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Review of literature pertaining to ecological and genetic effects of hatchery reared salmonids on naturally produced salmonids

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Citation	Species	Major findings
Beamish et al. 1997	Salmonids (not specified)	It has been shown that both short term (El Nino) and long term (Pacific decadal oscilation) affect the productivity of the Pacific Ocean. So if hatchery production does not change in accordance with changes in the ocean environment, large releases of large hatchery smolts have the potential to negatively impact wild stocks through competition in the ocean, even though hatchery stocks tend to have lower survival in the ocean. Environmental indices changed about 1989-1990 and may indicate that the productive regime of the 1980s has ended. This would imply that under natural conditions Pacific salmon abundance would decline. It is apparent that the massive production of artificially reared Pacific salmon would not be necessary in a less productive regime. Of concern is the impact that the large numbers of artificially reared salmon will have on wild salmon stock levels. Ignoring natural fluctuations in the ocean ecosystem may result in costly and wasteful investments; more importantly, the intervention into a poorly understood process may create problems that are not easily corrected. Based on hatchery releases of nearly 203 million fish and an estimated 145 million naturally produced fish, a total of almost 348 million salmonid smolts were present in the Columbia R. basin in 1992. This is 32% above estimated smolt numbers prior to 1850, yet adult returns remain low. Authors also state that as wild spawning and rearing habitat is increased [freshwater environment], hatchery production must be reduced.
Berejikian 1995	Steelhead	The results are also consistent with the hypothesis that relaxation of benthic predation pressure during the juvenile stages, over several generations, may have increased the frequency of predator-suceptible phenotypes in the hatchery population relative to the wild populaiton. That is, predator avoidance ability has been negatively altered through domestication and attempts to condition hatchery-reared steelhead to avoid predators may be limited for domesticated populations. In two seperate laboratory experiments, fry raised from eggs of wild steelhead survived predation better than size-matched hatchery fry in a natural stream, which were reared under similar conditions.

Berejikian et al. 1996	Steelhead	The combination of of potentially superior competitive ability (high agression 2-3 months after hatching), and inferior predator avoidance of hatchery fry suggest that caution should be excecised in designing hatchery programs to supplement wild populations. Hatchery fry reared in a natural stream channel for 105 days were more aggressive than those reared in hatchery tanks or wild fry reared in either environment. In otherwise identical tanks, low density and low food rations were associated with agnostic behavior by hatchery fry, but not wild fry. This study suggests that four to seven generations of domestication has resulted in behavioral divergence of the hatchery population from its wild donor population. The extent to which such differences deterrmine the outcomes of interactions between offspring of wild and hatchery steelhead spawning in streams will depend on the size differences and emergence dates of the populations as well as the geneticc bases of aggression.
Chilcote 2003	Steelhead	For natural populations, removal rather than addition of hatchery fish may be the most effective strategy to improve productivity and resilience. The proportion of wild fish in 12 mixed populations of hatchery and wild steelhead was evaluated for its relationship to mean and intrinsic measures of population productivity. The population mean of ln(recruits/spawner) was used to represent mean productivity. Intrinsic productivity was represented by values for the Ricker a parameter as estimated from fits of spawner and recruit data. Significant regressions ($p < 0.001$) were found between both measures of productivity and the proportion of wild fish in the spawning population (Pw). The slopes of the two regressions were not significantly different ($p = 0.55$) and defined a relationship suggesting that 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. Study findings were not sensitive to likely levels of data error or confounded by extraneous habitat correlation with Pw. Population status assessments and conservation monitoring efforts should include Pw as a critical variable.
Chilcote et al. 1986	Steelhead	Relative reproductive success of naturally spawning, summer-run hatchery and wild steelhead was compared by electrophoretic examination of juveniles for a specific genetic marker. The success of hatchery fish in producing smolt offspring was only 28% of that for wild fish. Authors 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. Authors suggest that under these conditions, the genetic integrity of wild populations may be threatened, but hatchery fish may be an important component of the spawner-to-smolt recruitment relationship for summer-run steelhead simply due to their high abundance relative to wild steelhead.

