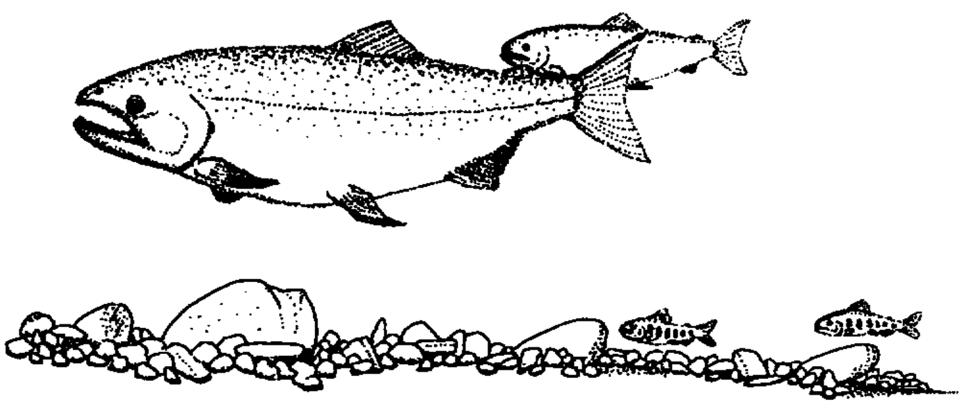
U.S. FISH AND WILDLIFE SERVICE

A REVIEW OF METHODS TO RE-INTRODUCE ANADROMOUS FISH IN THE ELWHA RIVER



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A Review of Methods to Re-Introduce Anadromous Fish in the Elwha River

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ABSTRACT

This review focuses on topics associated with supplementation of anadromous fish, through which guidelines were developed to assist in the refinement of the Elwha River fish restoration plan. With removal of the Elwha River dams, restoration of the river's anadromous fish resources can be accomplished in two ways: by letting nature take its course, and by releasing hatchery-reared fish into newly available habitat (supplementation). Different methods of supplementation are discussed, as are concerns with the supplementation process. A prime concern with supplementation is that hatchery/wild interactions can adversely affect recovery of natural runs. Fish reared in a hatchery may develop maladaptive, genetically-related survival traits which not only decrease their ability to survive in the natural environment, but may also decrease the fitness of the existing population through interbreeding. With this in mind, a number of available options for brood selection, brood development, and stock re-introduction are reviewed. Guidelines for brood selection include genetic, ecological, and life history considerations. Merits and rationale for traditional and captive brood development programs are discussed. Options for re-introduction include natural recolonization and outplanting of adults, eggs, pre-smolts, or smolts. Pros and cons of each option are discussed from both biological and economic standpoints. Monitoring and evaluating are critical components of the Elwha River fishery restoration plan.

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INTRODUCTION

The Elwha River Ecosystem and Fisheries Restoration Act (Public Law 102-495) was signed into law in October 1992. The goal of the act is the full restoration of the Elwha River's ecosystem and native anadromous fisheries, to be accomplished by removal of the Elwha River dams (U.S. Department of the Interior (USDI) et al. 1994). Ten anadromous fish stocks were historically present in the Elwha River prior to construction of the dams, but loss of upriver habitat acutely reduced their numbers.

The fish restoration plan included in the report submitted to Congress pursuant to Public Law 102-495 (USDI et al. 1994) provided prioritized options for the full restoration of all Elwha River anadromous fish stocks in the event of dam removal. As part of advanced planning for dam removal and fish restoration, the Elwha fish restoration plan will be refined so that it serves as a guide for future efforts. Owing to the depressed status of a number of anadromous Elwha River fish stocks, options in the Elwha fish restoration plan ranged from natural recolonization to hatchery brood development and subsequent outplanting.

The Federal Energy Regulatory Commission (FERC) also developed an anadromous fish restoration plan in the event Glines Canyon and Elwha Dams were removed (FERC 1992). It differed from the USDI et al. (1994) plan in these respects: 1) hatchery supplementation would be needed to speed recovery of all stocks, 2) outplanting would be limited to 10 years, 3) only fish from stocks in the Elwha basin would be used, 4) only wild, native stocks would be used for enhancement, 5) only smolt-sized fish would be released.

This review is intended to assist in refinement of the Elwha River fish restoration plan, and represents a search of available published and unpublished literature, summary of basin-specific work, and review of other major anadromous salmonid restoration efforts for fish stocks of interest. This review is divided into three categories in relation to Elwha River fisheries restoration: 1) broodstock selection; 2) broodstock development; and 3) re-introduction of anadromous fish after dam removal.

The literature supplies several definitions for supplementation. For this paper, supplementation is defined as: "the use of artificial propagation, while conserving genetic resources, for restoration of locally extinct populations to self-sustaining levels or augmentation of depressed populations to their carrying capacity" (Kapuscinski et al. 1993). The objective of Elwha River supplementation is restoration of native fish species to habitats where they have been extirpated, and hatchery involvement is proposed to accomplish this end (USDI et al. 1994).

It is important to note that successful attempts at restoring natural, self-propagating runs of Pacific salmon in depleted or barren areas, within their native range by means of hatchery-reared outplants, are few and far between. Most success from transplanting has occurred where access to unused spawning and rearing areas was provided by removing barriers to upstream migration. Pacific salmon have been successful transplanted outside their normal range (i.e., introduction), such as chinook in New Zealand, and coho and chinook in the North American Great Lakes (Withler 1982). Unfortunately, however, even supplementation projects perceived to be successful have been poorly evaluated and documented, and most supplementation projects have attempted to produce adult fish solely for harvest.

For the purpose of supplementing wild populations, several concerns with hatchery propagation have been recently voiced (Stickney 1994). These concerns are: 1) levels of genetic variability in hatchery and wild populations may differ, 2) hatchery fish may become increasingly homozygous compared to their wild counterparts, and 3) negative consequences may be associated with stocking hatchery fish on wild fish of a different stock, thereby altering the genetic makeup of locally adapted gene pools.

With these concerns in mind and considering the goals of Elwha River restoration, several lessons from supplementation of chinook salmon in British Columbia (Winton and Hilborn 1994) apply towards hatchery supplementation in the Elwha River restoration program:

- A system of monitoring and feedback should be in place to ensure program goals are being met.

- Supplementation should be viewed as an unproven technology, so the time required to accomplish restoration goals may be longer than anticipated.

- Supplementation facilities should be flexible constructions, ones that can be altered to incorporate the findings of experiments - rather than large, permanent structures built before it is known whether such facilities can accomplish the goals of the program.

BROODSTOCK SELECTION

Genetic and Ecological Concerns

There is a widespread, growing concern that enhancing existing populations of salmonids with fish that have spent part of their life in a hatchery can lead to adverse genetic and ecological effects. These concerns are due in part to the many uncertainties involved in manipulating a biological resource, and where there is uncertainty, there are risks (Bonneville Power Administration (BPA) 1992a). Busack (1990) defined four genetic risks associated with using artificial propagation to improve the production of naturally-spawning populations:

1) Extinction.

2) Loss of within-population variability.

3) Loss of population identity (between-population variability).

4) Inadvertent artificial selection (domestication).

Purposeful and inadvertent selection that occurs in a hatchery can result in fish that are maladapted for life in streams (e.g., inefficient foragers), and these non-adaptive traits can be passed on to the existing population, potentially adversely affecting its survival and fitness. Salmonid species are specifically adapted to features in the environment in which they develop; each stock is composed of genetically distinct, reproductively isolated sub-stocks (Lichatowich and McIntyre 1987). Natural selection ensures that genes and genotypes associated with fitness-enhancing traits increase in relative frequency, and thus stocks adapt to local environmental conditions (Steward and Bjornn 1990).

Genetically related behavioral and physiological traits of fish have been altered within the first generation of hatchery experience, and these can cause poor performance in the natural environment and ultimately decrease survival and fitness of the stocked population. If interbreeding with a wild population takes place, it can decrease its survival (BPA 1992a). Lichatowich and McIntyre (1987) provided evidence that progeny of hatchery parents have a lower survival in the natural environment than progeny of wild parents.

Tables 1 and 2 list the survival-related characteristics of Pacific salmonids which can be altered by the hatchery environment, and the specific hatchery treatments affecting survival of hatchery fish (BPA 1992a).

The conservation of a species requires protection of its genetic resource so it retains the capacity for adapting to a changing environment. Since the genetic structure of a local fish population enables adaptation to specific environmental conditions, interference with this close match of genotype and environment through the introduction of foreign stocks is potentially disastrous (Reisenbichler and McIntyre 1986).

When hatchery fish are genetically different from wild stocks and interbreeding takes place, there is a decrease in survival-to-adult and considerable loss of desirable genes that natural selection has provided to increase the fitness for a particular environment (Reisenbichler and McIntyre 1986). The migration of sockeye fry from the incubation area to the nursery lake appears to be a deliberate, genetically controlled movement (Brannon 1967), an example of the crucial role genetics play in the survival of a particular salmonid stock. Chilcote et al. (1986) presented evidence that the survival-to-smolt of progeny of hatchery steelhead was approximately 28% that of offspring from wild spawners. Reisenbichler and McIntyre (1977) demonstrated significantly higher survival among offspring of wild steelhead compared to hatchery X wild progeny stocked in natural streams, and concluded that when hatchery fish interbreed with wild fish there is potential for a reduced number of smolts produced in the wild.

Potential also exists for a naturally existing population to go extinct as a result of interbreeding with an outplanted population. As reported by Altukhov (1981), the genetic characteristics of a chum salmon stock returning to the Soviet Union's Naiba River gradually shifted from those of the naturally existing stock to those of the introduced stock.

Not only is the survival and fitness of the stock to be supplemented a concern, but also the ability of the hatchery-reared fish to adapt to the natural environment. Reisenbichler and Brown (1994) noted that three separate studies found steelhead populations genetically less fit for rearing in natural streams than wild fish after two generations of hatchery rearing, and fitness declined further with increasing generations. Behavior learned in the hatchery potentially predisposes hatchery fish to higher rates of predation, lower feeding efficiency, or suboptimal habitat use, the degree of which is unknown (BPA 1992a).

Hatchery fish released into a natural stream also affect and are affected by ecological interactions within the system, including, but not limited to, the physical habitat and its biota, which includes predators and competitors (BPA 1992a). The total extent to which the introduction of hatchery-reared fish affects the ecology of a stream community is unknown.

In any fish culture program, genetic drift and inbreeding may result in eventual reduction of genetic diversity within the population (Quinton 1991). Allendorf and Ryman (1987) reported that even a 10% reduction in genetic variation had detectible harmful effects on vital traits such as growth rate and survival. It is crucial, therefore, that if artificial propagation is used to improve the production of naturally-spawning populations without negative genetic and ecological effects, the program must be designed to conserve the genetic identity and variability of the target population and hold the competitive and predatory impacts on other populations within prescribed limits (BPA 1992a). Preserving the genetic characteristics of the population to be supplemented should be the primary consideration in developing a supplementation strategy (Ryman and Stahl 1980).

Brood Selection Concerns

Preventing the erosion of existing genetic diversity is essential if stock productivity is to be maintained (Wilkins 1981). In supplementing a remnant stock with hatchery-reared fish, the primary choice for brood stock should be that of the existing wild population, if the target population has a good chance of maintaining natural reproduction in the face of broodstock collection (Reisenbichler and McIntyre 1977; Reisenbichler 1984; Krueger et al. 1981; BPA 1992a; Lichatowich and McIntyre 1987; Kapuscinski et al. 1993). Alaska Department of Fish and Game's genetic policy for aquaculture practices requires that a watershed with significant wild stocks only be stocked with progeny of existing stocks (Davis 1985).

If a remnant population is non-existent or so small that the loss of genetic variation through inbreeding is probable, Krueger et al. (1981) suggested collecting gametes from many wild populations, performing all possible crosses to maximize genetic variation, then stocking the progeny and allowing the natural environment select the most fit individuals. Similarly, Bams (1976) proposed increasing the genetic diversity of a remnant stock by means of hybrid introduction may actually increase the fitness of the remnant stock and decrease the time it takes for a stock to genetically adapt to a stream.

If the use of local stock is not feasible, or a local stock is not available, the donor stock should be drawn from a neighboring population which is genetically similar, has similar life history patterns, and is from an environment of greatest ecological similarity (Kapuscinski et al 1993; Reisenbichler and McIntyre 1986; Krueger et al. 1981). Fedorenko and Shepherd (1986) suggest that a donor stock originate within 100 km of the recipient stream as measured between mouths of systems along connecting bodies of water. Lichatowich and McIntyre (1987) note that if interbreeding takes place between a natural/wild stock and a hatchery-reared stock which is genetically and geographically different, the resulting population could be less adaptive with an impaired ability to respond to environmental changes.

If suitable neighboring populations are unavailable or too vulnerable, the next choice of a donor stock should be a non-neighboring stock from an ecologically similar environment, with similar life history patterns, and a close phylogenetic relationship (Kapuscinski et al. 1993).

The last priority for selecting a donor stock is a hatchery stock, preferably one derived from the now-extirpated population (Kapuscinski et al. 1993).

