HATCHERIES AND WILD SALMON RECOVERY

By Bill Bakke, Director

Introduction:

Evaluation of hatchery fish effects on native, wild populations of salmonids is a relatively new endeavor. Since the 1870s hatcheries have been used as mitigation for harvest and habitat impacts. Spencer Baird, the U.S. Fish Commissioner, set the stage for the arrival of artificial propagation in the Columbia Basin. In a report he completed in 1875, Baird listed the threats to the continued productivity of Pacific salmon in the Columbia Basin – dams, habitat change and overharvest – and he recommended artificial propagation as the solution to those problems. According to Baird, an investment of $15,000 - $20,000 in artificial propagation would make salmon so abundant that there would be no need for restrictive regulations (Brannon 1999, Baird 1875).

Even though Baird had no credible scientific information for his recommendation, the concept of maintaining and even increasing the abundance of salmon through hatcheries was met with approval. The belief that hatcheries could eliminate the need for restrictive regulations was in agreement with the laissez-faire access to natural resources, a policy the public supported and the government encouraged. Its clear Baird's endorsement had social and political roots rather than scientific ones. From this inauspicious start, hatcheries quickly became the preferred approach to maintaining salmon production (Brannon 1999).

The promise that hatcheries could replace wild salmon and their habitats and maintain productive fisheries has continued through today. Since 1875, salmon fisheries have declined along with salmon abundance. The hatchery promise was not kept, but the optimism for hatcheries continues. Hatcheries are a primary investment to support salmon fisheries and salmon recovery for the last 132 years.

In 1939 a research biologist, Willis Rich, determined that salmon are locally adapted, based on tagging studies and developed the conservation concept of the home stream theory for salmon management. Each run had to have enough spawners to maintain the supply and the fisheries as well as habitat protection must be based on conserving the local stock. Even though his ideas were based on scientific evaluation, they never gained traction with fish managers or the public. Only after the Snake River chinook and sockeye salmon were listed under the federal Endangered Species Act, did a shift in management take place. This shift began to recognize the importance of protecting local populations as the basis of recovery. But the hatchery continues to play a key role in salmon recovery.

The conceptual framework for present day salmonid management was established by Baird in 1875. The fish management agencies have promoted the simple model of stock and kill as their preferred salmon management formula. As long as this mechanistic, technology based conceptual framework persists, an ecologically based and scientifically informed management program for salmon will be defeated by the agencies that have the public trust authority to maintain healthy salmon populations. It is unreasonable to expect an ecologically relevant management program informed by science to emerge out of this 132 year conceptual framework. One can expect the agencies to acknowledge new information that should be incorporated into management, but the purpose of management will remain the same. The effect of management that homogenizes biological and life history diversity will continue, the runs will continue to decline, extinctions will increase, and fishing opportunities will be depleted.

The following excepts from peer reviewed scientific studies and expert opinion challenge the efficacy of relying on hatcheries to recover native wild salmonids. Hatcheries may have a role to play in preventing extinction of a severely depleted run of salmon or steelhead, but they are also recognized as a contributing factor to salmonid decline. Using hatcheries to recover wild salmon populations is experimental, that is, it is unproven. Testing this technological approach to salmon recovery is the subject of these studies and their findings are informative. Hatcheries are not a replacement for wild salmon or their habitat. However, it is recognized that if hatcheries are to remain productive wild populations and the genetic and life history diversity they represent must be maintained. It is also recognized that the salmon life cycle habitats are key to maintaining both the hatchery and wild populations.

McLean, Jennifer E., Paul Bentzen, and Thomas P. Quinn. 2003. Differential reproductive success of sympatric, naturally spawning hatchery and wild steelhead trout through the adult stage. Can. J. Aquat. Sci. 60: 433-440.

Hatchery steelhead spawning in the wild had markedly lower reproductive success than native wild steelhead. Wild females that spawned in 1996 produced 9 times as many adult offspring per capita as did hatchery females that spawned in the wild. Wild females that spawned in 1997 produced 42 times as many adult offspring as hatchery females. The wild steelhead population more than met replacement requirements (approximately 3.7-6.7 adult offspring were produced per female), but the hatchery steelhead were far below replacement requirements (<0.5 adults per female).

Kostow, Kathryn E., Anne R. Marshall, and Stevan R. Phelps. 2003. Naturally spawning hatchery steelhead contribute to smolt production but experience low reproductive success. Trans. Am. Fish. Soc. 132: 780-790.

In the 2 years of our study, summer steelhead (introduced non-native steelhead), mostly hatchery fish, made up 60% to 80% of the natural spawners in the river. Genetic results provided evidence that interbreeding between hatchery summer and wild winter steelhead was likely minor. Hatchery summer steelhead reproductive success was relatively poor. We estimated that they produced only about one-third the number of smolts per parent that wild winter steelhead produced. However, the proportions of summer natural smolts were large (33%-53% of the total naturally produced smolts in the basin) because hatchery adults predominated on the spawning grounds during our study. Very few natural origin summer steelhead adults were observed, suggesting high mortality of the naturally produced smolts following emigration. Our data support a conclusion that hatchery summer steelhead adults and their offspring contribute to wild steelhead population declines through competition for spawning and rearing habitats.

Kostow, Kathryn, E. 2004. Differences in juvenile phenotypes and survival between hatchery stocks and a natural population provide evidence for modified selection due to captive breeding. Can. J. Fish. Aquat. Sci. 61: 577-589

Abstract: Juvenile phenotypes and fitness as indicated by survival were compared for naturally produced steelhead (*Oncorhynchus mykiss*), a new local hatchery stock, and an old nonlocal hatchery stock on the Hood River, Oregon, U.S.A. Although the new hatchery stock and the naturally produced fish came from the same parent gene pool, they differed significantly at every phenotype measured except saltwater age. The characteristics of the new hatchery stock were similar to those of the old hatchery stock. Most of the phenotypic differences were probably environmentally caused. Although such character changes would not be inherited, they may influence the relative fitness of the hatchery and natural fish when they are in the same environment, as selection responds to phenotypic distributions. A difference in fitness between the new hatchery stock and naturally produced fish was indicated by significant survival differences. Acclimation of the new hatchery stock in a "seminatural" pond before release was associated with a further decrease in relative smolt-to-adult survival with little increase in phenotypic similarity between the natural and hatchery fish. These results suggest that modified selection begins immediately in the first generation of a new hatchery stock and may provide a mechanism for genetic change.

