HATCHERY SALMON ARE DIFFERENT FROM AND HAVE IMPACTS ON WILD SALMON: OUOTES FROM THE SCIENTIFIC LITERATURE

Allendorf et al. 1994: "We are not aware of a single empirical example in which (hatchery) supplementation has been successfully used as a temporary strategy to permanently increase abundance of naturally spawning populations of Pacific salmon."

Altukhov et al 1991: "Artificial reproduction, commercial fisheries, and transfers result in the impairment of gene diversity in salmon populations, and so cause their biological degradation."

Araki et al. 2007: "We show that genetic effects of domestication reduce subsequent reproductive capabilities by ~40% per captive-reared generation when fish are moved to natural environments. These results suggest that even a few generations of domestication may have negative effects on natural reproduction in the wild and that the repeated use of captive-reared parents to supplement wild populations should be carefully reconsidered."

Araki et al. 2008: "Captive breeding is used to supplement populations of many species that are declining in the wild. The suitability of and long-term species survival from such programs remain largely untested, however. We measured lifetime reproductive success of the first two generations of steelhead trout that were reared in captivity and bred in the wild after they were released. By reconstructing a three-generation pedigree with microsatellite markers, we show that genetic effects of domestication reduce subsequent reproductive capabilities by ~40% per captive-reared generation when fish are moved to natural environments. These results suggest that even a few generations of domestication may have negative effects on natural reproduction in the wild and that the repeated use of captive-reared parents to supplement wild populations should be carefully reconsidered."

"Our review indicates that salmonids appear to be very susceptible to fitness loss while in captivity. The degree of fitness loss appears to be mitigated to some extent by using local, wild fish for broodstock, but we found little evidence to suggest that it can be avoided altogether. The general finding of low relative fitness of hatchery fish combined with studies that have found broad scale negative associations between the presence of hatchery fish and wild population performance, should give fisheries managers pause as they consider whether to include hatchery production in their conservation toolbox."

"Accumulating data indicate that hatchery fish have lower fitness in natural environments than wild fish. This fitness decline can occur very quickly, sometimes following only one or two generations of captive rearing."

Araki, Hitoshi, Becky Cooper, and Michael S. Blouin. 2009. Carry-over effect of captive breeding reduces reproductive fitness of wild-born descendants in the wild. Biological Letters 5: (5) 621-624.

"Supplementation of wild populations with captive-bred organisms is a common practice for conservation of threatened wild populations. Yet it is largely unknown whether such programmes actually help population size recovery. While a negative genetic effect of captive breeding that decreases fitness of *captive-bred* organisms has been detected, there is no direct evidence for a carry-over effect of captive breeding in their *wild-born* descendants, which would drag down the fitness of the wild population in subsequent generations. In this study, we use genetic parentage assignments to reconstruct a pedigree and estimate reproductive fitness of the wild-born descendants of captive-bred parents in a supplemented population of steelhead trout (*Oncorhynchus mykiss*).

"The estimated fitness varied among years, but overall relative reproductive fitness was only 37 per cent in wild-born fish from two captive-bred parents and 87 per cent in those from one captive-bred and one wild parent (relative to those from two wild parents). Our results suggest a significant carry-over effect of captive breeding, which has negative influence on the size of the wild population in the generation after supplementation. In this population, the population fitness could have been 8 per cent higher if there was no carry-over effect during the study period.

"The F2 individuals compared in the study were all born in the same river, presumably experienced the same environment, and spawned in the river in the same year. Thus, genetic differentiation during captive breeding in the previous generation is most likely responsible for the reduced fitness of wild-born fish from hatchery parents. A strong genetic effect of captive breeding is consistent with the results of previous studies (Araki et al. 2007, 2008). However, this study also suggests a carry-over effect of the captive breeding, which reduces the reproductive fitness of wild-born descendants in the wild and the population fitness of subsequent generations."

Araki and Schmid 2010: "We summarized 266 peer-reviewed papers that were published in the last 50 years, which describe empirical case studies on ecology and genetics of hatchery stocks and their effects on stock enhancement. Specifically, we asked whether hatchery stock and wild stock differed in fitness and the level of genetic variation, and whether stocking affected population abundance. Seventy studies contained comparisons between hatchery and wild stocks, out of which 23 studies showed significantly negative effects of hatchery rearing on the fitness of stocked fish, and 28 studies showed reduced genetic variation in hatchery populations. None of these studies suggested a positive genetic effect on the fitness of hatchery-reared individuals after release.

"The answer to the question whether hatchery stocking is helpful or harmful to wild stock depends on the goal of the hatcheries, species and the cases. A major limitation in our knowledge is the link between the performance of hatchery fish in the wild and their influence on the stocked populations. Parentage analyses based on genetic methods seem useful to investigate this link. Until we find a way to mitigate the negative genetic impacts on wild stock, however, hatchery stocking should not be assumed as an effective remedy for stock enhancement."

Bachman 1984: "Hatchery brown trout fed less, moved more, and expended more energy than wild brown trout in streams."

Bacon, et al. 2015 Atlantic Salmon conservation stocking at the Girnock Burn was designed to reduce the overwinter mortality associated with poor in-redd survival (Malcolm et al. 2004, 2005) and the within-cohort competition associated with patchy spawning habitat (Webb et al. 2001b; Einum et al. 2008). The procedures were implemented under low stock sizes when spawner numbers were thought to be inadequate to maximize freshwater production. Under these conditions, the beneficial effects of stocking were expected to be large. However, this study found no beneficial effect of artificial incubation and stocking over and above natural processes.

Bams 1970: "Hatchery pink salmon migrated to the ocean one to two weeks earlier than wild pinks."

Berejikian and Ford 2004: "All of the studies we found for Scenarios 1 (nonlocal, domesticated hatchery stocks) and 4 (captive and farmed stocks) found evidence of highly reduced relative fitness for nonlocal, domesticated hatchery stocks, captive broodstocks, and farmed populations. We therefore conclude that it is reasonable to assume that steelhead, coho, and Atlantic salmon stocks in these categories will have low (<30%) lifetime relative fitness in the wild compared to native, natural populations."

Berntson et al. 2011. "Hatchery supplementation programs are designed to enhance natural production and maintain the fitness of the target population, however, the relative reproductive success (RRS) of hatchery-origin fish was 30–60% that of their natural-origin counterparts. There is acute interest in evaluating the reproductive performance of hatchery fish that are allowed to spawn in the wild.

"Despite the higher reproductive success for natural individuals, hatchery fish outnumbered natural ones by more than five to one, yielding an overall hatchery contribution to our offspring sample that was nearly twice that of natural fish… yet it is equally clear that hatchery-reared fish left fewer offspring per individual than their natural counterparts."

Bingham et al 2014: "We examined whether a supplementation program for steelhead *Oncorhynchus mykiss* in southwestern Washington could produce hatchery fish that contained genetic characteristics of the endemic population from which it was derived and simultaneously meet a production goal. Hatchery fish were produced for three consecutive years by using broodstock comprised of endemic juveniles that were caught in the wild and raised to maturity, and then the program transitioned to an integrated broodstock comprised of wild and hatchery adults that returned to spawn.

"Importantly, some auxiliary conservation-based husbandry protocols were attempted (i.e., pairwise mating between males and females) but not always completed due to insufficient broodstock and conflict between production and conservation goals.

"The hatchery met production goals in 6 of 9 years, but wild-type genetic integrity of hatchery fish was degraded every year.

