Effects of Hatchery Programs on Salmon and Steelhead Populations: Reference Document for NMFS ESA Hatchery Consultations

NMFS Northwest Regional Office

Salmon Management Division

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Introduction

This document describes the various effects of hatchery programs on salmon and steelhead populations, and summarizes pertinent scientific literature and other documents addressing them. It is intended to be a reference document both for NMFS staffers conducting effects analysis, and for readers of biological opinions interested in the outcome of the effects analysis. It is a living document. The intent is to update from periodic searches of the scientific literature and from information brought to our attention by reviewers of this document. Additionally, we intend to expand its scope to include details on methodology on system evaluation of hatchery programs as they are developed.

Because the ultimate job of the consultation biologist is to determine if approving a hatchery program constitutes jeopardy, hatchery consultations to a large degree deal with risk. Thus this document to a large extent deals with risk. The *Biological Opinion on Artificial Propagation in the Columbia River* (NMFS 1999a), the *Biological Opinion on Effects of the Upper Columbia River Spring Chinook Salmon Supplementation Program and Associated Scientific Research and Monitoring Conducted by the Washington Department of Fish and Wildlife and the U.S. Fish and Wildlife Service* (NMFS 2002a), *Biological Opinion on Artificial Propagation in the Hood Canal and Eastern Strait of Juan de Fuca Regions of Washington State* (NMFS 2002b), and the *Biological Opinion on Artificial Propagation of non-listed species in the Upper Columbia River region of Washington State* (NMFS 2003), identify multiple general types of potential adverse effects of hatchery operations and production on population viability. NMFS acknowledges that in evaluating hatchery actions that benefits as well as risks need to be considered (NMFS 2008), and that the discussion of hatchery benefits in the past has been inadequate. Therefore as recommended in NMFS (2008), this document will also include discussion of benefits. A benefits section does not appear in this version, but is currently under development and will appear in subsequent versions.

In this document, we have revised that basic list of 11 impact/risk categories that was used in earlier documents, reorganizing the risks into six major categories:

1) Facility effects
2) Fish removal
3) Genetics
4) Ecological interactions

5) Harvest
6) Monitoring and evaluation.

Most of these elements include subcategories, for a total of 17. All the previously existing impacts/risks are included in the new system, and there are some new subcategories. Specifically, facility risk now includes a structures subcategory, and monitoring includes subcategories on methodology, adequacy, and adaptive management.

Risks/Impacts

1. Facility effects- Risks/impacts arising from the physical existence and basic operation of the hatchery, including specific fish culture impacts. There are three subcategories: general facility failure, water intake, effluent, and structures.

A. *General facility failure*- Risks/impacts to fish in hatchery and in the wild as a result of electrical failure, flooding, fire, etc. This risk is of particular concern when facilities rear listed species, but must be addressed to ensure meeting program goals and objectives. Factors such as flow reductions, flooding and poor fish culture practices may all cause hatchery facility failure or the catastrophic loss of fish under propagation. The following measures are considered important in reducing the risk of catastrophic loss resulting from propagation facility failures:

- Minimizing the time adult fish are held in traps.
- Minimizing hatchery facility failure through on-site residence by hatchery personnel to allow rapid response to power or facility failures.
- Using low pressure/low water level alarms for water supplies to notify personnel of water emergencies.
- Installing back-up generators to respond to power loss.
- Training all hatchery personnel in standard fish propagation and fish health maintenance methods.

B. *Water intake*- Risks/impacts to environment from water withdrawal and to fish in stream from impingement on intake screens. Water withdrawals for hatcheries within spawning and rearing areas can diminish stream flow, impeding migration and affecting the spawning behavior of listed fish. Water withdrawals may also affect other stream-dwelling organisms that serve as food for juvenile salmonids by reducing habitat and through displacement, and physical injury. Hatchery intakes must be screened to prevent fish injury from impingement or permanent removal from streams. To prevent these outcomes, water rights issued for regional hatcheries are conditioned to prevent salmon migration, rearing, or spawning areas from becoming de-watered. Hatcheries can also be designed to be non-consumptive. That is, water used in the facility can be returned near the point where it was withdrawn to minimize effects on naturally produced fish and other aquatic fauna. The risks associated with water withdrawals can generally be minimized by complying with water right permits and meeting NMFS screening criteria (NMFS

1995a; NMFS 1996; NMFS 2004). These screening criteria for water withdrawal devices set forth conservative standards that help minimize the risk of harming naturally produced salmonids and other aquatic fauna. These risks can also be reduced through the use of well water sources for the operation of all or portion of the facility production.

C. *Effluent discharge*- Risks/impacts to fish in streams environment from water quality changes caused by effluent discharges. Effluent discharges can change water temperature, pH, suspended solids, ammonia, organic nitrogen, total phosphorus, and chemical oxygen demand in the receiving stream's mixing zone (Kendra 1991). It is usually not known how a hatchery's effluent affects listed salmonids and other stream-dwelling organisms. The level of impact depends on the amount of discharge and the flow volume of the receiving stream. Any adverse impacts probably occur at the immediate point of discharge, because effluent dilutes rapidly. The Clean Water Act requires hatcheries (i.e. "aquatic animal production facilities") with annual production greater than 20,000 lbs to obtain a National Pollutant Discharge Elimination System (NPDES) permit in order to discharge hatchery effluent to surface waters. These permits are intended to protect aquatic life and public health and ensure that every facility treats its wastewater. The impacts from the releases are analyzed, and the permit sets site-specific discharge limits and monitoring and reporting requirements for the permits and is subject to enforcement actions (EPA 1999). In addition, hatcheries in the Columbia River Basin operate under the policies and guidelines developed by the Integrated Hatchery Operations Team (IHOT 1995) to reduce hatchery impacts on listed fish. Impacts on listed salmon and steelhead are effectively minimized by having the program facilities maintain NPDES permits for discharge of hatchery effluent, and by meeting IHOT guidelines.

D. *Structures*- Risks/impacts to physical stream environment from physical existence of hatchery structures and fish movement blockages caused by structures.

2. Fish removal- Risks/impacts to the target population and non target population caused by removal of fish for culture, usually adults for broodstock but can be juveniles or eggs. Broodstock collection can affect listed salmonids through the method of collection and by the removal of adults from the spawning population.

A. *Collection*- Injury and death to target and nontarget populations caused by collection of fish for the hatchery program (usually but not always adults). There are a number of methods for collecting salmonid broodstock: taking volunteers returning to the hatchery, using a weir or a fish ladder-trap combination associated with a barrier, such as a dam. These devices are employed to effectively block upstream migration and force returning adult fish to enter a trap and holding area. Trapped fish are counted and either retained for use in the hatchery or released to spawn naturally. The physical presence of a weir or trap can affect salmonids by:

- Delaying upstream migration;

- Causing the fish to reject the weir or fishway structure, thus inducing spawning downstream of the trap (displaced spawning);
- Contributing to fallback of fish that have passed above the weir; and
- Injuring or killing fish when they attempt to jump the barrier (Hevlin and Rainey 1993, Spence *et al.* 1996).
- Effect the spatial distribution of juvenile salmon and steelhead seeking preferred habitats.

Impacts associated with operating a weir or trap include:

- Physically harming the fish during their capture and retention whether in the fish holding area within a weir or trap, or by the snagging, netting or seining methods used for certain programs;
- Harming fish by holding them for long durations;
- Physically harming fish during handling; and
- Increasing their susceptibility to displacement downstream and predation, during the recovery period.

The proper design and operation of the weirs and traps can reduce many of their potential negative impacts (see Hevlin and Rainey 1993; NMFS 2004). The installation and operation of weirs and traps are very dependent on water conditions at the trap site. High flows can delay the installation of a weir or make a trap inoperable. A weir or trap is usually operated in one of two modes. Continuously – where up to 100 percent of the run is collected and those fish not needed for broodstock are released upstream to spawn naturally, or periodically – where the weir is operated for a number of days each week to collect broodstock and otherwise left opened to provide fish unimpeded passage for the rest of the week. The mode of operation is established during the development of site-based broodstock collection protocols and can be adjusted based on in-season escapement estimates and environmental factors.

The potential impacts of weir rejection, fallback and injury from the operation of a weir or trap can be minimized by allowing unimpeded passage for a period each week. Trained hatchery personnel can reduce the impacts of weir or trap operation, by removing debris, preventing poaching and ensuring safe and proper facility operation. Delay and handling stress may also be reduced by holding fish for the shortest time possible, less than 24 hours and any fish not needed for broodstock should quickly be allowed to recover from handling and be immediately released upstream to spawn naturally (NMFS 2004). However, it may be necessary to hold fish longer at the beginning and the end of the trapping season when the adult numbers are low.

Beach seines, hook and line, gillnets and snorkeling are other methods used to collect adult broodstock for artificial production programs. All these methods can adversely affect listed fish through injury, delaying their migration, changing their holding and spawning behavior, and increasing their susceptibility to predation and poaching. Some artificial production programs collect juveniles for their source of broodstock. Programs can collect developing eggs or fry by

hydraulically sampling redds or collected emerging juvenile fish by capping redds (Young and Marlowe 1996; Shaklee *et al.* 1995; WDFW *et al.* 1995; WDFW 1998). Seines, screw traps and hand nets can also be used to collect juveniles. Each of these methods can adversely affect listed fish through handling or harming the juvenile fish that remain.

B. *Demographic*- Risk posed to natural-origin component from decreasing numbers due to taking fish into hatchery. The removal of adults from a naturally-spawning population has the potential to reduce the size of the natural population (sometimes called "mining"), cause selection effects, and remove nutrients from upstream reaches (Spence *et al.* 1996; NRC 1996; Kapusinski 1997). In cases where listed salmonid populations are not even replacing themselves and a supplementation hatchery program can slow trends toward extinction and buy time until the factors limiting population viability are corrected, risks to the natural population, including numerical reduction and selection effects, are in some cases subordinate to the need to expeditiously implement the artificial production programs that will reduce the likelihood of extinction in the short term of the populations and potentially the ESU (i.e., Redfish Lake sockeye).