Crozier 1998	Atlantic salmon	The null hypothesis that was tested was that fish from the same gene pool would retain genetic homogeneity whether reared under hatchery or wild conditions. The author rejected the null hypothesis because the results indicated that the genetic compositition of the progeny from a group of crosses of salmon of known genotype did not remain homogeneous throughout the period of freshwater rearing in the hatchery and wild environments. Author examined allozyme variation at five polymorphic loci of know initial genetic composition in Atlantic salmon that were reared throughout freshwater life in a hatchery or stocked in the wild as swim up fry. The genetic composition of juveniles in the hatchery remained homogeneous from fertilization up to stocking, and from stocking to 2+ in the wild, however, those remaining in the hatchery developed genetic differences among smolting and non-smolting 1+ parr. These differences were attributed to conditions leading to early smolting at 1+ among hatchery fish, with 1+ smolts diverging from the gene pool from which they were derived. Whereas those stocked into the wild did not smolt until a year later and retained the original genetic composition.
Currens et al. 1997	Rainbow trout	Based the data, the authors concluded that introgression with nonnative hatchery rainbow trout has reduced the abilities of wild rainbow trout in the Metolius River to survive when conditions for ceratomyxosis infection occur. Disease challenges revealed that rainbow trout from the Metolius River had much greater susceptibility to C. shasta than rainbow trout from the Deschutes River, which have genetic resistance to the lethal disease. But genetic and meristic data indicated introgression with non-native hatchery fish. Suceptability of wild fish to C. Shasta was thought to be due to introgression with hatchery stocks.
Einum and Flemming 1997	Atlantic salmon	The results showed that native Atlantic salmon may differ genetically from farmed and native/farmed hybrid salmon in important fitness related traits. The authors compared, both in the hatchery and in the wild, fitness-related traits and examined interactions among farmed, native and hybrid 0+ parr derived from controlled crosses and reared under common conditions. The farmed salmon were seventh-generation fish from the principal commercial strain in Norway and native salmon were from the rivers Imsa and Lone, Norway. In the hatchery, farmed salmon were more aggressive than both native populations and tended to dominate them in pairwise contests. Farmed salmon were also more prone to risk, leaving cover sooner after a simulated predator attack, and had higher growth rates than native fish. Interbreeding between farmed and native fish generally resulted in intermediate expression of the above traits. There was, however, evidence of hybrid vigour in Lone/farmed crosses which were able to dominate both pure Lone and farmed parr in pairwise contests. In the wild, observations of habitat use and diet suggested that the populations compete for territory and food, and both farmed fish and hybrids expressed higher growth rates than native fish. Our results suggest that these innate differences in behaviour and growth, that probably are linked closely to fitness, will threaten native populations through competition and disruption of local adaptations. Although there were no differences in survival among the populations, innate differences in response to predators may lead to decreased survival in the farmed fish and hybrids during other life stages. Consequently, extensive interbreeding with farmed fish may eventually lead to an overall reduction in population size.