"Specifically, we analyzed 10 microsatellites and observed a 60% reduction in the effective number of breeders in the hatchery.

Hatchery fish consequently displayed reduced genetic diversity and large temporal genetic divergence compared with wild counterparts. To ensure the benefit of conservation-based husbandry, spawning protocols should be based on scientific theory and be practical within the physical and biological constraints of the system. Finally, if conservation issues are considered to be the most important issue for hatchery propagation, then production goals may need to be forfeited.

"The goal of this study was to evaluate whether broodstock management at the AFTC hatchery maintained wild-type genetic characteristics in hatchery fish used to supplement the steelhead population in Abernathy Creek.

<u>Blouin 2003:</u> "Non-local domesticated hatchery summer-run steelhead achieved 17-54% the lifetime fitness of natural native fish."

<u>Blouin 2009:</u> "If anyone ever had any doubts about the genetic differences between hatchery and wild fish, the data are now pretty clear. The effect is so strong that it carries over into the first wild-born generation. Even if fish are born in the wild and survive to reproduce, those adults that had hatchery parents still produce substantially fewer surviving offspring than those with wild parents. That's pretty remarkable."

<u>Blouin 2009</u>: "The implication is that hatchery salmonids – many of which do survive to reproduce in the wild– could be gradually reducing the fitness of the wild populations with which they interbreed. Those hatchery fish provide one more hurdle to overcome in the goal of sustaining wild runs, along with problems caused by dams, loss or degradation of habitat, pollution, overfishing and other causes. Aside from weakening the wild gene pool, the release of captive-bred fish also raises the risk of introducing diseases and increasing competition for limited resources."

<u>Blouin 2009:</u> "There is about a 40% loss in reproductive fitness for each generation spent in a hatchery."

<u>Blouin 2012:</u> Rapid Adaptation to Captivity in Steelhead. We previously demonstrated that first and second generation hatchery steelhead from the Hood River have lower fitness in the wild than do wild fish, and that the difference between first and second generation fish is genetically based. Furthermore, wild-born fish have lower fitness if their parents were first-generation hatchery fish. The mechanism for these fitness declines has remained elusive, but hypotheses include: environmental effects of captive rearing, inbreeding among close relatives, relaxed natural selection, and unintentional domestication selection (adaptation to captivity). We used a multigenerational pedigree analysis to demonstrate that domestication selection can explain the precipitous decline in fitness observed in hatchery steelhead released into the Hood River, Oregon. After returning from the ocean, wild-born and first-generation hatchery fish were used as broodstock in the hatchery. First-generation hatchery fish had higher reproductive success (measured as the number of returning adult offspring) when spawned in captivity than did wild fish spawned under identical conditions, which is a clear demonstration of adaptation to captivity. We also documented a tradeoff among the wild-born broodstock: those with the greatest fitness in a captive environment produced offspring that performed the worst in the wild. These results demonstrate that a

single generation in captivity can result in a substantial response to selection on traits that are beneficial in captivity but maladaptive in the wild. Circumstantial evidence points to crowding in the hatchery as a potential selective mechanism.

Bowles 2008: "Hatchery programs are not a substitute for, or an alternative to, achieving a viable wild population according to NOAA Fisheries' Hatchery Policy. Instead, any hatchery programs have to support natural production."

"The threats to wild populations caused by stray hatchery fish are well documented in the scientific literature. Among the impacts are substantial genetic risks that affect the fitness, productivity and genetic diversity of wild populations. Genetic risks increase substantially when the proportion of the adult population that is hatchery fish increases over 5% (Lynch and O'Hely 2001, Ford 2002)."

"Hatchery programs also pose ecological risks to wild populations that can further decrease abundance and productivity (reviewed by Kostow 2008). The level of risk is related to both the proportion of the fish in a basin that are hatchery fish and to the source of the hatchery fish. Ecological risks due to the presence of hatchery adults (including adults of a different species) have been demonstrated when the proportion that is hatchery fish is over 10% (Kostow and Zhou 2006).

"In comparison to these risk levels, the proportion of adults in the Deschutes that are out-of-basin hatchery steelhead has been as high as 73%, while the proportion in the lower John Day has been as high as 30% (note that additional out-of-basin stray hatchery Chinook are also present in these basins and also may contribute to the ecological risks). Threats to productivity and genetic diversity are particularly critical when the hatchery fish originate from a substantial distance away from the natal basin of the wild population (Reisenbichler 1988, Waples 1995). This increased threat applies to the Deschutes and John Day populations since the stray hatchery fish are from a different DPS, primarily the Snake River DPS."

"The recovery plan for Oregon populations in the Mid-Columbia Steelhead DPS found that out-of-basin hatchery strays are a primary threat to Deschutes River and John Day River steelhead populations (Carmichael et al. 2008). According to the recovery plan, the Mid-Columbia Expert Panel found, regarding these strays, that 'The principal concern relates to a continuing detrimental impact of stray hatchery fish in natural spawning areas on the genetic traits and productivity of naturally produced steelhead'(Carmichael et al. 2007, section 8.1.2)."

"Origin of broodstock will not alleviate ecological hatchery risks (Kostow and Zhou 2006), and by itself it may not be enough to substantially reduce genetic risks."

"While it is reasonable to expect that a substantial decrease in hatchery fraction would contribute to recovery, the proposed hatchery actions for most of the populations are just a change in broodstock. A population that is supported by a hatchery program is not "trending toward recovery" until the hatchery influence can be removed and the wild population is demonstrated to be self-sustaining without it."

Brannon et al. 1999: (Independent Scientific Advisory Board) : "The three recent independent reviews of fish and wildlife recovery efforts in the Columbia River Basin addressed hatcheries. 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.

Braun et al. 2015: "While we found that genetic differences among populations and life history diversity are correlated with asynchrony and response diversity, human impacts on salmon populations, including dams (McClure et al. 2008a), hatcheries and fishing (McClure et al. 2008b), continue to erode biological diversity in salmon populations (Waples et al. 2009). For example, the dynamics of populations impacted by dams and hatcheries are becoming increasingly synchronous (Moore et al. 2010, Carlson and Satterthwaite 2011)."

Braun, Douglas C., Jonathan W. Moore , John Candy and Richard E. Bailey. 2015. Population diversity in salmon: linkages among response, genetic and life history diversity. Ecography 38: 001–012, 2015

Brauner 1994: "In freshwater swimming velocity tests, wild coho salmon smolts swam faster than hatchery fish. In seawater hatchery fish performance compared to wild fish was poor. Hatchery fish had more difficulty osmoregulating."

Briggs 1953: ""It was possible to obtain some indications of the efficiency of artificial propagation through information supplied by state and federal agencies engaged in fish cultural operations in the three Pacific coast states and in New Zealand. For the portion of the life cycle up to the free-swimming fry stage, the survival of individuals was computed, beginning with the eggs which were brought upstream by the mature females. Utilizing the small amount of information available, a crude percentage survival was calculated as follows: Silver salmon, 58.5; king salmon, 65.1, and steelhead trout, 47.8 percent. These percentages may be compared to the survival data for the same three species under natural conditions in Prairie Creek: Silver salmon, 74.3; king salmon, 86.0, and steelhead trout, 64.9 percent. Therefore, there is no doubt that, during the period of study, substantially more young fish were introduced as fry into Prairie Creek via natural propagation than could be supplied through standard hatchery methods utilizing the entire run in the creek.

