

Viability Criteria Overview

Our determination of a population's status relative to viability criteria considers its condition relative both to abundance and productivity (A/P), and to spatial structure and diversity (SS/D) (Interior Columbia Technical Recovery Team 2007c). Hatchery-origin fish are treated in both areas. The status of populations within an MPG determines the MPG-level viability, and the status of constituent MPGs determines ESU level viability.

ESU- and MPG-level viability assessment

Under the ESA, it is the listed units, or ESUs that are the "delisting unit" (Waples 1991). Viability at this level is thus a key component for ultimate de-listing. The ICTRT recommends that for an ESU to be considered viable, all extant MPGs should be viable. For MPGs with multiple populations to be considered viable, half or a minimum of two (whichever is greater) of its constituent populations should meet population viability criteria, with at least one meeting criteria for "high viability" (Interior Columbia Technical Recovery Team 2007c). In addition, all major life history types in the MPG (e.g. spring and summer run, anadromous and resident, etc.) should be represented among the populations that achieve viable status, and the larger populations in the MPG should be proportionately represented in the set of populations meeting viability criteria. All remaining populations should be "maintained" at levels so that they are not a significant sink for other populations or the MPG as a whole. At this level, they provide a buffer for some of the uncertainties in the adequacy of the viability criteria and in the success of recovery efforts aimed at other populations and perform relevant ecological functions (e.g. contribute to the maintenance of natural patterns of dispersal).

Population-level Viability

Full details of the methods for deriving an SS/D risk rating, an A/P rating and a population-level rating are described elsewhere (Interior Columbia Technical Recovery Team 2007c). Here we present a brief overview.

Abundance and productivity. Because biological viability criteria aim to identify the conditions under which a population would be naturally self-sustaining, the ICTRT metrics are focused on natural production. Abundance is measured in terms of spawners of natural origin, a direct measure of the ability of a population to sustain natural production at a sufficient level to protect against demographic and genetic losses. Productivity is expressed as a ratio of the naturally produced offspring from spawning in a given brood year to the corresponding total number of parent spawners -- both hatchery and natural origin -- producing the returns. Including the hatchery-origin adults as spawners and their natural-origin offspring as recruits in the calculation provides an appropriate estimate of natural population productivity when the relative reproductive success of hatchery-origin spawners is not known. When the relative reproductive success of hatchery and natural-origin spawners[1] is well-documented, the productivity estimates for the natural and hatchery origin components of the population can be partitioned. In general, hatchery-origin fish with lower reproductive success than their wild counterparts will result in an estimate of population-level productivity that is lower than that of the wild fish alone (Gross 1998). Thus, from the perspective of planning

[1] The aggregate natural productivity of a population including hatchery origin spawners can be affected by a variety of factors. These include differences in fitness that would arise in any habitat, but also include factors such as differences in the distribution of hatchery and natural origin spawners across relatively good and relatively poor habitat.

recovery strategies, there are two substantial benefits to knowing the reproductive success of both components of the population. First, knowing the reproductive success of wild and hatchery fish can provide a more accurate estimate of the improvements in productivity required to meet viability goals. Second, continued interbreeding with hatchery-origin fish of lower fitness can lower the fitness of the wild population; knowing the reproductive rates can potentially identify situations in which such interbreeding has been detrimental to the wild population. A detailed description of the methodology used to construct the viability curves for our A/P risk assessments, and examples of current status assessments can be found in ICTRT (2007) Appendix A and on the ICTRT website: www.nwfsc.noaa.gov/trt/columbia_trt.

Spatial Structure and Diversity (SS/D). Our SS/D criteria are divided into two general goals, each having several criteria addressing the goal. The first goal is to allow spatially mediated processes to function at rates and in patterns that support viability. In other words, this goal aims to allow normal biological and ecological processes, such as gene flow, local extirpations and re-colonizations to occur in a manner and at a rate that is not substantially anthropogenically dictated. This goal is primarily achieved by maintaining a distribution of spawners that is generally consistent with that of the historical population. The second goal is to maintain normative levels of variation. This goal recognizes both direct measures of variation (in terms of genetic and phenotypic characteristics) and indirect measures that have the potential to affect the diversity within and between populations, such as the range of habitats occupied. (See (Interior Columbia Technical Recovery Team 2007c) for a complete description of all metrics.)

Several of our SS/D metrics rely upon determining which spawning areas are currently occupied. For these metrics, occupancy is defined on the basis of natural-origin spawners in either a MaSA or MiSA (see Interior Columbia Technical Recovery Team 2007c, p. 51 for a more complete description of our occupancy rules). As such, the presence of hatchery origin spawners does not contribute to occupancy for these metrics. However, their natural origin offspring that return to spawn do contribute to occupancy. Our rationale for this decision is similar to the rationale that excludes hatchery fish from abundance estimates. The distribution of hatchery fish spawning naturally may not be indicative of any natural function or process and, therefore, does not lessen the risk associated with those spatial metrics. This point can be illustrated using an extreme example. Hatchery adults could be outplanted above Dworshak Dam and might display natural spawning behavior. However, the impassable fish barrier precludes recovery of a naturally reproducing population in this case making the presence of those hatchery fish irrelevant from a viability standpoint.

We deal directly with the presence of hatchery fish in populations in a metric assessing spawner composition. Categorization of risk associated with spawner composition is determined following Figure 1 (reprinted from Interior Columbia Technical Recovery Team 2007c). The risk associated with hatchery programs increases when hatchery fish: a) are from outside the population, MPG or ESU (in increasing order of risk); b) constitute a high proportion of the natural spawners; c) are from a program not using “best management practices;” or d) if the artificial propagation program is of long duration (Table 2).

The final SS/D metric on which artificial propagation programs can have an impact is the direct measure of genetic variability. This metric relies on evaluating the degree to which the genetic structure of a population likely varies from its probable historical condition, or whether, if divergent, it is trending toward conditions that are more normative. This means that populations that are persistently genetically similar to artificially propagated stocks that are not locally derived will be at higher risk than those that maintain their local patterns of genetic variation.

A composite SS/D rating, considering all nine SS/D metrics is developed using a weighting system across the two goals.

Population-level viability assessment. Overall population-level status is determined by the combination of the abundance and productivity risk level and a composite spatial structure and diversity risk rating. Populations are considered highly viable, viable, maintained, or high risk (Figure 2). The population(s) meeting "high viability" criteria will necessarily be large and spatially complex. This means that only a subset of the populations in MPGs with multiple populations can be candidates for this status.

The methods for developing the composite SS/D rating place some constraints on the use of artificial propagation. Specifically, a population can meet the criteria to be considered viable with an ongoing, but low-level artificial propagation program, but only when most other SS/D metrics are rated as "low" or "very low" risk. This means that in order to meet these criteria there should be little or no introgression between the hatchery fish and the wild component of the population, which would affect the metric assessing genetic variation, nor should there be significant artificial selection or reduction in spatial distribution. In order to meet all the conditions to be considered maintained, the population will need either to achieve these same, low-risk SS/D ratings and a "moderate" risk for A/P, or achieve a "low" or "very low" risk rating for abundance and productivity. Importantly, achieving high abundance and productivity will require increases in productivity above current levels for most populations in the Interior Columbia Basin.

Although populations supported by hatchery supplementation for more than three generations do not in most cases meet ICTRT viability criteria at the population level, the ICTRT criteria do not preclude the use of hatcheries to meet the broader goals of salmonid management. The risk associated with hatchery fish is largely dependent upon the design of the program and the population setting in which the program is found (Mobrand et al. 2005). For example, hatchery programs designed to bolster a population until it reaches a point of being self-sustaining can achieve a low-risk rating for the spawner composition metric even when up to 15% of the spawners are of hatchery origin for three generations, provided that "best management practices" are used. This same level of hatchery spawners would result in a "high" risk rating for that metric if the hatchery spawners originated from outside the MPG. There may also be opportunities to isolate hatchery programs within large, complex populations, or in areas not occupied by listed populations (see below).

The effect that artificial propagation programs can have on the risk level assigned to individual populations has implications for risk levels at the ESU and MPG levels as well. First, it is impossible for any MPG (and thus any ESU) with long-term hatchery programs that dominate production in a majority of its constituent populations to be classified as viable, since few of these populations will meet viability criteria. Similarly, in many cases an MPG contains one or more "must-have" populations – populations that must meet viability criteria by virtue of their size or life history characteristics represented.

ASSESSING THE IMPACTS OF ARTIFICIAL PROPAGATION PROGRAMS IN RECOVERY PLANNING

Gauging the impact of artificial propagation programs in the short and long-term is clearly challenging. In the following sections, we demonstrate the effect on population and MPG viability posed by a range of potential or proposed artificial propagation programs. In the first case study, we discuss the impact on within-population variation and population-level viability of several possible approaches to artificial propagation in the Wenatchee River. In the second case study, we present the potential effects of current and proposed artificial propagation programs in the Grande Ronde/Imnaha spring/summer Chinook salmon MPG on overall MPG and ESU viability and variation. We present these case studies as examples of the factors that should be weighed, and how the relative risk to the population or MPG would change under each scenario. We intend for recovery planners to use these examples to frame the risk-benefit analysis of other situations, and anticipate a continuing iterative process to evaluate the effects and relative risks of artificial propagation programs.

Each of the alternative approaches presented in the case studies has a different set of risks and benefits, but each set is dependent on several principles. First, genetic homogenization within and between populations will increase the risk to affected populations by reducing available genetic variation. Second, any artificial propagation program carries some risk of domestication selection and consequent outbreeding depression from strays. Third, when demographic extinction risk is very high, the benefit of artificial propagation increases, and may surpass the costs associated with domestication or minor homogenization in a short time frame. Finally, all impacts of an artificial propagation program on wild fish, including those out of basin, should be considered.

A Case Study of the Wenatchee River Spring Chinook Population -- Potential effects of artificial propagation on within-population variation

<u>The Setting of the Wenatchee River Spring/Summer Chinook Population</u>

The Wenatchee River drainage comprises 3,550 km^2 (1370 mi^2) on the east slope of the Cascade Mountains in Washington State. The stream network supporting this population is dendritic in structure, and the population has been classified as “very large” in size based on historical intrinsic habitat potential (Interior Columbia Technical Recovery Team 2007a), which also identified five Major Spawning Areas (MaSAs) within this population: the Chiwawa River, the White River, the Little Wenatchee River, Nason Creek, and the upper mainstem Wenatchee. In addition, there are four historical Minor Spawning Areas (MiSAs) (Icicle Creek, Peshatin Creek, Mission Creek, and Chumstick Creek) in the downstream portions of the drainage (Fig. 3). Given the small number of populations and the single extant MPGs in the Upper Columbia spring Chinook salmon ESU, as well as this population's size, the Wenatchee is a population that must meet viability criteria, and it is recommended that this population meet criteria for high viability in order for the MPG and ESU to be considered viable (Interior Columbia Technical Recovery Team 2007b).

Of the watersheds containing spawning areas, the White River, which contributes 25% of the total annual flow of the Wenatchee River, is distinct in its geology and hydrologic patterns. It is fed by melting glaciers resulting in substantial input of glacial till leading to both the name of the river, and a set of environmental conditions that are substantially different from other streams in this system. Finally, the White River drains into a deep, cold lake that must be navigated by migratory fishes returning to spawn in the upper reaches of the White River. Recent studies have found spring Chinook salmon parr in the littoral zone of Lake Wenatchee during summer months, but the duration and extent of juvenile rearing in the lake is not well-quantified (K. Polivka, USFS, pers. comm.)