Fleming and Gross 1993	Coho salmon	The results imply that hatchery fish have restricted abilities to rehabilitate wild populations and may pose ecological and genetic threats to conservation. Hatchery males and females attained 62% and 82%, respectively, of the breeding success of wild males and females. Hatchery males were denied access to ovipositing females, partook in fewer spanings and held more distal positions in spawning hierarchies. Hatchery females suffered greater delays in the onset of spawning, failed to deposit a larger portion of eggs, and lost more eggs to redd destruction by other females.
Fleming et al. 1994	Atlantic salmon	The body form of Atlantic salmon changes extensively from the wild type within a single generation of culture. The authors quantified phenotypic divergence in sea-ranched, farmed and wild Atlantic salmon from a common genetic stock. These first generation fish were also contrasted with a fifth generation farmed population and with wild and multigeneration sea-ranched populations of coho salmon. In comparisons between mature Atlantic salmon male parr, cultured juveniles had smaller heads and fins and narrower caudal peduncles and could be distinguished from wild juveniles with 100% accuracy. When juveniles were reared to adulthood in the natural marine environment, some of the morphological differences due to hatchery rearing persisted but many disappeared. Greater adult divergence from the wild state was was observ ed in multigeneration sea-ranched coho salmon, suggesting that evolutionary changes may accumulate with time. Continued farming of juveniles through adulthood increased environmentally induced phenotypic divergence considerably. Both rayed fin sizes and body streamlining decreased. Fifth generation farmed salmon showed the greatest morphological differences . Both the proportion of a fish's life history and the number of generations spent in culture are probably important determinents of phenotypic diveregence of cultured fish from their wild state.
Fleming et al. 1996	Atlantic salmon	Farmed and wild females had similar competitive behavior, but they differed in reproductive behavior and success. Farmed females displayed less breeding behavior, constructed fewer nests, retained a greater wieght of unspawned eggs, were less efficient at nest covering, incurred more nest destruction, and suffered greater egg mortality than wild females. As a result, farmed females had less than 33% of the reproductive success of wild females. Farmed males were even less successful than farmed females in competition with wild fish. They were less aggressive, courted less, partook in fewer spawnings and achieved only an estimated 1-3% of the reproductive success of wild males. Farmed males exhibited inappropriate mating behavior that led to poor reproductive success, even in the absence of competition with wild males. Adult farmed fish are likely to be relatively unsuccessful in natural environments due to competitive and reproductive inferiority likely resulting from domestication. To increase the success of hatchery programs detrimental effects of captive-rearing on an organisms phenotype and genotype, including its behavioral, morpholigical and physiological traits must be minimized. This may be accomplished by keeping the number of generations a species needs to be in captivity low and exposing it to naturalistic experiences and selection in that time period.

Fleming et al. 2000	Atlantic salmon	Farm Atlantic salmon escape and invade rivers throughout the North Atlantic annually, which has generated growing concern about their impacts on native salmon populations. A large-scale experiment was therefore undertaken in order to quantify the lifetime success and interactions of farm salmon invading a Norwegian river. Sexually mature farm and native salmon were genetically screened, radio tagged and released into the River Imsa where no other salmon had been allowed to ascend. The farm fishes were competitively and reproductively inferior, achieving less than one-third the breeding success of the native fishes. Moreover, this inferiority was sex biased, being more pronounced in farm males than females, resulting in the principal route of gene flow involving native males mating with farm females. There were also indications of selection against farm genotypes during early survival but not thereafter. 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.
Ford 2002	Salmonids (not specified)	The author used a quantitative genetic model to explore the effects of selection on the fitness of a wild population subject to supportive breeding. Supportive breeding is the boosting is the boosting the size of a wild population by breeding part of the population in captivity and releasing the progeny back into the wild. The results showed that selection in captivity may significantly reduce a wild population's fitness during supportive breeding and that even continually introducing wild individuals into the captive population will not eliminate this effect entirely. Additionally, sensitivity of the outcome of the model to changes in the quality of the spawning environment suggests that conserving or restoring a populations habitat is important for preventing fitness loss during supportive breeding.
Ford et al. 2004	Coho salmon	Authors tried to determine if releases of Washington hatchery coho salmon in the 1980's into Oregon Coast streams resulted in measurable introgression into nearby wild Oregon Coast coho populations. They suggested that introductions of Washington coho salmon did not result in large scale introgression into Oregon populations. The populations surveyed were characterized by a high degree of variation within populations and a relatively low degree of variation among populations. Overall, 97.5% of the genetic variance was found within populations, and only 2% of the variance was found among geographic locations, with the remainder found among temporal replicates within locations. Weak geographic population structure appeared to be characteristic of many coho salmon populations, although the absolute level of differentiation observed is lower than has been found for coho salmon from other studies in Alaska and California.