Steward and Bjornn (1990) suggest that broodstock should be continually "refreshed" with wild genes. More specifically, Allendorf and Ryman (1987) suggest a 10% contribution of wild genes every second or third generation to introduce new alleles and to minimize adaptation to the hatchery.

The Yakima Fisheries Project (YFP) aims to increase naturally reproducing salmonid stocks in the Yakima River Basin by re-introducing anadromous fish stocks formerly present (BPA 1992b). The YFP relies on hatchery outplants of juveniles. Stocks currently absent from the Yakima basin would be enhanced by releasing the hatchery-released progeny of adults collected in other, ecologically similar sub-basins (BPA 1992b). The main feature of the YFP is to conserve genetic resources by implementing strategies which would minimize potential for adverse genetic impacts. These strategies include:

- Using native adults for broodstock.

- Marking all hatchery outplants and using only unmarked adults as brood.

- Using large numbers of adults for brood so that the adults obtained represent the donor stock, but not so many adults that broodstock collection would impair its viability or long-term fitness.

- Using mating schemes that maximize genetic diversity of offspring, and reducing or eliminating hatchery practices that subject fish to adverse selection pressures.

Life History and Behavioral Concerns

In developing broodstock for supplementation, genetic and environmental similarity and geographic location are primary criteria, but other important factors include: 1) matching life history patterns to maintain the fitness of the population targeted for supplementation (Kapuscinski et al. 1993); and 2) matching the freshwater and marine conditions of the donor and recipient sites to maximize the biological and environmental suitability of the donor stock (Fedorenko and Shepherd 1986). Relevant life-history patterns include: prespawning adult migration and spawning; age structure of spawning adults; habitat preference; fry emergence; length of juvenile residency; migration distance; and route orientation (Fedorenko and Shepherd 1986; Kapuscinski et al. 1993).

Winter et al. (1990) emphasized the importance of gaining a better understanding of habitat requirements and life history patterns of the stock to be supplemented before actual supplementation takes place. Lichatowich and McIntyre (1987) cautioned, however, that life history behavior of salmonids cannot be totally predicted since such characteristics will be strongly influenced by the new environment. In Elwha River fishery restoration, spawn time of brood fish should match the expected optimum spawn time of fish in various portions of the Elwha River (Reg Reisenbichler, National Biological Survey, personal communication). An example of specific behavior that must be matched when selecting a brood source is in sockeye salmon fry which, after incubation migrate to the nursery lake specifically from either upriver, downriver, or directly from the beach (Brannon 1967).

Selective Breeding Concerns

Selective breeding has been used in aquaculture to increase the incidence of desired traits of a hatchery stock, but this practice at the same time may alter the gene pool of wild stocks and decrease genetic diversity (Steward and Bjornn 1990). As reported by McIntyre et al. (1988), selective breeding to increase survival of Oregon's Big Creek Hatchery coho did not provide sustained increases in survival, and may have inadvertently contributed to an overall decline in stock fitness.

The most direct way to achieve a genetic optimum may be to avoid selective breeding in hatcheries and to select brood fish randomly from among all adults produced in the outplanting system (Reisenbichler and McIntyre 1986). Krueger et al. (1981) also suggested that since the fitness of a planted stock is unpredictable, artificial selection for single traits should be avoided since it both decreases genetic variability and the ability of the population to adapt. However, selective breeding for time of spawning may be necessary because hatchery populations typically spawn earlier than comparable wild populations (Reisenbichler and McIntyre 1986).

Fish Health Concerns

A major consideration in stock selection is the transfer of pathogens. The use of pathogen-free donor stocks is necessary to prevent the spread or introduction of disease agents, and to increase overall transplant survival (Steward and Bjornn 1990). The Washington State Salmonid Disease Control Policy lists restrictions and guidelines to be followed when transferring eggs and fish within and outside health management zones, as listed in Section VII of the policy (Northwest Indian Fisheries Commission (NWIFC) et al. 1991).

According to Ray Brunson (U. S. Fish and Wildlife Service (USFWS), Olympia Fish Health Center, personal communication) egg transfers are preferred over adult transfers primarily because of logistical reasons. He strongly suggests that if eggs are imported, the receiving hatchery should have the capacity to isolate the eggs until the status of the adults is known.

The Salmonid Disease Control Policy states that eggs from anadromous and captive broodstocks may be transferred within an egg health management zone (EHMZ) (Figure 1), provided the adults are screened for reportable viral pathogens and the eggs are held in isolation until their status is known. Screening adults involves collection of ovarian fluid and kidney/spleen tissue, thereby sacrificing each adult screened. Eggs from anadromous and captive brood stocks may be transferred outside an EHMZ only if all adults from a specific spawn date, whose progeny are to be transferred, have their ovarian fluid and milt or kidney/spleen tissues screened for viruses at the 100% level.

Transfers within a Fish Health Management Zone (FHMZ) (Figure 2) must meet the following:

- An adult health inspection report.
- An on-site pre-transfer/release health examination if fish have been exposed to untreated surface water.
- A five-year history of reportable pathogens found within the facility and watershed.

The policy also states that fish transfers between watersheds within a FHMZ are permitted, provided that the transfer does not expose the receiving watershed to a reportable bacterial or parasitic pathogen which has not been detected there within the last five years. Fish may be transferred outside of a FHMZ if the conditions listed above are met, and if: 1) the fish are being transferred from fresh to saltwater, or from salt to freshwater; 2) the fish were reared on specific reportable pathogen-free water; and 3) 100% screening of adult ovarian fluid and milt has been performed (NWIFC et al. 1991). The disease control policy also states that fish testing positive for a reportable viral pathogen will not be transferred outside their natal watershed unless the transfer is to an approved quarantine research facility.

Imports from outside the United States, including live or dead uneviscerated salmonids, live fertilized eggs, or gametes, must be accompanied by a "Title 50" inspection report in addition to the requirements listed under transfer outside an EHMZ or FHMZ (NWIFC et al. 1991). The Title 50 report certifies that the lot has been sampled according to methods described in Section 16 of Title 50, and that IHN, IPN, and *Oncorhynchus masou* virus have not been detected in fish stocks from which the samples were taken (USDI 1993). A lot is defined as "a group of fish of the same species and age that originated from the same discrete spawning population and that have always shared a common water supply" (USDI 1993). Sampling includes tissue and fluid collection from fish and disinfection of eggs, with specific requirements on methods and processing described in Section (e)(1)-(4), Title 50. In addition, live salmonids can be imported into the United States only upon written approval from the Director of the USFWS.

The Elwha fish restoration plan included several brood selection options involving the transfer of adults within and outside health management zones (USDI et al. 1994). Option 3 for re-establishing the Elwha summer steelhead run is to import a suitable stock from the Soleduck River or Calawah River, which are both outside the Elwha FHMZ (Figure 2). Secondary options for re-establishing pink and spring chinook salmon include importing stocks from the Dungeness River, which are inside the Elwha FHMZ (Figure 2). If these options are chosen for implementation, the adults must be screened in accordance with Section VII of the Salmonid Disease Control Policy. The screening process is potentially costly and time consuming, and cross-zone transfers may not be biologically practical since 100% screening of ovarian fluid and milt is required.

BROODSTOCK DEVELOPMENT

There are two primary options in brood stock development: 1) a traditional hatchery program, and 2) captive brood, a more recent strategy generally reserved for populations threatened with extinction. Both methods require the collection of gametes, and the rearing of progeny in an artificial environment. Both methods also pose risks from unforeseen failure of the program.

In broodstock development, the following should be considered to maximize genetic variability:

1) Number of breeders. A key consideration is that brood collection take into account the potential effect of supplementation on the total effective breeding population, as well as representation in the collection itself (National Marine Fisheries Service (NMFS) 1992). The number of spawners used should ensure that genetic variability is passed from one generation to the next (Wilkins 1981), without adversely affecting the source population. Recommendations on minimum numbers of breeders vary depending on objectives and species; a qualified geneticist should be consulted in developing specific brood collection plans. Generally, when large numbers of individuals (100 or more) are randomly mated, less than 0.5% reduction in the original genetic variation may be expected after one generation (Steward and Bjornn 1990). Shaklee and Marlowe (1994) reported that to avoid substantial reductions in genetic variability in the short-term (fewer than five generations), an effective population size of at least 50 per generation is necessary, while in medium- (5-20 generations) and long-term (> 20 generations) programs, an effective population size may be 500 or more. In species with little or no overlap in year classes, such as pink salmon, even more breeders may be desirable (NMFS 1992). Additionally, Quinton (1991) and Kincaid (1979) suggested a minimum of 250 breeding pairs, while Ryman and Stahl (1980) suggested no less than 30 pairs. In Alaska, Davis (1985) recommended a minimum of 200 pairs, while for Washington state salmon hatcheries, Hershberger and Iwamoto (1983) suggested a minimum of 100 pairs.

2) Sex ratio. There is general agreement in the literature that maintaining a male-to-female ratio of 1:1 minimizes inbreeding (Shaklee and Marlowe 1994; Kapuscinski and Jacobson 1987; Quinton 1991; Kapuscinski et al. 1993). Gametes from different individuals should not be mixed prior to fertilization, as differences in potency of milt exist (Withler 1988).

3) Mating pattern. Random mating and avoiding deliberate selection of breeding pairs for phenotypic patterns should be followed (Quinton 1991). Factorial designs increase the probability of unique genetic combinations in the progeny (NMFS 1992). Cryopreserving milt can also increase the effective population size; maintaining a "sire bank" can provide additional breeders in years when then number of males is low (NMFS 1992). However, low fertilization rates have occurred with cryopreserved sperm, possibly because it blocks micropyles (Smith 1994). Recent cryopreservation experiments with chinook milt at Coleman National Fish Hatchery, California, showed fertilization decreased 2-21% during the twelve minutes it took to freeze samples. Samples frozen one week yielded eyeups ranging from 75-82%, and after one month, 70-89% (Freid 1994).

4) Source population. Given the risks involved in all supplementation programs, particularly those targeting depressed populations, adverse impacts to the natural population should be avoided. Winter et al. (1990) suggested that in brood collection, at least 75% of the native population should remain in the river to guard against failure of the supplementation effort.

5) Brood collection. To obtain a sufficient sample of the existing gene pool, brood should be collected from the entire run without regard to size, age, and other measurable phenotypic characters, if possible, so that gametes reflect those of the natural population (Quinton 1991; NMFS 1992). A common phenomenon in hatchery populations is advancement and compression of run timing due to brood selection practices; these changes can affect future generations of naturally spawning fish (NMFS 1994).

6) Duration of program. To minimize the potential selection of maladaptive traits within the hatchery, brood collection should be restricted to one generation, if possible (Davis 1985).

Traditional Hatchery Program

The traditional hatchery program requires the collection of adults, collection of gametes, and the production of pre-smolts or smolts for release. This strategy has been successful in a number of instances, but primarily for increased production for harvest. A variation of this approach in run rebuilding is to rear fish to smolt and release them in an environmentally "safe" stream (such as White River spring chinook released in Minter Creek), although this tactic assumes that selection will not work against eventual re-establishment in native habitat, and that survival of transplants will be favorable (Shaklee and Marlowe 1994).

Additional strategies in traditional rearing which lessen risk include combinations of fish culture, such as the White River chinook program which uses saltwater net pens in combination with anadromous returns to a facility on a non-native stream (Minter Creek) and the native stream (White River) (Shaklee and Marlowe 1994). This approach also guards against accidental loss by dividing gametes into two or more independent facilities, as is advocated for rebuilding depressed or threatened stocks (NMFS 1992).

Another issue with traditional hatchery programs is that hatchery releases may coincide with smaller, younger, newly emergent fry produced by natural spawners. This may result in predation and competition, decreasing the survival of naturally produced fish (Shaklee and Marlowe 1994).

Hatchery environments may alter both environmental and genetic components of performance traits through inadvertent artificial selection. The closer the hatchery environment is to the natural conditions found instream, the better adapted fish will be when released into the wild, potentially increasing their survival.

It is desirable to design and incorporate natural incubation and rearing techniques in hatchery programs designed for supplementation. Such techniques are termed *innovative* hatchery practices. Lestelle et al. (1994) suggested the use of innovative hatchery practices to improve survival of hatchery-reared fish in the Columbia basin. These practices included exposure to habitat complexity, predator training, and use of live food. Kapuscinski et al. (1993) also suggested simulating natural incubation and rearing conditions by incorporating the following in supplementation programs:

1) Simulate natural intragravel environment during incubation, including substrate, light, temperature, and oxygen conditions. For example, the use of rugose substrate (5 layers of plastic mesh) in incubating coho salmon was examined by Fuss and Johnson (1988), who found that alevins reared on artificial substrate were longer and heavier than those reared without over a 12-month period. Survival in raceways was also higher in the artificial substrate group. The use of artificial substrates has also been used to improve the quality of chum and pink salmon fry (Fuss and Johnson 1982, as cited by Fuss and Johnson 1988).

2) Simulate natural juvenile rearing conditions. This includes maintaining rearing densities below full carrying capacity in order to yield the highest number of natural spawners per unit volume of rearing area; incorporating key structural components of salmonid habitat into hatchery design (e.g., artificial cover for development of antipredator responses); and modifying current feeding practices to reflect natural feeding opportunities.