This population is not currently viable. In fact, it has a high risk rating for both A/P and SS/D. The population as a whole is depressed, with a current geometric mean productivity of less than one, even at low densities (Upper Columbia Salmon Recovery Board 2006, Interior Columbia Technical Recovery Team 2007a). The White River spawning aggregation, in particular, is severely depressed and persistently experiences escapement levels below White River HGMP (Washington Department of Fish and Wildlife 2005) critical population thresholds. A five-year geometric mean between 1988-1992 of 25 spawners was the lowest within the major spawning areas of the Wenatchee River population (Myers et al. 1998). The Wenatchee population's SS/D rating is also high risk (Interior Columbia Technical Recovery Team 2007a). This rating is related to a very high proportion of within-population hatchery fish on the spawning grounds from the Chiwawa supplementation program, high stray rates from that program to other non-target spawning aggregations, and out-of-ESU spawners straying in the basin (Tonseth 2003, 2004, Upper Columbia Salmon Recovery Board 2006, Interior Columbia Technical Recovery Team 2007b). In addition, the genetic structure both within this population and between the Wenatchee and other Upper Columbia spring Chinook salmon populations is greatly homogenized likely due to past propagation practices and some years of extremely low returns.

Hatchery Programs Past and Present

Principal ongoing hatchery activities in the Wenatchee population that have a potential effect on the genetic substructure (Chapman et al. 1995, Utter et al. 1995, Murdoch et al. 2005, Murdoch et al. 2007) include:

- Leavenworth National Fish Hatchery (Icicle Creek). This program uses spring Chinook salmon originating from a composite Columbia River stock (predominantly Carson Hatchery) that is classified as an out-of-ESU stock. These fish have been reared and released from the Leavenworth Hatchery since 1981. Broodfish from upstream populations have been excluded and no outplantings to upstream areas have been conducted. Tagging studies indicate that LNFH stray rates are generally low (<1%) (Pastor 2004). However, based on expanded carcass recoveries from spawning ground surveys (2001-2004), LNFH and other out-of-basin spawners have comprised from 3-27% of the spawner composition in the five MaSAs above Tumwater Canyon (WDFW unpub. data).

- Chiwawa River. An integrated supplementation program (sensu (Mobrand et al. 2005) initiated in 1989 includes rearing, acclimation and release of juveniles at the Chiwawa hatchery facility. There is widespread straying from this program to other tributaries (Tonseth 2003, 2004), presumably due in part to the use of Wenatchee River water for periods in the winter when Chiwawa River ice prevents use of the natal water source. Additionally, this program uses as few as 30% natural origin fish in the broodstock with no limit on the proportion of hatchery origin fish on the spawning grounds. There is commonly a very high proportion (>50%) of hatchery fish on the spawning grounds of the Chiwawa River and a high stray rate (40% in 2002) to adjacent MaSAs (Tonseth 2003, 2004). Actions to reduce straying were implemented beginning with the 2005 brood year released in 2007.

- White River. A captive broodstock program was initiated in 1999 for White River spring Chinook salmon. Broodstock were generated from eggs excavated from redds of natural origin spawners in the White River. The first yearling smolt release occurred in the spring of 2004. Because this program is new, evaluation of its efficacy is currently ongoing (UCSRB 2006). The program is described in the Draft

Upper Columbia Spring Chinook Salmon, Steelhead, and Bull Trout Recovery Plan (UCSRB 2006) as follows:

> "The White River program is designed to be integrated with the natural population and is intended to increase the number of White River spring Chinook adults on the spawning grounds. After hatching, fish are reared in a hatchery facility until maturity, which can occur at three to six years. These fish are spawned and their progeny are reared to a yearling smolt stage. The smolts are tagged or marked for monitoring purposes and subsequently released into the White River. Gametes collected from naturally produced White River spring Chinook may be used to augment the gametes from the adults reared in captivity."

Plans are underway to convert the program to an adult based supplementation program by 2013. This program will have a smolt release target of up to 150,000 within basin rearing and acclimation (Kirk Truscott, pers. comm.)

– Nason Creek. A captive broodstock program was initiated in the late 1990s when escapements were very low but was subsequently abandoned in the early 2000s based on improvements in adult returns (HGMP 2005). Some of the captive brood adults and smolts were released into Nason Creek from that program; however, the numbers were very limited (Kirk Truscott, pers. comm.) Currently, there are plans to start an adult based supplementation program in Nason Creek using natural origin spring Chinook from Nason Creek. Mitigation agreements include a reduction in the Chiwawa River smolt releases corresponding to the smolt release numbers from the

Nason Creek Program (target = 250,000). An integrated supplementation program for this tributary is in the planning stages.

Currently, the Little Wenatchee and upper Wenatchee MaSA are not supplemented with hatchery fish and no plans are in development to initiate hatchery programs in those areas.

Genetic Structure within the Wenatchee Population

The genetic structure of the Wenatchee population was probably dramatically affected by at least two periods of dam construction. First, a dam on the mainstem Wenatchee River near the town of Leavenworth may have blocked almost all access by anadromous fish in the early 1900s (Craig and Suomela 1941, Mullan et al. 1992). The current spring-run Chinook salmon population of the Wenatchee River is descended from ancestors relocated over five consecutive years (1939-1943) under the Grand Coulee Fishery Management Plan (GCFMP, reviewed in Utter et al. 1995). The GCFMP intercepted adults destined for all upstream areas both above and below Grand Coulee Dam at Rock Island Dam and transported them to Nason Creek. This mixing of spawners would probably have eliminated any natural structure that may have existed within the Wenatchee basin. Indeed, genetic samples of spring Chinook salmon from the Wenatchee, Methow and Entiat basins are nearly indistinguishable from one another (Ford 2001, Interior Columbia Technical Recovery Team 2003, in prep) This raises the likelihood that any divergence among present spawning groups has occurred within the past 70 years.

The current genetic population structure within the Wenatchee is somewhat ambiguous. Samples from most locations within the basin are not significantly differentiated, consistent with past translocation, bottlenecks and ongoing artificial propagation activities. However, despite these actions, a clear genetic signal indicating that the White River group was isolated from other spring Chinook salmon in the Wenatchee River and adjacent basins based on allozyme data collected in the late 1980s (Utter et al. 1995, Ford 2001, Interior Columbia Technical Recovery Team 2003, in prep). Microsatellite analyses of more recent samples are conflicting regarding the persistence of this distinction. Analysis of samples collected in 2000 that encompass a geographic range similar to the earlier collections were consistent with a loss of the White River distinction, reflecting recent bottlenecks in spawning population size and apparent region-wide homogenization from translocations and straying (Interior Columbia Technical Recovery Team 2003, Moran and Waples 2004, Lundrigan et al. in prep). This conclusion is supported by high similarity of Wenatchee Chinook to all UC hatchery samples and AMOVA analysis indicating no apparent structure between populations (Interior Columbia Technical Recovery Team 2003, in prep). However, microsatellite analysis of samples collected in 2004 and 2005 (Figure 4) suggested a persistence of White River distinction within the Wenatchee basin. Unfortunately, a different suite of microsatellites was used in this study and region-wide collections were not available for comparison with the earlier microsatellite data set. In addition, the samples were restricted to the Wenatchee Basin, so the apparent difference in clustering may reflect the lack of a wider range of samples (Figure 3). This more ambiguous result could be real – in other words, the genetically distinct group that was present in the 1980s could have been overwhelmed by hatchery strays, experienced an extreme reduction in genetic diversity due to exceptionally low returns in the 1990s (range = 1-12 spawners, median = 5) or otherwise have been functionally extirpated. Alternatively, the ambiguity could be a byproduct, or result of the sample range, the loci used or other similar factors. Thus, the persistence of this distinction remains uncertain.

<u>Impact of Alternative Artificial Propagation Programs on Population Viability</u>

Managers in the Wenatchee basin face a conundrum in their recovery planning related to artificial propagation. The Wenatchee population is clearly at very high risk with respect to abundance and productivity, and the White River spawning area, one of the only locations with any apparent genetic differentiation in the entire Upper Columbia ESU is among the areas most at-risk. Artificial propagation programs may help the population avoid extinction if downward trends in ocean conditions continue and mortality rates through the hydropower system do not improve. Moreover, there is a strong desire to maintain negotiated mitigation agreements for the operation of Mid-Columbia PUD dams that include smolt releases as well as the harvest augmentation hatchery program in Icicle Creek as mitigation for the loss of areas above Grand Coulee Dam. These factors all provide support for some artificial propagation. However, the implementation or continuation of any artificial propagation program carries its own risk to the natural population. And, because this population should ultimately achieve a status consistent with viability for the ESU to be recovered, these risks have the potential to affect long-term recovery. Because the effect of artificial propagation in TRT viability criteria are calculated as an average over the most recent three generations, continuing or expanding existing programs will increase the time frame in which recovery can be achieved, even though they may be deemed necessary to preserve existing genetic variation and mitigate short-term extinction risk. Improving culture practices will decrease the risk associated with any programs, but may not allow the population to reach a desired status, depending on the degree to which high proportions of hatchery-origin spawners on the spawning grounds can be reduced.

Complicating matters, the current uncertainty about the degree of differentiation in the White River makes it harder to assess definitively the priority that should be placed on preserving the genetic makeup of that tributary. However, a recovery strategy that preserves and promotes natural patterns of local adaptation of salmon to each of the major spawning areas would decrease extinction risks associated with spatial distribution and diversity metrics and buffer the population against environmental variability. Such a strategy would allow natural differentiation between primary spawning areas and neither increase nor decrease gene flow artificially. This strategy would support either a differentiated or an undifferentiated White River, and could be achieved by avoiding outplanting fish or progeny from other sub-areas to the White River.

The White River subgroup's demographic peril and the lingering uncertainty regarding its genetic isolation have focused particular attention on its hatchery program. Consequently, a range of options exists for artificial propagation intended to deal with the current low abundance in the population and preservation of the genetic diversity potentially in the White River drainage. In general, the high level of straying from the Chiwawa supplementation program increases the risk to the Wenatchee population as a whole with respect to diversity, by altering likely patterns of gene flow. However, because the Wenatchee is at high demographic risk, the impact of each alternative on the population's short-term extinction risk must also be considered. In Table 3, we describe a range of potential (and hypothetical) artificial propagation programs and their effects on population-level risk.

The current captive breeding strategy, which maintains a separate broodstock for the White River, would support a genetically distinct White River subpopulation. Once self-sustaining, the expectation would be that natural patterns of diversification within the Wenatchee population would eventually be re-established, as the group was released from domestication effects from the initial generations of supplementation. If those conditions were realized, the risk due to the proportion of exogenous spawners could be downgraded, and the expectation would be that natural patterns of diversification within the Wenatchee population would eventually be re-established. This program also mitigates short-term extinction risk, but carries a risk of ongoing domestication.