The processes indicated by these results can be expected to lead to eventual genetic divergence between the new hatchery stock and its wild source

population, thus limiting the usefulness of the stock for conservation purposes to only the first few generations.

Nickelson, Thomas. 2003. The influence of hatchery coho salmon on the productivity of wild coho salmon populations in Oregon coastal basins. Can. J. Fish. Aquat. Sci. 60: 1050-1056.

To aid in the recovery of depressed wild salmon populations, the operation of hatcheries must be changed to reduce interactions of juvenile hatchery fish with wild fish. Evidence suggests that productivity of wild populations can be reduced by the presence of large numbers of hatchery smolts in lower rivers and estuaries that attract predators. …productivity…in 12 Oregon coastal basins and two lake basins was negatively correlated with the average number of hatchery coho salmon smolts released in each basin. Alterations to hatchery programs that could encourage recovery of wild populations include (*I)* avoiding release of large numbers of smolts in areas with high concentrations of wild fish, (ii) decreasing the number of smolts released, and (iii) using volitional release strategy or a strategy that employs smaller release groups spread temporally.

Chilcote, Mark. 2003. Relationship between natural productivity and the frequency of wild fish in mixed spawning populations of wild and hatchery steelhead. Can. J. Fish. Aquat.. Sci. 60: 1057-1067.

… a spawning population comprised of equal numbers of hatchery and wild fish would produce 63% fewer recruits per spawner than one comprised entirely of wild fish. For natural populations, removal rather than addition of hatchery fish may be the most effective strategy to improve productivity and resilience.

Mark Chilcote Quotes from the paper: Oregon Department of Fish and Wildlife'sEndangered Species Management Plan for Lower Columbia Coho Salmon July 12, 2001

ODFW initiated a hatchery-based program in the 1980s to restore natural production for these depressed populations. This program consisted of releasing large numbers of hatchery pre-smolt and adult coho throughout the lower Columbia basin for a period of almost 10 years. This program failed to restore wild populations. In fact, the ecological and genetic effects caused by a large in-flux of hatchery fish not adapted to local environmental conditions likely caused a further weakening of already depressed wild populations (Chilcote, 1999). Extinction of many local wild coho populations in the lower Columbia basin occurred shortly after this hatchery intervention program was initiated.

Chilcote, Mark, W. 2002. Revised survival estimates for Clackamas coho wild broodstock program. ODFW Memorandum February 1, 2002. Oregon Department of Fish and Wildlife, Fish Division.

"…there will be little benefit to bringing some of the wild fish into the hatchery environment if the resulting hatchery smolts will have ocean survival rates that are 1/10 of those for wild smolts….all indications are that hatchery fish, even from wild broodstocks, are not as successful as wild fish in producing viable offspring under natural conditions…."

Fleming, Ian. 2003. Artificial Production Review. N.W. Power Planning and Conservation Council. Portland, Oregon. Doc. 2003-17.

…the establishment of locally based hatchery broodstock does not eliminate concerns about domestication selection and the introduction of hatchery traits into the supplemented wild population. The constant, year-after-year supplementation of wild populations with hatchery fish means that both domestication selection on the hatchery-reared component and natural selection on the wild-reared component will operate on the combined population. This will disrupt and/or impede local adaptation to the wild environment, and consequently, will reduce the ability of the population to respond to environmental change. Moreover, if the abundance of hatchery fish is greater than that of the wild fish, the population will evolve in response to domestication (hatchery) selection rather than natural selection. This would occur despite fish spawning in the wild and annual mixing of wild fish into the hatchery broodstock.

Marchetti, Michael, P. and Gabrielle A. Nevitt. 2003. Effects of hatchery rearing on brain structure of rainbow trout. Environmental Biology of Fishes 66: 9-14.

We find…that the brains of hatchery reared fish are relatively smaller in several critical measures than their wild counterparts. Our work may suggest a mechanistic basis for the observed vulnerability of hatchery fish to predation and their general low survival upon release into the wild. Our results are the first to highlight the effects of hatchery rearing on changes in brain development in fishes.

Oosterhout, G. R., C. Huntington, T. E. Nickelson, and P. W. Lawson. 2005. A stochastic model investigation of the potential benefits of a conservation hatchery program for supplementing Oregon Coast coho salmon (Oncorhynchus kisutch). Can. J. Fish. Aquat. Sci. 62:1920-1935.

This study developed a stochastic life-cycle model to simulate idealized

supplementation strategies in order to investigate the question: Under what circumstances could hatchery fish stocking contribute to the recovery of Oregon Coast coho salmon (Oncorhynchus kisutch)? Simulations were used to find a "solution space," defined by the attributes of wild and hatchery-bred salmon, their offspring, and their environments, where hatchery fish could supplement natural production without further depressing it until natural or human factors restricting production were relieved.

These simulations suggest that short-duration, tightly controlled, low intensity "conservation hatchery" programs designed to minimize genetic and ecological risks may yield minor short-term increases in adult coho salmon abundance while posing significant ecological and genetic risks. No solution space was found that indicated clear long-term benefits from such a supplementation program. Of all the management actions modeled, habitat restoration offered by far the largest and only permanent gains in coho salmon abundance while posing no genetic or ecological risk to the fish. The modeled benefits of habitat restoration were significant regardless of assumptions made about the fitness of hatchery fish and their offspring.

Reisenbichler, R. R. and S.P. Rubin. 1999. Genetic changes from artificial propagation of Pacific salmon affect the productivity and viability of supplementated populations. ICES Journal of Marine Science, 56: 459-466.

All five of the studies in natural streams suggest the same conclusion: hatchery programmes that rear steelhead or chinook salmon for 1 year or longer before release genetically change the population and thereby reduce reproductive success when these fish spawn in natural systems. The results are consistent and confirm the results from the eight studies summarized (in this paper) which included additional species and work on two continents. In view of this consistency, one conclusion seems obvious: substantial genetic change in fitness results from traditional artificial propagation of anadromous salmonids held in captivity for one-quarter or more of their life. (page 463-464)

Lynch, Michael and Martin O'Hely.2001. Captive breeding and the genetic fitness of natural populations. Conservation Genetics. 2: 363-378.