In the Yakima basin, fish restoration plans include hatchery-rearing methods which encourage adaptation of released fish to the natural environment, promoting traits to avoid predators and improve foraging for food (BPA 1992b).

Ongoing research by Washington Department of Fish and Wildlife (WDFW) also suggests that innovative hatchery techniques significantly improved survival of Satsop River fall chinook salmon (Steve Schroeder, WDFW, personal communication). Fall chinook reared under semi-natural conditions at Simpson Hatchery (using Christmas tree cover, underwater feeding, and camouflage netting in raceways) survived about 30% higher than traditionally-reared controls during initial emigration (to a trap 19 river km below the hatchery). At the trap, "natural" reared chinook exhibited more natural coloration than controls, and appeared to have improved foraging and predator-avoidance behaviors. These findings were consistent with similar studies in Anderson Creek (Hood Canal) and the Yakima River basin.

Further work at Simpson Hatchery will focus on identifying features to incorporate in the hatchery environment which are manageable in a traditional production facility. Although long-term survival has not yet been assessed, innovative hatchery techniques appear to have significant potential for Elwha River fish restoration efforts.

Captive Brood Program

A captive broodstock program typically involves the collection of gametes or fish from the natural population which are held for their entire life cycle in fresh of saltwater pens (or a combination of both), spawned at maturity, and their progeny returned to the source watershed (Shaklee and Marlowe 1994). The high fecundity of salmon coupled with potentially high survival in protective culture offer a unique opportunity to produce large numbers of juveniles for supplementation in a single generation, and it may be the preferred option if extinction is imminent (NMFS 1992).

The primary disadvantage of captive brood is increased biological and genetic risks due to the extended period of time spent in an artificial environment, which exempts fish from normal effects of natural selection, possibly inducing unfavorable genetic change in the existing population (Shaklee and Marlowe 1994). Captive brood is highly experimental, with uncertainties regarding the life stage to collect. The later the life stage collected, the greater the opportunity for natural selection to occur and the closer the broodstock resembles the natural population, but the greater the difficulty in acclimating to the hatchery environment (NMFS 1992).

Additional concerns include whether to culture in fresh or saltwater, and whether fish health can be maintained (Shaklee and Marlowe 1994). BPA (1992c) and Kapuscinski et al. (1993) recommended that captive brood be used only as a last resort when a population is close to extinction. Joyce et al. (1993) report viable spawning can be accomplished with adult chinook reared to maturity in seawater pens; however, cultured fish matured younger and smaller, therefore producing smaller eggs and fry than did wild or anadromous fish of the same stock.

The White River spring chinook captive broodstock program, cooperatively managed by the Muckleshoot Tribe and WDFW, is successful in rearing spring chinook salmon. This program was developed in the 1970s to restore spring chinook indigenous to the White River (WDFW 1994a). In the last four years, 800,000-1,000,000 smolts have been released into the White River, with 70% of the eggs taken from the captive brood program (Andy Appleby, WDFW, personal communication). Each year, the program receives 3,500 yearling fish, which are selected randomly from a pond containing yearling smolts for release. The parentage of these smolts is a mixture of anadromous (Hupp Springs and Muckleshoot Hatcheries) and the captive brood programs. Smolts are transferred to saltwater net pens and, upon maturation, moved to freshwater for spawning (WDFW 1994a). To reduce the impacts of environmental stress, rearing densities are kept low in the net pens. Although this program has great potential and has increased the number of viable chinook eggs, fecundity and egg viability have been less than from anadromous sources (WDFW 1994a).

In reviewing the proposed Dungeness chinook captive brood program, Winter et al. (1990) suggested that no cultured broodstock line be maintained beyond a single generation in captivity and that captive brood programs be of short duration. They also recommended a captive brood program be designed to withdraw as few adult fish from the native population as possible (less than 25%), yet maintain a genetically viable broodstock reflective of the wild genome. This may be accomplished by using appropriate line-crossing breeding schemes, enabling the withdrawal of 25-50 pairs from the native population for only three years and reducing the withdrawal to 10 pairs or less in subsequent generations.

STOCK INTRODUCTION

There is no single re-introduction strategy considered best under all circumstances. Many considerations for releasing hatchery fish must be taken into account when supplementing wild or natural populations. The age, time, size, density, location, and duration of releases can have a major impact on the growth and survival of fish released and on the existing fish population. As suggested by Kapuscinski et al. (1993), the age at release should match the dynamics of the target population and its environment, and the size and time of release should match patterns of resident fish.

Fedorenko and Shepherd (1986), in their review of production-oriented transplants of Pacific and Atlantic salmon, noted three factors common to successful introductions of self-sustaining runs: 1) massive outplants, 2) persistence of the transplant effort, and 3) release of large and healthy juveniles. However, relatively few examples of self-sustaining transplants were reported overall, and success varied by species.

Among Pacific salmon, coho are probably the easiest species to transplant or re-introduce (Fedorenko and Shepherd 1986). Coho are very plastic as indicated by their wide geographical and ecological distribution, high disease resistance, and affinity for artificial propagation. Coho also exhibit a shorter grazing range and are therefore less likely to stray during ocean migration. Coho may be the most rapid colonizers of new habitat, using small tributaries that experience relatively frequent, temporary blockages -- many examples exist where coho have rapidly colonized previously available habitat (NMFS 1994). On the other hand, chinook and sockeye salmon have been outplanted extensively, but relatively few self-perpetuating stocks have resulted. Pink salmon have the lowest outplant success because of high vulnerability to predation, straying, and their rigid two-year age structure that places entire year classes at risk under adverse conditions (Fedorenko and Shepherd 1986). Specific examples applicable to Elwha restoration follow.

The Regional Assessment of Supplementation Project (RASP), an initiative to assist in planning supplementation for the Columbia Basin, developed the Ecosystem Diagnosis and Treatment (EDT) Model (Lestelle et al. 1994). This model is a tool for planning supplementation projects. It attempts to consider the possible outcomes, and assess risks and benefits of supplementation, under different sets of assumptions about the natural production system and the integration of artificially propagated fish into that system. The central uncertainty the model attempts to clarify is "under what set of conditions will supplementation of natural and wild salmon production with hatchery production add to the total production of salmon, steelhead, or other targeted fish over the long term?" (Lestelle et al. 1994).

Although based on assumptions, the EDT model is intended to refine expectations or objectives, *not* predict a specific outcome. It is a spreadsheet model, and is especially useful for examining interactions between life stages, effects of population density, and the role of habitat quantity and quality characteristics. The EDT model is currently configured for chinook populations that smolt as yearlings, so would require modification before applying it to the Elwha. Spreadsheet software is not available at this date.

A plan prepared by Gaia Northwest Inc. (GNW) (1993) outlines strategies for the re-establishment of anadromous fish runs in the upper Cowlitz River. The plan includes spawning anadromous adults (chinook, coho, and steelhead), incubating their eggs, and releasing smolts, fed fry, or pre-smolts into appropriate habitats. Possible fry-release strategies include use of satellite ponds, with volitional migration into the river, or direct introduction into mainstem and tributaries. Two other proposed strategies for implementation include: 1) collecting adult salmon and releasing them in the upper river; and 2) incubating surplus eggs in streamside incubation boxes, allowing volitional migration. GNW recommended that each strategy be attempted and that results be evaluated to guide future enhancement. No details were given in regards to timing or location of release, or to brood sources.

Adult Colonization

Reliance on natural colonization by adults was not considered a primary option for most stocks in the Elwha restoration plan (USDI et al. 1994). Adult fish could be expected to penetrate the upper drainage and establish themselves over varying lengths of time once access was re-established, provided a reasonable source stock exists in the lower river. However, in some cases (e.g, pink salmon) a source stock may not exist, or the existing stock may not be desirable for long-term natural production in the system because of genetic, disease, or other considerations (e.g., non-native summer steelhead). Additionally, natural colonization could be lengthy compared to outplanting.

However, adult colonization can be effective, if not rapid, as indicated by available case studies. In the South Fork of the Skykomish River, when access to 145 rkm above Sunset Falls (a natural barrier) was provided, adult chinook and pink salmon penetrated the upper reaches of the basin, and their populations peaked in 15 and 25 years, respectively (Seiler 1991). In particular, the initial pink salmon escapement was only 150 individuals and escapements remained low for the following ten cycles, then trebled over each of the next two cycles and reached 20,000, due in part to the species' short, two-year life cycle.

Pink salmon use of upriver portions of the Kakweiken River, Alaska, coincided with years in which a fishway was installed, allowing passage around a previously impassable falls (Withler 1982). As well, Fraser River pink salmon now numbering millions have re-established areas above Hell's Gate, where a slide in 1913 completely barred them from upriver spawning grounds (Withler 1982).

In the upper Snake River basin of Idaho, construction of Sunbeam Dam in 1910 may have totally blocked all sockeye salmon native to the Stanley Lakes for over 10 years. After Sunbeam Dam was removed in 1934, several thousand sockeye were again returning to the basin by the 1950s (Bjornn et al. 1968, as cited by Rieman et al. 1993).

In Oregon's Clackamas River, failure of the Cazadero Dam fishway in 1917 blocked all coho salmon passage to the upper basin until the fishway was repaired in 1939. Coho re-invaded the upper Clackamas watershed immediately after access was regained, although exact escapement counts are not available (Douglas Cramer, Portland Gas and Electric Company, personal communication). By at least 1958, however, the coho run had naturally rebuilt (Cramer and Cramer 1994).

Adult Outplanting

Adult outplanting was not proposed in the Elwha fish restoration plan (USDI et al. 1993); natural adult recolonization was perceived to be a more effective, albeit slower, adult re-introduction approach. Some basin-specific information exists on adult outplanting which indicates that at least steelhead will continue to ascend the river and spawn after outplanting, although fallback could be substantial because outplants would not be imprinted to the upper watershed. As well, evaluation of spawning success can be especially difficult (particularly during the winter survey period), as noted below.

In 1983, adult summer-run steelhead (non-native lower river hatchery returns) were radio-tagged and released from July to September at Lake Mills and the upper mainstem (Wampler 1984). Some late-summer outplants ascended the upper river almost 16 km, but nearly one-third of all outplants eventually fell back. Due to transmitter failure, no spawning was observed. In addition to the stress of tagging, lack of imprinting to the upper river was undoubtedly a factor in the high fallback rate. Similar studies of summer run steelhead fallback in Oregon's South Santiam River suggested greater fallback among lower-river imprinted adults than upper-river imprinted adults at Foster Dam (D. Buchanon, Oregon Department of Fish and Wildlife (ODFW), personal communication, as cited by Wampler (1984)).

Four additional adult outplants were made in the mid and upper Elwha River, and surveys indicated that some spawning occurred near the release sites (Table 3). Adult summer steelhead and coho salmon were outplanted in Indian Creek, but spawner surveys and subsequent juvenile surveys (for coho fry) were ineffective due to poor survey conditions. Adult winter steelhead outplants in Lake Mills spawned in Cat Creek (a Lake Mills tributary) and also in the mainstem immediately above Lake Mills. Several spawned-out winter steelhead fallbacks were later recovered in Lake Aldwell (Wunderlich and Dilley 1986).

In their review of salmon transplant efforts, Federenko and Shepherd (1986) noted only one clearly successful example where a salmon run was developed with adult outplants, and this occurred in conjunction with outplants of other life stages (eggs and fry). Sockeye transplants in Frazer Lake, Kodiak Island, Alaska, over one decade resulted in a significant, self-sustaining sockeye run in a previously inaccessible lake system. Over 30,000 adult sockeye (and 3 million fry and 8 million eggs) were introduced from a nearby stock. The relative value of adult versus egg and fry outplants in developing the run was never fully determined, however.

Outplants of adult (and juvenile) coho in historically inaccessible habitat in the Willamette River basin began in 1970 with improvement of a fishway over Willamette Falls. However, returns never met expectations and, after one decade, adult outplants were discontinued due to low fishery contributions and concerns regarding competition with native game fish (Douglas Cramer, Portland Gas and Electric Company, personal communication; Foster 1993).

Egg Outplanting

Egg outplanting involves the introduction of fertilized eggs in the streambed itself, or in containers within or alongside the stream, allowing embryos to hatch and volitionally enter the stream.

Unlike other outplants (e.g. pre-smolts or smolts), which require some degree of hatchery rearing, eggs requires little hatchery involvement. Other advantages of egg outplanting, particularly in streamside containers, include (Zimmer 1964):

1) No transport-related stress during release as with pre-smolt or smolt outplants.

2) Emergence timing, behavior, and pace of introduction to the stream is more natural (assuming temperature of the water source and the stream is similar).

3) Potentially low maintenance and cost.

4) Potentially high survival during incubation.

Successful stock introductions from egg outplanting include development of a sockeye run to Great Central Lake, Vancouver Island, which was historically inaccessible (Federenko and Shepherd 1986). After massive annual egg plants (20 million eyed eggs in total) for one decade in the lake's headwater tributary, a self-sustaining run was eventually established.