At the other extreme, managing the entire upper Wenatchee drainage above Tumwater Dam as a single unit poses a different set of costs and benefits. This action would consist of collecting upriver-bound fish at Tumwater Dam, breeding and managing these fish as an integrated single composite stock, and releasing progeny indiscriminately across the upstream areas over multiple generations. Collection at Tumwater could help ensure that "full program" numbers for broodstock are regularly met when run sizes are sufficient. In "normal" return years, this would put high proportions of hatchery fish on the spawning grounds and could reduce short-term extinction risks for the population during extremely low escapement years. However, this thorough mixing of fish bound for upstream tributaries would eliminate any existing population substructure and preclude its re-establishment through the life of the program. This, in turn, would increase risk to the population, most notably with respect to the metrics assessing natural patterns of variation, and the long-term presence of hatchery-origin spawners produced using practices that inhibit natural differentiation. Achieving viability for this population could thus be substantially delayed at best and precluded at worst (without discontinuation of the program), with the implementation of this option.

There is clearly no single "right" answer for artificial propagation aimed at conservation of the Wenatchee population. However, it is clear that programs that would result in continued or worsened homogenization within the population increase its long-term risk and that the lack of any artificial propagation increases the short-term demographic risk. Key to any program's implementation or continuation will be the elimination or near-elimination of straying from the program and robust monitoring coupled with appropriate adaptive modifications. For long-term viability, which includes raising abundance and productivity to viability targets, the artificial propagation program will need to be phased out of the majority of main tributaries or MaSAs, and may need to be modified in other ways as the factors limiting recovery are addressed successfully.

The Leavenworth National Fish Hatchery harvest augmentation program poses a somewhat different situation. This program is geographically isolated and located in habitat that is not thought to have been a primary spring chinook production area (Upper Columbia Salmon Recovery Board 2006), and that is not categorized as a Major Spawning Area (Interior Columbia Technical Recovery Team 2007c). This program is a good candidate for an isolated program that could be continued in the long-term without significant impacts to the potential viability of the Wenatchee spring Chinook salmon population. However, for this to be the case, two conditions would need to be met. First, straying from the LNFH program would have either to be extremely low or be subject to management actions such as removal of strays at Tumwater Dam. Persistent straying, even at relatively low levels from this out-of-ESU stock would increase the risk to the population as a whole. Second, the presence of the hatchery releases should not reduce the productivity and abundance of the population below levels that would make it viable. In other words, if the fish released from this program compete with the wild population in the lower reaches of the Wenatchee River or reduce the productivity of the wild population in any other way (e.g., predation), these effects will need to be weighed with other impacts to productivity, such as hydropower actions, harvest and habitat condition in achieving long-term abundance and productivity goals. Clearly, robust monitoring and adaptive approaches to recovery implementation will also be key in this situation.

A case study of the Grande Ronde/Imnaha River Spring/summer Chinook populations -- Potential among-population effects of artificial propagation

<u>The Setting of the Grande Ronde/Imnaha Major Population Group</u>

The Grande Ronde/Imnaha Major Population Group, one of five MPGs in the Snake River spring/summer Chinook ESU, includes eight populations, two of which have been rendered functionally extirpated (historical gene pool not likely present -- see further detail below). It is located in the NE corner of Oregon in the Grande Ronde and Imnaha drainages. These adjacent tributaries flow directly into the Snake River (Fig. 5) and drain high mountain peaks as well as dry lower elevation plateaus. While some areas are designated wilderness areas, others have been heavily affected by agriculture, grazing and timber management practices.

To meet the Interior Columbia TRT viability criteria, this MPG should include at least four populations with "viable" status, one of which must meet high viability criteria. In addition, the set of viable populations should include two of the three large populations and the Imnaha River population because it has a unique spring/summer life history strategy (Myers et al. 1998, Interior Columbia Technical Recovery Team 2003, 2007c). The remainder of the populations in the MPG should meet criteria for maintenance to ensure that these populations contribute to the structure and ecological functioning of the MPG and thus contribute to the long-term persistence of the ESU. Given these, and a variety of spatial structure considerations, the TRT has recommended that the populations in the Imnaha River, the Wallowa-Lostine River, either the Catherine Creek or the Upper Grande Ronde River populations, and either the Wenaha or Minam River populations meet viability criteria, and that all remaining populations be maintained (Interior Columbia Technical Recovery Team 2007b).

Artificial Propagation Past and Present

Chinook populations within the Grande Ronde and Imnaha sub-basins have been subjected to a variety of hatchery practices under the Lower Snake River Compensation

Plan over the last forty years. From its initiation, management objectives for the hatchery program included both harvest augmentation and supplementation (Carmichael et al. 1998a).

In response to declining runs in the Grande Ronde basin, fish from the Rapid River stock were released directly into Lookingglass Creek in 1978 as an initial broodstock for a Grande Ronde subbasin program, and a hatchery was built on that creek in 1982. The Rapid River hatchery stock was originally derived from spring Chinook salmon collected at the base of the Hells Canyon Dam complex, and raised at the Rapid River hatchery (a tributary to the Little Salmon, and then the Salmon River) and other hatcheries in Idaho for many generations. This hatchery stock is not considered part of the Snake River spring/summer Chinook salmon ESU (Myers et al. 1998), although the original fish used to establish this stock were likely destined for upstream locations within the Snake River. After initial releases of Rapid River stock in Lookingglass Creek, its use was discontinued for a number of years due to disease concerns. Carson stock from lower Columbia River hatcheries was used for the 1980-1989 broodyears (with the exception of 1988); adult fish from this stock were present in the tributaries from 1983-1994. For the 1985-1989 broodyears both Carson and Rapid River stocks were produced at Lookingglass Hatchery; however, each stock was uniquely marked and maintained separately (Carmichael et al. 1998a). Access to Lookingglass Creek above stream km 3.7 was completely blocked at the hatchery, eliminating any remaining elements of the wild population as interbreeding with hatchery stocks occurred in accessible areas. Although most releases occurred at Lookingglass Creek, hatchery presmolts, smolts and adults were outplanted into Catherine Creek, the Upper Grande

Ronde River and the Wallowa River periodically from the early 1980's until the early 1990's Significant straying of both Carson and Rapid River stock hatchery fish from this program into the Lostine, Minam and Wenaha Rivers occurred during this time (Carmichael et al. 1992). Hatchery-origin spawners comprised 58% of the natural spawners in the Wenaha River from 1986 through 1995, and 41% of the spawners in the Minam River at that time. In the Upper Grande Ronde River and Catherine Creek, over 60% and 70% of the spawners, respectively, were hatchery-origin fish during this same period. Samples of naturally spawning fish in Lookingglass Creek collected in the 1990s were genetically indistinguishable from Rapid River hatchery stock; samples of natural-origin parr from other populations in the Grande Ronde (Lostine, Catherine Creek, Upper Grande Ronde and Wenaha) were closely related to the hatchery stocks, but were distinct from it in most years (Figure 6; Waples et al. 1993, Interior Columbia Technical Recovery Team 2003).

In the early 1990s, two significant policy rulings influenced the direction of the Grande Ronde Chinook salmon hatchery program. Oregon Department of Fish and Wildlife (ODFW) adopted guidelines for the proportion of non-local hatchery fish spawning in nature as a component of the Wild Fish Policy, and the National Marine Fisheries Service listed the Snake River spring/summer Chinook ESU including Grande Ronde and Imnaha populations as threatened in 1991 (National Marine Fisheries Service 1991). The hatchery program was producing strays well outside of the ODFW policy guidelines and the program was inconsistent with conservation of an ESA-listed population. In addition, both the populations that were supplemented directly and those that received significant strays showed very poor productivity during the period that supplementation was ongoing. As a result, several major reform measures were taken to modify this hatchery program.

Foremost in these reform actions were elimination of the use of any stocks from outside the basin and initiation of local broodstocks in the Wallowa-Lostine River, Catherine Creek and the Upper Grande Ronde River populations. Beginning with the 1994 brood year, the development of local broodstock for these three tributaries was initiated. Use of Rapid River stock was restricted to releases only in Lookingglass Creek after 1994, and was completely discontinued in the basin after the 1997 brood year. A re-introduction effort in Lookingglass Creek using Catherine Creek broodstock releases began with releases of 2000 broodyear parr, and all adults with presumed Rapid River or Carson stock had been removed from brood stock used to form the release groups. Currently, this local broodstock supplementation effort continues in Lookingglass Creek. Captive broodstock and conventional broodstock supplementation programs using local broodstock sources are ongoing in the Wallowa-Lostine River, Catherine Creek and the Upper Grande Ronde River populations. In these three populations, the programs use different broodstock and natural escapement management strategies to evaluate the effect of the proportion of natural-origin fish in the broodstock and the naturally spawning population on population status. The Upper Grande Ronde program allows for the greatest level of hatchery influence while the Catherine Creek program is the most conservative, allowing the least influence. The captive broodstock program in the Wallowa-Lostine River and Catherine Creek populations is planned to be discontinued after the spawning of the 2006 cohort, while the conventional broodstock programs in all three rivers are planned to continue indefinitely. A new fish-rearing facility on the

Lostine River to support the Wallowa-Lostine program is planned under the Northeast Oregon Hatchery Project.

The Imnaha River program has taken a different approach to broodstock development and management since its initiation. An "integrated" hatchery program, founded with locally derived fish was initiated in 1982. This program, like that in the Grande Ronde, was initiated to restore historic fisheries and to enhance natural production with hatchery supplementation (Carmichael et al. 1998b). Broodstock management and management of natural escapement above the weir have varied considerably since program initiation. Initially a high proportion of natural returns to the weir were retained for hatchery broodstock and once hatchery fish began returning, hatchery fish comprised a high proportion of the broodstock and a high proportion of natural spawners above the weir (Carmichael et al. 1998b). Under current management guidelines a sliding scale is used to manage the proportions of natural fish retained, the proportions of natural fish in broodstock and the hatchery proportions released to spawn naturally. At lower escapement levels, higher hatchery proportions are allowed in both the broodstock and in the natural spawners. At escapement levels above 1400 the guidelines aim for a minimum of 30% of broodstock as natural origin and no more than 50% hatchery origin above the weir to spawn naturally. Logistical constraints prevent the weir from being installed prior to the return of the early part of the run in most all years. This constraint has lead to selective broodstock collection of late returning fish (Carmichael and Messmer 1995). In fact, hatchery fish return at a later time, but at an earlier age than natural origin fish, and appear to have a different spawning distribution, centered around the smolt release location (Carmichael and Messmer 1995, Hoffnagle et al. in press). In addition, hatchery-origin fish comprise a high proportion of both the broodstock (~70%) and the natural spawners.

Impact of Alternative Hatchery Practices on MPG Viability

Currently, none of the Chinook populations within the Grande Ronde/Imnaha MPG can be considered viable using the IC-TRT criteria (Interior Columbia Technical Recovery Team 2007a). Current abundance and productivity puts all of these populations at high risk, and most populations are also impaired with respect to spatial structure and/or diversity (Table 4). The Upper Grande Ronde population, for example, is currently at extremely low abundance (geometric mean spawner number = 38 for the last 10 years), with a very low recent productivity (R/S= 0.42, lambda = 1.02) and the current spawner distribution is severely restricted relative to its likely historical distribution. Failure to maintain the population with artificial propagation could result in a high probability of extinction in the relatively short term. However, a long-term supplementation program will also increase risks to natural patterns of diversity due the potential for domestication and outbreeding depression to occur.