3. Genetic effects- Losses of fitness and decreases in diversity caused by genetic mechanisms.

A defining characteristic of anadromous salmonids is their high fidelity to their natal streams. Their ability to home with great accuracy and maintain high fidelity to natal streams has encouraged the development of locally adapted genetic characteristics that allow the fish to use specific habitats. The genetic risks that artificial propagation pose to naturally produced populations can be separated into reductions or changes in the genetic variability (diversity) among and within populations (Hard *et al.* 1992; Cuenco *et al.* 1993; NRC 1996; Waples and Drake 2004). We consider three types of effects: loss of within-population diversity, outbreeding effects, and domestication selection. In most cases, genetic change is caused by the hatchery environment or by management of the hatchery program, and does not become an issue until mating occurs between hatchery-origin and natural-origin fish, either of the same or different populations. Therefore the following measures are generally applicable for reducing genetic risk:

- Releasing fewer or no hatchery fish into the natural population.
- Releasing hatchery fish only at the hatchery or at locations where they are unlikely to interbreed with natural fish when returning as adults.
- Advancing or retarding the time of spawning for hatchery fish, to minimize the overlap in spawning time between hatchery and natural fish.
- Acclimating hatchery fish prior to release to improve homing precision.
- Acclimating and releasing hatchery fish at locations where returning adults can be harvested at high rates (harvest augmentation programs), locations away from natural production areas and sites where returning adults can be sorted and removed from the spawning population.

A. *Loss of within-population diversity*- Diversity/fitness loss caused by genetic drift and inbreeding depression.

Loss of within-population genetic diversity (variability) is defined as the reduction in quantity, variety and combinations of alleles in a population (Busack and Currens 1995). Quantity is defined as the proportion of an allele in the population and variety is the number of different kinds of alleles in the population.

Genetic diversity within a population can change from random genetic drift and from inbreeding. Random genetic drift occurs because the progeny of one generation represents a sample of the quantity and variety of alleles in the parent population. Since the next generation is not an exact copy of the parent generation, rare alleles can be lost, especially in small populations where a rare allele is less likely to be represented in the next generation (Busack and Currens 1995).

The process of genetic drift is governed by the *effective population size* rather than the observed number of breeders. The effective size of a population is defined as the size of an idealized population that would produce the same level of inbreeding or genetic drift seen in an observed population of interest (Halliburton 2004). Attributes of such an idealized population typically include discrete generations, equal sex ratios, random mating and specific assumptions about the variance of family size. Real populations almost always violate one or more of these idealized attributes, and the effective size of a population is therefore almost always smaller than the observed census size. Small effective population size in hatchery programs can be caused by:

- Using a small number of adults for hatchery broodstock.
- Using more females than males (or males than females) for the hatchery broodstock.
- Pooling the gametes of many adults during spawning which would allow one male to potentially dominate during fertilization.
- Changing the age structure of the spawning population from what would have occurred naturally.
- Allowing progeny of some matings to have greater survival than allowed others (Gharrett and Shirley 1985; Simon *et al.* 1986; Withler 1988; Waples 1991; Campton 1995).

Some hatchery stocks have been found to have less genetic diversity and higher rates of genetic drift than some naturally produced populations, presumably as a result of a small effective number of breeders in the hatcheries (Waples *et al.* 1990). Potential, negative impacts of artificial propagation on within population diversity may be indicated by changes in morphology (e.g., Bugert *et al.* 1992) or behavior of salmonids (e.g. Berejikian 1995). Busack and Currens (1995) observed that it would be difficult to totally control random loss of within population genetic diversity in hatchery populations, but by controlling the broodstock number, sex ratios, and age structure, loss could be minimized. Theoretical work has demonstrated that hatcheries can reduce the effective size of a natural population in cases where a large number of hatchery strays are produced by a relatively small number of hatchery breeders (Ryman *et al.* 1995). This

risk can be minimized by having hatcheries with large effective population sizes and by controlling the rate of straying of hatchery fish into naturally produced populations.

Inbreeding depression is the interbreeding of related individuals. Inbreeding *per se* does not lead directly to changes in the quantity and variety of alleles but can increase both individual and population   homozygosity. This homozygosity can change the frequency of phenotypes in the population which are then acted upon by the environment. If the environment is selective towards specific phenotypes then the frequency of alleles in the population can change (Busack and Currens 1995). Increased homozygosity is also often expected to lead to a reduction in fitness called *inbreeding depression.* Inbreeding depression occurs primarily because nearly all individuals harbor large numbers of deleterious alleles whose effects are masked because they also carry a non-deleterious 'wild type' allele for the same gene. The increased homozygosity caused by inbreeding leads to a higher frequency of individuals homozygous for deleterious alleles, and thus a reduction in the mean fitness of the population (see Waldman and McKinnon 1993 for a review).

It is important to note that there is little empirical data on inbreeding depression or substantial loss of genetic variability in any natural or hatchery population of Pacific salmon or steelhead, although there are considerable data on the effects of inbreeding in rainbow trout (Hard and Hershberger 1995, quoted in Myers *et al.* 1998). Studying inbreeding depression is particularly difficult in anadromous Pacific salmon because of their relatively long generation times, and the logistical complexities of rearing and keeping track of large numbers of families. Monitoring the rate of loss of molecular genetic variation in hatchery and naturally produced populations is one alternative method for studying the impacts of hatcheries on genetic variability (e.g., Waples *et al.* 1993), but does not provide information on inbreeding depression or other fitness effects associated with changes in genetic variation. Many of these changes are also expected to occur over many generations, so long term monitoring is likely to be necessary to observe all but the most obvious changes.

B. *Outbreeding effects*- Fitness/diversity change caused by gene flow from other populations Genetic differences among salmon populations arise as a natural consequence of their homing tendency. Homing leads to a relatively high degree of demographic isolation among populations. This demographic isolation produces conditions where evolutionary forces such as natural selection and random genetic drift create differences in allele frequencies among populations. Many of these differences are believed to be adaptive – meaning that populations have been shaped by natural selection to have a particularly good fit to their local environment (see Taylor 1991, and McElhany *et al.* 2000 for reviews).

Despite the strong tendency of salmon and steelhead to home to their natal streams, some return to other streams, a process called straying. If strays reproduce, this results in gene flow. Straying is common in salmon and steelhead but varies in pattern and intensity (Quinn1993). Straying is thought to serve a valuable purpose in nature in terms of reducing loss of diversity

through drift, and in colonization of vacant habitat. However, hatcheries can create unnatural gene flow situations, either in terms of sources or rates. Gene flow from unnatural sources or at unnatural levels can have two effects. One is simply a loss of among-population diversity. The genetic diversity contained in a population represents its adaptive potential. The more similar populations are made by gene flow, although there may be no discernible immediate consequence, the less able will they be to adapt differently to new environmental challenges. There is a clear negative correlation in several areas of the Pacific Northwest between among-population diversity and gene flow from hatcheries (e.g., Phelps et al. 1994), and changes to diversity have been seen in Europe as well (e.g., Ayllon et al. 2006). However, in other areas where hatchery production has been extensive, native steelhead genotypes have been shown to persist (Phelps *et al.* 1994; Narum *et al.* 2006). This does not mean that there has not been an effect on among-population diversity, but is rather a demonstration that intensive use of nonnative hatchery fish does not necessarily result in genetic homogenization.

 The other outbreeding effect is outbreeding depression, a loss of fitness in the first or subsequent generations after interbreeding. Outbreeding depression can be a simple loss of adaptation caused by changes in allele frequency or by the introduction of new alleles. In this case, results should be apparent the first generation after interbreeding. It can also result in the disruption of coadapted gene complexes, sets of alleles at different genes that work well together (Busack and Currens 1995, Naish et al. 2008). In this case, the effect is not observable until the second generation after the interbreeding event. The greater the geographic separation between the source and recipient population, the greater is likely to be the genetic difference between the two populations (ICTRT 2007). Therefore a hatchery-origin fish whose origins are geographically distant likely will genetically differ from a local natural population, regardless of additional differences that might develop due to the impact of the hatchery rearing environment (domestication selection- see below) resulting in outbreeding depression (Darwish and Hutchings 2009, Miller et al. 2004, Philipp et al. 2002). Such distant-origin hatchery fish therefore may pose a greater risk to the genetic character of a local natural-origin population than hatchery-origin fish originating from the same local natural-origin population.

Experimental designs to specifically test for outbreeding depression require control of the test organisms/populations over multiple generations (McClelland and Naish 2007, Naish et al. 2008) Such studies are therefore logistically difficult to set up, particularly for organisms with multi-year generation times and even more so for tests in a natural environment. As such, many published reports on hybridization/straying/hatchery stocking only provide results suggestive of outbreeding depression – see Hallerman (2003) for studies with aquatic organisms. Published studies presenting direct empirical evidence of outbreeding effects are few in number and come mostly from studies of plants in greenhouse settings, or invertebrates in laboratory settings - there are very few studies of outbreeding in vertebrates (Edmands 2007). There are a few noteworthy studies in fish, however. Gharrett et al. (1999) created F1 and F2 hybrids between even- and odd- year pink salmon. No differences in adult return rates were observed between F1

and control fish, but there was a significant difference between F2 fish and the controls – indicative of outbreeding depression via disruption of coadapted gene complexes. The two populations but highly isolated genetically due to lack of natural interbreeding between odd and even year fish. In another study of pink salmon, Gilk et al. (2004) compared return rates between native control pink salmon (both odd and even year) and F1 and F2 hybrids with a population whose natal stream was at a similar latitude, but over 1000 km distant. Return rate of odd- year F1 hybrids and controls was similar – similar to results of Gharett et al. 1999. In contrast, even-year F1 hybrids returned at a rate significantly lower than that of controls - suggesting a lack of outbreeding depression in the odd year crosses, but presence of an effect in the even year crosses. In both even and odd year crosses, however, the F2 fish showed significantly lower return rate relative to controls, suggesting disruption of coadapted gene complexes. Dann et al. 2010 created control crosses and F1 and F2 hybrids with a native coho stock and two other stocks SE Alaska hatchery stocks (the furthest hatchery of the two being 500 km distant), and compared return rates. They observed no significant differences between any of the F2 and control groups, indicative of a lack of outbreeding depression. And, in comparisons between F1 hybrids and controls they actually observed an increase in survival of the F1 relative to the controls –an unexpected incidence of heterosis (hybrid vigor). The authors attribute the lack of evidence for outbreeding depression to low power (limited sample size) of their study, and possibly to diminished genetic isolation of the three stocks. Darwish and Hutchings (2009) compared Atlantic salmon backcrosses that differed only in the population originally outcrossed to, and found significant differences in reaction norms in several traits. Philipp et al. (2002) found that Illinois largemouth bass (Micropterus salmoides) had much higher reproductive success in an Illinois test pond than an introgressed population descended from bass from Illinois and two other states.