Two other successful sockeye introductions involving egg outplanting occurred in: 1) the Upper Adams River in the Fraser system, British Columbia, following clearing of blockages in Hell's Gate, and 2) the Frazer Lake, Kodiak Island, Alaska, after passage was provided to this system (as noted above). However, in each of these cases, juvenile outplants were made in conjunction with egg outplants, so the relative contribution of each life stage in establishing sockeye runs was not fully determined (Federenko and Shepherd 1986).

Direct Outplanting

Salmonid eggs can be outplanted directly into artificial redds excavated by shovel (or introduced by cylinder where water velocity or depth is great) in the stream gravel. However, this method is labor intensive and the possibility of scouring and total egg loss is unpredictable. Monitoring and evaluation are also difficult. Preferred locations for outplanting are the upper part of a riffle, similar to known spawning areas. In British Columbia enhancement programs, Kerrwood et al. (1980) reported egg-to-fry survivals of up to 90% in artificial spawning channels directly outplanted with eggs; however, in natural streams, less than 30% egg-to-fry survival was more typical.

The Whitlock Vibert (WV) Box is an approach to direct egg outplanting which affords some protection to eggs during incubation. WV Boxes are made of polypropylene and measure 15 X 9 X 6 cm, hold approximately 200-300 eggs, and contain slots to allow flow of water and fry emergence. Boxes are buried and anchored in the streambed at a depth of 10-20 cm. However, Kerrwood et al. (1980) noted that WV Boxes have not been adequately assessed in British Columbia. Moreover, in a controlled study, Harshbarger and Porter (1982) reported that survival of trout eggs directly outplanted in a streambed was several times higher than those outplanted in WV boxes, apparently because of sediment accumulation in WV Boxes.

Direct egg outplanting via "egg tubes" can result in survival greater than 90% (Fraser 1987). Egg tubes are corrugated (non-perforated) plastic drain pipes with end screens in which a mixture of eggs and spawning-sized gravel are placed. Egg tubes are secured on the stream bottom, parallel to the stream flow. Fraser (1987) suggests egg densities of 1,000 for 10-cm diameter tubes, and 2,500 for 15-cm diameter tubes. A stable streambed is essential to prevent egg loss from scour or siltation. Vandalism is not a major concern because multiple tubes can be dispersed and hidden from view in a stream reach.

Outplant Incubators

Outplanting may be accomplished by use of streamside incubators, which can produce high-quality fry at five times the rate of a natural streambed (Bauersfeld et al. 1981). Several types of streamside incubators have been developed. Each consists essentially of a box in which eggs are placed between layers of graded gravel (Kerrwood et al. 1980). Egg boxes can be constructed of fiberglass, aluminum, or wood, and can be round, square, or rectangular. Water is piped to the box and introduced at the bottom in a manner which provides an evenly-distributed upwelling flow pattern. A filter or silt-settling basin should be located between the intake and the incubation box. Gravel is necessary to produce fry which are comparable in size and emergence timing to those incubated under natural conditions. Typical incubator loadings are 50,000 eggs requiring a water flow of 50 L/min, or 1 L/min per 1,000 eggs (Kerrwood et al. 1980).

The most important consideration in establishing a streamside incubation facility is to ensure that the water supply is reliable, free of silt and debris, and the temperature regime is suitable. If the water supply is relatively free of silt, an egg-to-fry survival of 70-90% have been reported (Kerrwood et al. 1980). Vandalism can be a concern, as units are unattended.

Streamside gravel boxes were used by Bauersfeld et al. (1981) as part of Washington State's Salmonid Enhancement Program aimed at supplementing natural production. Incubation units were constructed of plywood, held together with steel tie rods, and divided into four individual, vertical compartments. Water first entered a small anterior compartment and passed through a subfloor on top of which was a layer of gravel, supported by an aluminum grating. Water passed through the remaining three compartments and out a discharge pipe. Bauersfeld et. al. suggested these units were well-suited for chum and pink salmon because emigration occurs soon after emergence, and for sockeye which utilize lakes for freshwater rearing. Although the concept and technology of streamside gravel incubation boxes were sound, the production unit size was not, on average, determined to be cost effective (WDF 1992).

The remote site incubator, or RSI, is a recently developed, low-maintenance device that has potential for supplementing small adult populations with limited access in remote locations (Wampler and Manuel 1992). Each system includes a 250-L (55-gallon) drum with a series of stacked, rounded screens positioned over a gravel/artificial substrate. Inside each unit, a 5-cm diameter PVC pipe conveys water into a diffuser assembly, from which flow upwells first through a layer of pea gravel, a layer of bio saddles (5-cm long, irregularly shaped polypropylene pieces), a series of egg trays also containing bio saddles, and finally out a PVC outlet pipe located near the top of the barrel. From 1,000 to 5,000 eggs are loaded onto each tray for a total of up to 100,000 eggs per unit. After hatching, alevins drop through the trays, continue to develop, and eventually pass through the outlet pipe.

The RSI is easy to construct, install, and move. As with other streamside incubators, the site requires an adequate flow (at least 40 L per minute) of clean water, sufficient hydraulic head to provide upwelled (gravity) flow, and a location above the stream's floodway. Survival of green, untreated chinook eggs has exceeded 95% (Wampler and Manuel 1992). The RSI is a viable option for introducing and incubating eggs in a remote location with minimum operator visits. As with other streamside incubators, the RSI is unattended, so vandalism is a concern.

Juvenile Outplanting

Juvenile salmonids have been released at various life stages in attempts to re-establish native runs, depending on species and program objectives. However, as previously noted, few definitive evaluations of successful supplementation exist. WDF (1992) noted that pre-smolt outplants, in streams devoid of the target species, generally have a proven track record of success when used to introduce or re-introduce salmon. However, when the target species is already present, adverse hatchery/wild interactions can occur. With regard to smolt outplanting to introduce or supplement salmon populations, WDF (1992) further noted that relatively little is known, and available information is "not particularly favorable." Issues surrounding each strategy are summarized below.

Pre-smolt Release

The Elwha fish restoration plan (USDI et al. 1994) proposed outplanting chinook and coho salmon pre-smolts. Pre-smolt outplanting has been used to supplement declining natural populations as well as seed underutilized areas (Fedorenko and Shepherd 1986). According to Alexander and Galbraith (1982), advantages of pre-smolt releases include:

1) Increased natural selection.

2) Sufficient time for imprinting.

3) Good gene pool size, (i.e., smaller-sized fish will allow larger outplant numbers, resulting in a larger gene pool and increased genetic variability).

4) Lower cost due to decreased hatchery rearing.

In addition to the advantages listed above, Salonius and Iwama (1993) found that outplanting fry (instead of smolts) resulted in a higher quality smolt (i.e., more similar to wild smolts in terms of disease resistance and physiological response to stress after natural rearing to smolthood).

Reisenbichler (1994) emphasized the economic and biological advantages of releasing eyed embryos or swim-up fry, suggesting that instream natural selection processes acting on pre-smolt outplants may confer long-term survival advantages compared to smolt outplants. Stocking hatchery-reared eyed embryos or swim-up fry, therefore, may decrease the number of generations necessary to achieve self-sustaining runs.

Principal disadvantages of releasing hatchery-reared fry are the intensive dispersal needed for good survival and smoltification, interactions and interference with naturally spawned juveniles, as well as increased possibility of mortality during transport to the release site (Lichatowich and McIntyre 1987; Alexander and Galbraith 1982).

Parkinson and Slaney (1975) noted that, in British Columbia, stream stocking of salmonid fry or fingerlings was generally a failure where a substantial wild population of the same or a predatory species existed. However, where few competitors or predators exist, hatchery fry survival appeared to be comparable to that of wild fry. In the upper Elwha basin, an analogy to this experience may exist in that proposed salmon outplants would target barren habitat (initially); however, steelhead outplants would contend with an extensive resident rainbow population (Bill Freymond, WDFW, personal communication).

An evaluation of steelhead fry outplants in barren lower British Columbia streams (Hume and Parkinson 1988) confirmed a pattern of decreasing (short-term) mortality with larger size at release and later release date. As release date progressed from May to October and fish size increased from unfed fry (0.2 g) to 6.0 g, mean monthly mortality rates to age 1+ parr decreased from more than 15% to less than 10%. Generally, late releases of larger fry were considered to survive best, but these fish were also considered more expensive to rear and produced fewer parr per weight of fish released than smaller fish, so a trade-off in potential production versus costs was apparent.

An evaluation of coho fry outplants in underseeded lower British Columbia streams (Hurst 1993) also suggested decreasing (short-term) mortality with larger size at release and later release date. Based on fry-to-smolt survival, a late pre-summer, 2-g release was considered the best strategy in general and an effective method of coho enhancement. Fry-to-smolt survivals ranged from 6 to 25%. In areas of high trout predation, both hatchery and hatchery/wild hybrid outplants survived better with larger fry release size. Pre-summer outplanting was considered to have these principal advantages:

- Lower cost than outplanting larger-sized coho.

- Oversummer genetic selection would maintain maximum diversity and strength within the gene pool.

- Longer opportunity to acclimate prior to summer temperature extremes.

Other evaluations of pre-smolt coho outplants in this region include:

- Minter Creek stock coho fry outplants in barren reaches of Minter Creek (Salo and Bayliff 1958). Survival to smolt and total survival generally increased with increased hatchery rearing in studies ranging over a 16-year period, summarized as follows:

Hatchery rearing (months)	Survival to smolt (%)	Total survival (%)
2½ - 4	10	-
3	-	<0.5
6	20	0.6
8 - 9	40	1.3 - 1.9
12	70	1.1
14	87	<0.8

- Minter Creek coho fry outplants in barren reaches of Gorst Creek (Chuck Baranski, WDFW, personal communication). In this evaluation, a series of unfed and fed fry outplants was made in barren habitat. Results suggested greater short-term survival with larger fry size, as follows:

Outplant date	Stage	Size (g)	Survival to smolt (%)
4/30/82	Fed	0.9	8.0
3/18/83	Unfed	0.4	2.5
5/07/84	Fed	1.3	10.4
5/21/85	Fed	1.3	6.9

- Clearwater stock coho fry outplants in underseeded Clearwater tributaries (Roger Peters, Western Washington Fishery Resource Office (WWFRO), personal communication). After one summer's rearing, data on survival of outplants (first generation hatchery) and their progeny (first generation returns) were collected by the Quinault Tribe. No differences in planted (wild/hatchery parents) and non-planted (wild parents) were found after the initial outplanting, but data on survival of the outplants' progeny has not yet been analyzed.

Long-term, coded-wire-tag (CWT) evaluations of pre-smolt outplants are virtually non-existent. Review of all CWT releases on record with the Pacific States Marine Fisheries Commission (PSFMC) suggested no CWT evaluations of pre-smolts, except releases of:

- Chinook fry in the upper Green River above Howard Hanson Dam. In this evaluation, 400,000 half-tagged Green River fall stock (0.9 g; ~500/pound) were scatter-planted during March/April 1994 in historically accessible habitat throughout the upper basin. Two more years of outplanting is planned, but preliminary recovery data will not be available for several years.

- Coho fingerlings in the upper Elwha River (Wunderlich 1993; Table 3). Lower river Elwha stock coho were outplanted in historically accessible reaches of the upper river. Results suggested comparable smolt-to-adult survival (~ 2.2 to 2.6%) and catch distribution as Elwha Tribal Hatchery smolt releases, although 29% fewer tribal hatchery rack recoveries were observed compared to tagged hatchery production from the same brood (presumably due to upriver imprinting of the fingerling release).

- Coho fingerlings in the Raft River (stock unknown) which exhibited survival-to-adult of 0.41%, based on PSFMC recovery data.

A classic example of inappropriate supplementation was reported by Nickelson et al. (1986) who examined the effectiveness of releasing hatchery pre-smolt coho to rebuild wild populations in Oregon coastal streams. Results showed that outplanting non-native coho fry, fry larger than native fry, and fry having dissimilar run timing reduced wild fry densities and yielded no increase in adult return from either the planted (hatchery) or wild fry. Nickelson et al. concluded that hatchery coho salmon outplants should have the same spawn timing as the wild stock they supplement, and outplants should be similar to wild fish at time and size of release.

Skykomish and Green River hatchery coho outplants (fry and fingerling) in historically inaccessible habitat in the upper South Fork Skykomish River were evaluated by Seiler (1991). Seven broods (averaging from ~0.3 to 2.8 g size) were outplanted in the upper basin after access was provided (at Sunset Falls, a natural barrier), and full coho production (commensurate with available habitat) was realized within 10 years of initial outplanting.

According to Blackett (1979), a self-sustaining chinook run in the Frazer River system on Kodiak Island, Alaska, was developed by planting 160,000 fry annually over a four-year period from 1966 to 1969. A natural run did not exist before the transplant program, but suitable spawning and rearing habitat was available in the system.

Self-sustaining runs of chinook were developed in New Zealand primarily by outplanting pre-smolts (mostly 5-g fingerlings; 90 per pound Sacramento River stock) for six years, followed by three decades of enhancing adult returns (Federenko and Shepherd 1986).