Developing recovery strategies that are consistent with viability criteria and goals requires consideration of short-term and long-term risks to individual populations as well as the current and desired status of populations within the overall context of the Major Population Group and ESU. A recovery strategy that incorporates long-term, moderate-to-large-scale supplementation of a high proportion of the populations within an MPG cannot meet viability criteria at the Major Population Group level and thus, not at the

ESU-level. On the other hand, well-designed artificial propagation can alleviate short-term demographic risks, and the increased risk to diversity may thus be tolerable for populations with very low current abundance. In fact, the termination of a supplementation program for populations such as the Upper Grande Ronde may more greatly jeopardize the population than its continuation. However, the continuation of such a program indefinitely confers considerable ongoing risks to the population.

For those populations without extreme short-term risks of extinction, however, other considerations such as population size and potential viability status come into play. Because one population in each MPG should meet standards for "high viability", it will be important that one of the larger populations has at most a short-term supplementation program and ultimately no hatchery program and minimal strays from other populations. In the Grande Ronde, these conditions mean that there are a variety of scenarios of hatchery production or supplementation that would yield an MPG status consistent with ICTRT viability criteria, while other scenarios would not. Table 5 presents several hypothetical scenarios of artificial production within the MPG and the risk associated with each scenario (this table does not present an exhaustive description of viability or artificial propagation possibilities.) Scenarios that ensure that artificial propagation programs are isolated from other populations, and that include plans to use supplementation as a short-term measure while other actions are implemented are most consistent with TRT viability criteria. However, if the programs continue to operate under the current management strategies, six of the eight historical populations in this MPG will have relatively aggressive hatchery supplementation programs indefinitely, with only the Wenaha and Minam Rivers populations unsupplemented. Such a long-term and widespread hatchery supplementation program will make it unlikely, if not impossible, to achieve MPG viability criteria. However, there are actions, such as increasing the Proportion Natural Influence (PNI) and implementing other best management practices that can reduce the risk associated with planned artificial propagation programs, even if viability is not fully achieved (see Table 5).

CONCLUSIONS

The multiple mandates in the region – for recovery of anadromous fish; for electrical generation; for agricultural water supplies; for tribal, recreational and commercial fisheries – make the management of the Columbia River system highly complex and contentious. Artificial propagation is, at first glance, a straightforward way to meet many of these obligations simultaneously. However, there are more examples of negative effects to natural population status than there are demonstrated benefits of artificial propagation (Reisenbichler and Rubin 1999, Hindar and Fleming 2007, Waples et al. in press). With increased use of artificially produced fish (in duration or quantity), with poor management practices, or with unexpected outcomes, come increased risks to the long-term evolutionary trajectory and viability of populations, MPGs and ESUs. Because of those risks, hatchery programs are not a substitute for addressing other limiting factors that prevent achieving viability. Critical for achieving the multiple goals of viability and a natural range of ecosystem functions (e.g. harvest, nutrient transport) for salmonids are the following:

- Consideration of all the impacts of artificial propagation. These range from impacts on genetic diversity (through homogenization or domestication), mitigation of short-term extinction risk, and other effects on productivity (predation, density-dependence, etc). The uncertainties in the implementation of effects of the effort must be included in the costs and benefits of the program as well.

- Consideration of the program within the context of the viability goals at the population, MPG and ESU levels.

- Robust monitoring programs and appropriate adaptive actions in response to that monitoring.

In general, artificial propagation programs with shorter duration; minimal domestication selection; a lesser number of hatchery-origin spawners in the wild; and minimal straying of hatchery fish will lessen the risks posed by these efforts.

Populations facing very high, short-term extinction risks may merit the use of a supplementation program in spite of increased risks to diversity. Populations or ESUs like Redfish Lake sockeye, which has had fewer than 20 fish return in 14 of the last twenty years, are obvious candidates for continuing captive culture programs or supplementation to maintain the extant diversity and reduce short-term extinction risk. Even in these situations, implementation of other actions that can contribute to increased abundance and productivity, and normative diversity and spatial structure of the population and planned withdrawal of supplementation support are important elements of long-term viability.

Some supplementation programs aimed at goals other than wild population viability, such as harvest, can be compatible with IC-TRT viability criteria, if executed with forethought. In large, complex populations, there may be opportunities to isolate a supplementation or harvest augmentation program to reduce the risk that such a program would pose at the population level. However, in these populations, managers need to be specifically concerned about maintaining within-population substructure. For example, the current practice in the Wallowa-Lostine supplementation program of outplanting Lostine River hatchery adults into the Wallowa River and Bear Creek poses significant risks to maintaining within-population substructure. Populations that are currently extirpated are also good candidates for isolated artificial propagation programs because there are no initial within-population risks. The risk of a within-population harvest-oriented supplementation program in small, linear populations is much greater than the isolated programs in large populations, since an entire small population is likely to be impacted.

For an MPG to meet viability criteria, all populations not meeting viability criteria must be maintained at levels that provide appropriate ecological function and do not preclude opportunities for potential future recovery needs. Thus, populations supporting a supplementation program must also have relatively high natural abundance and productivity coupled with few additional problems in spatial structure or diversity. Generally, large, long-term hatchery programs that dominate production of a population is a high risk factor for certain viability criteria and can lead to increased risk for the population. In some cases, these programs can also result in increase in risk for the maintenance of natural production in other populations, depending on stray rates.

Initiating or continuing a supplementation program in a population could also delay when some of the viability criteria can be met. Generally, large, long-term hatchery programs that dominate production of a population is a high risk factor for certain viability criteria and can lead to increased risk for the population. In some cases, these programs can also result in increase in risk for the maintenance of natural production in other populations, depending on stray rates. Initiating or continuing a supplementation program in a population could also delay when some of the viability criteria can be met.

A final important consideration for supplementation programs is the potential out-of-population impacts from that program. The most common concern relates to straying into non-target populations and all the associated genetic and ecological risks associated with those strays. While this is illustrated in the Grande Ronde case study (above) for within-MPG straying, it is also important to consider straying from a program that affects other MPGs and ESUs. Straying is not the only potential out-of-population impact, however. Harvest management strategies that are coupled with hatchery production can increase the impact of a mixed stock ocean fishery, potentially reducing productivity and abundance of the wild population (Fraidenberg and Lincoln 1985). Artificial production is hypothesized to increase competition in a number of environments (Fresh, 1997) and may increase predation rates directly or indirectly (Sholes and Hallock 1979, Menchen 1981, Cannamella 1993) depending on hatchery practices (review in (Flagg et al. 2000)). In these cases, the benefits of that hatchery program must be weighed carefully against those impacts, and programs should not increase the risk to any other population to the degree that it cannot meet its desired status.

While hatcheries may be used to increase fish numbers in the short term, this apparent benefit may mask the effects of a threat that is unchanged or perhaps even increasing. Viability is dependent upon natural abundance and productivity. Short-term increases in abundance due to hatchery returns may not be associated with the increases in productivity that would be associated with a self-sustaining population. Unless the factors limiting abundance and productivity have been addressed, hatchery supplementation will not lead to a self-sustaining, viable population. In addition, many of the genetic risks outlined above (e.g. domestication and homogenization) become increasingly severe as the duration of hatchery programs increase. Thus, at the population level, artificial propagation programs supporting recovery must be viewed as a short-term approach to avoid imminent extinction, not a long-term strategy to achieve population viability.

There remains considerable uncertainty regarding the long-term capability of supplementation to enhance population status. A sound conservation strategy must recognize this uncertainty and provide a balance of strategies among populations within an MPG, including a significant proportion of populations that have minimal or no hatchery influence.

The region aims to achieve both viable salmon populations and thriving human economies. Artificial propagation programs both have a role to play in meeting those goals, and have the potential to pose additional risks to affected populations, MPGs and ESUs. Therefore, it is critical that their benefits and impacts in both the near and long-term be weighed carefully against goals for populations and ESUs. In addition, sufficient effort in other arenas should be made so that unnecessary programs or efforts precluding viability can be phased out.

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Table 1. Definition of artificial propagation related terms for the purposes of this paper. This table largely follows Ford and Berejikian (2004), Mobrand et al. (2005), and Araki et al. (2007) to describe the goals and management of hatchery programs.

Term	Usage in this paper
Artificial propagation	General term used to refer to all forms of human-assisted culture or production of salmonids
Broodstocks	Adult fish used in an artificial propagation program to produce progeny for release or rearing.
Local broodstock	Broodstock that is derived from the population or from an identified sub-population within the subbasin where the artificial propagation program is operated, and used only within the source area.
Captive broodstock	Broodstock that consists of fish that were reared in captivity for a substantial portion of their life cycle and are typically used to produce gametes or progeny for release.
Integrated broodstock	Broodstock used to produce progeny for artificial propagation that consists of a mixture of hatchery, natural and wild origin fish. The wild/natural origin and hatchery origin components are managed as a single population.
Segregated broodstock	Broodstock used to produce progeny for artificial propagation that are maintained in isolation from naturally-produced fish. The wild/natural origin and hatchery origin components are managed as separate populations.
Hatcheries	Any facility in which fish are artificially propagated.
Integrated hatchery	An artificial propagation program in which the wild and hatchery components are treated as a single population. The intent is for the natural environment to drive the adaptation and fitness of a composite population of fish that spawns both in a hatchery and in the wild.
Segregated hatchery	Maintains a hatchery broodstock in isolation from natural spawners (see Fig. 2 in Mobrand et al. 2005).

Term	Usage in this paper
Best hatchery management practices	Those artificial rearing practices which produce the least impact to the wild population and the captive component. This includes (but is not limited to) considerations for breeding protocols, selection of broodstock, rearing protocols, and release strategies. As the benchmarks that define "best" are specific to the goals of each program and are likely to change as additional data accumulate, we do not describe a specific set of criteria that define best. Rather, we provide some general guidelines (Cooney et al. 2007) and recommend Flagg et al. (2004), Olsen et al. (2004), and Mobrand et al. (2005) for reviews of the currently accepted "best management practices").
Hatchery Programs – Management objectives	
Conservation hatchery	An artificial propagation program aimed entirely at conservation of a population. These programs are intended to minimize demographic risks to a population, and typically try to use best hatchery management practices. A key additional purpose is often the preservation of genetic variation. A variety of techniques, including captive rearing and release can be incorporated into conservation hatcheries
Harvest Augmentation or Production hatchery	Addition of fish to a system with the sole purpose of providing additional opportunities for harvest. Typically, the focus of these facilities has been on the release of large numbers of juveniles.
Supplementation	The addition of hatchery fish to a native population to increase abundance of spawners and natural production. Harvest is often used to help regulate escapement of hatchery origin fish.
Fish Origin	
Hatchery fish	A fish produced by artificial spawning in a hatchery (Berejikian and Ford 2004).
Natural	Refers to fish that are born in natural environments (from either wild or hatchery-origin parents), or are the progeny of parents that spawned naturally.
Wild	Refers to fish that are born in natural environments of local, natural-origin fish.
Legacy Effects	Term referring to impacts of discontinued practices that are still present or observable in populations, MPGs or ESUs.

Table 2. Genetic issues potentially associated with artificial propagation management practices or outcomes of management practices.

	Domestication Selection	Outbreeding Depression	Homogenization	Reduced Effective Population Size
Persistence of a stock in a hatchery setting for multiple generations	X			
Widespread straying or intentional release of artificially propagated fish to non-local areas		X	X	
Within-hatchery breeding strategies that rely heavily on a few individuals				X
Breeding strategies that randomly breed fish from more than one population or subpopulation		X	X	
Heavy representation of artificially propagated fish on the spawning grounds	X	X	X	X
Disproportionate representation of parents in subsequent generations (due either to selection in breeding program or disproportionate presence on spawning grounds)				X
Artificial selection for a particular phenotypic characteristic (e.g. broodstock consists of primarily early-returning fish)	X	X		

Table 3. Relative demographic and diversity risk associated with alternative management strategies for the Wenatchee River spring Chinook salmon population.