A salient characteristic of all these studies is the use of distantly related populations, presumably chosen to detect an effect. The largemouth bass example is relevant to management of that species, because the geographical separation of the test populations is representative of the long-distance transplants that largemouth bass have been subjected to. The salmon examples, however, involve populations that are geographically or genetically separated much more than populations that are likely to have gene flow between them. It is unclear how much outbreeding depression can be expected from genetic exchange between populations with similar life histories within an ESU/DPS, or even between ESUs/DPSs.

To deal with this issue, a 1995 NMFS-sponsored workshop focused on the biological consequences of hatchery fish straying into natural salmonid populations (Grant 1997). The workshop addressed how much gene flow can occur and still remain compatible with the long-term conservation of local adaptations and genetic diversity among populations. Based on selection effects in other animals, a gene flow rate of greater than 5 percent between local and non-local populations would quickly lead to replacement of neutral and locally-adapted genes (Grant 1997). NMFS notes that gene flow is expected to be much less than 5 percent when the

stray rate of non-local fish into a local population is 5 percent because not all fish that stray will spawn successfully. Thus, NMFS supports the standard that hatchery stray rates should be managed such that less than 5 percent of the naturally spawning population consists of hatchery fish from a different area. Furthermore, the number of non-local strays in a particular population should be as low as possible to minimize outbreeding effects.

The approach taken by the workshop has been applied by the ICTRT and WLCTRT in their development of population viability criteria for the recovery of listed species (ICTRT 2005; WLCTRT 2006). The ICTRT (2005) developed a flow-chart approach to assigning risk associated with exogenous spawners in the salmon population (they define exogenous spawners as all hatchery-origin and all natural-origin fish that are present due to unnatural, anthropogenically induced conditions (Figure 11). The WLCTRT developed similar metrics to describe risk to the diversity of listed populations, including one measuring the potential loss of fitness over time (Figure 3b and 3c in WLCTRT 2006) that is based on a statistic called proportionate natural influence (PNI). PNI is approximated as a relationship between the percentage of natural spawners comprised of hatchery-origin fish and the percentage of natural-origin fish in the hatchery broodstock (see HSRG *et al.* 2004). Another metric for diversity looked at the influence of non-local origin fish strays, both within ESU and out-of-ESU, on diversity, but considered these strays only if there was evidence of interbreeding (WLCTRT 2006).
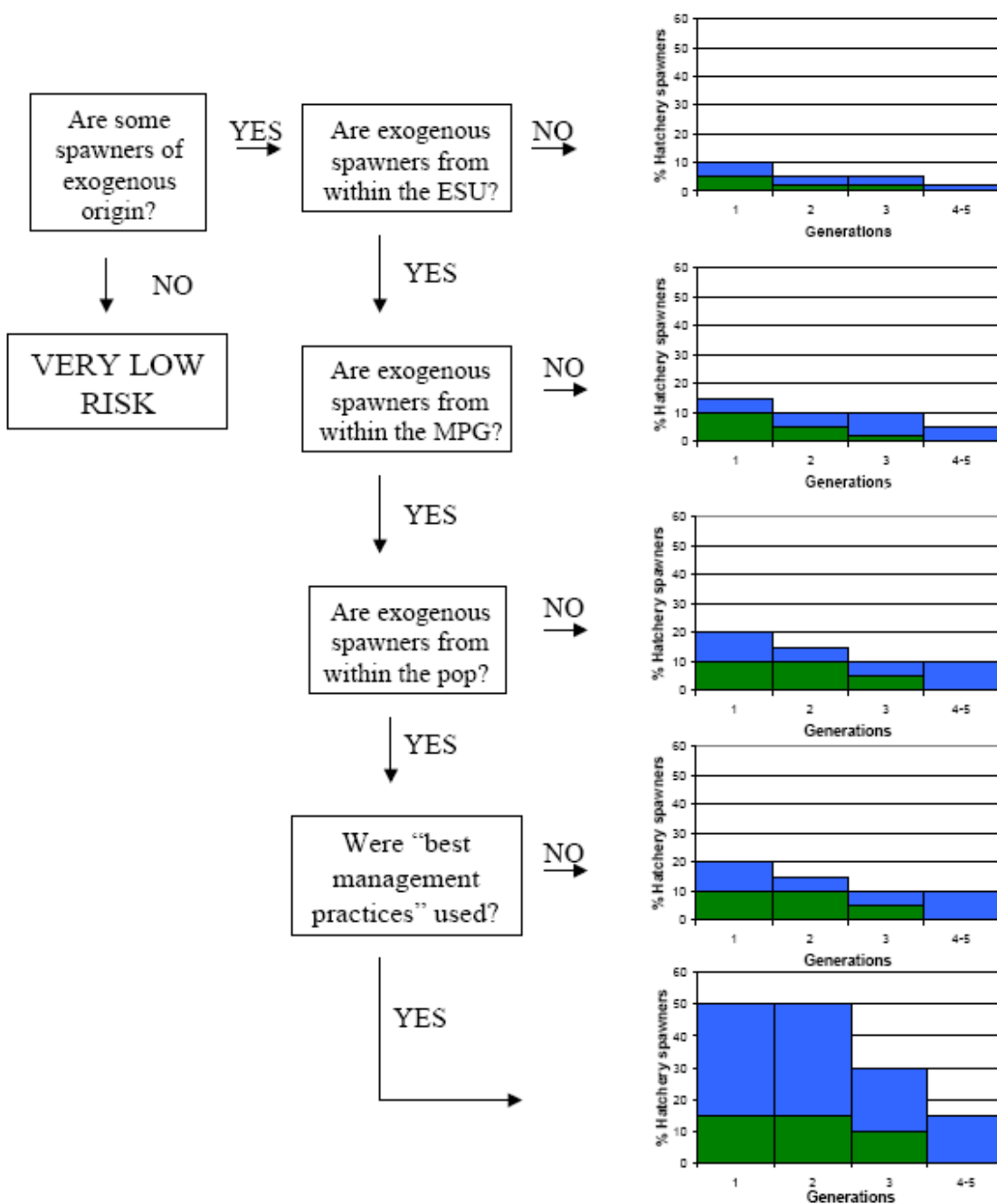
Figure 1. Graphical representation of risk criteria associated with spawner composition. Green areas indicate low risk combinations of duration and proportion of spawners, blue areas indicate moderate risk areas and red-striped areas and areas outside the range graphed indicate high risk. Exogenous fish are considered to be all fish of hatchery origin, and non-normative strays of natural origin (ICTRT 2005). As with the ICTRT, the WLCTRT combined these and other metrics together to develop a score for the diversity criteria, used to determine the overall viability of a population. The methods for weighing the different metrics within the criteria and

developing a final combined score have not been finalized. It should also be noted that the failure in one of the metrics (e.g. loss of fitness over time) does not prevent the population from meeting the diversity criteria.

Measures to reduce the risk of outbreeding effects include:

- Propagating and releasing only fish from the local indigenous population or spawning aggregate.
- Avoiding or adequately reducing, gene-flow from a hatchery program into a natural population.
- Limiting the transfers of fish between different areas.
- Acclimate hatchery fish in the target watershed to ensure that the hatchery fish retain a high fidelity to the targeted stream (Clarke et al. 2010).
- Using returning spawners rather than the transferred donor population as broodstock for restoration programs to foster local adaptation.
- Maintaining natural populations that represent sufficient proportions of the existing total abundance and diversity of an ESU/DPS without hatchery intervention.
- Visually marking all hatchery-produced salmonids to allow for monitoring and evaluation of straying and contribution to natural production (Kapuscinski and Miller 1993; Flagg and Nash 1999).

A final note on outbreeding effects. It is important to note that genetic differences between populations may or may not include domestication effects, but the outbreeding effects just discussed result from genetic differences between distinct populations due to their origins, apart from domestication. These effects are not the same as those arising from the interbreeding between the hatchery- and natural-origin components of a single population.

C. *Domestication selection*- Fitness loss and phenotypic change caused by differences between the hatchery and natural environments (includes intentional selection and relaxation of selection), and sampling "errors" during fish culture. Domestication means changes in quantity, variety and combination of alleles between a hatchery population and its source population that are the result of selection in the hatchery environment (Busack and Currens 1995). Domestication is also defined as the selection for traits that favor survival in a hatchery environment and that reduce survival in natural environments (NMFS 1999b). Domestication can result from rearing fish in an artificial environment that imposes different selection pressures than what they would encounter in the wild. The concern is that domestication effects will decrease the performance of hatchery fish and their descendants in the wild. Busack and Currens (1995) identified three types of domestication selection (1) intentional or artificial selection, (2) biased sampling during some stage of culture, and (3) unintentional or relaxed selection.

(1)   Intentional or artificial selection is the attempt to change the population to meet management needs, such as time of return or spawning time. Hatchery fish selected to perform well in a hatchery environment tend not to perform well when released into the

wild, due to differences between the hatchery and the naturally produced populations resulting from the artificial propagation. Natural populations can be impacted when hatchery adults spawn with natural-origin fish and the performance of the natural population is reduced (a form of outbreeding depression) (Busack and Currens 1995).

(2)   Biased sampling leading to domestication can be caused by errors during any stage of hatchery operation. Broodstock selection is a common source of biased sampling when adults are selected based on particular traits. Hatchery operations can be a source of biased sampling when groups of fish are selected against when feeding, ponding, sorting and during disease treatments because different groups of fish will respond differently to these activities.

(3)   Genetic changes due to unintentional or relaxed selection occur because salmon in hatcheries usually have (by design) much higher survival rates than they would have in the wild. Hatchery fish are reared in a sheltered environment that increases their survival relative to similar life stages in the natural environment allowing deleterious genotypes that would have been lost in the natural environment to potentially contribute to the next generation.