Pre-smolt sockeye (mostl fry and fingerlings) from the nearby Baker River were used to develop the Lake Washington run. Nearly three decades of outplanting occurred, including enhancement of adult returns for two decades, which resulted in a major self-sustaining run. Suggested reasons for success included: excellent habitat (as evidenced in part by historically exceptional kokanee production), the closeness and physical similarity of the freshwater migration route of Baker River sockeye, and the probable lack of IHN in the donor stock (Federenko and Shepherd 1986).

Two years of pre-smolt sockeye releases in the upper Willamette River (Green Peter Reservoir of the Santiam River), which was historically inaccessible, resulted in natural returns over the next two decades. This stock was Adams River (British Columbia). However, the stock was not deemed compatible with current management plans and is being eliminated (Foster 1993).

Preliminary results from recent sockeye enhancement efforts in Auke Bay, Alaska, suggest that subyearling release of sockeye smolts is feasible and that survival may be improved by brief saltwater rearing prior to release (Taylor and Heard 1994). In the Auke Bay program, sockeye subyearlings reared for 4-6 weeks in seawater pens prior to early summer release were larger at release and exhibited significantly greater adult survival than cohorts reared entirely in freshwater. Moreover, adult returns from this program were indistinguishable from naturally reared sockeye of the same stock, and they contributed significantly to recovery of sockeye salmon in the Auke Creek basin. Release of subyearling sockeye was deemed feasible in this enhancement program, even with a sockeye stock that normally smolts as yearlings.

Time and size of release of pink salmon fry have significantly affected early survival and growth in Alaska and British Columbia enhancement programs. Marine conditions are critically important to survival of pink salmon fry; abundant food resources in the nearshore environment allow juvenile pink salmon to escape size-selective predation and attendant huge mortality losses during early marine residence (Sturdevant et al. 1991; Cooney 1994). Key pink salmon food resources are zooplankton; matching pink salmon hatchery releases with zooplankton abundance has significantly survival of hatchery releases in British Columbia (Beacham 1992). Early rearing in brackish water (instead of totally fresh or saltwater) may substantially favor early survival of coastal-spawning pink salmon (Beacham 1992), such as stocks targetted for the Elwha River. In this enhancement strategy, estuarine net pen rearing could substantially benefit early marine survival, and may have application in development of pink salmon brood for the Elwha River (Steve Evans, WDFW, personal communication).

Interestingly, a one-time accidental release of pre-smolt pink salmon (21,000 Skeena River fingerlings) in Lake Superior resulted in a firmly established, self-sustaining population which spread throughout the Great Lakes within two decades, and which now numbers in the millions of spawners (Federenko and Shepherd 1986). Success of the transplant was attributed to the species' brief two-year life cycle, depressed predator and competitor populations during the building phase, absence of marine mortality and straying, and the development of both odd- *and* even-year runs from this single introduction.

Smolt Release

The Elwha fish restoration plan suggested releasing only pink and chum salmon smolts (USDI et al. 1994), while the FERC restoration plan assumed that all juveniles would be raised to smolt size before release because this is a common release strategy in the Northwest (FERC 1992). The advantages of smolt stocking include the following (Alexander and Galbraith 1982):

1) Potentially less predation loss.

2) Interactions (i.e., food competition) with the natural population are reduced due to short period of time spent in fresh water.

The disadvantages of smolt stocking include:

1) Higher cost of hatchery production.

2) Less natural selection within the stream which may result in poor long-term survival.

3) Poor imprinting and higher straying than naturally produced smolts.

4) Increased potential for disease and inadvertent alteration of genetic and environmental components of performance traits due to increased hatchery rearing time.

An example of successful smolt transplanting is the Great Lakes chinook program (Withler 1982). A total of six million smolts were released between 1967 and 1970 which resulted in a successful sport fishery. Although annual hatchery releases supplement the introduced runs, natural reproduction is common. Miller et al. (1990) also note excellent adult returns from sockeye smolt releases in Alaska (as high as 35%).

In Nova Scotia and New Brunswick, Atlantic salmon smolts have out-performed pre-smolt stages in most environments (Marshall et al. 1994), although success in these programs was often measured by adult hatchery returns and commercial fishery catch rather than successful natural spawning. However, plants of Atlantic salmon smolts established a self-sustaining run in a previously inaccessible portion above Morgan Falls in the LaHave River, Nova Scotia (Gray and Cameron 1974; Cutting and Gray 1984, as cited by Marshall et al. 1994).

Smolt outplanting remains a common supplementation strategy. BPA (1992a) reported that of fifty-nine ongoing and planned supplementation projects within the Columbia Basin in Washington, Idaho, and Oregon, the majority involved smolt releases whose purpose was to augment natural production of spring, fall, and summer chinook and summer steelhead, rather than to strictly augment harvest. The majority of stocks being supplemented were either declining or extinct, and were a native/hatchery mix. Likewise, Mobrand Biometrics, Inc. (1991, as cited by FERC (1993)) reported smolts were the primary means of supplementation in the Northwest.

Time, Size, and Location of Release

In developing a strategy for outplanting, the time, size and location of release must be carefully considered as these factors have been shown to affect the growth, survival, and age at maturity of salmon through competition, predation, and straying (Bilton et al. 1982; Hume and Parkinson 1984; Lister et al. 1981; Brannon 1981; Nickelson et al. 1986). As noted above, the size and time of release should match patterns of resident fish.

Homing, Imprinting, and Straying

Homing refers to the movement of adult salmon back to their natal stream. Homing behavior in Pacific salmon appears to be a response to odors acquired (imprinted) as a juvenile that are related to the environmental chemistry unique to its particular habitat (Brannon 1981). There are two hypotheses regarding odors anadromous salmonids respond to: 1) soil and vegetation particular to the stream, imprinted upon by juveniles prior to migration (learning the local odor) (Hasler et al. 1978); and 2) the odor of descending smolts from the same stock (innate learned recognition) (Solomon 1973). According to Brannon (1981), strong evidence exists for the former hypothesis, learning odors of both organic and inorganic substances. Lister et al. (1981) indicate that wild stocks of anadromous salmonid adults return to the spawning area from which they emerged as fry, rather than the area where smolt migration was initiated.

The "sequential imprint hypothesis" is based on the assumption that during sea migration, salmon receive a succession of olfactory cues or other imprints which are recalled in reverse order by the upstream migrating adult, assisting them in returning to their natal spawning area (Lister et al. 1981).

Homing behavior is an important factor to consider when developing a release strategy. In outplanting, it is imperative that the hatchery fish remain in the stream long enough for imprinting to take place. It is not known exactly when imprinting takes place, or how much exposure to the release stream is necessary to ensure return. A review of available literature led Hasler et al. (1978) to conclude that imprinting of anadromous salmonids would be most successful at the smolt stage. Bjornn et al. (1981) theorized that salmonid smolts receive imprinting stimuli once they actually commence downstream movement. Brannon (1981) concluded that imprinting must occur very early for those populations that commence downstream movement soon after emergence, such as pink and chum salmon.

Straying refers to the return of an adult fish to a stream other than the one in which it originated. Some straying in natural populations occurs, and provides insurance against loss of an entire stock due to a catastrophe in the home stream (Ricker 1972). Several studies indicate that the life stage at release can influence the homing ability of returning adult salmon (Lister et al. 1981). McHenry (1981, as cited by Lister et al. 1981) outplanted subyearling and smolted coho in Resurrection Bay, Alaska, and found that smolts strayed at a much higher rate than subyearlings, indicating that length of exposure to a release stream influenced the strength of imprinting. In a review of enhancement strategies on homing and straying of Pacific salmon, Lister et al. (1981) noted that, in general, pre-smolt outplants strayed less than smolt outplants.

Straying can also be influenced by release location, i.e., upstream or downstream of hatchery rearing site or in a non-natal stream. For example, cues from a lower river hatchery outfall may cause adults to return to the hatchery rather than an upper river release site (Lister et al. 1981). Transferring salmonid juveniles from a hatchery rearing site to another stream or river system can break one or more links in the imprint sequence, causing adults to return to the release site instead of the rearing site. In their review of enhancement-related straying, Lister et al. (1981) concluded:

1) Within-system smolt releases at locations other than the rearing site, i.e., off-station, normally result in more straying than smolt releases directly from the rearing site.

2) Straying increases with decreasing distance between release and rearing sites.

3) Downstream releases are likely to produce less straying to rearing site than upstream releases.

4) Out-system releases are less likely to stray than within-system releases away from the rearing station.

In developing a release strategy, Lister et al. (1981) recommended that the hatchery be located, if possible, in a river other than that proposed for outplanting. However, if rearing and release sites are in close proximity, pre-smolt instead of smolt releases should be considered, provided under-utilized rearing habitat exists and outplants are evenly distributed. These may be key considerations in refining the Elwha River fish restoration plan, as proposed release sites and hatchery facilities may be in close proximity.

The accuracy in which hatchery fish return to the stream in which they were outplanted is also influenced by stocking and transportation practices (Steward and Bjornn 1990). Straying increases if outplants have completed smolt transformation (Scholz et al. 1978), and if portions of the downstream migration are bypassed by outplanting below desired spawning sites (therefore omitting necessary imprinting sequences (Hansen et al. 1989)).

Competition and Predation

Inter- and intra-specific competition occurs when the demand for a resource in the environment exceeds its actual or perceived availability (Larkin 1956); the degree of competition depends on spacial and temporal overlap. The time, size, and density of hatchery releases greatly influence survival and growth of hatchery and wild fish.

Size differences between hatchery trout or salmon and other species of fish affect competitive interactions and the partitioning of stream resources (Lister and Genoe 1970). Coho are territorial and aggressive, establishing hierarchies according to fish size (Chapman 1962). Nickelson et al. (1986) observed a 40% decrease in the average density of wild coho pre-smolts following outplants of larger hatchery cohorts because of intra-specific competition. Martin et al. (1993), in a review of supplementation in Washington state, also found competition occurred when hatchery outplants were larger than wild cohorts. Steward and

Bjornn (1990) noted that differences in fish size are important in determining the outcome of competitive interactions; larger salmonids generally dominate and therefore grow and survive better than smaller salmonids.

Predation is a particular concern when outplanting pink and chum fry. A study by Neave (1965) indicated that, along with predator abundance, the size of pink salmon at emigration affects their survival; fry emigrating at 0.35 g were not preyed upon as heavily as those at 0.2 g. Bilton et al. (1982) observed that hatchery-released juvenile coho preyed upon small pink and chum fry, and large pink and chum were less susceptible to predation than smaller cohorts. Experiments have shown that yearling coho prey selectively on pinks over other salmonid species (Hargreaves and LeBrasseur 1985). Ames (1980) linked a 50% decline in the Stilliguamish pink run to a nearby coho enhancement project in Puget Sound. Pink juveniles usually remain in the littoral zone until they reach a less vulnerable size, about 55 to 70 mm (Crain 1992). Mass outplanting of these species may substantially reduce predation losses (Fedorenko and Shepherd 1986; Rensel et al. 1984). Enhancement populations of pink and chum are most vulnerable in freshwater when predators are large and abundant, environmental conditions favor high visibility, and fish are concentrated in small streams, are stressed, and release densities are low (Rensel et al. 1984).

Release location is an important factor in supplementation because it helps regulate the extent and magnitude of competitive and predatory interactions between hatchery and wild fish (Steward and Bjornn 1990). Parkinson and Slaney (1975) report that when salmon fry are stocked into a stream with few competitors or predators, survival appears to be comparable to that of wild fry.

The potential for interspecific competition depends on the relative abundance of the stocked and resident fish species; competition is minimized when stocked smolts migrate soon after release (Steward and Bjornn 1990). The density of stocked fish must be limited to prevent displacement of, or competition with, the existing population (Miller et al 1990). Timing releases and modelling stream carrying capacity can help avoid excessive competition. Steward and Bjornn (1990) conclude that fish held in the hatchery for extended periods before release as pre-smolts may have different food and habitat preferenda than wild fish, therefore making them unlikely to outcompete wild fish, and that post-release growth rates and survival will be low if the wild stock is at or near carrying capacity.

Hatchery reared fish may adversely affect the growth and survival of resident populations. In two small Vancouver Island streams, Tripp and McCart (1983) reported that stocked coho fry eventually displaced both young-of-the-year and older cutthroat trout.

Predation is a major source of mortality for hatchery and wild fish, although losses to predation may be higher for hatchery fish due to: 1) inappropriate avoidance and foraging behaviors; 2) inability to assess predation risks; 3) stress from handling and/or transport; and 4) unfamiliarity with new surroundings (Steward and Bjornn 1990). Wood (1987) observed that if high densities of hatchery outplants are conspicuous relative to other species, the outplants become the preferred prey of opportunistic avian predators such as gulls and mergansers.

Salmonids released from hatcheries at sizes larger than wild residents are potential predators. Species-specific predation has been widely documented. Martin et al. (1993) observed that hatchery-released rainbow and steelhead trout preyed upon smaller-sized chinook. The timing of release in relation to size is also important in minimizing the predation of hatchery-reared fish upon the existing population. Releasing large-size hatchery fish should not coincide with newly emergent fry.