	Genetic Effects on Diversity				Ecological Effects				Demographic Effects		
Option/Action	Domestication	Outbreeding Depression	Homogenization	Reduced Effective Population Size	Competition	Predation	Disease	Nutrient Enhancement	Demographic Effect	Demographic Risk	**Relative Risk and Viability Conclusions**
Leavenworth Fish Hatchery -- Current	Carson stock likely subject to high domestication effects due to long-term maintenance in hatchery	If interbreeding occurs between LFNH fish and wild Wenatchee fish, potential for outbreeding depression is substantial	Carson stock is a composite stock originally collected at Bonneville. This stock is highly homogenized. Interbreeding with wild Wenatchee fish could pose a significant risk of homogenization.	Unlikely to pose a risk to Ne for the natural Wenatchee population.	Adults that stray into spawning areas could compete for spawning habitat; potential in out-of-basin environments.	If smolts are released at very large size, potential for predation on listed juvenile salmonids.	Some risk due to intermingling in lower Wenatchee, mainstem Columbia and estuarine environments	Unlikely, due to restriction to Icicle Creek.	Out-of ESU origin, no demographic benefits for the listed population	No effect on Wenatchee demographic risk.	This program poses some risks to the Wenatchee population if apparent stray rates to the upper basin are maintained. If these are overestimated or curtailed, the population could meet viability criteria with this program in place. No benefit to population persistence would be realized.
Chiwawa River -- Current	Some risk due to use of program over multiple generations and a low proportion of natural-origin fish in the broodstock.	Some risk, as a high proportion of natural spawners are hatchery origin. Local-origin broodstock mitigates some of this risk	Significant risk since there is a high straying rate from the Chiwawa program to other spawning areas.	Some potential for reductions in Ne given the high proportion of hatchery fish present on the spawning grounds (Ryman-Laikre effect) and within hatchery strategies that rely heavily on a few individuals	Potential in all shared habitats; likely dependent on the number of juveniles released.	Potential for some increased predation (e.g. by supporting higher predator population), dependent on practices	Some risk due to intermingling in all habitats.	Potential benefit due to higher returns	Increase total abundance of fish from the Wenatchee basin; however, there is no current evidence that there is a positive response in productivity or natural origin abundance.	Reduces extinction risk substantially	This program reduces short-term extinction risk and poses some moderate risks to diversity. With this program in place as currently run, the population could not meet viability criteria. Risks could be reduced with improved culture practices.

Option/Action	Genetic Effects on Diversity: Domestication	Outbreeding Depression	Homogenization	Reduced Effective Population Size	Ecological Effects: Competition	Predation	Disease	Nutrient Enhancement	Demographic Effects: Demographic Effect	Demographic Risk	Relative Risk and Viability Conclusions
White River Captive Broodstock -- Current	Some risk due to use of program over multiple generations.	Some risk, as a high proportion of natural spawners are hatchery origin. Local-origin broodstock mitigates some of this risk	Maintains potentially differentiated White River sub-group	Some potential for reductions in Ne given the high proportion of hatchery fish present on the spawning grounds (Ryman-Laikre effect)	Potential in all shared habitats; likely dependent on the number of juveniles released.	Potential for some increased predation (e.g. by supporting higher predator population), dependent on practices	Some risk due to intermingling in all habitats.	Potential benefit due to higher returns	Increase total abundance of fish from the White River.	Reduces extinction risk for the White River component.	This program is particularly beneficial if the differentiation apparent in the White River sub-group from 1980s allozyme samples is still present. Maintaining this diversity is important to overall population structure. The program also reduces extinction risk for the White River sub-group.
1. Planned programs, current trajectory -- - adult based supplementation with adult collection facilities (weir, fish wheel, other) located below natural spawning reaches and juvenile acclimation/release located adjacent to spawning/rearing habitat in the White River, Chiwawa River, and Nason Creek. Assume that actions to reduce Chiwawa River strays are effective. Assume that smolt release numbers and proportion of hatchery fish on the spawning grounds remains high based on mitigation agreements.	Some risk due to use of program over multiple generations and a low proportion of natural-origin fish in the broodstock.	Relatively high risk due to a high proportion of natural spawners of hatchery origin.	If unnatural straying is reduced to minimal levels, homogenization is not a great concern. This program, incorporating the White River captive brood program, also maintains the potentially differentiated White River sub-group	Some potential for reductions in Ne given the high proportion of hatchery fish present on the spawning grounds (Ryman-Laikre effect) and within hatchery strategies that rely heavily on a few individuals	Potential adult competition for limited pre-spawn holding habitat in high abundance years	Potential for some increased predation (e.g. by supporting higher predator population), dependent on practices	Some risk due to intermingling in all habitats.	Potential benefit due to higher returns	Increase total abundance of fish from the Wenatchee basin; however, there is no current evidence that there is a positive response in productivity or natural origin abundance.	Reduces extinction risk substantially	This program reduces short-term extinction risk. It does have some risks to diversity, but reduced in comparison with the current operations due to the implementation of improved culture practices. While the same magnitude of smolt releases and hatchery-origin spawners on the spawning grounds are maintained, viability criteria cannot be achieved; these risks can be reduced with gradual reduction in these proportions.
2. Current planned programs, but acclimate White River juveniles near the mouth or in net pens in Lake Wenatchee. Capture broodstock from returns to the Lower White River. Given the short distance between the mouths of the White and Little Wenatchee, this option would likely result in more	Some risk due to use of program over multiple generations and a low proportion of natural-origin fish in the broodstock.	Some risk due to a high proportion of natural spawners of hatchery origin.	Some risk due to likely straying from the White River program to non-target spawning areas	Some potential for reductions in Ne given the high proportion of hatchery fish present on the spawning grounds (Ryman-Laikre effect) and within hatchery strategies that rely heavily on a few individuals	Potential adult competition for limited pre-spawn holding habitat in high abundance years; possibly less for the White River than in the currently planned program	Potential for some increased predation (e.g. by supporting higher predator population), dependent on practices	Some risk due to intermingling in all habitats.	Potential benefit due to higher returns; possibly less in the White River due to possible dispersal of these fish across additional spawning areas.	Increase total abundance of fish from the Wenatchee basin; however, there is no current evidence that there is a positive response in productivity	Reduces extinction risk substantially	This program reduces short-term extinction risk. It does have some risks to diversity, but reduced in comparison with the current operations due to the implementation of improved culture practices. While the same magnitude of smolt releases and hatchery-origin spawners on the spawning grounds are maintained, viability criteria cannot be achieved; these risks can be reduced with gradual reduction in these proportions.

Option/Action	Genetic Effects on Diversity: Domestication	Outbreeding Depression	Homogenization	Reduced Effective Population Size	Ecological Effects: Competition	Predation	Disease	Nutrient Enhancement	Demographic Effects: Demographic Effect	Demographic Risk	Relative Risk and Viability Conclusions
intermingling of adults from both tributaries in hatchery broodstock collections and on the spawning grounds.									or natural origin abundance.		
3. Concentrate supplementation efforts on the spawning areas below Lake Wenatchee, cease artificial propagation in spawning areas above Lake Wenatchee. Assume that natural production would be restored based on returns from current spawning levels and minimal strays from other MaSAs. Assume that actions to reduce Chiwawa River strays are effective. Assume that smolt release numbers and proportion of hatchery fish on the spawning grounds remains high based on mitigation agreements.	Some risk due to use of program over multiple generations and a low proportion of natural-origin fish in the broodstock.	Some risk due to a high proportion of natural spawners of hatchery origin.	Some risk of losing any potential genetic diversity in the White River sub-group if natural returns are not sufficient to maintain this group.	Some potential for reductions in Ne given the high proportion of hatchery fish present on the spawning grounds (Ryman-Laikre effect) and within hatchery strategies that rely heavily on a few individuals	Competition for pre-spawn holding habitat likely lessened with fewer fish destined for upper tributaries	Potential for some increased predation (e.g. by supporting higher predator population), dependent on practices	Some risk due to intermingling in all habitats; risk to upper tributaries may be somewhat less without intermingling in tributary habitat.	Potential benefit due to higher returns; benefits would not be felt in tributaries above Lake Wenatchee.	Increase total abundance of fish from the Wenatchee basin; however, there is no current evidence that there is a positive response in productivity or natural origin abundance.	Reduces extinction risk for the Wenatchee population, but increases risk of extinction for the White River sub-group.	This program reduces short-term extinction risk for the Wenatchee population, but increases the risk for the White River sub-group. Since the White River has some apparent genetic differentiation, its extinction would increase the diversity risk as well. With the magnitude of smolt releases and hatchery-origin spawners on the spawning grounds are maintained, viability criteria cannot be achieved; these risks can be reduced with gradual reduction in these proportions.
4. Collection of broodstock at Tumwater Dam and manage all areas upstream of Tumwater Dam as a single composite stock suitable for release in any area above Tumwater Dam. Some	Some risk due to use of program over multiple generations and a low proportion of natural-origin fish in the broodstock.	Higher risk due to homogenization and loss of any population substructure	Very high risk of homogenization within the population due to intentional interbreeding of spawners from sub-areas and widespread release of	Some potential for reductions in Ne given the high proportion of hatchery fish present on the spawning grounds (Ryman-Laikre effect) and	Potential adult competition for limited pre-spawn holding habitat in high abundance years	Potential for some increased predation (e.g. by supporting higher predator population), dependent	Some risk due to intermingling in all habitats.	Potential benefit due to higher returns; benefits may be lower due to likely production of fish with lower homing	Increase total abundance of fish from the Wenatchee basin; however, there is no current	Reduces short term extinction risk for the Wenatchee population in years of extremely low abundance.	This strategy reduces demographic extinction risk, but increases diversity risk substantially. Apparent differentiation in the White River sub-group would likely be lost and natural patterns of gene flow (and thus local adaptation) would not be expressed. Viability criteria for diversity could not be achieved through the duration of

Option/Action	Genetic Effects on Diversity				Ecological Effects				Demographic Effects		Relative Risk and Viability Conclusions
	Domestication	Outbreeding Depression	Homogenization	Reduced Effective Population Size	Competition	Predation	Disease	Nutrient Enhancement	Demographic Effect	Demographic Risk	
managers have argued for using this strategy given the difficulty of obtaining broodstock for separate production areas and the collateral impacts collection and acclimation facilities would have in natural production areas. Assume that smolt release numbers and proportion of hatchery fish on the spawning grounds remains high based on mitigation agreements.			progeny across spawning grounds.	within hatchery strategies that rely heavily on a few individuals		on practices		fidelity.	evidence that there is a positive response in productivity or natural origin abundance. Potential for greater relative impact in lower abundance years due to greater likelihood of full-scale program.		this program.
<u>5. Supplementation program with phased reduction in smolt release numbers and proportion of hatchery-origin natural spawners; isolated production program at LNFH.</u> This program is not currently proposed. It assumes best management practices for supplementation programs in the Chiwawa, White and Nason Creeks, including the reduction of releases and the proportion of hatchery-origin spawners as natural productivity increases. It also assumes a production program in Icicle Creek with little or no straying to up-river areas.	Some risk due to use of program over multiple generations. Risks due to low proportion of natural-origin fish in the broodstock would be reduced through time.	Some risk due to initial high proportion of natural-origin fish on the spawning grounds, but reduced through time.	Relatively low, if population sub-structure is maintained in the artificial propagation program.	Some potential for reductions in Ne that would be reduced through time.	Potential adult competition for limited pre-spawn holding habitat in high abundance years	Potential for some short-term increased predation (e.g. by supporting higher predator population), dependent on practices	Some risk due to intermingling in all habitats, but reduced through time.	Potential benefit due to higher returns	Increase total abundance of fish from the Wenatchee basin; however, there is no current evidence that there is a positive response in productivity or natural origin abundance.	Reduces extinction risk for the Wenatchee population.	This strategy reduces demographic extinction risk while maintaining likely population sub-structure. Its impacts to diversity would be relatively short-lived. The population could meet viability criteria with this strategy, but substantial increases in current abundance and productivity would be required to preclude a significant extinction risk.