Buhle et al. 2009: "Our analyses highlight four critical factors influencing the productivity of these populations: (1) negative density-dependent effects of hatchery-origin spawners were ~5 times greater than those of wild spawners; (2) the productivity of wild salmon decreased as releases of hatchery juveniles increased; (3) salmon production was positively related to an index of freshwater habitat quality; and (4) ocean conditions strongly affect productivity at large spatial scales, potentially masking more localized drivers. These results suggest that hatchery programs' unintended negative effects on wild salmon populations, and their role in salmon recovery, should be considered in the context of other ecological drivers."

"We found that wild populations of Oregon coast coho salmon responded to changing hatchery practices during the 1990s. Productivity, expressed as the per capita growth rate in the absence of harvest, improved with reductions in the density of hatchery origin fish spawning in the wild and the numbers of hatchery smolts released into rivers. The strongest negative effects of hatcheries were associated with hatchery-reared adults breeding in the wild, precisely the pathway that might be expected to contribute most to population rebuilding."

Byrne et al. 1992: "Building more hatcheries should cause alarm to biologists concerned with the preservation of native stocks until it is demonstrated that supplementation can be done in a way that does not reduce fitness of the native stock."

"It is unlikely that hatchery propagation, no matter how enlightened, can optimize traits necessary for the long-term survival of steelhead in a natural stream."

<u>Byrne and Copeland 2012</u>: "Given the SAR (smolt to adult survival) rates measured during the study period and plausible over-winter survival rates in the study streams, we predicted that the observed juvenile production would produce few adults and would not result in a self-sustaining population. This conclusion was corroborated by adult return data. We found no evidence that adult outplanting increased wild population levels, i.e., there was no demographic boost in adult spawners. Further, the differences between the two study streams showed that supplementation programs should carefully assess each target stream.

"Even the most well-planned supplementation programs may have unpredictable consequences and should be carefully monitored to avoid negative effects (Naish et al. 2008). Unfortunately, evaluations of *ad hoc* adult outplant programs are seldom done. Decisions to introduce hatchery reared adults for spawning in the wild should be based on the needs of the target population and the ability of the habitat to support additional reproduction and rearing (ISAB 2002)."

<u>Caroffino, David C. et al. 2008:</u> "Through genetic monitoring of two year classes, we determined that hatchery adults produced 1.3-6.2 times as many age-2 juveniles per female than naturally spawning fish. Survival of stocked fry of parents born in a hatchery relative to those of parents born in the wild was 70% in paired-stocking comparisons. These results suggest that stocking local-origin fry can increase the short term abundance of depleted populations and that fish with no hatchery history are a better source for supplemental stocking. Additionally, sampling small numbers of adults for broodstock created genetically distinct groups, which could potentially cause long-term genetic change to the population. Genetic monitoring of adults will be essential to determining whether differences observed persist through the life cycle of the stocked fish."

<u>Chilcote et al. 1986:</u> "The success of hatchery fish in producing smolt offspring was only 28% of that for wild fish. We also found that 62% of the naturally produced summer-run smolts were offspring of hatchery spawners. Their dominance occurred because hatchery spawners within the watershed we examined effectively outnumbered wild spawners by at least 4 .5 to 1. We suggest that, under such conditions, the genetic integrity of wild populations may be threatened."

<u>Chilcote 2002</u>: Based upon a multiple regression analysis, recruitment and productivity in 12 naturally reproducing populations of Oregon steelhead were found to be significantly influenced by four variables, one of which was the level of hatchery fish in the spawning population. It appeared that the presence of hatchery fish depressed overall population productivity, reduced the number of recruits, and lowered the fitness of wild fish. This negative effect was insensitive to the type of hatchery fish. Although hatchery fish represented in five of the study populations were from hatchery broodstocks developed from local wild populations and managed in a manner to avoid domestication, the advantages of this strategy were not apparent. The negative effect of hatchery fish on natural production was not trivial. For example, in a mixed population where hatchery fish comprised 30% of the spawning population, the number of recruits produced was 1/3 less than in a population comprised entirely of wild fish. A variety of supplementation simulations, based upon these findings, demonstrated that the recruitment response of natural populations to the addition of naturally spawning hatchery fish was very weak and carried the additional penalty of reducing the genetic fitness of the wild fish. Various genetic and non-genetic explanations for these results were explored, including the consequences of reduced genetic diversity in hatchery populations as a result of having fewer families than would be found for a wild population of similar size. The management implications of these results are that hatchery steelhead, regardless of their broodstock type, are poor substitutes for wild fish in their natural environments. The addition of hatchery spawners to the natural environment does not appear a useful tool for rebuilding depressed populations of wild steelhead. These results support the view that hatchery programs should be managed to minimize the number of hatchery fish that spawn and rear in natural habitats.

<u>Chilcote 2002</u>: "…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…."

<u>Chilcote 2003:</u> "Naturally 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."

<u>Chilcote 2008</u>**:** **"**At a recent meeting of lower Columbia River Salmon Recovery Stakeholders, the document , *Recovery Strategies to Close the Conservation Gap Methods and Assumptions*, hatchery fish impacts are discussed. It says, "…relative population survival rates (recruits produced per spawner) were found to decrease at a rate equal to or greater than the proportion of hatchery fish in the natural spawning population. In other words, a spawning population with 20% hatchery strays (regardless of the type of hatchery program and whether they are integrated or segregated) had the net survival rate (recruits per spawner) that was 20% less than a population comprised entirely of wild fish (0% hatchery strays). Likewise, a population with 40% hatchery strays had a population survival rate that was 40% lower than a population comprised entirely of wild fish."

<u>Chilcote et al. 2011, 2013:</u> "We found a negative relationship between the reproductive performance in natural populations of steelhead, coho, and Chinook salmon and the proportion of hatchery fish in the spawning population. We used intrinsic productivity as estimated from fitting a variety of recruitment models to abundance data for each population as our indicator of reproductive performance. The magnitude of this negative relationship is such that we predict the recruitment performance for a population comprised entirely of hatchery fish would be 0.128 of that for a population comprised entirely of wild fish. The effect of hatchery fish was the same among all three species. Further, the impact of hatchery fish from 'wild type' hatchery broodstocks was no less adverse than hatchery fish from traditional, domesticated broodstocks. We also found no support for the hypothesis that a population's productivity was affected by the length of exposure to hatchery fish. In most cases, measures that minimize the interactions between wild and hatchery fish will be the best long-term conservation strategy for wild populations."

<u>Christie et al. 2011:</u> "These results demonstrate that a single generation in captivity can result in a substantial response to selection on traits that are beneficial in captivity but severely maladaptive in the wild. We also documented a tradeoff among the wild-born broodstock: Those with the greatest fitness in a captive environment produced offspring that performed the worst in the wild."

<u>Christie et al. 2014:</u> Here, we review recent studies on the reproductive success of such 'early-generation' hatchery fish that spawn in the wild. Combining 51 estimates from six studies on four salmon species, we found that

(i) early-generation hatchery fish averaged only half the reproductive success of their wild-origin counterparts when spawning in the wild,

(ii) the reduction in reproductive success was more severe for males than for females, and

(iii) all species showed reduced fitness due to hatchery rearing. We review commonalities among studies that point to possible mechanisms (e.g., environmental versus genetic effects).

Furthermore, we illustrate that sample sizes typical of these studies result in low statistical power to detect fitness differences unless the differences are substantial. This review demonstrates that reduced fitness of early-generation hatchery fish may be a general phenomenon. Future research should focus on determining the causes of those fitness reductions and whether they lead to long-term reductions in the fitness of wild populations.