Cardwell and Fresh (1979) make the following recommendations in order to minimize the losses of hatchery-released salmon in freshwater:

1) Coincide releases with natural emigration schedules, making sure the hatchery fish are not larger than the existing population.

2) Release only large numbers of fish to "swamp" predators.

3) Release as quickly as possible to minimize predator attraction to the release site.

4) Time releases with maximum stream flows and turbidity (within natural emigration schedules) and release at night to reduce visibility to predators.

5) Avoid releasing fish where known predators exist (e.g., avoid releasing chum fry in areas where coho are abundant).

Growth and Survival

The time, size, and location of release affects the growth, survival, and age at maturity of salmon. Bilton et al. (1982) observed that size and time of release of juvenile coho salmon have a dominant influence on the success of returns at maturity. A study conducted by Hume and Parkinson (1984) also suggests that the time and size at release affects the survival and growth of steelhead fry.

According to Steward and Bjornn (1990), returns of hatchery salmon are positively related to their size at release. These investigators found that a large release size may reduce the length of time spent in the stream, thereby increasing chances for survival to smolt stage. However, when hatchery fish are larger than their wild cohorts, the more likely that wild fish will be competitively displaced, reducing their survival (Nickelson et al. 1986). Size-related effects can be avoided by imposing spawning, incubation, and feeding schedules that ensure hatchery fish are not present in the stream ahead of wild fish and that they are not larger than wild fish (Reisenbichler and McIntyre 1986).

Age at return may also be directly related to size at release. Messmer et al. (1989) found that chinook smolt releases in the Imnaha River, Oregon, produced adults with a younger age-at-return than wild fish of the same brood year.

Life stage at release is an important factor in that hatchery-released smolts may induce wild fish to join them in their seaward migration, known as the "pied piper effect" (Hansen et al. 1984). If wild fish have not reached smolt stage yet, this movement increases their susceptibility to predation.

Location of release affects growth and survival of hatchery-reared fish in terms of predation and food and space availability. For pink and chum fry, the risk of predation loss increases with longer freshwater migration. Bird predators have been shown to congregate in favorable feeding areas, such as near hatchery release points (Mace 1983). Space requirements vary with fish size, therefore the productivity and availability of outplant sites must be considered in supplementation, especially for those species which spend more than one year in freshwater (Steward and Bjornn 1990).

Transportation to Release Site

Transporting juvenile fish potentially induces stress and may increase post-release mortality. Both ground and air transport were proposed within the Elwha basin depending on road access (USDI et al. 1994). Factors to consider in ground transport include efficiency of the aeration system, duration of the haul, water temperature, fish size, fish species, and fish density (Piper et al. 1982). Additionally, with air transport, barometric pressure changes may induce stress and cause tissue damage in fish due to gas bubble disease (Hauck 1986).

Historical outplants of fingerling rainbow trout were made in the upper Elwha basin by means of containers on pack horses during the 1940s and 1950s, but survival was questionable due to the small size of fish released and logistical problems associated with transport, so the program was discontinued (Morton 1958).

Within the roaded portions of the Elwha basin, conventional tank trucking should permit efficient fish distribution of outplants. Piper et al. (1982) reported that normal transport densities for salmon and steelhead range from 0.06 to 0.36 kg/L (0.5 to 3.0 lb of fish per gallon of water in the transport container). In recent years, all juvenile salmonid outplants in the upper Elwha basin (Table 3) occurred without apparent stress or mortality at a transport density of 0.12 kg/L (1.0 lb/gal) in aerated tanks (WWFRO file data). At this density (0.12 kg/L), using conventional tank trucks (1,135-L capacity), the maximum proposed outplanting of all stocks in the Elwha fish restoration plan (USDI et al. 1994, Table G-3) would entail about 43 trips annually within the roaded portions of the basin.

In contrast, air transport involves additional fish health concerns, some of which can be mitigated. As noted above, stress from gas bubble disease has been reported. Mitigating this adverse effect can be accomplished by aerating water, stabilizing water temperature (to avoid warming and supersaturation), minimizing altitude changes during transport, and calming fish prior to site release (Hauck 1986). Also, fish size is important in successful air transport; larval and smaller fish are more susceptible to stress and trauma from supersaturation than larger fish (Hauck 1986).

In the upper Elwha basin, air transport has been accomplished by helicopter. WWFRO successfully transported fingerling coho and steelhead in polyethylene fish totes (300-L capacity with 0.12 kg fish per L of water) suspended from a helicopter, and ground crews hand-distributed fish at release sites. To speed outplanting in the Elwha basin, Wunderlich et al. (1993) used a fire bucket (bambi bucket) suspended from a helicopter to successfully outplant 428,000 chinook fingerlings in two days (Table 3). In this method, fish (36-kg loads at same density as above) were transferred to a preloading holding box at a lower river staging site, then dispensed into a helicopter-transported fire bucket modified for water aeration. Fish were released by lowering the bucket to the water's surface by means of a 15-m cable, and the cable's length permitted helicopter access to confined reaches of the river. Although partial release of fish loads was not possible in this method, more elaborate, aluminum-fabricated devices for aircraft allow partial releases at altitude (Conley 1983; Billings undated).

Air transport of fish is not as efficient as ground transport. Payloads are typically smaller than ground transport and involve special problems. At acceptable fish loadings (0.12 kg/L), air transport by helicopter bucket would require about 225 trips annually in the upper Elwha basin to accomplish the currently proposed outplanting program (USDI et al. 1994). Moreover, helicopter outplanting may conflict with the federally-listed marbled murrelet's nesting and roosting activity, which occurs spring through fall (Kim Flotly, USFWS, personal communication).

Distribution at Release Site

Outplanted salmon must be evenly dispersed after release in order to maximize use of available spawning and rearing habitat, and to minimize mortality from displacement of and competition with existing populations. The preferred method of distributing hatchery-reared fish is scattering them over a large area to promote equitable distribution of juveniles into available habitat and relieve competitive pressures (Kapuscinski et al. 1993; Rensel et al. 1984). Scatter planting (as opposed to point release) has been shown to result in the most even distribution of stocked coho (Tripp and McCart 1983), and is also suggested as a method of release by Fedorenko and Shepherd (1986) and Steward and Bjornn (1990). However, Tripp and McCart (1983) presented data suggesting point release plants of fed fry would also produce a relatively even distribution of juvenile coho. For point releases, they recommended a maximum distance between release sites of 500 m.

Outplant Densities

Outplant densities should be based on habitat availability and protection of resident, naturally-produced fish. According to Kapuscinski et al. (1993), outplant densities should reflect:

1) The distribution and carrying capacity of habitats intended for outplanting.

2) The proportion of limiting resources already used by resident fish.

3) The fitness (survival and reproductive success) of hatchery-produced fish.

The Elwha fish restoration plan (USDI et al. 1994) called for outplanting fish at a level consistent with carrying capacity; stocks with a long fresh water rearing stage were to be seeded at the low range of carrying capacity; those spending little time (i.e., smolts) in freshwater were to be seeded at or near carrying capacity.

Outplant densities affect both hatchery and wild fish. Steward and Bjornn (1990) found that when a stream is "overseeded", growth and survival are adversely affected as a result of sharing limited resources. Hume and Parkinson (1984) found that growth and survival of steelhead fry decreased with increasing stocking density. Tripp and McCart (1983) also reported that coho fry-to-smolt survival was highest at low outplant densities. However, McIntyre et al. (1989) suggested that a relatively high threshold density of sockeye smolts may significantly reduce the risk of predation by coho. Fedorenko and Shepherd (1986) also suggested large scale outplanting to avoid predation loss.

Outplant Duration

The USDI et al. (1994) plan for Elwha restoration called for outplanting 8 years (or 2 generations, depending on species), while FERC (1992) proposed 10 years. Elsewhere, Bams (1976) suggested stocking for several generations since non-adaptive donor characteristics may be inherited in future progeny, which would eventually be selected against. In a review of salmon transplant procedures in British Columbia, Fedorenko and Shepherd (1986) recommended outplanting for 10 years to establish salmon populations in new habitat.

Acclimation Sites

Possible use of acclimation sites was noted in the USDI et al. (1994) Elwha restoration plan, but no specific plans were proposed. This review suggested that acclimation sites are considered advantageous in stock restoration projects, but in-depth evaluations of their utility are limited and available results are mixed. WDFW (1994b) defined acclimation sites as concrete, vinyl, or earthen ponds used for rearing and imprinting juvenile fish of a particular stream or stream reach before releasing the fish in that stream. Development of such sites may temporarily disturb the natural landscape, depending on their design, location, and operation. If evaluation by means of coded-wire tagging is anticipated, the acclimation site must be sufficiently large to accommodate a minimum tag group size (e.g., 100,000 subyearling chinook) for meaningful recovery information (Cowan and Smith 1994).

A primary advantage of acclimation sites is allowing fish to recover from stress caused by handling, transportation, and release, thereby increasing their survival (Mark Kimbel, WDFW, personal communication; Rottiers and Segarich 1988). Other perceived advantages of acclimation include imprinting fish to the vicinity of the site, thus expanding the range of adult returns in anadromous fish restoration projects. Acclimation may also allow fish to adapt to the complexity of watershed and landscape features, including water temperature and chemistry, before release. On-site acclimation also permits voluntary emigration, which simulates a more natural process (Sele 1994). According to Schuck et al. (1994), acclimation ponds in the Touchet River, Oregon, may also have decreased steelhead residualization.

In Puget Sound, spring chinook acclimation sites exist in the upper White River and in the North Fork of the Nooksack River. Subyearling chinook are transported to the sites in early spring prior to initial smoltification, held and fed for 1 to 2 months, and then allowed to volitionally emigrate.

Initial returns from the North Fork Nooksack River spring chinook acclimation sites, located on Boyd and Deadhorse Creeks, were very different, however (Ken Bruya, WDFW, personal communication). Survival of Boyd Creek fish was approximately 0.6%, which exceeded average hatchery release survival of 0.1% for Nooksack stock, while Deadhorse Creek fish experienced dismal survival. A possible reason for higher returns of Boyd Creek chinook was the difference in acclimation pond designs. The Boyd Creek site mimics natural stream conditions, including instream cover, insect production, and clear water, while the Deadhorse Creek site is basically a cement-lined pond with no cover.

Acclimation is proposed in the Dungeness chinook rebuilding program, which involves captive brood development. Spring subyearling chinook (offspring of captive brood) would acclimate for two to four weeks per release group each year, over an eight-year period, to allow fingerlings the opportunity to adapt to the river and promote imprinting to its upper reaches (Sele 1994).

In Oregon's Suislaw Basin, ODFW evaluated straying and survival of acclimated winter steelhead held 30 days in portable, water-pumped, cement acclimation ponds. The first year's results showed no significant difference between acclimated and control groups in straying, imprinting, or survival (Lindsay 1993). In the Grand Ronde River basin, however, acclimated steelhead smolts appeared to have greater survival-to-adult than non-acclimated controls, which was attributed to differences in their ability to respond to environmental stressors (Whitesel et al. 1994).

Part of the effort to enhance steelhead and re-establish salmon in the Umatilla River Basin involves use of acclimation sites. Results of summer steelhead acclimation studies are inconclusive, however (Rowan 1994). To date, total survival of one acclimated steelhead brood was higher than its control, but for two other broods, the same. Likewise, spring chinook acclimation studies have also been inconclusive, as estimated survival of one acclimated group was lower than its control, while two other acclimated groups' survival was similar or higher than their controls.

To enhance and re-introduce anadromous fish stocks formerly present in the Yakima basin, annual transfers of 2.5 million hatchery juveniles to thirty acclimation ponds has been proposed (BPA 1992b). Acclimation is expected to reduce stress from transport and increase imprinting to the release site. Acclimation sites would be located on the floodplain of nearby tributaries with interior sideslopes and bottom lined with river rock. Site design would incorporate innovative feeding techniques, stream cover design, and predator conditioning, and allow fish to become accustomed to natural conditions before release. Acclimated chinook reportedly experienced nearly twice the survival of non-acclimated chinook in the Yakima basin (Sele 1994).

Off-Channel Habitat Enhancement

Off-channel habitat enhancement may significantly increase the production and range of anadromous salmonids by improving spawning, incubation, and rearing habitat. In the Elwha, such enhancement may serve to stabilize or increase remnant native populations (e.g., chum salmon), provide a refuge from adverse flow and/or water quality conditions in the main channel (e.g., temporarily increased sediment and turbidity during dam removal), and improve smoltification as well as imprinting to upriver outplant sites.

Significant increases in juvenile production from off-channel enhancement sites (versus mainstem habitat) have been observed for steelhead (Mundie and Traber (1983), coho (Lewis 1990; Sheng et al. 1990), chinook (Richards et al. 1992), chum (Dunphy 1991), and Atlantic salmon (Rottiers and Segarich 1988). However, careful planning and evaluation are essential to realize benefits from off-channel enhancement. Projects appear to fail in two major ways: 1) the desired change in habitat was not created because of poor engineering design; and 2) project planners failed to recognize and improve habitat that was *limiting* the fish population (Nickelson et al. 1992).