Unless selective pressures of the captive environment are closely managed to resemble those in the wild, long-term supplementation programs are expected to result in genetic transformation that can eventually lead to natural populations no longer capable of sustaining themselves.

Fleming, Ian. 2003. Artificial Production Review. N.W. Power Planning and Conservation Council. Portland, Oregon. Doc. 2003-17.

…the establishment of locally based hatchery broodstock does not eliminate concerns about domestication selection and the introduction of hatchery traits into the supplemented wild population. The constant, year-after-year supplementation of wild populations with hatchery fish means that both domestication selection on the hatchery-reared component and natural selection on the wild-reared component will operate on the combined population. This will disrupt and/or impede local adaptation to the wild environment, and consequently, will reduce the ability of the population to respond to environmental change. Moreover, if the abundance of hatchery fish is greater than that of the wild fish, the population will evolve in response to domestication (hatchery) selection rather than natural selection. This would occur despite fish spawning in the wild and annual mixing of wild fish into the hatchery broodstock.

Reproductive Success in Salmonids: Abstracts

A symposium held at the American Society of Ichthyologists and Herpetologists Annual Meeting 1999.
Organized by *Andrew Hendry* and *Drew Hoysak.*
http://www.zoology.ubc.ca/~ahendry/RSsymp.html

Hatchery-wild interactions.

Gross, sMart, Bryan Neff, and *Ian Fleming.* Reproductive Success of Hatchery and Wild Coho Salmon.

Although salmon supplementation and conservation programs often use hatchery fish, there is a lack of empirical knowledge about their behaviour, ecology and reproductive success in the wild. We now present the results of several experiments in which we studied their behaviour and ecology and quantified their reproductive success. Both wild and hatchery coho salmon were allowed to freely breed within a spawning channel in the wild. The behaviors and interactions of the fish were recorded and after all spawning had been completed we collected the alevins from the nests. Using microsatellite genetic markers, we determined the parentage, including maternity and paternity, of the fish. Several important relationships emerged, including that between male position in the mating hierarchy and paternity, between male size and reproductive success, between stock type (hatchery or wild) and paternity, and between mating partner and success. Overall, hatchery males attended fewer mating hierarchies, obtained lower paternity within a position, and made up only about a third of the male contribution to the next generation. Hatchery females were also significantly less successful than wild females. Hatchery fish were therefore relatively maladapted and decreased the wild population's effective population size. Finally, our

measures of reproductive success within hierarchies may be widely applicable to studies of salmon in the field. This research is supported by NSERC and DFO of Canada, and NINA of Norway.

Hulett,Patrickt, Cameron Sharpe, and *Chris Wagemann.* Natural reproductive success of hatchery and wild steelhead in the Kalama River, Washington.

Allozyme genetic marking approaches were used in two long-term studies to estimate the reproductive success of non-locally derived stocks of hatchery summer and hatchery winter steelhead spawning naturally in the Kalama River. Results of the winter-run study corroborate those previously published from the summer-run study. Reproductive success (offspring produced per spawner) of the hatchery steelhead was substantially lower than that of the wild fish. Also, the disparity in reproductive success was increasingly pronounced at successive (subyearling, smolt, and adult) life history stages of the offspring. These results are believed to reflect genetic differences between the wild and non-local hatchery stocks. Because their natural spawning poses genetic and ecological risks to wild steelhead, the non-local hatchery adults are no longer permitted access to principal wild Kalama steelhead spawning areas. Moreover, new research has been initiated to assess the wild stock conservation merits of using locally derived wild broodstock as a source for hatchery steelhead production. Specifically, the reproductive success of hatchery-reared steelhead spawned from wild Kalama summer-run broodstock will be compared to that of their wild-reared counterparts by relating microsatellite DNA profiles of naturally produced offspring to those of their prospective hatchery and wild parents.

Park, Linda, Jeff Hard, Barry Berejikian, Skip Tezak, and *Eric LaHood.* Reproductive success of captively-reared, naturally spawning coho salmon.

One captive broodstock strategy being used in the management of Pacific salmon involves capturing juveniles, rearing them to maturity in captivity, and releasing them to spawn naturally with returning wild adults; however, captively-reared fish typically do not exhibit many of the physical characteristics of sexually mature adults. Since salmon compete for mates in a courtship ritual, it is not clear whether such fish would successfully mate with wild fish. In one experiment, captively-reared adult coho salmon were placed in experimental channels with an equal number of wild-caught adults. The fish were allowed to court and spawn undisturbed. Microsatellite genotyping of the resulting progeny was used to evaluate reproductive success of the two groups. We were able to assign over 98% of the progeny examined to single pair matings. The variance in reproductive success among individuals was quite high. Because all potentially spawning parents were known and their

number was limited (20 per channel), the number of loci needed to determine individual pedigrees was minimal (from 3-5); however, we also genotyped additional individuals from the adult source populations and performed simulations to examine how many loci might be necessary to perform such an analysis with a larger population.

Berejikian,Barry, Skip Tezak, Linda Park, Steve Schroder, and *Edward Beall.* Male competition and breeding success in captively reared and wild coho salmon.

In the Pacific Northwest, releasing captively reared adult salmon (*Oncorhynchus* spp.) for natural spawning is an evolving strategy for the recovery of imperiled populations. The ability of captively reared fish to spawn naturally may be compromised by their artificial rearing environments, which differ markedly from those experienced by wild fish. In this study, wild coho salmon (*O. kisutch*) males dominated access to spawning females in 11 of 14 independent trials. In two cases where satellite males (both captively reared) were observed participating in spawning, DNA fingerprinting results determined that they did not sire any of the progeny. When spawning occurred at night and was not observable, DNA results confirmed continuation of behaviour-based hierarchies determined before nightfall. Aggression data collected during the first hour of competition indicated that dominance was established soon after the males were introduced into a common arena containing a sexually active female. We hypothesize that status signaling and decisions by subordinate males to avoid direct competition may have minimized conflict. The competitive inferiority of captively reared coho salmon in this and a previous study probably reflects deficiencies in culture environments which fail to produce appropriate body coloration, body shape, and perhaps alter natural behavioral development.