<u>Christie et al. 2016:</u> "…we measured differential gene expression in the offspring of wild and first-generation hatchery steelhead trout (Oncorhynchus mykiss) reared in a common environment. Remarkably, we find that there were 723 genes differentially expressed between the two groups of offspring.

We find that there are hundreds of genes that are differentially expressed (DE) between the offspring of wild fish (WxW) and of the offspring of hatchery fish (HxH) reared in a common environment. By using

reciprocal crosses, we further show that these differences in gene expression cannot be explained as maternal effects, sampling noise, or false discovery. Thus, our data suggest that the very first stages of domestication are characterized by massive, heritable changes to gene expression. That the DE genes were dominated by pathways in wound repair, immunity and metabolism adds to growing evidence that adaptation to crowded conditions is an important early stage of domestication.
The large extent of divergence that occurs at the gene-expression level, but not at the genomic level, suggests that selection and not genetic drift is responsible for the large differences in expression detected between the offspring of wild and first-generation hatchery fish.

"Taken together, these results suggest that rearing density may play an important role in facilitating genetic adaptation to captivity, and that adjusting to large numbers of conspecifics may be an important first step towards domestication.

"O. mykiss are one of the few fish species considered to have been fully domesticated31. Phenotypic responses to selection routinely occur in this species with less than ten generations of captive breeding. However, this is the first study to demonstrate that the earliest stages of domestication are characterized by large changes in heritable patterns of gene expression. As subsequent generations of domestication accrue, we speculate that the regulatory changes to expression become codified with gradual and more targeted shifts in allele frequencies (for example, selective sweeps). We hypothesize that adaptation to crowded conditions may drive much of this early domestication. Regardless of the mechanism, it is remarkable that a single generation of domestication can translate into heritable differences in expression at hundreds of genes.

de Eyto et al. 2016: "In Burrishoole, the most important determinant of freshwater survival of salmon was the deleterious effect of hatchery fish in the spawning cohort for salmon. While stocking is seen by many as a possible management action to conserve and bolster stocks, evidence continues to mount that where a wild population is present, and habitat is available, stocking is misguided."

Dickson 1982: "Juvenile hatchery fish show a behavioral shift in stream feeding position compared to wild fish. Hatchery fish feed nearer the surface. This may expose them to greater predation."

Ersbak et al. 1983: "Hatchery trout conditions declined after stocking. Hatchery fish were less flexible in switching to available food in the stream."

Fenderson, 1968: "Hatchery fish are more aggressive and dominate wild fish, and hatchery fish have a higher mortality."

Flagg and Nash, 1999: "The reviews conclude that artificial culture environments condition salmonids to respond to food, habitat, conspecifics and predators differently than fish reared in natural environments. It is now recognized that artificial rearing conditions can produce fish distinctly different from wild cohorts in behavior, morphology, and physiology."

Fleming and M.R. Gross 1993: "The divergence of hatchery fish in traits important for reproductive success has raised concerns. This study shows that hatchery coho salmon males are competitively inferior to wild fish, and attained only 62% of the breeding success of wild males. Hatchery females had more difficulty in spawning than wild fish and hatchery fish had only 82% of the breeding success of wild fish. These results indicate hatchery fish may pose an ecological and genetic threat to wild fish."

Fleming et al. 1994: "Results of this study imply that hatchery fish have restricted abilities to rehabilitate wild populations, and may pose ecological and genetic threats to the conservation of wild populations."

Fleming et al. 1997: "Reproductive success defined in the study as the ability to produce viable eyed embryos did not differ between hatchery and natural females. Hatchery males, however, achieved only 51% the estimated relative reproductive success of natural males under conditions of mutual competition. Hatchery males were less able to monopolize access to spawning females and suffered more severe wounding and greater mortality than natural males."

Fleming and Einum 1997: "Our results thus indicate that the farming of Atlantic salmon can generate rapid genetic change in fitness related traits as a result of domestication due to intentional and unintentional selection. As much of this change appears to be an adaptive response to the culture environment, it can be of value for programmes attempting to improve aquaculture production (e.g. Doyle *et al.*, 1991). This change, however, is a threat to wild populations when these fish escape, and compete and breed with wild salmon. The invasion of escaped farmed salmon into rivers not only increases competition for resources, but also results in the infusion of different genetic traits into wild populations. Many of these traits are likely to be maladaptive for the local environment both because of the non-indigenous origins of the farmed salmon (Einum and Fleming, 1997) and because of the changes that have occurred due to culturing. While natural selection may be able to purge wild populations of such maladaptive traits, its actions are severely hindered by the year-after-year introgression of farmed salmon. The net result is almost certainly a decline in population fitness, as the influence of selection from the culture environment overrides that in the wild."

Fleming et al. 2000: "The farm fishes were competitively and reproductively inferior, achieving less than one–third the breeding success of the native fishes. However, evidence of resource competition and competitive displacement existed as the productivity of the native population was depressed by more than 30%. Ultimately, the lifetime reproductive success (adult to adult) of the farm fishes was 16% that of the native salmon. Our results indicate that such annual invasions have the potential for impacting on population productivity, disrupting local adaptations and reducing the genetic diversity of wild salmon populations."

Flick, et al. 1964: "Wild brook trout had higher summer and winter survival than hatchery fish."

Ford, 2002: "Substantial phenotypic changes and fitness reductions can occur even if a large fraction of the captive broodstock is brought in from the wild every generation. This suggests that regularly bringing wild-origin broodstock into captive populations cannot be relied upon to eliminate the effects of inadvertent domestication selection."

Ford 2010: "What is known from peer-reviewed scientific studies on the impact of hatchery salmonids on wild salmonids? Hatchery fish reproductive success is poor; there is a large scale negative correlation between the presence of hatchery fish and wild population performance; hatchery fish reproductive success is lower than for wild fish and this is true for both supplementation and production hatchery programs; there is evidence of both environmental and heritable effects; effects were detected for both release and proportion of hatchery spawners; negative correlations between hatchery influence and wild productivity are widespread; habitat or ocean conditions do not appear to explain the pattern; current science indicates that limiting natural spawning of hatchery fish is generally beneficial to wild populations; there is evidence that reducing hatchery production leads to increased wild production, and cumulative effects of hatchery could be a factor limiting recovery of some ESUs."

Hilborn 1992: "Pacific salmon hatcheries have failed to deliver expected benefits and they pose the greatest single threat to the long-term maintenance of salmonids."

Hjort and Schreck 1982: "The results of this study also suggest a potential weakness in hatchery supplementation. Selection through hatchery environment and hatchery practices may be changing the overall phenotype of hatchery stocks, as well as the between-year variability of individual genotypes (as we found for transferrin). If these changes result in reduced performance of the donor stocks in other stream systems, practices designed to increase hatchery production must be weighed against the actual benefits to wild production."

Hulett et al. 1994: "Hatchery winter steelhead were about one-half as effective as wild winter-run steelhead in naturally producing smolt offspring. Hatchery winter steelhead were about one sixth as effective as wild winter steelhead in naturally produced adult offspring."

Independent Economic Advisory Board (IEAB) 2002: "Augmentation and mitigation hatcheries, which seek to enhance fish harvests, can be judged by the cost incurred per additional fish harvested. The costs per harvested hatchery fish ranged from $23 for Priest Rapids fall chinook, to $55 per Spring Creek fall chinook, to $453 for Irrigon hatchery summer steelhead, to $1,051 for McCall summer chinook, to $4,800 - $68,031 at the Leavenworth hatchery complex."