	Genetic Effects on Diversity				Ecological Effects				Demographic Effects		
Option/Action	Domestication	Outbreeding Depression	Homogenization	Reduced Effective Population Size	Competition	Predation	Disease	Nutrient Enhancement	Demographic Effect	Demographic Risk	**Relative Risk and Viability Conclusions**
6. Elimination of all artificial propagation programs in the Wenatchee River. This option is not currently proposed. It assumes that no artificial propagation programs would be in place for any portion of the Wenatchee population.	None	None	Moderate risk of loss of the White River sub-group.	Relatively high risk of reduced Ne if the Wenatchee population decreases in abundance in response to ceasing artificial propagation.	None	Potential for a short-term increase in predation if current artificial propagation programs have been sustaining relatively high predator levels.	None	Potential loss of nutrients with fewer adults returning to tributaries.	Likely reduction in total abundance of Wenatchee population and all component spawning areas.	Increases extinction risk for the Wenatchee population.	This strategy decreases diversity risks associated with artificial propagation while increasing demographic risk. This increased extinction risk is large enough that it also brings with it the likelihood of reduced effective population size. The population could meet viability criteria with this strategy, but substantial increases in current abundance and productivity would be required to preclude a significant extinction risk.

Table 4. Grande Ronde/Imnaha populations, their current status, and factors leading to the SS/D risk rating.

Population	*Risk Ratings*			*Factors leading to the SSD risk rating*
	A/P	*SSD*	*Composite*	
Wallowa/Lostine	High	Moderate	High	Goal B: Loss of late spawning adults (Oct spawners), high spawner comp risk due to past out-of-ESU strays, and recent high fraction of local origin hatchery fish
Upper GR	High	High	High	Goal A: Metrics for number and arrangement of spawning areas, range of pop, and changes in gaps/continuity were rated High Risk. Goal B: impairment for all Goal B metrics. Genetic variation and out-of-ESU hatchery strays likely to improve over time (improved broodstock management).
Catherine	High	Moderate	High	Goal A: Metrics for number/arrangement of spawning areas, range of pop, and changes in gaps/continuity rated at Mod Risk. Goal B: rated Mod Risk due to loss in life history, reduced phenotypic variation, genetic variation, past effects of out-of-ESU hatchery strays (likely to improve because of improved broodstocking).
Imnaha	High	Moderate	High	Goal B: metrics for genetic variation (low within-pop interannual variation), spawner comp (long-term high natural spawner hatchery fraction of Imnaha hatchery fish), and hatchery selective change (selective natural of broodstock collection) were the primary drivers of Goal Bs Mod Risk rating.
Lookingglass Creek	NA	NA	High	Functionally extirpated (Access has been blocked to upstream reaches; Rapid River broodstock propagated heavily in the area for many years.)
Big Sheep Creek	NA	NA	High	Functionally extirpated. (Big Sheep Creek and Imnaha are currently managed as a single unit in an integrated hatchery program. Returns in recent years to Big Sheep Creek have been extremely low.)

Population	*Risk Ratings*			*Factors leading to the SSD risk rating*
	A/P	*SSD*	*Composite*	
Minam	High	Moderate	High	Goal B: driven by 2 metrics: genetic variation (similarity with out-of-ESU hatchery fish used in the LSRCP program from the late 1970s to the mid 1990s), and spawner composition (strays from the program comprised a high prop of spawners in the Minam). Risk ratings for both metrics are likely to improve since out-of-ESU hatchery fish are no longer released into the GR basin.
Wenaha	High	Moderate	High	Goal B: driven by genetic variation (similarity with out-of-ESU hatch fish from LSRCP), spawner comp (high prop hatchery fish from LSRCP), and hydro selective mortality. Ratings for genetic variation and spawner comp are likely to improve since out-of-ESU hatchery fish are no longer released into the GR basin.

Table 5. Example artificial propagation strategies for the Grande Ronde/Imnaha Major Population group. The cells describe population-specific programs for each strategy. Two asterisks indicate that the population could meet population-level spatial structure and diversity criteria for viability with this program, dependent on its total influence (time frame unspecified). One asterisk indicates that the population would likely meet spatial structure and diversity criteria to be classified as "maintained." These consider ONLY the artificial propagation impacts within the population; other criteria would have to be met as well, such as levels of within-MPG strays from other populations. The strategies described here are as follows: "Currently Planned" – outlines the current artificial propagation strategy in the Grande Ronde/Imnaha MPG; "Improvement .. to Best Management Practices" – outlines some program changes to the current program that would more closely align it with BMP, and consequently reduce the risk to the MPG as a whole, though viability would likely not be achieved; "Short-term Conservation or Long-Term Supplementation/Harvest Augmentation with BMP in Selected Populations" – describes a scenario in which some populations within the MPG are managed with short-term supplementation to help recover the population, some are managed using long-term supplementation to maintain the populations and contribute to harvest, and some populations are managed using BMP to achieve viability; "Short-term Conservation or Long-Term Supplementation with BMP" – is similar to the previous scenario but does not include provisions for hatchery augmentation in the Lookingglass and Big Sheep populations and all long-term supplementation programs include BMP.

Population	**Size and Life History**	**Hatchery Strategies**			
		Currently Planned	**Improvement in Current Program, Closer to Best Management Practices**	**Short-term Conservation or Long-Term Supplementation/Harvest Augmentation with BMP in Selected Populations**	**Short-term Conservation or Long-Term Supplementation with BMP**
Wenaha	Intermediate; Spring	None **	None **	None **	None **
Minam	Intermediate Spring	None **	None **	None **	None **
Wallowa/ Lostine	Large Spring	Indefinite integrated supplementation*	Indefinite supplementation with local broodstock *	Short-term supplementation with local broodstock; phased out after 3-5 generations. **	Short-term supplementation with local broodstock; phased out after 3-5 generations.**

Population	Size and Life History	Hatchery Strategies			
		Currently Planned	**Improvement in Current Program, Closer to Best Management Practices**	**Short-term Conservation or Long-Term Supplementation/Harvest Augmentation with BMP in Selected Populations**	**Short-term Conservation or Long-Term Supplementation with BMP**
Lookingglass	Basic; Spring (Functionally extirpated)	Reintroduction, using neighboring stock underway; indefinite supplementation	Indefinite supplementation and harvest augmentation using locally-derived broodstock to the extent possible program that produces minimal strays	Indefinite integrated supplementation and harvest augmentation program	Indefinite integrated supplementation with BMP
Catherine	Large Spring	Indefinite integrated supplementation*	Indefinite integrated supplementation reformed to have an improved PNI *	Short-term supplementation with local broodstock, phased out after 3-5 generations. **	Short-term supplementation with local broodstock; phased out after 3-5 generations.**
Upper GR	Large Spring	Indefinite integrated supplementation*	Indefinite integrated supplementation reformed to have an improved PNI *	Indefinite integrated supplementation reformed to have an improved PNI *	Indefinite supplementation isolated in a MaSA with BMP
Imnaha	Intermediate Spring/Summer	Indefinite integrated supplementation*	Indefinite integrated supplementation reformed to have an improved PNI *	Integrated supplementation phased out as other recovery actions increase OR long-term supplementation using BMP and harvest to maintain high PNI **	Integrated supplementation phased out as other recovery actions improve population status**
Big Sheep	Basic; Spring (Functionally extirpated)	Indefinite integrated reintroduction/ supplementation program. This area treated as part of the Imnaha population.	Discontinue use of Imnaha-origin fish; indefinite integrated supplementation with local broodstock	Indefinite integrated supplementation and harvest augmentation program	Indefinite integrated supplementation with BMP

Population	Size and Life History	Hatchery Strategies			
		Currently Planned	Improvement in Current Program, Closer to Best Management Practices	Short-term Conservation or Long-Term Supplementation/Harvest Augmentation with BMP in Selected Populations	Short-term Conservation or Long-Term Supplementation with BMP
MPG Viability Conclusions		**NOT VIABLE**	**NOT VIABLE**	**Potentially VIABLE if other criteria are met (e.g., 1 unsupplemented population at high viability)**	**Potentially VIABLE if other criteria are met (e.g., 1 unsupplemented population at high viability)**
Relative Risk (compared to Current Program)		**Same**	**Lower**	**Much Lower**	**Lowest**

FIGURE LEGENDS

Figure 1. Risk criteria associated with spawner composition for viability assessment of exogenous spawners on maintaining natural patterns of gene flow. Green (darkest) areas indicate low risk combinations of duration and proportion of spawners, blue (intermediate areas) indicate moderate risk areas and white areas and areas outside the graphed range indicate high risk. Exogenous fish are considered to be all fish hatchery origin, and non-normative strays of natural origin.