Planning, implementation, and evaluation of off-channel enhancement were summarized by Cowan (1988). Three common types of projects were considered: groundwater channels, over-wintering ponds, and side channels. First, improvements in groundwater channels have significantly increased intra-gravel survival of chum eggs and alevins, and incidental benefits to coho production have also been noted. Such a candidate improvement project at rkm 2.8 in the lower Elwha River was identified by Hosey and Associates (1989) and more recently by Wunderlich et al. (1994). Second, over-wintering ponds have the potential to significantly increase coho production by providing critical winter habitat for coho parr. However, at this date, coho salmon are not specifically targeted for habitat enhancement in the Elwha fish restoration plan (USDI et al. 1993). Third, side channel development offers potential for improved off-channel spawning and rearing for all stocks of interest, and typically involves a diversion structure to supply water from the mainstem or tributary stream. However, potential impacts to non-target species need to be considered. In British Columbia, for example, side channel improvements intended for chum have shown greater benefit to coho, partly because coho prey heavily on emergent chum fry (up to 250,000 chum fry were consumed by coho smolts in Upper Paradise Channel over one spring season) (Sheng et al. 1990).

In planning and implementing off-channel enhancement work, these factors should be considered (Cowan 1988):

- A site search must consider the current (and projected, in the case of the Elwha basin) range of the target species and life history stage, as well as the specific goals of the enhancement effort. This is especially true for chum salmon, where adult access and in-river juvenile movement are generally more constraining than other species. Field site review would include: water source, quantity, and quality; substrate type; entrance conditions; and flood security. Up to one year's monitoring may be needed to fully identify hydraulic conditions at a potential enhancement site. Current fish utilization should also be monitored to infer predation potential for target species and general habitat suitability. For example, juvenile coho and steelhead may be important predators of chum and pink salmon in off-channel enhancement sites. Bird predators can also significantly impact salmonid production. Site morphology, cover, and entrance design affect predator access and abundance (bird and fish) at enhancement sites, and therefore need to be carefully considered in project design.

- Construction timing, site permits, maintenance, and pre- and post-project monitoring of fish use are additional considerations that influence cost and utility of off-channel enhancement sites.

SUMMARY AND RECOMMENDATIONS

Natural Recolonization versus Supplementation

Although not considered a primary restoration option for most Elwha fish stocks, natural recolonization is recognized as a viable alternative. Adult fish can be expected to penetrate the upper drainage, eventually establishing self-sustaining populations over an indefinite time scale. However, few documented cases of natural colonization of new habitat by anadromous fish were found in this review. The few cases found included the colonization of chinook and pink salmon in the South Fork Skykomish River (Seiler 1991); the return of sockeye in the upper Snake River after removal of Sunbeam Dam (Bjornn et al. 1968); the re-invasion of Fraser pinks upriver of Hell's Gate (Withler 1982); and the re-establishment of coho in the upper Clackamas River after fish passage was provided (Cramer and Cramer 1994). In these instances, colonization (or recolonization) occurred over two decades or more. Important factors influencing colonization included strength of the source stock and harvest pressure.

Natural recolonization is desirable because it is a mechanism which has none of the genetic and ecological risks of supplementation. Re-establishment of salmonid runs by natural recolonization *may* take longer than supplementation, but whether outplanting hatchery-reared fish truly accelerates occupation of a new territory is not entirely certain, since no objective comparisons have been made.

Supplementation as defined in this paper is the use of artificial propagation, while conserving genetic resources, to restore locally extinct or depressed populations to self-sustaining levels consistent with the habitat's carrying capacity. This review supplied no significant evidence that supplementation can consistently enhance natural production. Clearly, however, there are cases where wild salmonid runs have been established or re-established through supplementation. The best known successful establishments of Pacific salmon outside their native range are those of chinook in New Zealand, and coho and chinook in the North American Great Lakes (Withler 1982).

Many biological and ecological uncertainties and risks are associated with supplementation, most notably the adverse effects the artificial rearing environment has on growth and survival of wild fish. These include altering the behavior and genetic composition of stocked fish, and the potential for passing maladaptive traits on to the existing population through interbreeding. There is also uncertainty regarding the degree to which behavior learned in the hatchery predisposes hatchery fish to higher risks of predation, lower feeding efficiency, or suboptimal habitat use. Information on genetics, life history, ecological characteristics, and interactions of hatchery and wild fish necessary to effectively employ supplementation is extremely limited.

One benefit of supplementation specific to Elwha River restoration is hatchery involvement may provide a temporary refuge for existing stocks during adverse habitat conditions associated with dam removal. In some instances, supplementation would also allow the introduction of preferred stocks over existing lower river stocks, as in the case of summer steelhead.

Supplementation Guidelines

Where supplementation is considered appropriate because of lack of source stock, undesirable lower river stock, and/or interest in expediting re-establishment of wild runs, this review suggested the following guidelines for Elwha River fish restoration. (Table 4 also summarizes stock development and transfer guidelines applicable to the Elwha based on the review by Fedorenko and Shepherd (1986)).

Broodstock Selection

- Conserving genetic diversity of existing and donor stocks is the first priority in brood selection and development.

- If available, an existing remnant stock is the first choice, provided brood collection does not jeopardize it. Genetic considerations suggest using large numbers to establish a brood line: a minimum of 100 individuals per year (but preferably 200 or more); at an even sex ratio; leaving at least 75% of source population in the river; and selecting the brood randomly, throughout the entire run, to reduce artificial selection of specific traits.

- If remnant populations are unavailable, use genetically and geographically closest donor stocks from an ecologically similar environment whose freshwater and marine life histories match as closely as possible those of the recipient site. One source suggested collecting gametes from numerous wild populations and performing all possible crosses. In British Columbia's salmonid enhancement program, donor stocks should originate within 100 km (river mouth-to-river mouth) of the recipient stream.

- If neighboring stocks are unavailable, import a stock applying the brood selection guidelines listed above. In addition, fish health guidelines restrict certain egg and fish transfers within the state and across international boundaries. With respect to the existing fish restoration plan, these stock imports for Elwha are potentially affected by fish health considerations:

    - Summer steelhead - coastal import

    - Pink salmon - Dungeness or Hood Canal import

    - Chum salmon - Straits transfer

    - Sockeye - regional or international transfer

Broodstock Development

Primary considerations include:

- Limit hatchery exposure: first-generation hatchery impacts occur which could affect long-term survival; genetic alteration can occur within the first generation of hatchery experience.

- Use innovative hatchery practices to mimic natural incubation and rearing (e.g., limit density, provide cover, and natural feed).

• Continually infuse hatchery brood with wild brood by incorporating 10% wild genes every 2nd or 3rd generation, or by marking all hatchery releases and using entirely wild brood each generation, as is proposed for Yakima fishery restoration. Enhancing adult returns of *transplants* has been a common strategy in successfully establishing self-sustaining runs in new habitat.

Stock Introduction

No single introduction strategy is considered best under all circumstances. A strategy should reflect numerous factors, including: program goals; status of the existing stock; the target stream's carrying capacity and non-target fish populations; and its biological and economic implications. It may be beneficial to use a modified version of the EDT Model developed for RASP to compare and contrast the possible outcomes of various introduction strategies.

Adult Outplanting

This strategy is not proposed in the Elwha fish restoration because of logistical difficulties and the likelihood of fallback.

Egg and Juvenile Outplanting

Case studies of successful supplementation through the outplanting of juveniles are few. Successful examples of introduction suggest that the following are important considerations:

• Transportation - Stress and post-release mortality associated with transportation can be reduced by ensuring good water quality and avoiding excessive handling, crowding, and transit times. Helicopter outplanting may be effectively employed in remote areas, but costs are high and conflicts with listed wildlife species in the Elwha basin may limit this method.

• Density - Stocking densities can have a major influence on post-release survival and can adversely affect the existing population. Recommendations are: do not exceed stream's carrying capacity at life stage outplanted; and where natural production exists, outplanting should be less than full carrying capacity to reduce displacement and competition.

• Size at release - Size of outplanted fish should match that of wild cohorts to reduce competition and predation.

• Time of release - Releases should coincide with available food sources and environmental cues (i.e., for smoltification), and should minimize interactions with existing populations.

• Life stage at release -

  ▸ Egg - Advantages include no transport-related stress; low cost; low maintenance; natural emergence timing and behavior; increased exposure to the stream resulting in higher imprinting and homing than advanced life stages. Disadvantages include installation costs and potential vandalism.

  ▸ Pre-smolts - Advantages include low hatchery cost; good natural selection; potentially greater natural survival due to limited hatchery exposure; increased exposure to the stream resulting in high imprinting and homing compared to advanced life stages; generally better track record of supplementation in barren habitat than smolts, although intraspecific interactions may suggest a mix of pre-smolt and smolt outplants to be most effective for steelhead/rainbow.

▸ Smolts - Advantages include high first-generation returns and less interspecific competition. Disadvantages include increased potential for disease; inadvertent alteration of genetic and environmental components of performance traits due to increased exposure to hatchery, which may result in decreased fitness and long-term survival in the wild; relatively poor imprinting and homing to release site; and high production costs.

• Duration - For planning purposes, the dominant recommendation is to outplant for 10 years. However, models, such as EDT, may assist in planning the phase-out of outplanting commensurate with recovery of natural production beginning with first generation returns.

• Location - Straying can be influenced by location of release. To decrease straying: release fish downstream of hatchery, or rear fish in a different river system. The further the release site is from the hatchery, the lower the straying rate. The release site must also have available space and food for the outplanted population.

▸ Point release - This practice may result in excessive local densities of fish and underseeded sections of stream between stocking sites, and may cause competitive interactions. Dispersal of hatchery fish from the point of release in streams is highly variable.

▸ Scatter planting - This is the preferred method of releasing hatchery-reared fish.

• Acclimation sites - Perceived benefits of acclimation sites are: increased post-release survival as fish recover from stress relating to handling, transportation, and release; increased imprinting to the release site; and voluntary emigration. Fish should acclimate for a minimum of two weeks, and effort should be made to mimic natural stream conditions within acclimation ponds (e.g., instream cover and insect production).

Off-channel habitat enhancement has potential to significantly increase the production and range of anadromous salmonids by improving spawning, incubation, and rearing habitat. Off-channel habitat may provide important refuges from increased turbidity and sediment in the main channel during and immediately after dam removal.

An essential elements to any supplementation program includes close monitoring of affected populations and a commitment to adaptive management. It must also be kept in mind that supplementation alone cannot be relied on to increase declining salmonid populations; but can only be effective when combined with other actions such as harvest regulation and improvement or protection of habitat.

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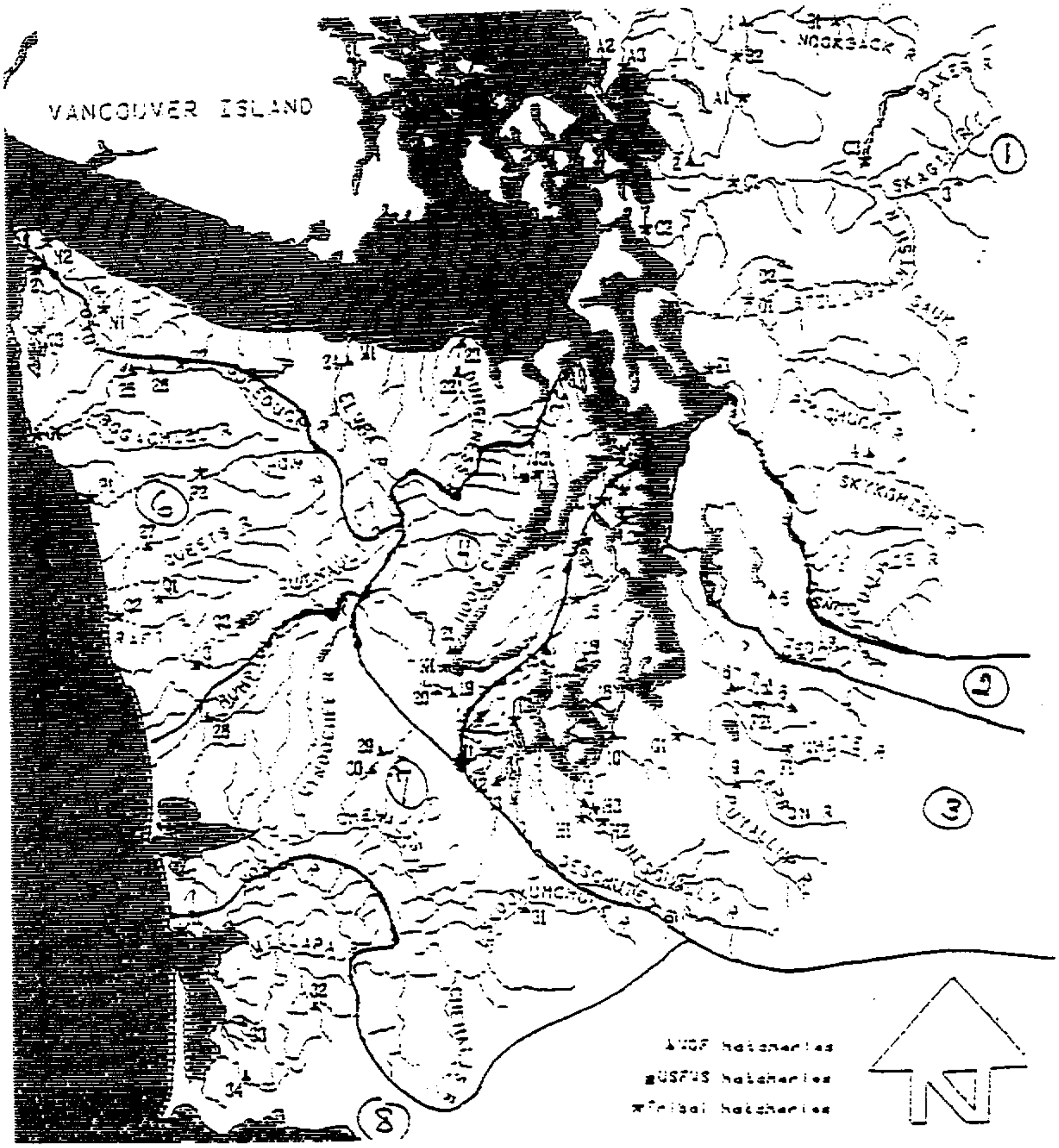

Figure 1. Egg Health Management Zones.