Goodman 2005	Salmonids (not specified)	Some salmon hatchery programs intentionally integrate the wild and hatchery population by taking naturally spawned fish as some fraction of the broodstock and allowing hatchery progeny to constitute some fraction of the adults spawning in the wild. This circumvents some ecological concerns about the effects of hatchery fish on the “wild” population while still reaping some of the benefits of increased potential for harvest, but it increases some genetic concerns. Here, we model phenotypic evolution in the integrated population to investigate the effects on natural spawning fitness at the joint selection and demographic equilibrium. We find a potential, but not a certainty, depending on quantitative aspects of the management interacting with biological characteristics of the stock, for substantial erosion of natural spawning fitness, compared with the original wild population, including the possibility of runaway selection driving natural spawning fitness effectively to zero. The vulnerability to such evolutionary deterioration increases with the magnitude of the contribution of hatchery breeding to the total production and increases with harvest. The response of the selection equilibrium to increasing contribution of hatchery progeny to the broodstock can exhibit a catastrophic discontinuity.
Hard et al. 2000	Coho salmon	The results suggest that the morphometric consequences of captive rearing for mate selection and reproductive activity of spawning fish may limit its effectiveness as a restoration tool. Multivariate analysis of shape variation by Procrustes coordinates, visualized by thin-plate splines, indicated that the captively reared adults were differentiated from the wild fish by sharply reduced sexual dimorphism as well as smaller heads and less hooked snouts, increased trunk depth, larger caudal peduncles, shorter dorsal fins, larger hindbodies and a reduction in body streamlining. The differences between the captively reared and wild fish were similar to but more pronounced than some differences previously reported between hatchery and wild coho salmon. The magnitude and pattern of differences suggested that at least some of them were environmentally induced. Shape variation showed an allometric relationship with variation in body (measured as centroid) size. Morphometric variation was a poor correlate of most spawning behaviors.
Hayes et al.	Coho salmon and Steelhead	100% wild broodstock are utilized for hatchery mating each year. Hatchery and wild juvenile populations of steelhead and coho salmon in a small coastal watershed in central California, were sampled throughout the year in a stream and at a hatchery. Both species grew faster in captivity than in the wild. Hatchery fish of both species had elevated gill Naþ, Kþ -ATPase activity, and thus were ready to enter sea water when planted during the wild fish migration. Downstream migrant trapping and stream surveys indicated that hatchery smolts went to sea soon after planting, consequently avoiding the effects of competition and predation that commonly occur when hatchery-bred juveniles are released. Adult steelhead were also sampled throughout the watershed. The return of hatchery steelhead was highly synchronized with that of wild steelhead, indicating that hatchery propagation had no adverse effects on the timing of the run. A disproportionate number of hatchery steelhead returned to the tributary where the hatchery was located, despite being planted throughout the watershed. Hatchery steelhead did not differ in mean age or size from wild steelhead. Observations of spawning indicated that hatchery and wild steelhead interbreed. Competition for mates or spawning substratum was rarely observed between hatchery and wild steelhead. Many of the problems commonly associated with artificial propagation can be avoided in small coastal watersheds when wild broodstock are used and fish are released as smolts.

Heggenes et al. 2006	Steelhead	Tests of population subdivision between prehatchery and posthatchery operation indicated no significant changes. Similar results were obtained using other measures of genetic differentiation (principal components analysis of microsatellite allele frequencies and Cavalli-Sforza genetic distance). The data, however, did indicate a slight but significant reduction in allelic richness after hatchery stocking. Pairwise tests for genetic differentiation among samples from different year classes were nonsignificant. The authors concluded that for the current management regime there is little apparent impact of hatchery practices on either the genetic structure or variation within the lower main-stem Kitimat River steelhead, but there may be a reduction in rare alleles. The practice of using substantial numbers of wild fish and multiple year-classes in the hatchery may have minimized genetic changes via genetic drift. Broodstock in nearly every year was taken from true wild, unclipped fish, so the authors detected little change in genetic variation in Kitimat River steelhead before and after enhancement started or over the intervening years.
Hillborn 1992	Salmonids (not specified)	Large-scale hatchery programs for salmonids in the Pacific Northwest have largely failed to provide the anticipated benefits; rather than benefiting the salmon populations, these programs may pose the greatest single threat to the long-term maintenance of salmonids. Proponents of artificial propagation like to think of their hatcheries as augmenting wild stocks, particularly by allowing surplus hatchery fish to spawn in the wild. These extra spawners, turned away from the hatchery, are hoped to add to the natural spawning population. Accumulating evidence suggests that hatchery fish often do poorly in the wild; the offspring of wild x hatchery matings do more poorly than wild x wild matings. When hatcheries allow surplus fish to spawn in the wild, they are allowing all of the genes that have been brought in from elsewhere and have been selected for hatchery life to dilute the naturally adapted genes of the wild fish. The net result may be that after a few generations there are no more wild fish-we will, and indeed in many places we now do have, mongrel fish not well-adapted to any particular river.
Hillborn and Eggers 2000	Pink salmon	The evidence suggests that the hatchery program in Prince William Sound replaced rather than augmented wild production. Two likely causes of the replacement were a decline in wild escapement associated with harvesting hatchery stocks and biological impacts of the hatchery fish on wild fish. Published papers disagree on the impact of the 1989 Exxon Valdez oil spill, but none of the estimates would account for more than a 2% reduction in wild-stock abundance, and the decline in wild stocks began well before the oil spill. No evidence in the Kodiak area program suggests any impact on wild stocks. This analysis suggests that agencies considering the use of hatcheries for augmenting salmonids or other marine species should be aware of the high probability that wild stocks may be adversely affected unless the harvesting of the hatchery fish is isolated from the wild stocks and the hatchery and wild fish do not share habitat during their early ocean life.