Reisenbichler and Rubin (1999) cite five studies indicating that hatchery programs for steelhead and stream-type Chinook salmon (i.e., programs holding fish in the hatchery for one year or longer) genetically change the population and thereby reduce survival for natural rearing. The authors report that substantial genetic change in fitness can result from traditional artificial propagation of salmonids held in captivity for one quarter or more of their life. Bugert *et al.* (1992) documented morphological and behavioral changes in returning adult hatchery spring Chinook salmon relative to natural adults, including younger age, smaller size, and reduced fecundity. However, since that study, differences in size and age at return have been found to be more related to smolt size at release than domestication selection. Differences in fecundity are still observed, but not fully understood.

Leider *et al.* (1990) reported diminished survival and natural reproductive success for the progeny of non-native hatchery steelhead when compared to native naturally produced steelhead in the lower Columbia River region. The poorer survival observed for the naturally produced offspring of hatchery fish could have been due to the long term artificial and domestication selection in the hatchery steelhead population, as well as maladaptation of the non-indigenous hatchery stock in the recipient stream (Leider *et al.* 1990). Ongoing research on winter steelhead in the Hood River basin (Blouin 2004; Blouin and Araki 2005) compared the reproductive success of hatchery and natural-origin adults. The old program, that used out-of-basin broodstock, was determined to be 17 to 54 percent as reproductively successful as the natural-origin adults. The new program used natural-origin winter steelhead adults for broodstock, and their progeny were determined to be 85 to 108 percent as successful as natural-origin adults in

producing adult returns to the basin. These results do not support the assumption of domestication selection in first generation of hatchery rearing for steelhead.

Chilcote (1998) reported a strong negative correlation between the proportion of naturally spawning hatchery steelhead and stock productivity, when examining spawner-recruit relationships for 26 Oregon steelhead populations. Based on the best scientific information, the NMFS FCRPS biological opinion assumed a relative reproductive success range of 20 percent to 80 percent for naturally spawning hatchery-origin fish compared to naturally produced fish (NMFS 2000a).

Berejikian (1995) reported that wild-origin steelhead fry survived predation by prickly sculpins (*Cottus asper*) to a statistically significant degree better than size-matched off-spring of locally-derived hatchery steelhead reared under similar conditions. Alteration of the innate predator avoidance ability through domestication was suggested by the results of this study. However, Joyce *et al.* (1998) reported that an Alaskan spring Chinook salmon stock under domestication for four generations did not significantly differ from offspring of naturally produced spawners in their ability to avoid predation. The domesticated and naturally produced Chinook salmon groups tested also showed similar growth and survival rates in freshwater performance trials.

Domestication effects from artificial propagation and the level of genetic differences between hatchery and natural fish can be minimized by:

- Randomly selecting adults for broodstock from throughout the natural population migration to provide an unbiased sample of the natural population with respect to run timing, size, age, sex ratio, and other traits identified as important for long term fitness.
- Ensuring that returning adults used as broodstock by a hatchery continually incorporate natural-origin fish over the duration of the program to reduce the likelihood for divergence of the hatchery population from the natural population.
- Limiting the duration of a supplementation program to a maximum of three salmon generations (approximately 12 years) to minimize the likelihood of divergence between hatchery broodstocks and target natural stocks and to reduce the risk of domestication of the composite hatchery/natural stock.
- Employing appropriate spawning protocols to avoid problems with inbreeding, genetic drift and selective breeding in the hatchery (e.g., Simon *et al.* 1986; Allendorf and Ryman 1987; Gall 1993). Methods include collection of broodstock proportionally across the breadth of the natural return, random matings with respect to size and phenotypic traits, application of at least 1:1 male to female mating schemes (Kapuscinski and Miller 1993), and avoidance of intentional selection for any life history or morphological trait.
- Using spawning protocols that equalize as much as possible the contributions of all parents to the next breeding generation.
- Using only natural fish for broodstock in the hatchery each year to reduce the level of domestication.

- Setting minimum broodstock collection objectives to allow for the spawning of the number of adults needed to minimize the loss of some alleles and the fixation of others (Kapuscinski and Miller 1993).
- Setting minimum escapements for natural spawners and maximum broodstock collection levels to allow for at least 50 percent of escaping fish to spawn naturally each year, to help maintain the genetic diversity of the donor natural population.
- Using hatchery methods that mimic the natural environment to the extent feasible (e.g. use of substrate during incubation, exposure to ambient river water temperature regimes and structure in the rearing ponds).
- Limiting the duration of rearing in the hatchery by releasing at early life-stages to minimize the level of intervention into the natural salmonid life cycle, minimizing the potential for domestication.

NMFS believes that the measures identified for minimizing the potential adverse genetic impacts of hatchery produced fish on naturally produced fish should be applied to protect listed species. The actual measures selected will depend on a number of factors including but not limited to:

- Program objectives (i.e. recovery, reintroduction or harvest augmentation).
- Broodstock source, history and level of domestication.
- Spawning protocols.
- Status of the natural population targeted by the hatchery program.
- Ability of fish managers to remove or control the number of hatchery adults in the natural spawning population.
- Rearing practices.
- Total number of hatchery fish released into the subbasin.

More detailed discussions on the measures to implement these strategies can be found in Reisenbichler (1997), Reisenbichler and McIntyre (1986), Nelson and Soule (1987), Goodman (1990), Hindar *et al.* (1991), and Waples (1991) among others.

4. Ecological effects- losses due to ecological interactions between hatchery-origin and natural-origin fish.

Ecological interactions include disease, competition (density-dependence), predation, and marine derived nutrients. In general, the literature on these factors is large and varied in terms of results, making it difficult to generalize about the significance of impacts. In a recent review paper on ecological interactions Pearsons (2008) presented a "myths and realities" treatment patterned after Waples (1991) paper on genetic effects. He listed seven misconceptions: 1) release of hatchery fish downstream of species of concern means impact will be negligible, 2) the published literature is a representative sample of ecological interactions between hatchery and wild fish, 3) interactions from hatchery fish are always negative, 4) historical coexistence translates into present coexistence, 5) acceptable impacts to wild fish should not be any less than

what is statistically detectable, 6) management can contain risks associated with ecological interactions within acceptable levels, and 7) ecosystems are so complicated that we can't predict what interactions will occur.

In another review paper Kostow (2009) lists five major factors contributing to ecological interactions between hatchery-origin and natural-origin fish: large releases of hatchery fish, hatchery fish increase density-dependent mortality, hatchery fish not migrating after release, hatchery fish having a physiological advantage over the wild fish, and hatchery fish being having a life history of long juvenile freshwater residency. She listed twelve major steps for reducing ecological risk, ranging from some that are very practical at local levels to those that would require major policy shifts: 1) operate hatchery programs within an integrated management context, 2) only implement hatchery programs that provide a benefit, 3) reduce the number of hatchery fish that are released, 4) scale hatchery programs to fit carrying capacity of the basin in which they are released, 5) limit the total number of hatchery fish that are released at a regional scale, 6) release only juveniles that are actively smolting and will promptly out-migrate, 7) release hatchery fish at smaller sizes (provided they are smolting), 8) use acclimation ponds and volitional releases, 9) locate large releases of hatchery fish away from important natural production areas, 10) time releases to minimize ecological risks, 11) restrict the number of hatchery adults allowed into natural production areas, 12) mark 100% of the hatchery fish and monitor the effects of hatchery programs. She notes that many of these recommendations will also reduce genetic risk.

A.Disease: risks/impacts of disease transmission from diseased hatchery fish or from pathogens in hatchery effluent. Hatchery effluent can transport fish pathogens out of the hatchery, where natural fish may be exposed to infection. Interactions between hatchery fish and natural fish in the environment may also result in the transmission of pathogens, if either the hatchery or natural fish are harboring fish disease. This latter impact may occur in tributary areas where hatchery fish are released and throughout the migration corridor where hatchery and naturally produced fish may interact. As the pathogens responsible for fish diseases are present in both hatchery and natural populations, there is some uncertainty associated with determining the source of the pathogen (Williams and Amend 1976; Hastein and Lindstad 1991). Hatchery-origin fish may have an increased risk of carrying fish disease pathogens because of relatively high rearing densities that increase stress and can lead to greater manifestation and spread of disease within the hatchery population. Under natural, low density conditions, most pathogens do not lead to a disease outbreak. When fish disease outbreaks do occur, they are often triggered by stressful hatchery rearing conditions, or by a deleterious change in the environment (Saunders 1991). Consequently, it is possible that the release of hatchery fish may lead to the loss of natural fish, if the hatchery fish are carrying a pathogen not carried by the natural fish, if that pathogen is transferred to the natural fish, and if the transfer of the pathogen leads to a disease outbreak.

Recent studies suggest that the incidence of some pathogens in naturally spawning populations may be higher than in hatchery populations (Elliott and Pascho 1994). The incidence of high ELISA titers for *Renibacterium salmoninarum*, the causative agent of Bacterial Kidney Disease (BKD), appears, in general, to be more prevalent to a statistically significant degree among wild

smolts of spring/summer Chinook salmon than hatchery smolts (Congleton *et al*. 1995; Elliot *et al*. 1997). For example, 95 percent and 68 percent of wild and hatchery smolts, respectively, at Lower Granite Dam in 1995 had detectable levels of *R. salmoninarum* (Congleton *et al*. 1995). Although pathogens may cause a high rate of post-release mortality among hatchery fish, there is little evidence, from the limited number of evaluations completed to date, that hatchery-origin fish routinely infect naturally produced salmon and steelhead in the Pacific Northwest (Enhancement Planning Team 1986; Steward and Bjornn 1990). To monitor and reduce the incidence of disease in hatchery fish state and federal fisheries agencies have established Fish Pathology labs and personnel who monitor and manage fish health in hatcheries. To help reduce the likelihood of disease transmission from hatchery salmonids to naturally produced fish, fish managers have established a number of fish health policies to ensure that fish health is monitored, sanitation practices are applied, and that hatchery fish are reared and released in healthy condition (PNFHPC 1989; IHOT 1995; WDFW 1996; WDFW and WWTIT 1998; USFWS 1995; USFWS 2004j).   Standard fish health monitoring under these policies include monthly and pre-release checks of propagated salmonid populations by a fish health specialist, with intensified efforts to monitor presence of specific pathogens that are known to occur in the populations. Specific reactive and proactive strategies for disease control and prevention are also included in the fish health policies. Fish mortality at the hatchery due to unknown cause(s) will trigger sampling for histopathological study. Incidence of viral pathogens in salmonid broodstocks is determined by sampling fish at spawning. Populations of particular concern may be sampled at the 100 percent level and may require segregation of eggs/progeny in early incubation or rearing. In some programs, progeny from parents likely infected with a vertically transmittable disease are culled as a precaution to lessen the recurrence of the disease in subsequent generations.   .