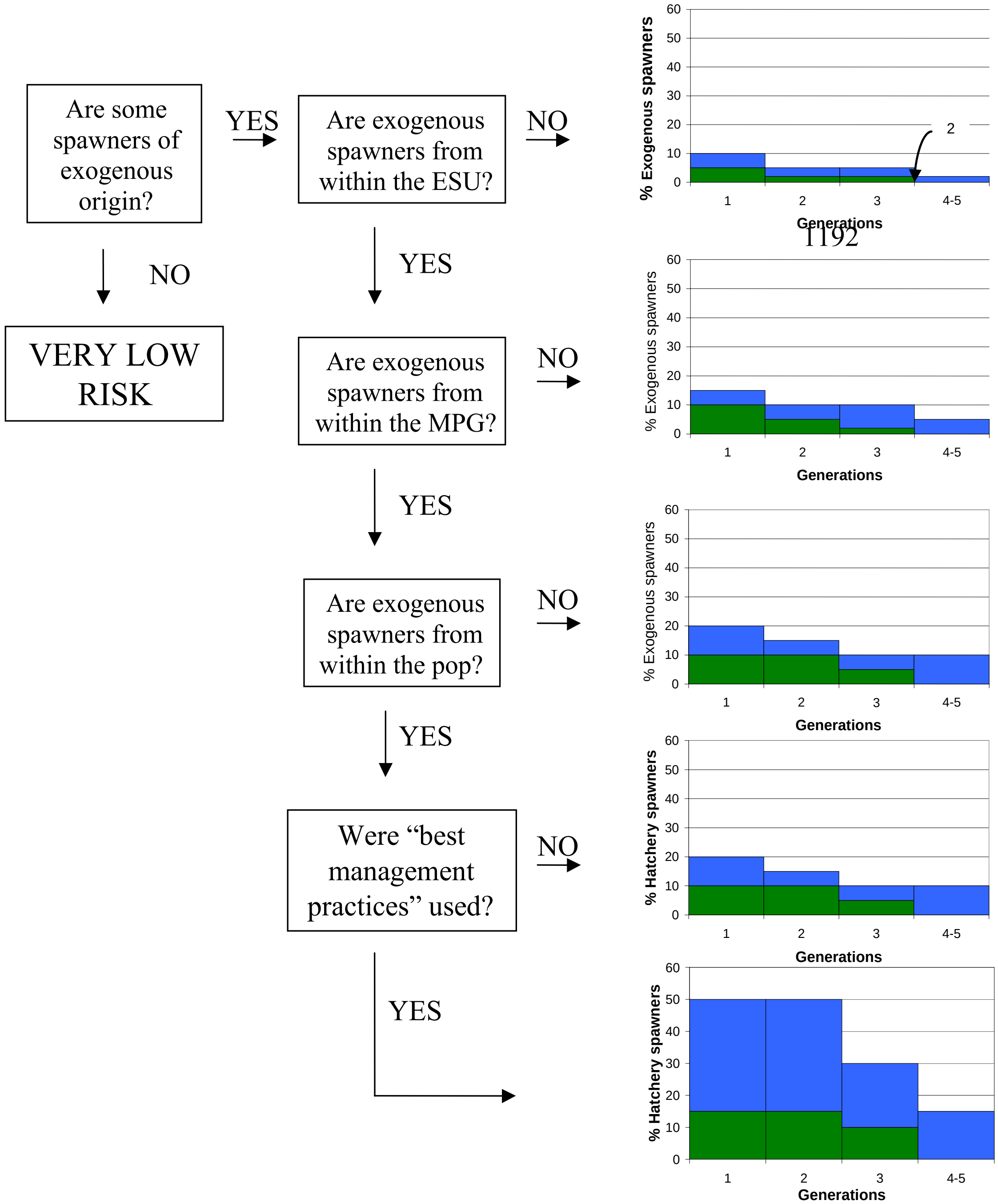
Figure 2. Population risk rating matrix, showing how A/P and SS/D risk levels are integrated. HV – Highly Viable; V – Viable; M* – Candidate for Maintained; Shaded cells-- not meeting viability criteria (darkest cells are at greatest risk).

Figure 3. Wenatchee River drainage, showing Major and Minor Spawning Areas.

Figure 4. Dendrograms based on Fst values and principle components plots for three data sets including multiple sites within the Wenatchee River. A, B: Allozyme data (WDFW); C, D: Microsatellite data (Moran and Waples, 2004); E,F: Microsatellite data (Murdoch et al. 2007). All analyses conducted by the IC-TRT. Note the relative position of the White River in each figure.

Figure 5. Grande Ronde-Imnaha Major Population Group showing all populations.

Figure 6. Dendrogram (a) and principle component plot (b) of genetic samples within the Snake River spring/summer Chinook salmon ESU.



Are some spawners of exogenous origin?
YES
NO
VERY LOW RISK
Are exogenous spawners from within the ESU?
NO
YES
Are exogenous spawners from within the MPG?
NO
YES
Are exogenous spawners from within the pop?
NO
YES
Were "best management practices" used?
NO
YES
% Exogenous spawners
Generations
2
% Exogenous spawners
Generations
% Exogenous spawners
Generations
% Hatchery spawners
Generations
% Hatchery spawners
Generations

Figure 1

1226

		Spatial Structure/Diversity Risk			
		Very Low	**Low**	**Moderate**	**High**
Abundance/ Productivity Risk	**Very Low** (<1%)	**HV**	**HV**	**V**	M*
	Low (1-5%)	**V**	**V**	**V**	M*
	Moderate (6 – 25%)	M*	M*	M*	
	High (>25%)				

Figure 2

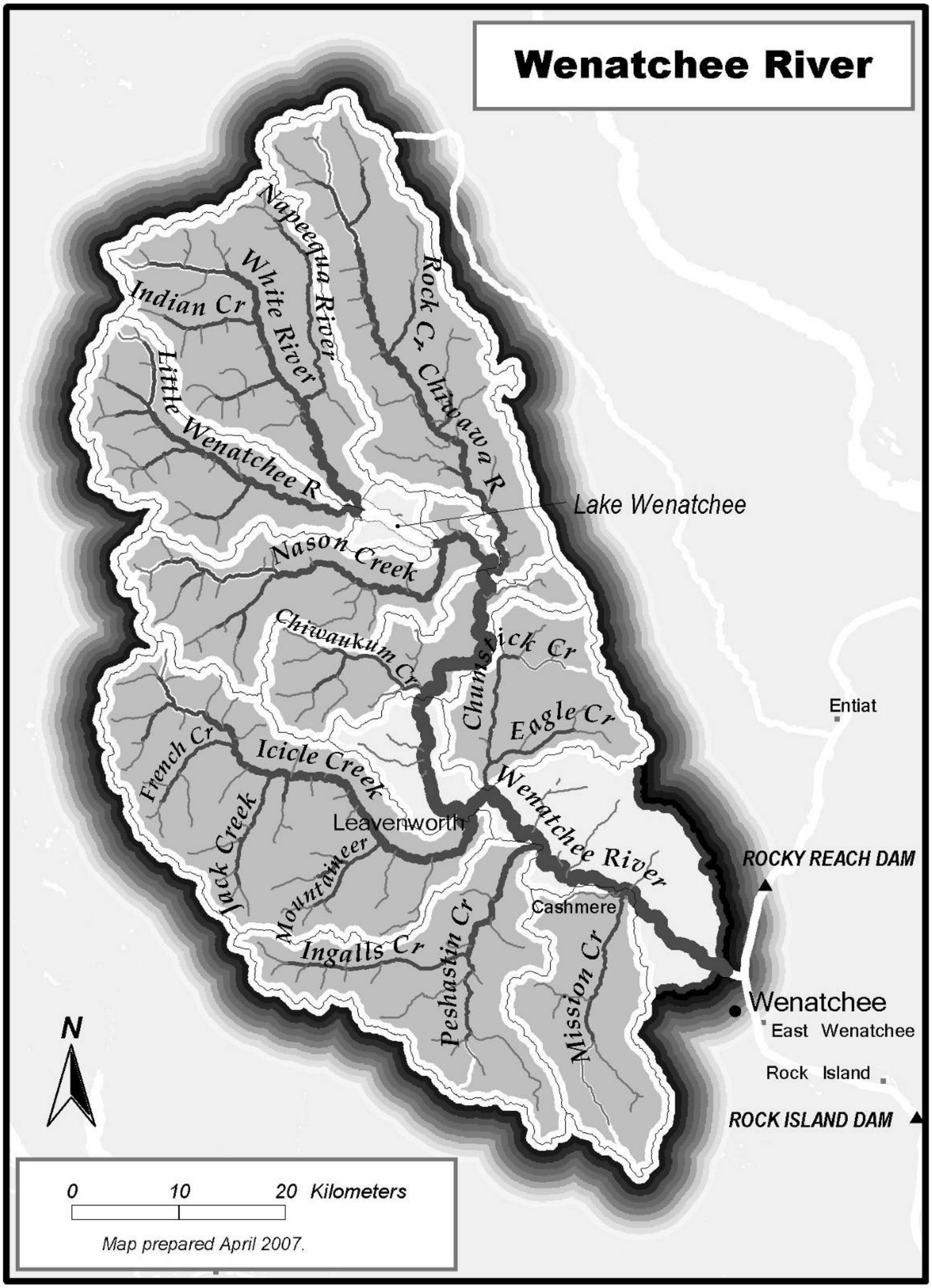

Wenatchee River
Napeequa River
White River
Rock Cr
Chiwawa R
Indian Cr
Little Wenatchee R
Lake Wenatchee
Nason Creek
Chiwaukum Cr
Chumstick Cr
Eagle Cr
French Cr
Icicle Creek
Jack Creek
Leavenworth
Mountaineer
Wenatchee River
Ingalls Cr
Peshastin Cr
Cashmere
Mission Cr
Entiat
ROCKY REACH DAM
Wenatchee
East Wenatchee
Rock Island
ROCK ISLAND DAM
N
0
10
20 Kilometers
Map prepared April 2007.