Reproductive success in the wild.

<u>*Hendry*</u> *Andrew, John Wenburg, Eric Volk,* and *Thomas* <u>*Quinn*</u>. Differential reproductive success of residents and immigrants (strays) in a wild population.

We demonstrate that sockeye salmon populations can exchange many migrants each generation and yet remain genetically distinct, owing to reduced reproductive success in strays. We studied a small beach population that receives strays each generation from a much larger river population (both in Lake Washington, Washington). Site-specific otolith microstructure patterns were used to determine which beach spawners had been born at the beach (residents) and which had been born in the river (strays). In each of two years, about 1% of the river population strayed to the beach but these strays composed 35 - 44% of the beach spawners. If strays and residents had similar reproductive success, such levels of gene flow would prevent any neutral

genetic divergence of the populations. However, allelic variation at microsatellite loci revealed that beach residents were distinct from the river population and from river fish that strayed to the beach. Strays were morphologically similar to river fish but quite different from beach fish, suggesting that local adaptation may play a role in their reduced success at the beach. Local adaptation of residents and declining success of strays can arise early in a population's history (the beach site was colonized less than 14 generations ago).

Smoker,Bill, Tony Gharrett, and *colleagues.* Genetic variation of life history traits and outbreeding depression in locally adapted populations of Pacific salmon.

Two isolated populations of pink salmon (*Oncorhynchus gorbuscha*) spawn in odd- or even-numbered years in Auke Creek, Alaska, and many other streams bordering the subarctic Pacific Ocean. We have used a series of breeding experiments to analyze variation of life history traits in those populations, and to test for outbreeding depression in F2 hybrids between them. Analysis of between family variation of embryonic traits (studied in the laboratory) and of adult traits (in fish liberated to sea and returning as adults to their natal stream) provides evidence of genetic variation of date of return, body size, fecundity, embryo development time, etc. Genetic variation of survival itself was high particularly when cohort survival at sea was high. Genotype by environment interaction was evident in our analysis of variation of embryo development time under different environmental (temperature) regimes. Outbreeding depression (reduced survival at sea in the second generation) was suggested in hybrids (formed by cryopreservation of semen) between sympatric Auke Creek populations, odd-year and even-year salmon. This evidence supports the notion that differences between local populations of salmon have evolved in response to selection in different local environments and that genetic variation.

Bentzen,Paul, Thomas Quinn, Gregory Mackey, and *Todd Seamons.* Variation in reproductive success within and among populations of steelhead trout.

Variation in reproductive success (RS) among individuals within populations is an important determinant of effective population size (Ne), a critical component of the process of natural selection, and an important management issue in the case where non-native populations are introduced to supplement local native production. We are studying individual RS in three populations of winter-run steelhead trout (*Oncorhynchus mykiss*) in Washington State to shed light on all of these issues. One population is entirely wild, native and non-fished. The other two populations occur in a second drainage; one is wild and native, and the other is a recently established hatchery population of allopatric origin that has been selected to spawn earlier than wild populations to

promote reproductive isolation between native wild and feral hatchery fish. We are non-lethally sampling pre-spawning adult steelhead in each of these populations, and their progeny at juvenile, smolt and adult life history stages. In each case we record phenotypic data (length, weight, time of upstream migration of adults) and take fin clips for DNA analysis. We are determining parentage, and hence realized reproductive success, through analysis of genetic variation in a suite of highly polymorphic microsatellite loci. Early results of this study will be discussed.

Goodman, Daniel. 2005. Selection equilibrium for hatchery and wild spawning fitness in integrated breeding programs. Can. J. Fish. Aquat. Sci. 62: 374-389.

Integrated Hatchery Issues:

"hatchery husbandry practices have advanced to the point where hatchery propagation of salmon can be an effective means to produce smolts for release to the wild, where they will rear, grow, and mature and return for harvest. While the smolt to adult return rates of hatchery salmon are often lower than those of the corresponding wild fish, the egg to smolt survival rates are generally enough higher in the hatchery, compared with the wild, to more than compensate. This results in a net numerical life cycle advantage for the hatchery stock in hatchery propagation, allowing a higher harvest rate. A salmon hatchery program that is successful from the standpoint of production for harvest may, nevertheless, be judged a liability because of harmful effects on wild salmon sharing the same natural habitats."

"The negative ecological effects of hatchery production on a wild stock with which it interacts can include competition and predation. An unselective harvest managed for the higher productivity of the hatchery stock will overharvest the wild stock."

"Straying of hatchery adults into the wild spawning grounds raises the potential for harmful genetic effects as well. Hatchery propagation of a hatchery stock gives rise to domestication selection, which results in accumulation of adaptations to hatchery conditions, with attendant deterioration of performance under natural conditions during the corresponding portion, of the life cycle. Further, the postrelease life history that evolves to mesh with the hatchery rearing may not prove adaptive when fish from the hatchery stock spawn in the wild."

"These models show that evolution towards lower natural spawning fitness is indeed a theoretical possibility in integrated production programs."

"Integrated hatchery breeding programs have been proposed as a possible solution to the problems posed by the negative effects of hatchery stocks on the wild stocks with which they interact. Once the integrated breeding program has been in place, the wild stock will no longer be distinct, so there is no point to asking whether the hatchery phase of the integrated population has a negative effect on the fitness of the natural spawning phase."

"All the models are in agreement that a reduction in natural spawning fitness is possible and that the reduction could be large, which lends credence to the concerns about large-scale implementation of integrated production programs and raises grave questions about the suitability of supplementation as a conservation measure for weak stocks that are still self-sustaining (Goodman 2004)"

"It would be prudent to proceed with careful experimental design and systematic monitoring to determine how frequently and sever the depression of natural spawning fitness really is. In particular, since the modeling shows that the depression of natural spawning fitness will increase with the magnitude of the hatchery contribution to total production, it would be good to determine empirically whether specific policy caps on the amount of hatchery contribution can limit the fitness erosion to a tolerable level."