B. *Competition-* risk/impact of productivity loss to target and nontarget populations from competition for limited resources with released hatchery fish. Competition occurs when the demand for a resource by two or more organisms exceeds the available supply. If the resource in question (e.g., food or space) is present in such abundance that it is not limiting, then competition is not occurring, even if both species are using the same resource. Adverse impacts of competition may result from direct interactions, whereby a hatchery-origin fish interferes with the accessibility to limited resources by naturally produced fish, or through indirect means, as in when utilization of a limited resource by hatchery fish reduces the amount available for naturally produced fish (SIWG 1984). Specific hazards associated with adverse competitive impacts of hatchery salmonids on listed naturally produced salmonids may include food resource competition, competition for juvenile rearing sites, and to a lesser extent competition for spawning sites. In an assessment of the potential ecological impacts of hatchery fish production on naturally produced salmonids, the Species Interaction Work Group (SIWG 1984) concluded that naturally produced steelhead, coho, and Chinook salmon are all potentially at "high risk" to competition (both interspecific and intraspecific) from hatchery fish of any of these three species.

In contrast, the risk of naturally produced pink, chum, and sockeye salmon to competition from hatchery salmon and steelhead was judged to be low.

The potential for competition between adult hatchery and naturally produced fish is assumed to be greatest in the spawning areas where competition for redd sites may be a concern (USFWS 1994). Adult salmonids originating from hatcheries can also compete with naturally produced fish of the same species for mates, perhaps resulting in a shorter spawning survival period for naturally produced fish because of the additional stress. Hatchery-origin adult salmonids may home to, or stray into, natural production areas during naturally produced fish spawning or egg incubation periods, posing an elevated competitive and behavioral modification risk. Two recent papers have noted density-dependent effects of hatchery on the spawning grounds. Buhle et al. (2009) estimated that in Oregon coastal coho populations one hatchery-origin fish on the spawning grounds had the same density impact as five natural-origin fish. Chilcote et al. (2011) examined productivity in hundreds of populations of coho, Chinook, and steelhead in the Pacific Northwest, and found a significant negative relationship between productivity and the proportion of hatchery fish on the spawning grounds for all three species. In both these studies the effect observed could have been in part due to genetic fitness depression.

The risk of competition for spawning sites can be minimized by actions that reduce the incidence of hatchery fish that spawn in the wild such as: release and rearing strategies to cause returning adults to home to areas where natural origin fish do not spawn, trapping and removal of hatchery fish at a weir downstream of primary spawning areas, and reducing the number of hatchery adults by releasing fewer hatchery smolts.

For juvenile salmonids rearing in freshwater, food and space are the resources in demand, and thus are the focus of inter- and intra-specific competition (SIWG 1984). Newly released hatchery smolts may compete with naturally produced fish for food and space in areas where they interact during downstream migration. Naturally produced fish may be competitively displaced by hatchery fish early in life, especially when hatchery fish are more numerous, of equal or greater size, and (if hatchery fish are released as non-migrants) the hatchery fish have taken up residency before naturally produced fry emerge from redds. Release of large numbers of hatchery pre-smolts in a small area is believed to have greater potential for competitive impacts because of the extended period of interaction between hatchery fish and natural fish. In particular, hatchery programs directed at fry and non-migrant fingerling releases will produce fish that compete for food and space with naturally produced salmonids for longer durations, if the hatchery fish are planted within, or disperse into, areas where naturally produced fish are present. A negative change in growth and condition of naturally produced fish through a change in their diet or feeding habits could occur following the release of hatchery salmonids. Any competitive impacts likely diminish as hatchery-produced fish disperse, but resource competition may continue to occur at some unknown, but lower level as natural-origin juvenile salmon and any commingled hatchery juveniles emigrate seaward.

Hatchery-origin smolts and sub-adults can also compete with naturally produced fish in estuarine and marine areas, leading to negative impacts on naturally produced fish in areas where preferred food is limiting.   Hatchery fish might alter naturally produced salmon behavioral patterns and habitat use, making them more susceptible to predators (Hillman and Mullan 1989; Steward and Bjornn 1990). Hatchery-origin fish may also alter naturally produced salmonid migratory responses or movement patterns, leading to a decrease in foraging success (Steward and Bjornn 1990; Hillman and Mullan 1989). In a review of the potential adverse impacts of hatchery releases on naturally produced salmonids, Steward and Bjornn (1990) indicated that it was indeterminate from the literature whether naturally produced parr face statistically significant risk of displacement by introduced hatchery fish, as a wide range of outcomes from hatchery-naturally produced fish interactions has been reported. The potential for negative impacts on the behavior, and hence survival, of naturally produced fish as a result of hatchery fish releases depends on the degree of spatial and temporal overlap in occurrence of hatchery and naturally produced fish. The relative size of affected naturally produced fish when compared to hatchery fish, as well as the abundance of hatchery fish encountered, also will determine the degree to which naturally produced fish are displaced (Steward and Bjornn 1990). Actual impacts on naturally produced fish would thus depend on the degree of dietary overlap, food availability, size-related differences in prey selection, foraging tactics, and differences in microhabitat use (Steward and Bjornn 1990).

En masse hatchery salmon smolt releases may cause displacement of rearing naturally produced juvenile salmonids from occupied stream areas, leading to abandonment of advantageous feeding stations, or premature out-migration (Pearsons *et al.* 1994). Pearsons *et al.* (1994) reported small scale displacement of juvenile naturally produced rainbow trout from discrete sections of streams by hatchery steelhead released into an upper Yakima River tributary. The authors found that small scale displacements and agonistic interactions observed between hatchery steelhead and naturally produced juvenile trout were most likely a result of the hatchery steelhead being larger than the juvenile trout and not something inherently different about hatchery fish,   However, they noted that these behavioral interactions between hatchery-reared steelhead did not have a statistically significant adverse effect on the overall trout populations examined in that the population abundance of naturally produced salmonids was not negatively affected by releases of hatchery steelhead. In the same stream, Pearsons and Temple (2010) later noted that after nine years of coho and spring Chinook releases in the Teanaway River, WA, the abundance and biomass of rainbow trout had significantly decreased relative to pre-supplementation years.

As noted earlier, competition between hatchery and naturally produced salmonids in freshwater may potentially be a high risk for coho, Chinook salmon, and steelhead, but not pink, chum, and sockeye. Juvenile coho salmon are apparently dominant in agonistic encounters with juveniles of other stream-rearing salmonid species, including Chinook salmon, steelhead, and cutthroat trout (*O. clarki*), and with wild-origin coho salmon (e.g., Stein *et al.* 1972; Allee 1974; Swain and Riddell 1990; Taylor 1991) when placed in the same test habitat.   However, there are

substantial differences in habitat preferences between older juveniles of the three species, in particular between coho and steelhead. Age one and older steelhead prefer steeper gradient streams and riffle habitat, coho favor lower gradient streams and pool habitat. Chinook salmon also have different habitat preferences than coho (Nilsson 1967; Lister and Genoe 1970; Taylor 1991). Along with the habitat differences exhibited by coho salmon and steelhead, they also show differences in foraging behavior. Peterson (1966) and Johnston (1967) reported that juvenile coho salmon are surface oriented and feed primarily on drifting and flying insects, while steelhead are bottom oriented and feed largely on benthic insects. A net result of these intrinsic habitat preference and feeding behavioral differences is that the incidence of competitive interactions among coho, Chinook, and steelhead in natural streams is much lower than interactions between members of the same species (intraspecific competition).

There is a hypothesis that large numbers of hatchery-produced smolts released into the Columbia River have adverse effects on naturally produced juveniles in the estuary and ocean. The potential for estuary impacts is greatest for chum salmon and sub-yearling fall Chinook because their life histories involve a period of extended residence in the estuary environment before migrating to the sea. Other anadromous salmonids in the Columbia (steelhead, coho, spring Chinook, sockeye, and sea-run cutthroat) are theoretically less vulnerable because they migrate directly to the ocean as smolts and do not have an estuary rearing period as part of their normal life history. However, all species share the ocean environment for a prolonged period and if there is a production limitation on the capacity of ocean to support salmonids then large numbers of hatchery-produced fish have the potential to create a more competitive environment, potentially having an adverse impact on naturally produced fish. In recent years, the potential for interactions between hatchery juveniles and naturally produced fish in the estuary has been likely reduced as the number of hatchery fish released by Columbia River basin hatchery programs has decreased.   A production ceiling for all artificial propagation programs in the Columbia River basin was described in the Proposed Recovery Plan (NMFS 1995b) and in the 1999 artificial propagation Biological Opinion (NMFS 1999a). This production ceiling was approximately 197.4 million anadromous fish. Although releases occur throughout the year, approximately 80 percent occur from April through June. It is worth noting, a significant portion of the releases into the upper portions of the Columbia and Snake basins do not survive the migration downstream to the ocean. For example, the historical passage index of hatchery fish released into the Snake River Basin surviving to Lower Granite Dam shows a survival rate of 0.23 for spring/summer Chinook salmon and 0.60 for steelhead. For releases of hatchery fish into the Columbia River above McNary Dam survival rates of 0.185 for spring/summer Chinook salmon, 0.477 for sub-yearling Chinook salmon, 0.093 for steelhead, and 0.215 for coho salmon have been observed (FPC 1992). While the actual number of hatchery fish entering the Columbia River estuary is unknown, it is substantially less than the numbers released.

The rapid travel of migrating smolts through the estuary serves to reduce interactions and competition with natural fish. Bell (1984) cites a rate of 13 miles/day (21 km/day) during low

flows and 23 miles/day (38 km/d) at moderate flows, as a general average for downstream migrants. Dawley *et al.* (1986) found rates of 1 to over 59 km/day in the estuary, depending on size, species and distance traveled, with the faster rates correlated with larger smolts from further upriver. In the free-flowing reaches of the Snake, Clearwater and Salmon, currents in excess of 10 km/hr are common during the spring freshet. Under average flow conditions smolt migration speeds in these reaches is likely to range from 40 to 50 km/day. .