Hatchery	**Species Produced**	**Cost of a Salmon that is caught**
Leavenworth	spring chinook	$4,800
Entiat	spring chinook	$68,031 (Highest $891,000)
Winthrop	spring chinook	$23,068
Priest Rapids	fall chinook	$12.00 (Highest - $293)
Irrigon	summer steelhead	$453
Spring Cr.	fall chinook	$237 (range 14.53 - $460)
Clatsop	coho	$124
	Spring chinook	$233
	Fall chinook	$65
Nez Perce	fall and spring chinook	$3,700
McCall	spring chinook	$786 (range $522 to $1,051)

"The benefit of the fishery is $45 to $77 per fish for the commercial fishery and $60 per fish for the sport fishery"

ISAB 2002. "We believe that available empirical evidence demonstrates a potential for deleterious interactions, both demographic and genetic, from allowing hatchery-origin salmon to spawn in the wild. Because it is virtually impossible to 'undo' the genetic changes caused by allowing hatchery and wild salmon to interbreed, the ISAB advocates great care in permitting hatchery-origin adult salmon to spawn in the wild."

ISRP 2011: ". The BACI analysis found that productivity in the Imnaha River had decreased relative to all nine unsupplemented sites. The ISRP concludes that a conservation benefit in terms of NOR abundance is unlikely from supplementation. Based on the analysis of productivity loss in the Imnaha River, the ISRP concludes that costs to population fitness are likely.

"Hatchery-origin adults spawning in the stream produced parr at slightly higher rates than natural-origin fish (1.03:1), produced smolts at an equal rate (1:1), but produced adults at a lower rate (0.77:1)."

"The supplementation projects as they are currently conducted with high proportions of hatchery fish in the hatchery broodstock and on the natural spawning grounds are likely compromising the long-term viability of the populations."

"Over the long-term, however, hatchery-dominated programs that are implemented to reduce extinction risk will result in genetic changes owing to domestication selection and drift that are likely to offset any demographic benefit."

Johnson et al. 2013: "Our findings of genetic introgression suggest that temporospatial overlap can occur between naturally spawning summer and winter steelhead in UWR subbasins, and that assortative mating and current management have not entirely prevented hybridization between native and introduced *O. mykiss* stocks. Interbreeding with hatchery summer steelhead could lower the fitness of native UWR winter steelhead, as hatchery-reared Skamania stock summer steelhead have low fitness in the wild (Chilcote et al. 1986; Kostow et al. 2003; Leider et al. 1990)."

Jonsson et al. 1993: "Differences were evident for hatchery Atlantic salmon relative to wild salmon, with common genetic backgrounds, in breeding success after a single generation in the hatchery. Hatchery females averaged about 80% the breeding success of wild females. Hatchery males had significantly reduced breeding success, averaging about 65% of the success of wild males."

Jonsson and Jonsson 2002: "During the past 150 years, (hatchery) enhancement and supplementation have become essential parts of salmonid management. Interaction is likely to have a negative effect on the viability of wild populations."

Kliess 2004: "Salmonid management based largely on hatchery production, with no overt and large-scale ecosystem-level recovery program, is doomed to failure. Not only does it fail to address the real causes of salmonid decline, but it may actually exacerbate the problem and accelerate the extinction process."

Knudsen et al. 2006. "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."

Knudsen et al. 2008: "Consequently, in this project, on a per capita basis hatchery-origin females are a minimum of 6-7% less fit than wild fish owing to lower fecundity. This demonstrates that hatcheries do not produce fish that are identical to wild fish."

Kostow 2003 : "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. We conclude that even though naturally spawning hatchery steelhead may experience poor reproductive success, they and their juvenile progeny may be abundant enough to occupy substantial portions of spawning and rearing habitat to the detriment of wild fish populations. Therefore, the large numbers of introduced summer steelhead would have competed heavily with wild winter steelhead for habitat resources, and this may have contributed to their decline. In the Clackamas basin, smolt offspring of hatchery fish appear to have wasted the production from natural habitat because very few return as adults." (emphasis added)

Kostow 2004: "In conclusion, this study demonstrated large average phenotype and survival differences between hatchery-produced and naturally produced fish from the same parent gene pool. These results indicate that a different selection regime was affecting each of the groups. 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."

Kostow and Zhou 2006: "In the Clackamas River basin, the summer steelhead hatchery adults had poor reproductive success; fewer smolts were produced per parent than in the wild population, and almost no offspring of hatchery fish survived to adulthood (Kostow et al. 2003). The hatchery program was meant to provide a sport fishery, and the production of adult offspring was not intended. If successful hatchery reproduction had occurred, at least the offspring could have contributed to fisheries. Instead, the hatchery fish wasted basin capacity by occupying habitat and depressing wild production while producing nothing useful themselves. It is not unusual for hatchery adults to have poor reproductive success when they spawn naturally (other examples are provided by Reisenbichler and Rubin 1999, Kostow 2004, and McLean et al. 2004). The combined effect of poor hatchery fish fitness and depressed wild fish production due to competition with the hatchery fish poses a double jeopardy that could quickly erode natural production in any system."

Leider, et. al., 1990: "The mean percentage of offspring from naturally spawning hatchery steelhead decreased at successive life history stages, compared to wild steelhead, from a potential of 85-87% at the egg stage to 42% at the adult stage. Reproductive success of naturally spawning hatchery steelhead compared to wild steelhead decreases from 75-78% at the subyearling stage to 10.8-12.9% at the adult stage."

Levings, et al., 1986: "Hatchery chinook used the estuary a shorter period of time than wild chinook. The greatest overlap between hatchery and wild chinook in the estuary is in the transition zone where greater competition could occur."

Lynch and O'Hely 2001: "Our results suggest that the apparent short-term demographic advantages of a supplementation program can be quite deceiving. Unless the 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 population no longer capable of sustaining themselves."

Marchetti and Nevitt. 2003: "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. The brains of hatchery raised rainbow trout are smaller in 7 out of 8 critical neuroanatomical measures than those of their wild reared counterparts. Our results are the first to highlight the effects of hatchery rearing on changes in brain development in fishes."

Mason, et al., 1997: "Hatchery x wild and wild x wild crosses had higher survival in the natural stream compared to hatchery x hatchery crosses."

McClure et al. 2008: "Continued interbreeding with hatchery-origin fish of lower fitness can lower the fitness of the wild population. Generally, large, long-term hatchery programs that dominate production of a population is a high risk factor for certain viability criteria and can lead to increased risk for the population. The populations meeting 'high viability' criteria will necessarily be large and spatially complex. In order to meet these criteria (spatial structure and diversity) there should be little or no introgression between hatchery fish and the wild component of the population. Populations supported by hatchery supplementation for more than three generations do not in most cases meet ICTRT viability criteria at the population level."

"Artificial propagation does not contribute to increased natural productivity needed for viability, and appears in most cases, to erode productivity of wild populations."

McLean et al. 2004: "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 (<0.5 adults per female)."

McMichael et al. 1997: "Our results indicate that residual hatchery steelhead reduced the growth of wild resident rainbow trout during summer under controlled conditions. We infer that when hatchery steelhead become residuals, thus increasing local densities of salmonids for extended periods, the growth of sympatric wild rainbow trout growth is likely to decrease. A reduction in size, due to slower growth during the summer, could decrease overwinter survival (Hunt 1969; Toneys and Coble 1979, 1980; Oliver and Holeton 1979), resulting in decreased population size (Cunjak et al. 1987).