S.L. Schroder, C.M. Knudsen, B. D. Watson, T. N. Pearsons, S. F. Young1, and J. A. Rau. 2003. Comparing The Reproductive Success Of Yakima River Hatchery- And Wild-Origin Spring Chinook. BPA Annual Report. Project No. 1955-064-24.

SUMMARY
In the Yakima Spring Chinook supplementation program, wild fish are brought into the Cle Elum Hatchery, artificially crossed, reared, transferred to acclimation sites, and released into the upper Yakima River as smolts. When these fish mature and return to the Yakima River most of them will be allowed to spawn naturally; a few, however, will be brought back to the hatchery and used for research purposes. In order for this supplementation approach to be successful, hatchery-origin fish must be able to spawn and produce offspring under natural conditions. Recent investigations on salmonid fishes have indicated that exposure to hatchery environments during juvenile life may cause significant behavioral, physiological, and morphological changes in adult fish. These changes appear to reduce the reproductive competence of hatchery fish. In general, males are more affected than females; species with prolonged freshwater rearing periods are more strongly impacted than those with shorter rearing periods; and stocks that have been exposed to artificial culture for multiple generations are more impaired than those with a relatively short exposure history to hatchery conditions.

Knudsen, Curtis, M., Steve L. Schroder, Craig A. Busack, Mark V. Johnson, Todd N. Pearsons, William J. Bosch, and David E. Fast. 2006. Comparisions of life history traits between first-generation hatchery and wild upper Yakima River spring chinook salmon. Trans. Am. Fish. Soc. 135: 1130-1144.

The intent is to have the Yakima River (hatchery) supplementation program be an integrated program with a constant infusion of hatchery-origin spawners each year and to use natural-origin fish only as hatchery broodstock. The intent is to increase natural production of spring chinook salmon while at the same time producing hatchery returns that are equivalent to naturally produced returns in terms of life history and reproductive success, at rates comparable to wild salmon.

Perhaps the most important conclusion of our study is that even a hatchery program designed to minimize differences between hatchery and wild fish did not produce fish that were identical to wild fish.

Reisenbichler, Reg and Steve Rubin Domestication in Steelhead: Caught in the Act. 1USGS, Western Fisheries Research Center, Seattle, WA 98115;

Genetic theory and data suggest that sea ranching of anadromous salmonids (*Oncorhynchus* spp. and *Salmo* spp.) results in domestication (increased fitness in the hatchery program) accompanied by a loss of fitness for natural production. We tested for genetic differences in growth, survival, and downstream migration of hatchery and wild steelhead (*O. mykiss*) reared together in a hatchery. We found little or no difference in survival during hatchery rearing but substantial differences in growth and subsequent downstream migration. Intense natural selection after release from the hatchery favored fish that had performed well (e.g., grew fast) in the hatchery. This selection in the natural environment genetically changes (domesticates) the population because at least some of the performance traits are heritable. Domestication should improve the economic efficiency for producing adult hatchery fish but compromise conservation of wild populations when hatchery fish interbreed with wild.

Fleming, Ian. 2003. Artificial Production Review. N.W. Power Planning and Conservation Council. Portland, Oregon. Doc. 2003-17.

…the establishment of locally based hatchery broodstock does not eliminate concerns about domestication selection and the introduction of hatchery traits into the supplemented wild population. The constant, year-after-year supplementation of wild populations with hatchery fish means that both domestication selection on the hatchery-reared component and natural

selection on the wild-reared component will operate on the combined population. This will disrupt and/or impede local adaptation to the wild environment, and consequently, will reduce the ability of the population to respond to environmental change. Moreover, if the abundance of hatchery fish is greater than that of the wild fish, the population will evolve in response to domestication (hatchery) selection rather than natural selection. This would occur despite fish spawning in the wild and annual mixing of wild fish into the hatchery broodstock.

Ward, Bruce. March 2006. The Case for Wild Steelhead Recovery Without Artificial Fish Culture Intervention. University of British Columbia, Vancouver, British Columbia, Canada.

Can hatchery fish speed the recovery of wild populations of steelhead when they are in low abundance?

Little evidence is available to support the contention that hatchery steelhead can serve as a tool to re-build the wild population directly through the spawning of hatchery returns in wild rivers. Indeed, the evidence suggests the opposite may be true. For example, Smith and Ward (2000) provided results from the steelhead harvest questionnaire indicating that the rate of decline of the catch of wild adult returns in rivers with hatchery fish present was greater than that rate in wild-only rivers. Despite the presence of hatchery steelhead in many rivers on Vancouver Island in the 1990s, wild stocks continued to decline, to the point where it was very difficult to locate wild broodstock (thus terminating hatchery releases in these streams). Walters (2005) listed several works where the reproductive success of hatchery fish was lower than wild. Lower reproductive success of hatchery steelhead, and the lowering of reproductive success of wild fish in the presence of hatchery fish, may be attributed to several factors, including morphology, behaviour and genetics. Many examples of factors listing differences between wild and hatchery fish are available in the scientific literature, and there have been several recent reviews.

The distribution and behaviour of hatchery-cultured fish into their natal watershed has been disrupted by the artificial spawning and farming process. Female returns from hatchery releases are smaller and have lower fecundity than in wild fish, automatically entailing lower reproductive success. Wild adults, particularly females, have fidelity in spawning to their family rearing area as juveniles, in general, or have adapted complex behavioural traits that insure survival of the progeny through upstream or downstream migrations of fry or parr. We have observed unique site-specific behaviours of upstream, downstream or off-channel seasonal migrations to refuge or feeding areas that

are more likely inherited than learned. That behavioral complexity and fine-scale adaptation is likely altered by the farming aspects of mate selection, the artificial rearing environment, and the release tactics. Returning hatchery fish are unlikely to sort in river according to their family heritage sites, and return mainly to the site of release, thus further lowering fitness compared to wild fish.

What is supplementation and why is it risky?