As occurs in rearing areas, habitat partitioning in the estuary among the species has evolved to reduce interspecific competition. Bell (1984) and Dawley *et al.* (1986) comment on differential habitat selection with steelhead choosing the thalweg and nearer to the surface, subyearling Chinook salmon being more likely to follow the shorelines and yearling Chinook salmon seeking greater depths.

Historically the bulk of the Columbia River adult returns were spring and summer Chinook salmon, coho salmon, sockeye salmon, and steelhead. Chapman (1986) calculated only 1.25 million adult fall Chinook salmon historically returned to the Columbia River, in his high estimate, so over 80 percent of the smolts would have been spring migrating, yearling smolts. Therefore, 160 to 320 million spring, yearling smolts (based on historical returns of approximately 10 million salmon and steelhead) would have passed through the estuary and entered the ocean in May and June each year, compared to less than 40 million under current conditions. In the past, when hatchery production in the basin reached nearly 200 million fish, over half of the production was fall Chinook salmon that produce sub-yearling, summer-migrating smolts. This level of sub-yearling Chinook was probably in significant excess of what occurred historically. In addition, the estuarine rearing habitat since historical times has been greatly reduced. Therefore, these releases of sub-yearling hatchery Chinook probably had an adverse impact on natural fall Chinook (and chum salmon) as they competed for the limited amount of remaining estuary habitat.

The limited information available concerning impacts from changes in the historical carrying capacity to listed salmon is insufficient to determine definitive effects, although for sub-yearling fall Chinook the potential for adverse competitive impacts within the estuary habitat is substantial. The effects of hatchery production on listed salmon and steelhead in the ocean would be speculative, since hatchery fish intermingle at the point of ocean entry with wild and hatchery anadromous salmonids from many other regions. Witty *et al.* (1995), assessing the effects of Columbia River hatchery salmonid production on wild fish concluded that mass enhancement of fish populations through fish culture could cause density-dependant affects during years of low ocean productivity, but that there were no studies that demonstrate, or even suggest, the magnitude of changes in numbers of smolts emigrating from the Columbia River Basin which might be associated with some level of change in survival rate of juveniles in the ocean.

There is no evidence in the literature to support the hypothesis that there is compensatory mortality of Chinook salmon and steelhead in the ocean environment as one would expect in a situation where the density of fish is approaching the limit of what the ocean can produce for these species. In contrast, there is evidence of density-dependent compensatory ocean survival in the cases of massive pink and chum salmon hatchery programs in Alaska, Russia and Japan (Pearcy 1992). Thus there seems to be little chance of density dependent effects like these from Columbia basin hatchery programs. There are currently only two small chum salmon hatchery programs in the lower Columbia River (Grays River and Duncan Creek). These produce chum salmon at a level that is only a fraction of a percent of the numbers seen produced by Alaskan and Asian hatcheries. There is no hatchery production of pink salmon in the Columbia basin, and pink salmon are functionally extinct there.

SIWG (1984) acknowledged that the risk of adverse competitive interactions in marine waters is difficult to assess, because of a lack of data collected at times when hatchery fish and naturally produced fish likely interact, and because competition depends on a variety of specific circumstances associated with hatchery-naturally produced fish interaction, including location, fish size, and food availability. In marine waters, the main limiting resource for naturally produced fish that could be affected through competition posed by hatchery-origin fish is food. The early marine life stage, when naturally produced fish have recently entered the estuary and populations are concentrated in a relatively small area, may create instances where food is in short supply, and growth and survival declines as a result (SIWG 1984). This period is viewed as of special concern regarding food resource competition posed by hatchery-origin chum salmon and pink salmon to naturally produced chum salmon and pink salmon populations (Cooney *et al.* 1978; Simenstad *et al.* 1980; Bax 1983). Further, this problem may be even greater for sub-yearly fall Chinook that have a longer period of estuary rearing before emigration to the ocean. The degree to which food is limiting after the early marine portion of a naturally produced fish's life depends upon the density of prey species. The risk of adverse competitive interactions can be minimized by:

- Releasing hatchery smolts that are physiologically ready to migrate. Hatchery fish released as smolts emigrate seaward soon after liberation, minimizing the potential for competition with juvenile naturally produced fish in freshwater (Steward and Bjornn 1990).
- Operating hatcheries such that hatchery fish are reared to sufficient size that smoltification occurs within nearly the entire population (Bugert *et al.* 1991).
- Monitor the incidence of non-migratory smolts (residuals) after release and adjust rearing strategies, release location and timing if substantial competition with naturally rearing juveniles is documented.

As discussed above, a variable proportion of the smolts released from a hatchery do not migrate to the ocean but rather set up stream residence in the vicinity of the release point. This is an undesirable behavior because these non-migratory smolts (residuals) may directly compete for

food and space with natural origin juvenile salmonids of similar age. They also may prey on younger, smaller sized juvenile salmonids. Although this behavior has been studied and observed most frequently in the case of hatchery steelhead, residualism has been reported as a potential issue for hatchery coho and Chinook as well.

For steelhead, the reported rate of residualism varies greatly, but typically averages 5-10 percent of the number of fish released (USFWS 1994). Studies examining the distribution of steelhead residuals within stream systems in the Snake basin report that in most cases these residuals set up residence near their release point (Whitesel et al. 1993; Jonasson et al. 1994; 1995 and 1996; Cannamela 1992). Partridge (1986) noted that most residual steelhead were within about 8 km of the upper Salmon River release site. Schuck et al. (1998) reported steelhead residuals were found about 20 km below and 10 km above release sites in the Tucannon River, Washington. Steelhead residual densities were highest within 8 km of release sites and decreased quickly above and below these sites in the Grande Ronde and Imnaha Rivers in Oregon (Whitesel et al. 1993).

The number of residual steelhead appears to decline steadily throughout the summer in most Snake River basin release areas. This may be due to harvest, other mortality, and outmigration. Viola and Schuck (1991) noted that residual populations in the Tucannon River of Washington declined at a rate of about 50 percent per month from June to October (declining from 4.3 to 0.8 percent of the total released). Whitesel et al. (1993) found residual steelhead up to twelve months after release, however, densities declined rapidly over time.

Acclimation ponds and volitional release strategies are currently the subject of active research in the Columbia River Basin. It is unclear at this time whether or not acclimating and volitionally releasing steelhead smolts can substantially reduce the proportion of residualized steelhead in all cases. WDFW appears to be able to substantially reduce the number of residualized steelhead by using a combination of acclimation, volitional release strategies, and active pond management whereby remaining steelhead are not released when sampling indicates the majority of remaining fish in a pond are males. This action is taken because preliminary WDFW research indicates that the majority of residualized steelhead are males. The ODFW monitoring has not confirmed WDFW results (USFWS 1994). The ODFW saw no reduction in steelhead residualism rates in 1993 from acclimated fish in comparison to direct stream releases; however, they did not employ active pond management strategies (USFWS 1994). Lindsay *et al.* (2001) found no difference in the number of residualized hatchery steelhead observed at the release site between acclimated and direct stream release groups. Lindsay *et al.* (2001) observed that residualism was related more to the size of the fish than to whether they were acclimated.

In the 1995-98 Biological Opinion for Hatchery Operations in the Columbia River Basin (NMFS 1995a), NMFS recommended that hatchery steelhead smolts be released at sizes between 170 and 220 mm total length (TL), approximately 163-212 mm fork length (FL), based primarily on

the work of two IDFG researchers, Cannamela (1992, 1993) and Partridge (1985). The maximum size recommendation was based on reports of higher residualism among steelhead over 240 mm TL and higher predation rates by residual steelhead over 250 mm TL. Analysis by IDFG suggests that the 220 mm maximum size is less than the ideal size to release smolts (Rhine *et al.* 1997). In several tests, these authors report that residualized steelhead are significantly smaller than smolts that emigrate. Of those steelhead smolts carrying PIT tags, 52.1 percent of fish released at 163-211 mm were detected at downstream dams, 66 percent of steelhead 212-250 mm TL were detected and 83.3 percent of steelhead greater than 250 mm TL were detected. Bigelow (1997) reported similar results in PIT tagged steelhead smolts released from Dworshak Hatchery. Over 70 percent of steelhead less than 180 mm TL were not detected at downstream sites, while approximately 85 percent of smolts over 180 mm TL were detected.

This information suggests that release of juvenile steelhead less than 180 mm TL will contribute to residualism and the ideal release size may be larger than 220 mm TL. However, concern for both residualism and predation by very large smolts (over 250 mm TL) is still valid. Jonasson *et al.* (1996) reported predation on naturally produced juvenile steelhead by residual hatchery steelhead as small as 189 mm TL, but in general the larger residual fish tended more toward predation. Overall, Jonasson *et al.* (1996) reports a low level of piscivory by residuals less than 230-250 mm TL.

As noted earlier, the topic of residualism has been traditionally associated with hatchery programs for steelhead. However, the adverse impact from residual Chinook and coho hatchery salmon on naturally produced salmonids is a possibility given that the number of smolts per release is generally higher and that the issue of residualism for these species has not been as widely investigated compared to steelhead. Therefore, for all species, the monitoring of natural stream areas downstream of hatchery release points is necessary to determine significance of hatchery smolt residualism on the natural origin juvenile salmonids.