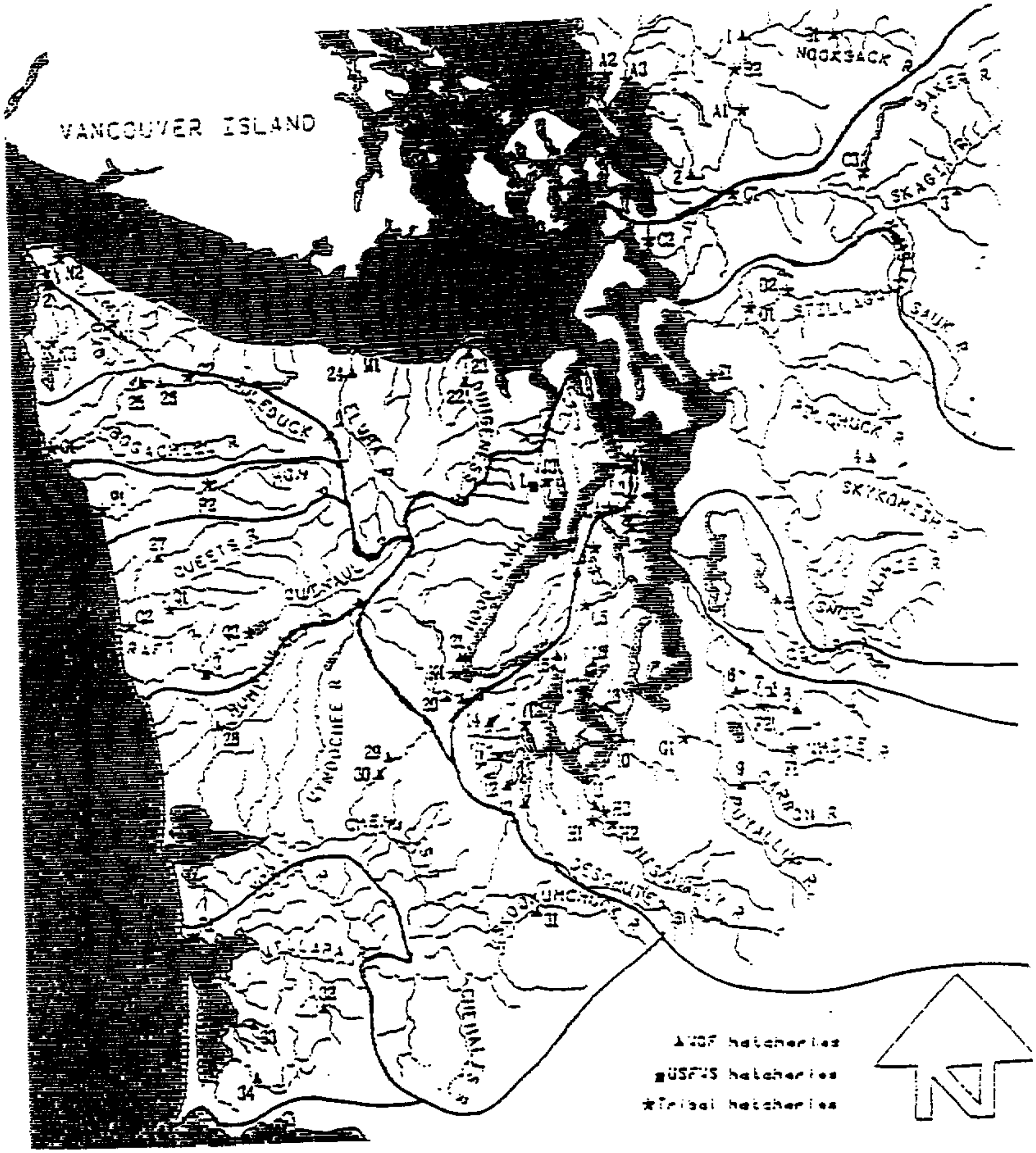

Figure 2. Fish Health Management Zones.

Table 1. Survival-related characteristics of salmonids potentially altered by hatchery practices within the first generation of hatchery experience (Source: BPA 1992a).

Characteristic	Description
Aggressiveness	Extent of inter- and intra-specific aggressive behavior within the natural environment.
Dispersiveness	Extent and rate of dispersal within the natural environment.
Downstream immigration pattern	Timing and rate of travel of the upstream spawning migration.
Amount of body fat	Quantity of body fat related to nutrition and exercise.
Feeding behavior	Use of foraging areas, prey selection, and associated energetics of feeding.
Habitat selection	Use of habitats by season, including depth, velocity, substrate type, and shelter.
Health	Overall health related to history of nutrition, exposure to pathogens and stressors, and exercise.
Homing/straying	Degree of homing to the home spawning stream (or stream of release).
Disease resistance	Immunity to disease, either due to immunologetic resistance or antibodies from prior exposure.
Maturation	Age at sexual maturity, or relative timing of sexual maturity within a particular season.
Predator recognition	Ability to detect both presence and associated danger of predators.
Prey recognition	Ability to recognize suitable prey items.
Size	Length and associated condition factor of fish at time or age.
Smoltification	Timing and degree of physiological transformation in advance of emigration.
Saltwater transfer efficiency	Effectiveness of successfully making a transition from fresh to saltwater.
Swimming ability	Burst speed, maneuverability, and stamina associated with swimming.
Social interaction	Set of behaviors associated with dispersal, territoriality, hierarchial associations, and schooling.
Catchability	Effectiveness, or lack thereof, at avoiding capture by a fishery.

Table 2. Hatchery treatments potentially affecting survival-related characteristics of salmonids within the first generation (Source: BPA 1992a).

Hatchery treatment	Component of treatment of potential concern
Broodstock origin	Indigenous natural stock or imported stock (hatchery or natural).
Broodstock capture/holding methods	Representativeness of timing and ages obtained by capture/holding methods.
Mating practices	Random vs. non-random, representation by age class, male/female ratio.
Incubator type and substrate	Degree of interaction between substrate and alevin; emergence or removal.
Diet	Type of food: dry vs. wet, buoyant vs. sinking, natural vs. manufactured.
Growth schedule	Rate of desired growth and size projected; ration adjusted to meet schedule.
Feeding method	Automatic feeders, demand feeders, broadcasting by humans, etc.
Density	Rearing density.
Grading	Consolidation of fish sizes in rearing with or with out culling of undesirable fish.
Predation exposure	Extent of experience with natural predators: birds, otters, fish.
Structural complexity	Exposure to variable habitat structure: overhanging cover, visual separators, etc.
Container design	Size, shape, and depth of rearing unit: raceway vs. pond, meander vs. straight.
Flow	Quantity and velocity of flow through rearing unit.
Water temperature	Range of temperatures during either incubation or rearing compared to nature.
Disease control	Extent of exposure to pathogens and treatments applied.
Hygiene	Rearing vessel cleaning practices (frequency and method).
Size of release	Number of fish released.
Release method	Volitional vs. forced, degree of acclimation, mode of transportation.
Release timing	Means of selecting date for release: relationship to natural timing.
Release location	Distance from hatchery, single point release vs. multiple release sites.

Table 3. Summary of anadromous fish outplants above Elwha Dam (other than fish released for dam-passage tests). Adult and juvenile outplants originated from lower Elwha River hatcheries.

Life stage	Date	Location	Number out-planted	Purpose	Comments/results
				Summer steelhead	
Adult	Jul-Sep 1983	L. Mills & upper mainstem	72	Assess migration & spawning via radio-tagging.	Tagged late-summer outplants ascended the upper river up to 16 km, but at least 35% of outplants fell back; no spawning was observed.
Adult	Oct 1986	Little River	53	Assess spawning success.	No spawning observed, but survey conditions were poor.
				Winter steelhead	
Adult	Apr 1985	L. Mills	96	Use upper river habitat.	Spawning observed in a L. Mills tributary (Cat Creek).
Adult	Mar 1986	L. Mills	22	Use upper river habitat.	Spawning observed in a L. Mills tributary (Cat Creek) and in mainstem above L. Mills. Several fallbacks (spawnouts) subsequently trapped in L. Aldwell the same spring.
Finger-ling	Jul 1983	Upper mainstem.	110,000	Assess fry-to-smolt survival via fin clipping & dam counts.	Very high fry-to-smolt survival (31%) based on hydroacoustic counts at Elwha Dam. Large (20.3 cm average) smolts produced.
Finger-ling	Jul 1986	Upper mainstem.	38,000	Assess fry-to-smolt via dam counts and total survival via CWT.	Average fry-to-smolt survival (7%) based on hydroacoustic counts at Glines Dam. Large (19.7 cm average) smolts produced. No CWT sampling conducted.

Life stage	Date	Location	Number out-planted	Purpose	Comments/results
				Coho salmon	
Adult	Oct 1986	Indian Cr.	20	Augment natural production.	Inconclusive - spawner surveys not effective.
Fry	Jun 1985	Indian Cr.	125,000	Augment natural production.	No evaluation.
Fry	May 1986	Indian Cr.	195,000	Augment natural production.	No evaluation.
Finger-ling	Jul 1987	Upper mainstem	132,000	Assess fry-to-smolt via dam counts and total survival via CWT.	Very high fry-to-smolt survival (33%) based on hydroacoustic counts at Glines Dam. Typical-sized (12 cm average) smolts produced. Allowing for dam passage losses, estimated smolt-to-adult survival comparable to tribal hatchery smolt releases. Catch distribution and adult size also comparable to tribal hatchery smolt releases.
				Chinook salmon	
Finger-ling	May-Jun 1987	L. Mills forebay	40,000	Assess emigration timing, exit selection.	Protracted emigration observed during the ensuing six months of passage monitoring at Glines Dam.
Finger-ling	Apr 1989	Upper mainstem	428,000	Assess survival and emigration timing (at Glines Dam).	Protracted emigration observed during the ensuing 15 months of passage monitoring at Glines Dam. A distinct peak in subyearling passage occurred in late summer. Over the total monitoring period, 28% of release group emigrated past Glines Dam.

Table 4. Summary of stock transfer guidelines applicable to Elwha River restoration efforts, adapted from Fedorenko and Shepherd (1986).

A. Consider the following characteristics in brood stock selection.

1. Geographic proximity to receiving systems: systems should be no more than 100 km apart, as measured between river mouths along connecting bodies of water.
2. Good access to broodstock in donor system.
3. Sufficiently strong escapement for long-term egg takes.
4. Match biological and environmental characteristics of:
   a. Life history types.
   b. Migration and spawn timing relative to recipient temperature regimen.
   c. Freshwater migration distance and route orientation.
   d. Marine conditions.
5. Disease profiles of donor and recipient sites.

B. Consider the following characteristics in receiving site selection.

1. Availability of suitable matched donor stocks.
2. Good access to release sites.
3. Suitable spawning and rearing environment.
4. Suitable forage base.
5. Suitable water source for holding juveniles prior to release.
6. Appropriate length and orientation of the freshwater migration route.
7. Limited predation and competition for food and space.

C. Select appropriate fish culture, release, and fishery strategies.

1. Conduct large-scale (minimum of 1 million eggs, depending on carrying capacity) and long-term (up to 10 yr) outplants until significant returns are developed.
2. Provide a large gene pool in donor stock.
3. Transplant a combination of life stages.
4. Use appropriate transfer and planting methods for eggs, juveniles, and adults.
5. Release juveniles at appropriate size and time.
6. Acclimate juveniles to release sites.
7. Ensure adequate dispersal of transplanted fish.
8. Limit predation and competition during freshwater phase.
9. Use techniques that improve homing to the release site.
10. Make optimal use of the returning progeny of transplants.
11. Develop and use innovative hatchery production techniques.
12. Regulate fishing pressure during developmental period.

D. Conduct feasibility and assessment studies at a level adequate to define reasons for success or failure of the project.