Supplementation, the use of artificially-reared fish to attempt to enhance numbers of juveniles and adults to increase the number of naturally-spawning adults in a target population has been a controversial option for rebuilding salmonid populations for over two decades (ISRP 2005). Supplementation can reduce the natural spawning fitness component in the integrated wild and hatchery spawners, and this reduction in wild fitness will persist for a number of generations after the termination of supplementation, according to the Independent Scientific Review Panel of the Northwest Power and Conservation Council for the Columbia River. In a further report on monitoring and evaluation of supplementation projects, they and the Independent Scientific Advisory Board (ISRP&ISAB 2005) go on to suggest that the critical uncertainties are whether supplementation provides a demographic increase in natural production (the potential benefit) and whether supplementation leads to decreased natural-spawning fitness (the potential harm) in the integrated population. Supplementation entails demographic, genetic (fitness), ecological, and disease risks and uncertainties.

Hey, Jody, Ernest L. Brannon, Donald E. Campton, Roger W. Doyle, Ian A. Fleming, Michael T. Kinnison, Russell Lande, Jeffrey Olsen, David P. Phillip, Joseph Travis, Chris C. Wood, and Holly Doremus (Facilitator). May 16, 2005. Considering life history, behavioral, and ecological complexity in defining conservation unites for Pacific salmon an independent panel report, requested by NOAA Fisheries.

In particular, hatchery-reared fish may have experienced a selective regime that shifts their allele frequencies in a direction quite different from what is occurring in the gene pool of a related natural population. Such divergence may not be detectable with randomly se4lected or neutral molecular genetic markers. A regular process of genetic admixture of hatchery-adapted fish to a wild population can prevent the wild population from evolving to meet changing conditions in the wild. Similarly, the behavior of hatchery-reared fish may differ sufficiently from wild fish such that a mixed group may have reduced reproductive success. By holding to a phylogenetic criterion and overlooking a population perspective of exchangeability, salmon ESUs are sometimes treated largely as taxonomic units rather than as evolutionary and

ecological role players. This can lead to a lumping of hatchery fish with related wild populations when in fact the two groups are biologically different in many ways.

…gene swamping by hatchery stocks has the capability of driving wild stocks to extinction, even in integrated breeding programs if there are genetic covariances between traits conferring high fitness in the hatchery environment and low fitness later in life in the wild environment.

Varanasi, Usha. 2004. Review of proposed hatchery listing policy. Memorandum to D. Robert Lohn, Regional Administrator, NW Region, National Marine Fisheries Service *from* Science Director, NW Fisheries Science Center, National Marine Fisheries Service.

There are not direct empirical data regarding the question whether hatcheries can contribute to long-term sustainability of salmon populations and ESUs.

…empirical and theoretical considerations indicate that domestication associated with hatchery propagation can lead to a situation in which a natural population becomes unable to sustain itself in the wild without continual supplementation with hatchery fish.

…we believe the only way to ensure the persistence of salmon in the long-term (centuries) is to conserve natural populations and natural ecosystems.

For nine years that it was in effect, the Interim (hatchery) Policy therefore put the focus of listing and recovery decisions entirely on natural populations…the interim policy and its application recognized three important biological facts about hatcheries: 1) under NOAA Fisheries' definition of an Evolutionarily Significant Unit (ESU) some hatchery and natural populations can be part of the same biological ESU, 2) hatcheries can in some cases be used to help conserve natural populations, at least in the short term, and 3) many existing hatchery populations, whether they are biologically part of an ESU or not, are unlikely to be useful for conservation and may even hinder recovery of natural populations.

We are aware of no new data or research, however, to suggest that a species or ESU that *requires* ongoing artificial propagation for its survival will be viable in the long- term. In fact, scientific review panels that have considered this subject have consistently emphasized the importance of conserving a rich diversity of viable natural populations. (e.g. National Research Council 1996, Brannon et al. 1999, Independent Scientific Advisory Board 2002 and 2003).

The proposed policy indicates that some special attention may be paid to naturally spawning populations, but the policy does not clearly state that self-sustaining natural populations are necessary to meet the goals of the ESA. That is a concern for two reasons: 1) The proposed policy provides no rationale for its reinterpretation of the ESA to de-emphasize the conservation of natural populations… 2) We are aware of no biological data or analysis collected over the last ten years that would justify this policy change. In particular, we believe that there is no biological justification for believing that populations dependent on artificial propagation can be considered viable in the long term.

(Note: the proposed hatchery policy was adopted by NMFS in spite of the reservations communicated by the NW Science Center biologists.)

…the status and trends of natural populations and their ecosystems are the best indicators of a species' or ESUs' long-term viability.

If the goals of the ESA are to prevent extinction and conserve species over time frames similar to which they have already existed (or at least to provide future generations with the option of doing so), then the available science indicates that this can only be done by conserving a diversity of self-sustaining natural populations and their natural ecosystems.

We recommend that when it is revised, the proposed (hatchery) policy clearly state that the status of an ESU with respect to listing and recovery be based largely or entirely on the status of its natural populations.

Evolutionary models predict that domestication and loss of productivity in the wild are expected to occur in populations that are supplemented for long periods of time. In the long-term, therefore, even use of local stocks to supplement natural populations has the potential to lead to declines in natural productivity and natural origin abundance.

…conservation strategies that rely heavily on hatchery production as a substitute for conservation of natural populations and ecosystems are far less likely to conserve diversity than strategies that conserve viable natural populations and natural ecosystems. For example, it is effectively impossible to create a sufficient number of hatchery stocks to replicate the thousands of genetically varying natural spawning populations that exist (or existed) naturally.

We point out, however, that many of the hatchery reform efforts underway will require the existence of healthy natural populations in order to be effective.

The HSRG (Hatchery Scientific Review Group) defines an integrated hatchery program as a program that uses local broodstock and attempts to avoid long-term loss of fitness due to domestication. One of the recommendations the HSRG makes for meeting this goal is to ensure that the hatchery broodstock consists of a substantial fraction of natural origin fish every year, while concurrently limiting natural spawning of hatchery fish to low levels. The only way to implement this recommendation in the long-term is to have self-sustaining natural populations as sources of hatchery broodstock. In other words, under some widely promoted hatchery reform strategies, the long-term viability of the reform hatchery system itself may depend upon the continued existence of healthy natural populations and an intact natural ecosystem.