C. Predation- productivity loss to target and nontarget populations due to predation caused by hatchery releases. Risks to naturally produced salmonids attributable to direct predation (direct consumption) or indirect predation (increases in predation by other predator species due to enhanced attraction) can result from hatchery salmonid releases in freshwater and estuarine areas. Hatchery-origin fish may prey upon juvenile naturally produced salmonids at several stages of their life history.   Newly released hatchery smolts have the potential to prey on naturally produced fry and fingerlings that are encountered in freshwater during downstream migration. Hatchery smolts that do not emigrate and take up stream residence near the point of release (residuals) have the potential prey on stream-rearing juveniles over a more prolonged period. Hatchery-origin smolts, sub-adults, and adults may also prey on naturally produced fish of susceptible sizes and life stages (smolt through sub-adult) in estuarine and marine areas where they commingle. Hatchery salmonids planted as non-migrant fry or fingerlings, also have the potential to prey upon natural-origin salmonids in freshwater and marine areas where they co-occur. In general, naturally produced salmonid populations will be most vulnerable to predation

when naturally produced populations are depressed and predator abundance is high, in small streams, where migration distances are long, and when environmental conditions favor high visibility. SIWG (1984) categorized species combinations as to whether there is a high, low, or unknown risk that direct predation by hatchery fish will have a negative impact on productivity of naturally produced salmonids (Table 18)

SIWG (1984) rated most risks associated with predation as unknown, because, although there is a high potential that hatchery and naturally produced species interact, due to a high probability of spatial and temporal overlap, there was relatively little literature documentation of predation interactions in either freshwater or marine areas. Predation may be greatest when large numbers of hatchery smolts encounter newly emerged fry or fingerlings, or when hatchery fish are large relative to naturally produced fish (SIWG 1984). Some reports suggest that hatchery fish can prey on fish that ½ their length (HSRG 2004; Pearsons and Fritts 1999), but other studies have concluded that salmonid predators prefer smaller fish and are generally thought to prey on fish 1/3 or less their length (Horner 1978; Hillman and Mullan 1989; Beauchamp 1990; Cannamela 1992; CBFWA 1996). Hatchery fish may also be less efficient predators as compared to natural-origin conspecifics, reducing the potential for predation impacts (Sosiak *et al*. 1979; Bachman 1984; Olla *et al*. 1998).

Table 1. Risk of hatchery salmonid species predation on naturally produced salmonid species in freshwater areas (SIWG 1984)

Hatchery Species	Naturally produced Species					
	Pink Salmon	Chum Salmon	Sockeye Salmon	Coho Salmon	Chinook Salmon	Steelhead
Pink Salmon	L	L	L	L	L	L
Chum salmon	L	L	L	L	L	L
Sockeye Salmon	L	L	L	L	L	L
Coho Salmon	H	H	H	U	U	U
Chinook Salmon	H	H	H	U	U	U
Steelhead	H	H	H	U	U	U

Note: "H" = High risk; "L" = Low risk; and "U" = Unknown risk of a significant impact occurring.

Due to their location, size, and time of emergence, newly emerged salmonid fry are likely to be the most vulnerable to predation by hatchery released fish. Their vulnerability is believed to be greatest as they emerge and decreases somewhat as they move into shallow, shoreline areas (USFWS 1994). Emigration out of hatchery release areas and foraging inefficiency of newly released hatchery smolts may minimize the degree of predation on salmonid fry (USFWS 1994).

Although considered as of "unknown" risk by SIWG (1984), data from hatchery salmonid migration studies on the Lewis River, Washington (Hawkins and Tipping 1998) provide evidence of hatchery coho salmon yearling predation on salmonid fry in freshwater. The WDFW Lewis River study indicated low levels of hatchery steelhead smolt predation on salmonids. In a total sample of 153 out-migrating hatchery-origin steelhead smolts captured through seining in the Lewis River between April and June 24, 12 fish (7.8 percent) were observed to have consumed juvenile salmonids (S. Hawkins, WDFW, personal communication, July 1997). The juvenile salmonids contained in the steelhead stomachs appeared to be Chinook

salmon fry. Sampling through this study indicated that no emergent wild-produced steelhead or trout fry (30-33 mm fl) were present during the first two months of sampling, however that is not surprising since wild steelhead in this system spawn primarily in April and May. Hawkins (1998) documented hatchery spring Chinook salmon yearling predation on naturally produced fall Chinook salmon juveniles in the Lewis River. A small number of spring Chinook salmon smolts were sampled (11), and remains of 10 salmonids were found (includes multiple observations of remains from some smolts). Predation on smaller Chinook salmon was found to be much higher in naturally produced smolts (coho salmon and cutthroat predominately) than their hatchery counterparts. Steward and Bjornn (1990) referenced a report from California that estimated, through indirect calculations, rather than actual field sampling methods, the potential for substantial predation impacts by hatchery yearling Chinook salmon on naturally produced Chinook salmon and steelhead fry. They also reference a study in British Columbia that reported no evidence of predation by hatchery Chinook salmon smolts on emigrating naturally produced Chinook salmon fry in the Nicola River.

Predation by hatchery fish on natural-origin smolts or sub-adults is less likely to occur than predation on fry. Fish consumed by coho salmon and Chinook salmon in the marine environment were observed by Brodeur (1991) to average one-fifth the length of the salmon examined.   During early marine life, predation on naturally produced Chinook salmon, coho, and steelhead will likely be highest in situations where large, yearling-sized hatchery fish encounter sub-yearling fish or fry (SIWG 1984). Juanes (1994), in a survey of studies examining prey size selection of piscivorous fishes, showed a consistent pattern of selection for small-sized prey. Hargreaves and LeBrasoeur (1985; 1986) reported that coho salmon smolts ranging in size from 100-120 mm fl selected for smaller chum salmon fry (sizes selected 43-52 mm fl) from an available chum salmon fry population including larger fish (available size range 43-63 mm fl). Ruggerone (1989; 1992) also found that coho salmon smolts (size range 70-150 mm fl) selected for the smallest sockeye fry (28-34 mm fl) within an available prey population that included larger fish (28-44 mm fl). However, extensive stomach content analyses of coho salmon smolts collected through several studies in marine waters of Puget Sound, Washington, do not substantiate any indication of significant predation upon juvenile salmonids (Simenstad and Kinney 1978). Similarly, Hood Canal, Nisqually Reach, and north Puget Sound data show little or no evidence of predation on juvenile salmonids by juvenile and immature Chinook salmon (Simenstad and Kinney 1978). In a recent literature review of Chinook salmon food habits and feeding ecology in Pacific Northwest marine waters, Buckley (1999) concluded that cannibalism and intra-generic predation by Chinook salmon are rare events. Likely reasons for apparent low predation rates on salmon juveniles, including Chinook salmon, by larger Chinook salmon and other marine predators suggested by Cardwell and Fresh (1979) include rapid growth in fry, resulting in the increased ability to elude predators and becoming accessible to a smaller proportion of predators due to size alone; and rapid dispersal of fry, making them present in lower densities relative to other fish and invertebrate prey. The learning or selection for predator avoidance.

Naman and Sharpe (in press) reviewed 14 studies of predation by yearling hatchery salmonids on subyearling wild fish. They found the level of predation generally to be low, but also found areas of localized heavy predation under certain circumstances. They concluded, as did McMichael et al. (1999) that managers can effectively minimize predation rate by minimizing the spatial and temporal overlap of the predator and prey populations. However, because even low predation rates could seriously impact prey populations that are at low numbers, they also recommend reducing the number of hatchery fish released in these situations.

Large concentrations of migrating hatchery fish may attract predators (birds, fish, and seals) and consequently contribute indirectly to predation of emigrating naturally produced fish (Steward and Bjornn 1990). The presence of large numbers of hatchery fish may also alter naturally produced salmonid behavioral patterns, potentially influencing their vulnerability and susceptibility to predation (Hillman and Mullan 1989; USFWS 1994). Hatchery fish released into naturally produced fish production areas, or into migration areas during naturally produced fish emigration periods, may therefore pose an elevated, indirect predation risk to commingled listed fish. Alternatively, a mass of hatchery fish migrating through an area may overwhelm established predator populations, providing a beneficial, protective effect to co-occurring listed naturally produced fish.

Hatchery impacts from predation can be minimized by:

- Releasing actively migrating smolts through volitional release practices.
- Ensuring that a high proportion of the population has physiologically achieved full smolt status. Juvenile salmon tend to migrate seaward rapidly when fully smolted, limiting the duration of interaction between hatchery fish and naturally produced fish present within, and downstream of, release areas.
- Releasing hatchery smolts in lower river areas, below upstream areas used for stream-rearing young-of-the-year naturally produced salmon fry, reducing the likelihood for interaction between the hatchery and naturally produced fish.
- Operating hatchery programs and releases to minimize the potential for residualism (see previous discussion).

D. *Marine-derived nutrients* - productivity decreases due to under- or overabundance of marine-derived nutrients from hatchery carcasses. The flow of energy and biomass from productive marine environments to relatively unproductive terrestrial environments supports high productivity in the ecotone where the two ecosystems meet (Polis and Hurd 1996). Anadromous salmon are a major vector for transporting marine nutrients across ecosystem boundaries (i.e. from marine to freshwater and terrestrial ecosystems). Because of the long migrations of some stocks of Pacific salmon, the link between marine and terrestrial production may be extended hundreds of miles inland. Nutrients and biomass extracted from the gametes and decomposing carcasses of spawning salmon may stimulate growth and restore the nutrients of aquatic ecosystems. Nutrients originating from salmon carcasses are also important to riparian plant

growth. Direct consumption of carcasses and secondary consumption of plants and small animals that are supported by carcasses is an important source of nutrition for terrestrial wildlife (Cederholm *et al.* 1999).

Current escapements of naturally produced and naturally spawning hatchery-produced anadromous salmonids in the Columbia Basin are estimated at about 7 percent of the historical biomass (Cederholm *et al.* 1999). Throughout the Pacific Northwest, the delivery of organic nitrogen and phosphorus to the spawning and rearing streams for anadromous salmonids has been estimated at 5 to 7 percent of the historical amount (Gresh *et al.* 2000). Cederholm *et al.* (1999) calculate the historical spawning escapement at 45,150 mt (metric ton) of biomass annually added to the aquatic ecosystems of the Columbia compared to 3,400 mt annually with current spawning escapements.

Artificial propagation programs in the basin add substantial amounts of fish biomass to the freshwater ecosystem. The annual hatchery production cap of nearly 200 million smolts, at 25 g/smolt average weight, adds about 5,000 mt of biomass to the Columbia Basin. Returning adults from artificial propagation programs have totaled 800,000 to 1,000,000 in recent years (ODFW and WDFW 1998). At the average weight of 6.75 kg used by Cederholm *et al.* (1999), 5,400 to 6,750 mt of fish biomass is potentially returned to the Columbia River annually due to artificial propagation programs. Of course, most of the hatchery smolt production is expected to leave freshwater and migrate to the marine ecosystem, but undoubtedly some is retained in freshwater and terrestrial ecosystems as post-release mortalities and consumption by predators such as bull trout, ospreys and otters. Much of the adult return from hatchery production may be removed from the ecosystem by selective fisheries or taken at hatchery weirs and traps.