Figure 3

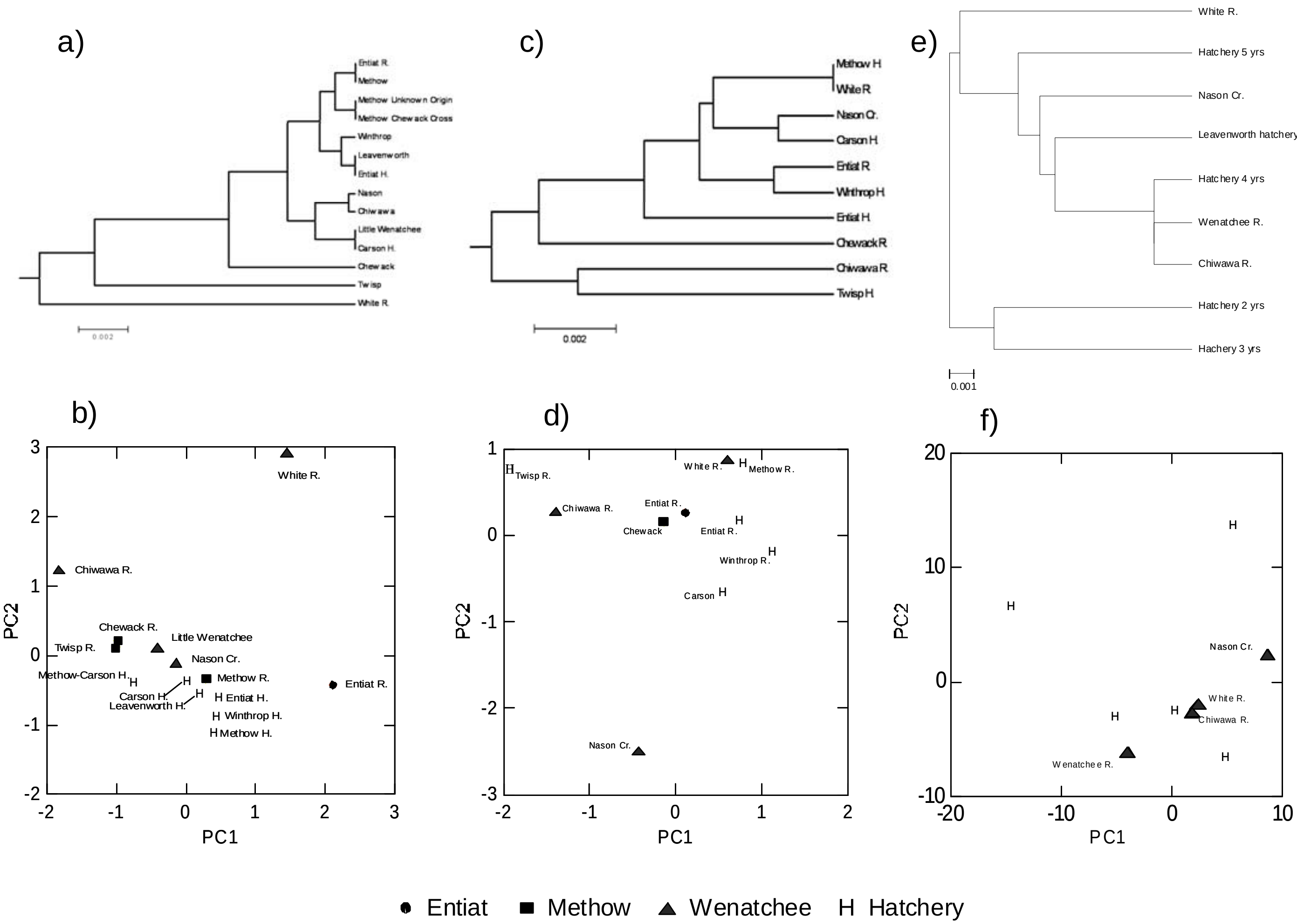

a)
Entiat R.
Methow
Methow Unknown Origin
Methow Chewack Cross
Winthrop
Leavenworth
Entiat H.
Nason
Chiwawa
Little Wenatchee
Carson H.
Chewack
Twisp
White R.
0.002
c)
Methow H
White R
Nason Cr.
Carson H.
Entiat R
Winthrop H
Entiat H
Chewack R
Chiwawa R
Twisp H
0.002
e)
White R.
Hatchery 5 yrs
Nason Cr.
Leavenworth hatchery
Hatchery 4 yrs
Wenatchee R.
Chiwawa R.
Hatchery 2 yrs
Hachery 3 yrs
0.001
b)
White R.
Chiwawa R.
Chewack R.
Twisp R.
Little Wenatchee
Nason Cr.
Methow-Carson H.
Methow R.
Entiat R.
Carson H.
Leavenworth H.
Entiat H.
Winthrop H.
Methow H.
PC1
PC2
d)
Twisp R.
White R.
Methow R.
Chiwawa R.
Entiat R.
Chewack
Entiat R.
Winthrop R.
Carson
Nason Cr.
PC1
PC2
f)
Nason Cr.
White R.
Chiwawa R.
Wenatchee R.
PC1
PC2
Entiat
Methow
Wenatchee
H Hatchery

Figure 4

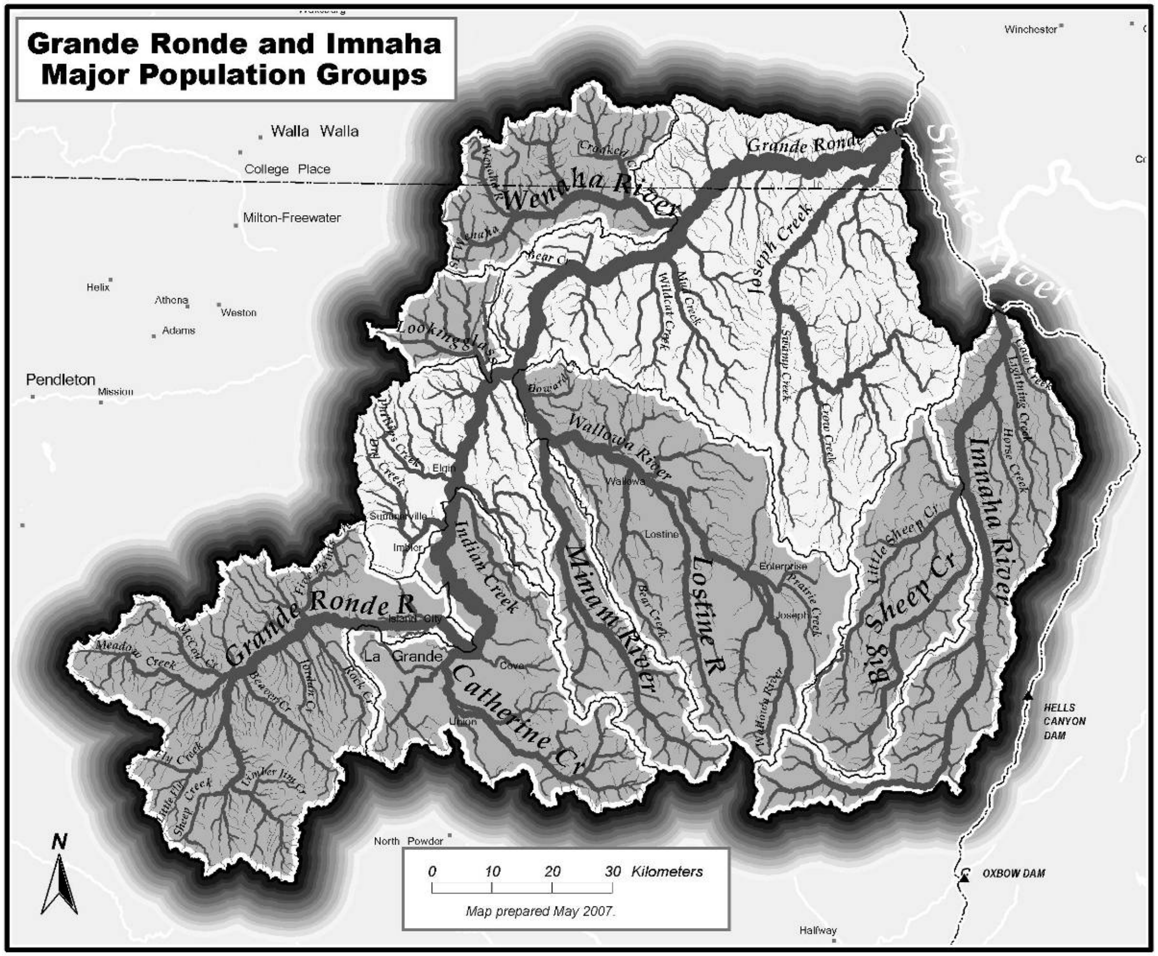
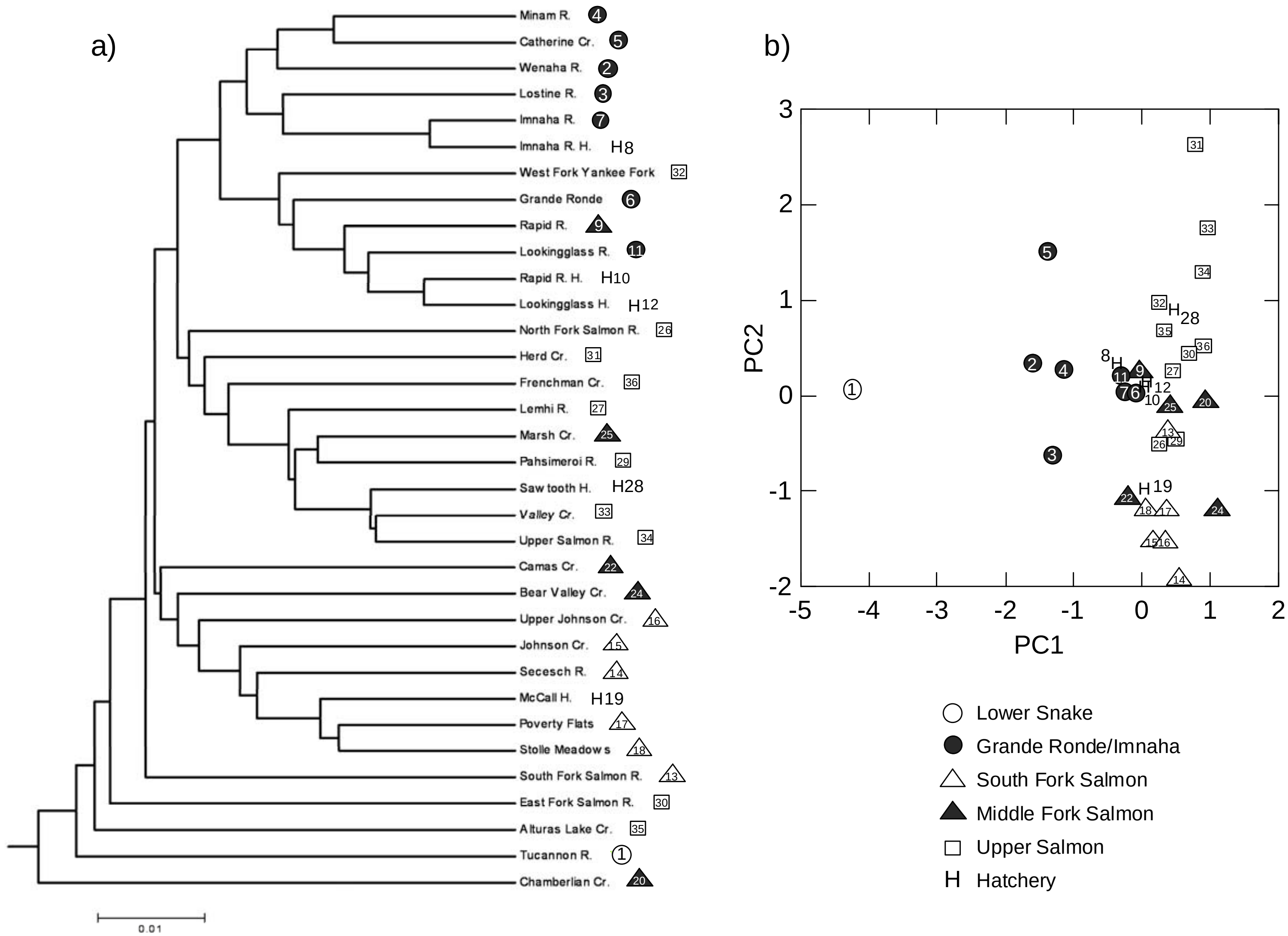

Grande Ronde and Imnaha
Major Population Groups
Walla Walla
College Place
Milton-Freewater
Helix
Athena
Weston
Adams
Pendleton
Mission
Winchester
Wenaha River
Grande Ronde
Snake River
Joseph Creek
Wildcat Creek
Swamp Creek
Crow Creek
Lookingglass
Wallowa River
Wallowa
Elgin
Summerville
Imbler
Indian Creek
Minam River
Lostine R
Lostine
Enterprise
Joseph
Prairie Creek
Bear Creek
Big Sheep Cr
Little Sheep Cr
Imnaha River
Horse Creek
Grande Ronde R
Island City
La Grande
Cove
Union
Catherine Cr
Meadow Creek
McCoy Cr
Beaver Cr
Rock Cr
Sheep Creek
HELLS
CANYON
DAM
OXBOW DAM
North Powder
Halfway
N
0 10 20 30 Kilometers
Map prepared May 2007.

Figure 5



a)
Minam R.
Catherine Cr.
Wenaha R.
Lostine R.
Imnaha R.
Imnaha R. H.
West Fork Yankee Fork
Grande Ronde
Rapid R.
Lookingglass R.
Rapid R. H.
Lookingglass H.
North Fork Salmon R.
Herd Cr.
Frenchman Cr.
Lemhi R.
Marsh Cr.
Pahsimeroi R.
Saw tooth H.
Valley Cr.
Upper Salmon R.
Camas Cr.
Bear Valley Cr.
Upper Johnson Cr.
Johnson Cr.
Secesch R.
McCall H.
Poverty Flats
Stolle Meadow s
South Fork Salmon R.
East Fork Salmon R.
Alturas Lake Cr.
Tucannon R.
Chamberlian Cr.
0.01
b)
PC1
PC2
Lower Snake
Grande Ronde/Imnaha
South Fork Salmon
Middle Fork Salmon
Upper Salmon
Hatchery

Figure 6