McMichael et al. 1999: "Hatchery steelhead behaviorally dominated wild O. mykiss in most situations. Hatchery steelhead were generally larger and behaved more aggressively and violently than wild fish, which may have contributed to their dominant status.

"Our study confirmed that releases of conventionally reared hatchery steelhead can pose ecological risks to preexisting wild populations.

"Acknowledging that releases of hatchery salmonids may affect preexisting wild salmonid populations is an important step toward protection and recovery of imperiled populations of wild anadromous salmonids. Thorough evaluation of current hatchery programs and implementation of rigorous monitoring programs should be required in watersheds where depressed stocks of wild salmonids occur, even though these precautions will not ensure that wild stocks are protected or restored (Waples 1999)."

Meffe 1992: "Countless salmon stocks have declined precipitously over the last century as a result of overfishing and widespread habitat destruction. A central feature of recovery efforts has been to build many hatcheries to produce large quantities of fish to restock streams. This approach addresses the symptoms but not the causes of the declines."

Miller, R. B. 1953: "Hatchery cutthroat trout had lower survival compared to wild fish due to absence of natural selection at early life stages."

Miller, W. H. et al. 1990: "Over 300 (hatchery) supplementation projects were reviewed and the authors found: 1) examples of success at rebuilding self-sustaining anadromous fish runs with hatchery fish are scarce (22 out of 316 projects reviewed), 2) success was primarily from providing fish for harvest, and 3) adverse impacts to wild stocks have been shown or postulated for every type of hatchery fish introduction to rebuild runs."

Miller L. M. 2004: "We have documented an early life survival advantage by naturalized populations of anadromous rainbow trout *Oncorhynchus mykiss* over a more recently introduced hatchery population and outbreeding depression resulting from interbreeding between the two strains. Averaging over years and streams, survival relative to naturalized offspring was 0.59 for hybrids with naturalized females, 0.37 for the reciprocal hybrids, and 0.21 for hatchery offspring. Our results indicate that naturalized rainbow trout are better adapted to the conditions of Minnesota's tributaries to Lake Superior so that they outperform the hatchery-propagated strain in the same manner that many native populations of salmonids outperform hatchery or transplanted fish. Continued stocking of the hatchery fish may conflict with a management goal of sustaining the naturalized populations.

Miller L. M. et al. 2014: "Reduced reproductive success of hatchery fish spawning in the natural environment will reduce the ability of stocking programs to enhance wild populations. . The reproductive success of hatchery females was significantly lower than that of wild females (approximately 60%) in all three study years; however, the reproductive success of hatchery males was only significantly lower in one year. Continued reliance on hatchery supplementation may hinder achievement of the long-term goal of a fishery supported largely by naturally reproducing populations."

Mobrand et al. 2005: "We concluded 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."

Moore et al. 2010: For a group of spatially distinct populations, synchrony in population dynamics can increase risk of simultaneous and global extinction. In contrast asynchronous population dynamics decrease extinction risk and may increase sustainability of long-term production from groups of populations. Pacific salmon exhibit fine-scale population structure and local adaptation to their natal habitats which likely contributes to asynchrony in population dynamics… artificial propagation programs may increase dispersal among populations, eliminating locally adapted life history variation. We document increased demographic synchrony among Chinook salmon populations within the Snake River region over the last 40 years, concurrent with increased intensity of human impacts…synchronization of Snake River salmon has compromised its performance. Management of spatially structured species can benefit from explicit consideration of population diversity.

"There was not only an increase in synchronization, but there was also a decrease in population productivity, further reducing portfolio (number of locally adapted stocks) performance.

"Chinook salmon populations within the Snake River Evolutionarily Significant Unit have become more synchronized; over 75% of the populations increased in synchrony over the last four decades.

"…hatchery releases, which increased substantially during the study period are associated with increased straying and decreased population structure. In addition, dams homogenize habitats and flow regimes, leading to the loss of habitat variability that maintains salmonid population diversity.

"Regardless of the underlying mechanisms, the observed increase in population synchrony has major conservation implications. First, the theory predicts that increased synchrony will increase extinction risk for the entire meta-population, which has already been identified as having a substantial risk of extinction.

"Improve salmon and steelhead management by 1) "Include population diversity as a goal for recovery; 2) Preserve the diverse habitats and natural processes that maintain response diversity. Preserving variable landscapes and the physical processes that maintain habitat variation will help maintain the different environmental conditions supporting adaptation and response diversity of phenotypic traits such as timing of migration and spawning; 3) Adjust artificial propagation programs to manage for response diversity. Reducing artificially inflated straying rates, using locally derived brood stock, and ensuring that hatchery-origin spawners are not overly represented on spawning grounds; 4) Manage harvest…to avoid depleting low productivity populations; 5) Monitoring should not just focus on currently productive populations but also include lower productivity populations."

Moran and Waples 2007: "…we show some compelling differences in reproductive success of hatchery and wild fish. Naturally spawning hatchery fish are less than half as productive as wild fish."

Mullan, "Mean hatchery spring chinook smolt to adult survival ranged from 0.16 to 0.55%, 1976-1988 compared to wild spring chinook survival rate of from 1.6 to 8.1%. Naturally produced smolts were about 10 – 80 times as viable as hatchery smolts."

Naish et al. 2008: "If one concern has been identified, it is that many hatchery programmes continue to be operated with few objectives, and with a poor understanding of the magnitude and importance of the impacts of genetic effects of hatchery releases and the role of this information in informing remedial actions."

"A rapidly growing body of literature points towards detrimental behavioural interactions between hatchery and wild fish. More is known about these interactions in freshwater rearing habitats than in estuarine and marine environments. There is also, however, a paucity of information on whether risk avoidance measures are effective at reducing competition and predation and, as far as we know, little attention is directed towards carrying capacity when the size of release is considered."

Naylor et al. 2005: "Interbreeding between wild and farmed fish can result in mixing gene pools if the hybrids can reproduce, and eventually can lead to a wild population composed entirely of individuals descended from hatchery fish. In a Norwegian study (Fleming et al. 2000), 55% of hatchery salmon in the experimental spawning population contributed 19% of the genes to adult fish in one generation later. Continued one-way gene flow at this rate would halve the genetic difference between hatchery and wild salmon every 3.3 generations and lead to rapid genetic homogenization."

Naylor et al. 2005: "In McGinnity and colleagues' (2003) recent farm release study in Ireland, the lifetime success of hybrids was only 27% to 89% as high as that of their wild cousins, and 70% of the embryos in the second generation died. These results provide strong evidence of how interbreeding might drive vulnerable salmon populations to extinction."

<u>Naylor et al. 2005</u>: “Aggressive farm and hybrid fish can also result in shifts of wild counterparts to poorer habitats, increasing mortality. The productivity of the native juvenile salmon population was depressed by more than 30% in the presence of farm and hybrid juveniles.”

<u>Naylor et al. 2005</u>: “An earlier review (Hindar et al. 1991) of the genetic effects following releases of nonnative salmonids reached two broad conclusions. First, the genetic effects of intentionally or accidentally released salmonids on natural populations are often unpredictable and may vary from no detectable effects to complete introgression or displacement. Second, when genetic effects on performance traits (e.g. survival in fresh water and seawater) have been detected, they appear always to be negative in comparison with the traits of unaffected native populations.”