Extinctions and recolonizations occur, and life history and other diversity is lost and gained in response to environmental perturbations and chance events. However, the species themselves are much more stable (on scales of millions of years), due in large part to a rich store of geographic, genetic, ecological and life history diversity maintained in natural populations. We can expect salmon to persist into the foreseeable future if something approximating these historical conditions is maintained. This is the only proven method for long term sustainability.

In contrast to the natural ecosystem, relying either solely or largely on hatcheries is highly uncertain as a strategy for the long-term conservation of a species or ESU. Here we will concentrate on two key factors: 1) Long-term dependence upon hatcheries is likely to lead salmon ESUs into an evolutionary and ecological path that will make the chance of full recovery in the wild more and more difficult as time passes, and 2) dependence upon hatcheries is intrinsically risky because it is a dependence upon human actions that could cease at any time.

Evolutionary theory and data predict that in the long-term artificially propagated populations may become maladapted to the natural environment as they adapt to the artificial environment. In the case of salmon, there are currently insufficient data to predict how rapidly this will happen, but it is reasonable to assume that the longer a population is propagated in captivity, the less likely it will be able to sustain itself wholly in the wild. This is also potentially a problem for mixed hatchery-natural populations. This means that choosing a conservation strategy that relies indefinitely on artificial propagation may preclude full recovery in the wild even if future generations decide to make that a priority. Second, reliance upon artificial propagation is likely to indirectly lead to further degradation and loss of habitat…further precluding future recovery in the wild. Making a choice to depend on artificial propagation now may reduce the risk of extinction to a low level in

the short-term (several decades), while simultaneously precluding any possibility of true recovery beyond that time frame.

A species or ESU that has been decoupled from ecological processes that play out over 10,000 year and longer time frames and is instead forced to rely on human technology and values that can change abruptly and unpredictably will therefore be at significant risk of extinction in the foreseeable future.

Species that depend upon the existence of reserves or conservation areas to survive…are dependent upon the human institutions that mandate the reserves' existence and protect them… It is important to distinguish between this sort of dependence on human intervention. Species and populations that are passively dependent still rely primarily on the natural ecosystem for their basic needs. This is different from a reliance on ongoing active human intervention, such as artificial propagation… Species that require ongoing, intensive human intervention cannot generally be considered at low risk of extinction because of the ephemeral nature of human institutions…

Helle, J.H. 1981. Significance of the stock concept in artificial propagation of salmonids in Alaska. Can. J. Fish. Aquat. Sci. 38:1665-1671.

"Our primary goal in management of our salmonid resources should be to maintain as many viable, diverse wild stocks as possible."

Recommendations:

1. Establish gene banks in certain watersheds
2. Protect gene banks from certain uses such as hatchery influence, dams, etc.
3. Use hatchery technology that causes minimal selection for hatchery-type fish.
4. Do not transplant fish stocks.
5. The hatchery should be adapted to the needs of the fish and operated within the ecosystem objectives.
6. Is the hatchery product manageable or will it impose unmanaged impacts on native stocks, selecting against a sustainable self-perpetuating resource through harvest, genetic introgression and weakening our resolve to protect habitats.

Lichatowich, James. 1999. Salmon Without Rivers. Island Press.

"With each small population that disappears, with every run that becomes extinct, biodiversity – the very quality that has enabled the salmon to withstand ice ages, mountain uplifts, lava flows, changing ocean conditions, and the whole onslaught of the industrial economy – is lost. Tragically, it is this biodiversity that habitat destruction, overharvest, and the technology of hatcheries have systematically whittled away for over 100 years. If the Pacific salmon are to survive, they will need all of their evolutionary biodiversity that remains. And they will need healthy rivers where that biodiversity is nurtured and maintained."

Snyder, J.O.1940. The trouts of California. Cal Fish and Game 20:96-138.

"Artificial propagation should supplement rather than supplant natural production....It should not, however, be charged with the entire responsibility of maintaining an unlimited supply of fish against and uncurbed and irresponsible demand."

Mobrand, Lars, John Barr, Lee Blankenship, Donald E. Campton, Trevor T.P. Evelyn, Tom A. Flagg, Conrad V.W. Mahnken, Lisa W. Seeb, Paul R. Seidel, William W. Smoker. June 2005. Hatchery Reform in Washington State: Principles and Emerging Issues. Amer. Fish. Soc. *Fisheries*. pp 11-23.

"We conclude that hatcheries must operate in new modes with increased scientific oversight and that they cannot meet their goals without healthy habitats and self-sustaining naturally spawning populations."

"Scientific monitoring and evaluation of hatchery programs needs to be expanded to determine whether hatcheries are achieving their goals…a major effort should be made to obtain a census of marked hatchery fish spawning with their natural counterparts and to estimate the impact of hatchery fish on the fitness of the natural component."
"Monitoring and evaluation should assess smolt-to-adult survival, return rates of adults, contribution of adults to harvest and natural spawning, the proportion of naturally-spawning fish composed of hatchery-origin adults, stray rates of adults to non-target watersheds, and life history traits related to fitness…assessments of genetic and ecological interactions (e.g., interbreeding, competition, predation, and reproductive success) between hatchery and natural-origin fish. Biologists should also monitor life history, morphological, and other traits related to fitness because of the potential domestication effects of hatcheries."

"Hatchery programs are often not consistent with goals or the best available scientific information."

"…hatcheries have historically had no formal genetic management plan or strategy for their component broodstocks."

"One goal of integrated hatchery programs is to minimize the genetic effects of domestication by allowing selection pressures in the natural environment to drive the genetic constitution of hatchery-origin fish and the mean fitness of the population as a whole. In contrast, segregated hatchery programs create a genetically distinct, hatchery adapted population."

"The goals of genetic integration can be achieved only if the rate of gene flow from the natural environment to the hatchery environment exceeds the reverse rate of gene flow."

"An integrated hatchery program requires, as a long-term goal, a self-sustaining, naturally spawning population capable of providing adult fish for broodstock each year. Integration thus requires suitable natural habitat capable of sustaining a natural population. Under this strategy, an integrated hatchery does not replace habitat but adds to existing habitat."