However, the potential to utilize the marine-derived nutrients that are imported to freshwater ecosystems in the carcasses of hatchery returns may be of value for stimulating ecosystem recovery. Experiments have shown that carcasses of hatchery-produced salmon can be an important source of nutrients for juvenile salmon rearing in streams (Bilby *et al.* 1998). Hatchery carcasses may also replace some of the nutrient deficit in riparian plant and terrestrial wildlife communities where naturally produced spawners are lacking. The contribution of artificial propagation programs has the potential to exceed the contribution of naturally produced fish in replenishing the nutrient capital of aquatic ecosystems in the short term, but should not be regarded as a long term solution to replacing the nutrient subsidy provided by naturally produced salmon.

5. Harvest- Mortalities to target and nontarget populations due to harvest Fisheries managed for, or directed at, the harvest of hatchery-origin fish have been identified as one of the primary factors leading to the decline of many naturally produced salmonid stocks (Flagg *et al.* 1995; Myers *et al.* 1998). Depending on the characteristics of a fishery regime, the commercial and recreational pursuit of hatchery fish can lead to the harvest of naturally produced fish in excess of levels compatible with their survival and recovery (NRC 1996). Listed salmon and steelhead

may be intercepted in mixed stock fisheries targeting predominately returning hatchery fish or healthy natural stocks (Mundy 1997). Fisheries can be managed for the aggregate return of hatchery and naturally produced fish, which can lead to higher than expected harvest of naturally produced stocks.

In recent years harvest management has undergone substantial reforms and many of the past problems have been addressed. Principles of weak-stock management are now the prevailing paradigm. Listed salmon and steelhead are no longer the target of fisheries, as a result, mixed stock fisheries are managed based on the needs of natural-origin stocks. In many areas fisheries have been closed to protect natural-origin populations (e.g., before 2005 upper Salmon River spring Chinook salmon fisheries were closed to non-treaty recreational fishing for more than 20 years). Managers also account, where possible, for total harvest mortality across all fisheries. The focus is now correctly on conservation and secondarily on providing harvest opportunity where possible directed at harvestable hatchery and natural-origin stocks. For an in depth review of harvest management actions affecting Columbia River salmon and steelhead see chapter 3 of the LCFRB's recovery plan (LCFRB 2004). These management changes have resulted in harvest no longer being considered one of the top five limiting factors for almost all of the listed species (see Table 14).

Rutter (1997) observed that the effects on listed stocks from harvesting hatchery-produced fish can be reduced by certain management actions:

- Externally marking hatchery fish so that they can be differentiated from unmarked, natural fish.
- Conducting fisheries that can selectively harvest only hatchery-produced fish with naturally produced fish being released.
- Managing fisheries for the cumulative harvest rate from all fisheries to ensure impacts are not higher than expected (Mundy 1997).
- Ensuring that harvest rates are not increased because of a large return of hatchery fish, fisheries can be managed based on the abundance and status of naturally produced fish.
- Releasing hatchery fish from terminal areas so that returning adults can be harvested with little or no interception of naturally produced fish. Fisheries can occur near acclimation sites or in other areas where released hatchery fish have a tendency to concentrate, which reduces the catch of naturally produced fish.
- Reducing or eliminating the number of fish released from hatcheries if fisheries targeting hatchery fish cannot be managed compatible with the survival and recovery of listed fish.

Many hatchery programs produce rainbow trout (and other trout species) for recreational fisheries to meet mitigation obligations for lost recreational harvest opportunities. These programs have had an adverse effect on anadromous steelhead juveniles.

6. Monitoring and evaluation

Monitoring and Evaluation programs are necessary to determine the performance of artificial propagation programs. The Artificial Production Review (NPPC 1999) listed four criteria for evaluating both augmentation and mitigation programs:

1. Has the hatchery achieved its objectives?

2. Has the hatchery incurred costs to natural production?

3. Are there genetic impacts associated with the hatchery production?

4. Is the benefit greater than the cost?

Historically, hatchery performance was determined solely on the hatchery's ability to release fish (NPPC 1999), this was further expanded to include hatchery contribution to fisheries (e.g. Wallis 1964; Wahle and Vreeland 1978; Vreeland 1989). Past program-wide reviews of artificial propagation programs in the Northwest have indicated that monitoring and evaluation has not been adequate to determine if the hatchery objectives are being met (ISG 1996; NRC 1996; NFHRP 1994). The lack of adequate monitoring and evaluation has resulted in the loss of information that could have been used to adaptively manage the hatchery programs (NRC 1996).

Under the ESA, monitoring and evaluation programs for artificial production are not only necessary for adaptive management purposes but are required to ensure that artificial propagation activities do not limit the recovery of listed populations. Monitoring and evaluation of artificial propagation activities are necessary to determine if management actions are adequate to reduce or minimize the impacts from the general effects discussed previously, and to determine if the hatchery is meeting its performance goals. Monitoring and evaluation activities will occur within the hatchery facilities as well as in the natural production areas. Monitoring and evaluation within the hatchery can include measurements to evaluate hatchery production (i.e., survival, nutrition, size at age, condition, disease prevention, genetic makeup, total released, percent smolted, etc.).

Monitoring and evaluation to determine impacts on listed fish from artificial propagation programs can itself have potential adverse impacts on listed fish in the hatchery though injuries incurred during sampling and marking. Sampling within the hatchery can include direct mortalities (e.g., genetic analysis, disease pathology, smolt condition) and indirect take (e.g. sorting, marking, transfers). Marking of hatchery fish prior to release is required for all programs to monitor and evaluate hatchery effects (positive and negative). Marking is necessary to evaluate a number of objectives including selecting broodstock, determining hatchery stray rates and hatchery contributions to fisheries, and for the implementation of selective fisheries that target hatchery fish.

For hatchery supplementation programs, the goal is to promote the viability of natural-origin populations as the factors limiting viability are reduced by using hatchery fish to increase the number of natural spawners. Monitoring and evaluation for this goal requires the sampling of naturally produced adults and juveniles in natural production areas.

Monitoring and evaluating fish and fish assemblages in the natural environment is necessary to determine any positive or negative effects the artificial production program is having on the natural population. Genetic and life-history data may need to be collected from the natural population to determine if the hatchery population has diverged from the natural population and if the natural population has been altered by the incorporation of hatchery fish into the spawning population. Sampling methods can include the use of weirs, electro-fishing, rotary screw traps, seines, hand nets, spawning ground surveys, snorkeling, radio tagging, and carcass recovery. Each sampling method can be used to collect a variety of information. Sample methods, like tagging methods, can adversely impact listed fish, both those targeted for data collection and those taken incidentally to the data collection.

NMFS has developed some general guidelines to reduce impacts when collecting listed adult and juvenile salmonids (NMFS 1999d; NMFS 2000b) which have been incorporated as terms and conditions into section 10 and section 7 permits for research and enhancement activities (e.g., NMFS 1999c). Though necessary to monitor and evaluate impacts on listed populations from artificial propagation programs, monitoring and evaluation programs should be designed and coordinated with other plans to maximize the data collection while minimizing take of listed fish.

A. *Marking/masking*- Loss of monitoring precision due to marking rate and type. Returning adult hatchery fish can stray into natural spawning areas confounding the ability to determine the annual abundance of naturally produced fish. This can lead to an over-estimation of the actual abundance and productivity of the natural population, and to an inability to assess the health and production potential of the critical habitat for that population. This latter factor exists because the hatchery fish are not subject to the same spawning and early life history productivity limits experienced by the natural population in the natural freshwater environment. The abundance and productivity of the naturally produced fish and the health of the habitat that sustains them, is therefore "masked" by the continued infusion of hatchery-produced fish.

Masking of natural fish status by naturally spawning hatchery fish produced for harvest augmentation purposes was one basis for the recommended listing of the Puget Sound Chinook salmon ESU as "threatened" under the ESA (Myers *et al.* 1998). Annual spawning ground censuses of fall Chinook salmon populations had historically aggregated naturally spawning hatchery and naturally produced fish. When an identifying mark was applied to a proportion of the hatchery fish, efforts were made to subtract out hatchery fish from escapement estimates through expanded mark recovery estimates. In many instances, however, the release of unmarked hatchery fall Chinook salmon groups, predominately of a single stock, led to the situation where salmon spawning escapement abundances were artificially sustained, and the

actual annual abundances of the indigenous naturally produced fall Chinook salmon populations in some watersheds were over-estimated or unknown. The situation in the Puget Sound has been corrected and now all hatchery-origin Chinook salmon are marked; the great majority of Chinook released into the Columbia are also marked.

Attempts to identify and remedy anthropogenic factors adversely affecting fish habitat may be impeded through masking of natural fish status. For example, instability and degradation of spawning gravel areas through flooding during critical spawning or egg incubation periods may not be recognized as a limiting factor to natural production if annual spawning ground censuses are subsidized by returning adults from annual hatchery releases. If the vast majority of the adult fish observed were of direct hatchery origin, the poor natural productivity status of the spawning areas will not be evident without additional, expansive monitoring efforts.

Resolution of the masking issue can be achieved by:

- Providing an effective means to easily differentiate hatchery fish from natural-origin fish on the spawning grounds. A readily visible external mark applied to hatchery fish prior to release, combined with an effective spawning ground census program designed to derive separate estimates of hatchery and natural fish, is one avenue available. Mass marking of hatchery fish using an internal mark (e.g., otolith banding) may also be used to differentiate hatchery from natural-origin fish on the spawning grounds, if a statistically valid adult sampling design to collect and analyze mark recovery data is also implemented.
- Plant or release fish only in areas where "masking" is not an issue but still mark enough fish to monitor straying.
- Removing hatchery fish through selective fisheries or at weirs and dams.
- Imprinting hatchery fish to return to lower river or tributary areas not used by natural fish in a watershed.
- Reducing or limiting hatchery fish release numbers leading to decreased adult hatchery fish returns may also reduce masking effects.

B. *Methodology*-Injury and death caused by monitoring measures. This section is not yet developed.

C. *Adequacy*- risk of undetected impacts from low power or not monitoring all necessary areas (including inadequate equipment). This section is not yet developed.

D. *Adaptive management*-Threat to target and nontarget population(s) from inadequate adaptive management plan. This section is not yet developed.

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