<u>Nickelson 1986</u>: “Hatchery coho juveniles are more abundant after stocking in streams but the result is fewer adult returns and fewer juvenile coho salmon in the next generation than in streams that were not stocked.”

<u>Nickelson 2003:</u> “Hatchery programs designed for harvest augmentation should be removed from basins with habitat that has high potential to produce wild salmonids. To aid recovery of depressed wild salmon, the operation of hatcheries must be changed to reduce interactions of hatchery smolts with wild smolts. A program that reduces harvest, restores habitat, and reduces hatchery effects is necessary.”

<u>NMFS 2010:</u> “Hatchery production has been reduced to a small fraction of the natural-origin production. Nickelson (2003) found that reduced hatchery production led directly to higher survival of naturally produced fish, and Buhle et al. (2009) found that the reduction in hatchery releases of Oregon coast coho salmon in the mid1990's resulted in increased natural coho salmon abundance.”

<u>ODFW 2010:</u> “Chilcote and Goodson examined data sets on population abundance for 121 populations of coho, steelhead, and Chinook in Oregon, Washington, and Idaho. They found that population productivity was inversely related to the average proportion of hatchery fish in the naturally-spawning population, consistent with the findings of Buhle et al. (2009). The magnitude of this effect was substantial. For example, a population comprised entirely of hatchery fish would have one tenth the intrinsic productivity of one comprised entirely of wild fish. There was no indication that the significance or strength of this relationship was different among the three species examined (chinook, coho and steelhead). In addition, there was no indication that the type of broodstock (integrated with the local natural-origin population versus segregated) affected the significance or intensity of the response.” (Section 2: Updating the Scientific Information in the 2008 FCRPS BiOp May 20, 2010, Page 118 and Lower Columbia River Salmon Recovery Plan 9-2010 ODFW)

<u>ODFW 2010a:</u> “For example, the reduction in productivity between a population comprised entirely of wild fish and one comprised of equal numbers of hatchery and wild fish is 66 percent for steelhead, 76 percent for coho, and 43 percent for Chinook.”

<u>ODFW 2010b</u>: “Hatchery programs have the potential to benefit or harm salmonid population viability by affecting abundance, productivity, distribution, and/or diversity. Hatchery related risks to salmon population viability include genetic changes that reduce fitness of wild fish, increase risk of disease outbreaks, and/or alter life history traits, and ecological effects—such as increased competition for food and space or amplified predation—that reduce population productivity and abundance. Hatcheries can also impose environmental changes by creating migration barriers that reduce a population’s spatial structure by limiting access to historical habitat.”

<u>ODFW 2011</u>: The study was able to determine that the F1 generation of coho released as unfed fry or as smolts both had a run time of 51 days compared to 73 days for wild-born fish. Coho released as smolts exceeded natural recruitment with a return rate of 3.1 to 3.5 per female compared to 1.3 to 1.4 per female for natural recruitment. Unfed fry varied with a recruitment rate of 1.0 and 2.0 per female. With the F2 generation, reproductive success (RS) was analyzed. The study found that compared to wild coho, the average reproductive success of progeny from the unfed fry releases which produced returning F2 coho was 38% lower for males and 16% lower for females. F2 coho from the smolts had even lower average

reproductive success being 47% and 25% lower respectively than wild coho. Hatchery jacks however had a RS more equal to wild coho. The mechanism for the difference is still unknown. However since both unfed fry and smolts have reduced RS, artificial mating and early life-stages in the hatchery likely had some impact on later reproductive success.

Ó Maoiléidigh 2008**:** **"**We conclude that extensive stocking programmes undertaken in Ireland over the last thirteen years have made little real contribution to the productivity of Irish rivers or to the goals of restoring self-sustaining salmon runs. Furthermore, evidence from recent experiments suggesting that artificial introductions are likely to depress rather than enhance the productivity of natural populations, including feral or quasi-wild populations that have been established by successful hatchery programmes, suggests that more caution and planning is required before hatchery reared progeny are released into the wild .

Paquet et al. 2011: "Hatcheries are by their very nature a compromise – a balancing of benefits and risks to the target populations, other populations, and the natural and human environment they affect."

Perry, et al. 1993: "Idaho has been trying to unravel the secrets of hatchery and wild salmon interactions in nature. Since hatchery salmon do not survive as well as wild salmon, it is important to fix this problem. It is possible that a hatchery supplementation program may inadvertently replace the target natural population with one having lower survival and reproductive potential."

Reisenbichler, et al. 1977: His research shows that hatchery x hatchery crosses of steelhead fry survival was lower than for wild x wild crosses and wild x hatchery crosses in streams. Likewise he found that hatchery x hatchery crosses survived better in the hatchery environment. The hatchery fish were derived from local wild steelhead and had changed in performance in two generations of hatchery rearing. Conclusion: differences in survival suggested that the short-term effect of hatchery adults spawning in the wild is the production of fewer smolts and ultimately, fewer returning adults than are produced from the same number of wild steelhead spawners.

Reisenbichler 1986: "Most (hatchery fish) outplanting programs have been unsuccessful. Rigorous planning, evaluation, and investigation are required to increase the likelihood of success and the ability to promptly discern failure."

Reisenbichler 1992: "Because anadromous salmonids home to their natal streams to spawn, managers can expect the fish in different streams to be from genetically distinct stocks. We recommend that steelhead from different coastal drainages be considered and managed as distinct stocks."

Reisenbichler 1994: "Gene flow from hatchery fish also is deleterious because hatchery populations genetically adapt to the unnatural conditions of the hatchery environment at the expense of adaptedness for living in natural streams. This domestication is significant even in the first generation of hatchery rearing."

Reisenbichler 1996: "Available data suggest progressively declining fitness for natural rearing with increasing generations in the hatchery. The reduction in survival from egg to adult may be about 25% after one generation in the hatchery and 85% after six generations. Reduction in survival from yearling to adult may be about 15% after one generation in the hatchery and 67% after many generations."

Reisenbichler and Rubin 1999: "When the published studies and three studies in progress are considered collectively… they provide strong evidence that the fitness for natural spawning and rearing can be rapidly and substantially reduced by artificial propagation. This issue takes on great importance in the Pacific Northwest where supplementation of wild salmon populations with hatchery fish has been identified as an important tool for restoring these populations. Recognition of negative aspects may lead to restricted use of supplementation, and better conservation, better evaluation, and greater benefits when supplementation is used.

"Apparently domestic selection is often intense. The fitness of stream type chinook (spring chinook) salmon was diminished after four generations of culture, despite continuous gene flow from the wild population (on average, wild fish comprised 38% of the hatchery broodstock). The fitness of steelhead was diminished after only two generations in the hatchery (Reisenbichler and McIntyre, 1977). Presumably substantial change occurs in the first generation."

"These conclusions imply that supplementation (wherein wild fish interbreed with hatchery fish of reduced fitness) will reduce the productivity of naturally spawning populations, and often may compromise conservation objectives."

"Relative survival of hatchery steelhead continued to decline with age of the cohort, at least until after emigration as smolts. This decline suggests that the fitness of the next generation would be low even before interbreeding with more hatchery fish, and that continuous supplementation should progressively diminish the productivity of the naturally spawning population."

"The typical population proposed for supplementation is presumably one of low productivity which is substantially below carrying capacity. Continued supplementation of such a population may reduce its productivity so that the population even becomes dependent on supplementation and cannot replace itself otherwise."