"An implicit goal of an integrated program is to demographically increase the abundance of natural population while minimizing the genetic effects of artificial propagation."

"However, the size of an integrated hatchery program will necessarily be limited by the habitat available to the natural populations with which it is integrated and by the ability of the hatchery program to restrain natural spawning by hatchery-origin adults."

"Hatchery reform cannot occur independently of 'harvest reform' and habitat improvements. All three components must be managed together to achieve long-term and sustainable conservation and harvest goals for Pacific salmon and steelhead resources."

"Trends in the carrying capacity of the marine environments must be considered for determining the number of fish released from a hatchery. Until recently, marine ecosystems were believed to be stable…"

"Based on earlier assumptions that marine carrying capacity was unlimited or had not yet been reached, the goal of increasing fisheries was pursued by building more hatcheries and releasing more fish. As a result, the number of juvenile salmon released from Pacific Northwest hatcheries increased substantially after the early 1960s."

"Decreasing smolt-to-adult survivals of southern North American hatchery stocks during the late 1970s and late 1980s only motivated co-managers to release more hatchery fish to compensate for reduced fisheries catch.

"A common feature of outplanting and net-pen programs is the absence of facilities to trap returning adults that escape target fisheries. Non-harvested adults can then spawn in streams far-removed from the source hatchery…"

"…stray rates of fish released off-station are generally greater than those of fish released directly from hatcheries…outplanting and net pen programs promote stray rates that far exceed natural levels."

"We conclude that outplanting and net pen releases pose significant, and potentially unacceptable, genetic risks to natural populations and recommend several measures to reduce risks associated with outplanting. These recommendations include reductions in the number of fish released from saltwater net pens, removal of all or nearly all hatchery returnees in concentrated fisheries, the construction of juvenile acclimation and adult recapture facilities, and the potential establishment of wild salmon and steelhead management zones."

. Natural –origin pink and chum salmon and ocean-type chinook salmon are most likely to be preyed upon by hatchery-reared salmonids in Washington. Yearling coho, stream type chinook salmon and steelhead smolts have the greatest likelihood of preying on wild salmonid fry due to their large relative size at release. Smolts that remain (residualize) in rivers for months or years after release may represent an important predation risk of wild salmonid populations."

"Returning adult salmon transfer marine nutrients into terrestrial and freshwater ecosystems, contributing significantly to primary production, riparian vegetation, and even old growth forests. Those nutrients also contribute significantly to the food sources of juvenile salmonids. For example, in one study, up to 60% of the fixed nitrogen in benthic insects was derived from salmon carcasses. Those…investigators also found that juvenile salmon have higher growth rates in streams with spawning adults. Hatchery-origin salmon carcasses also increased the density of age 0+ coho salmon and age 0+ and 1+ steelhead in small streams in southwestern Washington. Distributing spawned out salmon carcasses from hatcheries into watersheds can thus confer a positive ecological benefit to stream nitrification and naturally spawning populations."

"…we recommend that hatchery-origin spawners from genetically segregated programs represent < 5% of the natural spawners as an upper-limit guideline."

"We conclude that outplanting and net pen releases pose significant, and potentially unacceptable, genetic risks to natural populations.

"The need to develop broodstock genetic management plans for every hatchery program with the goal of managing each broodstock as either a genetically-segregated 'hatchery population' or as a genetically-integrated component of an existing 'natural population' became a fundamental foundation for our recommendations. Both strategies require the ability to distinguish hatchery and natural-origin adults, both in the hatchery and when adults are spawned for broodstock and on the natural spawning grounds, to assess the genetic risks and gene flow rates of hatchery-origin fish to natural populations."

"…one point is clear. Maintaining healthy habitat is critical not only for viable, self-sustaining natural populations, but also to adequately controls risks of hatchery programs and realize the benefits of hatcheries to recover populations and sustain healthy harvests.

Viability Assessment

High to low viability based on effective breeding population
>5,000 Ne High viability
<100 Ne Low viability

High to low mean number of recruits per spawner over ten years
>5 recruits per spawner High viability
<1 recruits per spawner Low viability

For natural populations only: What proportion of natural spawners is composed of hatchery fish?
<1% High viability
>30% Low viability

For hatchery populations only: What proportion of eggs, fry, juveniles, or adults are derived from another hatchery, watershed, or natural origin fish.
<1% High viability
>30% Low viability

Brannon, Ernest, Kenneth P. Currens, Daniel Goodman, James A. Lichatowich, Willis E. McConnaha, Brian E. Riddell, and Richard N. Williams. 1999. Review of artificial production of anadromous and resident fish in the Columbia River

Basin, Part I: A scientific basis for Columbia River production program, Northwest Power Planning Council, 139 pp.

The three recent independent reviews of fish and wildlife recovery efforts in the Columbia River Basin addressed hatcheries among other issues – one report addressed hatcheries specifically. These reviews collectively represent a concerted effort to assess hatchery production form the scientific perspective. There was consensus among the three panels (National Fish Hatchery Review Panel, National Research Council, Independent Science Group), which underscores the importance of their contributions in revising the scientific foundation for hatchery policy. The ten general conclusions made by the panels are listed below.

1. **Hatcheries generally have failed to meet their objectives**
2. **Hatcheries have imparted adverse effects on natural populations**
3. **Managers have failed to evaluate hatchery programs**
4. **Rationale justifying hatchery production was based on untested assumptions.**
5. **Hatchery supplementation should be linked with habitat improvements**
6. **Genetic considerations have to be included in hatchery programs.**
7. **More research and experimental approaches are required.**
8. **Stock transfers and introductions of non-native species should be discontinued.**
9. **Artificial production should have a new role in fisheries management.**
10. Hatcheries should be used as temporary refuges rather than for long-term production.

References:

Baird, S. 1875. Salmon fisheries of Oregon. *The Oregonian,* March 3, 1875, Portland, Oregon.

Brannon, Ernest, Kenneth P. Currens, Daniel Goodman, James A. Lichatowich, Willis E. McConnaha, Brian E. Riddell, and Richard N. Williams. 1999. Review of artificial production of anadromous and resident fish in the Columbia River Basin, Part I: A scientific basis for Columbia River production program, Northwest Power Planning Council, 139 pp.