Reisenbichler et al. 2004: "Genetic theory and data suggest that sea ranching (hatchery production) of anadromous salmonids (*Onchorhynchus 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 fish."

RIST 2009: "Most information available indicates that artificially-propagated fish do have ecological impacts on wild salmonid populations under most conditions (e.g. a 50% reduction in productivity for steelhead in an Oregon population). To the degree that the trait distributions seen in wild salmon populations are adaptations to their environments, selection imposed by the hatchery environment could result in reduced fitness of hatchery fish in the wild."

Scheuerell et al. 2015: Using 43 years of monitoring data, we asked whether 11–23 years of supplementation have increased the density of naturally produced adults (i.e., fish that were born in the wild, not reared in a hatchery) in 12 supplemented populations, and if so, by how much. We found that, on average, supplementation has increased adult density among the 12 supplemented populations by only 3.3%.

In the US Pacific Northwest, salmon hatcheries release about 400 million juveniles per year at a cost of roughly $40 million USD (Naish et al. 2008). Many of these fish are produced to meet tribal, commercial, or recreational harvest demands, or to mitigate for habitat loss.

Massive efforts are underway worldwide to conserve at risk species, and societies would like to know what they are getting for their investment.

Schenekar, Tamara and Steven Weiss 2017: Captive bred individuals are often released into natural environments to supplement resident populations. Captive bred salmonid fishes often exhibit lower survival rates than their wild brethren and stocking measures may have a negative influence on the overall fitness of natural populations. Stocked fish often stem from a different evolutionary lineage than the resident population and thus may be maladapted for life in the wild, but this phenomenon has also been linked to genetic changes that occur in captivity. In addition to overall loss of genetic diversity via captive breeding, adaptation to captivity has become a major concern. Altered selection pressure in captivity may favour alleles at adaptive loci like the Major Histocompatibility Complex (MHC) that are maladaptive in natural environments.

Our results support that stocking measures in autochthonous [native] populations should be avoided, especially with nonnative fish. If stocking measures are inevitable in natural habitats, ideally, locally established brood-stocks with local genetic material should be used. Adaptation to captivity should be minimized, e.g. by the continuous supplementation of new "natural" genetic material in order to keep the genetic composition of the captive population as close to its source population as possible. Nonetheless, genetic or epigenetic changes can begin in the first generation of captivity (Christie et al. 2016) and thus it appears to be extremely difficult or impossible to use hatchery operations in any capacity without risking deleterious effects to the wild population.

Schroder, et al. 2008: "Pedigree assignments based on microsatellite DNA, however, showed that the eggs deposited by wild females survived to the fry stage at a 5.6% higher rate than those spawned by hatchery females. Subtle differences between hatchery and wild females in redd abandonment, egg burial, and redd location choice may have been responsible for the difference observed. Other studies that have examined the effects of a single generation of hatchery culture on upper Yakima River chinook salmon have disclosed similar low-level effects on adult and juvenile traits. The cumulative effect of such differences will need to be considered when hatcheries are used to restore depressed populations of chinook salmon."

Seamons et al. 2012. "We tested the efficacy of the strategy of segregation by divergent life history in a steelhead trout, Oncorhynchus mykiss, system, where hatchery fish were selected to spawn months earlier than the indigenous wild population. The proportion of wild ancestry smolts and adults declined by 10–20% over the three generations since the hatchery program began. Up to 80% of the naturally produced steelhead in any given year were hatchery/wild hybrids.

"…proportions of hybrid smolts and adults were higher in years when the number of naturally spawning hatchery-produced adults was higher. Divergent life history failed to prevent interbreeding when physical isolation was ineffective, an inadequacy that is likely to prevail…"

"Controlling the behavior or breeding biology of captively reared animals released into the wild is one of the most significant issues for managers tasked with minimizing risks associated with captive rearing.

"Hatchery steelhead are intercepted and harvested downstream of the Forks Creek Hatchery, but harvest rates are clearly not sufficient to prevent large numbers of hatchery-produced fish from reaching spawning grounds. Indeed, the number of hatchery produced adults returning to the Forks Creek Hatchery equaled or exceeded the total number of wild fish estimated to be spawning in the entire Willapa River during the most recent three return years.

"Hatchery rearing may have negative fitness consequences even when the stocks are locally derived (Araki et al. 2007b, 2009). Nonlocal populations, like the hatchery broodstock used at Forks Creek, often have lower reproductive success than native wild populations because of a lack of local adaptation (Kostow et al. 2003; reviewed in Berejikian and Ford 2004; Araki et al. 2007a, 2008; Chilcote et al. 2011; Fraser et al. 2011). Interbreeding between hatchery and wild stocks could have long-term fitness consequences.

"One obvious solution is to reduce or cease production and release of steelhead from the hatchery; however, this option may be unpopular and difficult to implement. Physical segregation may be augmented by improving weirs. However, weirs or dams are costly and they affect the habitat to some extent. Flooding and debris compromise most weirs, allowing fish to bypass them. Even if barriers were completely effective at preventing upstream migration, the hatchery-produced fish might spawn elsewhere in the basin.

"Segregation by life history was thought to complement physical segregation, but our study shows that it failed to prevent genetic interactions between hatchery and wild steelhead populations. Thus, managers should also consider other options for minimizing interactions between wild and cultured animals."

Shrimpton, et al., 1994: "Juvenile hatchery coho showed a reduced tolerance to salt water compared to wild coho."

Slaney, et al., 1993: "Hatchery adult steelhead strayed more than wild steelhead."

Sosiak, et al., 1979: "As juveniles, hatchery fish had less stomach fullness and fed on fewer taxa than wild fish. This was determined after hatchery fish were in streams from one to three months."

Steward et al. 1990: Authors reviewed 606 hatchery supplementation studies and found that few directly assessed the effects on natural stocks. Genetic and ecological effects and changes in productivity of the native stocks that can result remain largely unmeasured. However, the general failure of supplementation to achieve management objectives is evident from the continued decline of wild stocks.

Swain, et al. 1991: Hatchery coho salmon diverged from the wild fish in fin size and body dimensions. These were considered adaptations to the hatchery environment.

Taylor, 1986: "Hatchery coho salmon diverged in body structure and variation from that of the wild coho."

Vincent 1987: Hatchery stocking ended in a Montana stream and wild trout more than doubled (160%) and the wild trout biomass increased by 10 times.

Theriault et al. 2011: "Supplementation of wild salmonids with captive-bred fish is a common practice for both commercial and conservation purposes. However, evidence for lower fitness of captive reared fish relative to wild fish has accumulated in recent years, diminishing the apparent effectiveness of supplementation as a management tool. To date, the mechanism(s) responsible for these fitness declines remain unknown. In this study, we showed with molecular parentage analysis that hatchery coho salmon (Oncorhynchus kisutch) had lower reproductive success than wild fish once they reproduced in the wild. This effect was more pronounced in males than in same-aged females. Hatchery spawned fish that were released as unfed fry (age 0), as well as hatchery fish raised for one year in the hatchery (released as smolts, age 1), both experienced lower lifetime reproductive success (RS) than wild fish.

Waples and Do 1994: Genetic interactions between hatchery and wild salmonids will increase as hatchery supplementation becomes a more dominate form of hatchery management.

Waples 1994: Hatchery captive brood stocks may shift genetic structure in natural populations.

Webster 1931: "To those of us interested in fisheries work, artificial propagation is never and should never be considered as replacing natural reproduction."

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