HSRG 2004	Salmonids (not specified)	The rate of gene flow from the natural environment to the hatchery environment must exceed the reverse rate of gene flow for the mean fitness of hatchery-origin fish, and the population as a whole, to be closer to the optimum fitness for the natural environment than to the optimum fitness for the hatchery environment. In other words, the proportion of a hatchery broodstock composed of natural-origin fish must exceed the proportional genetic contribution of hatchery-origin fish to the naturally spawning population if selection regimes in the natural environment are to dominate the mean fitness of the population as a whole. For example, if natural-origin adults constitute—on average—20% of a hatchery broodstock each year, then the genetic contribution of hatcheryorigin fish to the naturally spawning component must be less than 20% per year. By controlling gene flow in both directions (i.e., by ensuring sufficient gene flow into the hatchery and controlling natural spawning of hatchery-origin adults), the genetic risks imposed by an integrated hatchery program to a naturally spawning population can be substantially less than the risks posed by a segregated program of equal size.
ISAB 2002	Salmonids (not specified)	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. Substantial experimental evidence demonstrates that domestication selection can genetically alter hatchery populations in a few generations and that hatchery-origin adults returning from the ocean and spawning in the wild produce fewer progeny than adults of wild origin spawning in the wild. More limited evidence suggests that interbreeding between hatchery-origin adults and wild fish can reduce the fitness of the wild population. The authors conclude that decisions whether or not to permit hatchery-origin adults to spawn in the wild should be based on the needs of wild populations and the ability of the habitat to support additional reproduction, not based simply on the availability of hatchery-origin adults returning from the ocean.
Jokikokko et al. 2006	Atlantic salmon	The recapture rate and survival of hatchery-reared Atlantic salmon Salmo salar stocked as 1 year-old parr (semi-wild) with that of hatchery-reared Atlantic salmon stocked as 2 year-old smolts and wild smolts of Atlantic salmon in the northern Baltic Sea were compared. This was done through tagging experiments carried out in 1986–1988 and 1992. The recapture rate of the semi-wild groups varied from 1 0 to 13 1%, being similar in 3 tagging years and lower in 1 year than that of the wild groups (1 7–17 0%). The recapture rate of the semi-wild groups was similar (in 2 years) or higher (in 2 years) than that of the hatchery-reared groups stocked as smolts (1 3–6 3%). The survival of semi-wild smolts during the sea migration was as high as that of wild Atlantic salmon of an equal size and two to three times higher than hatchery-reared Atlantic salmon stocked as smolts. The survival rate was positively associated with smolt size.
Jonnnson et al. 2003	Atlantic salmon	Survival was significantly higher for wild than hatchery fish. Hatchery salmon released as 2-year-old smolts had lower survival, were captured more in coastal than freshwaters, grew more slowly and attained maturity younger than corresponding 1-year-old smolts. The survival rate of hatchery fish released as 2-year-old smolts, but not 1-year-olds and wild smolts, decreased during the 1980s and 1990s. Growth rates at sea, adult size and the proportion of multi-sea-winter fish of all three groups also decreased over time. Climatic conditions were speculated to be behind the decreases in survial rates during the 1980s and 1990s.

Jonsson 1997	Atlantic salmon	Lack of juvenile river experience is the prime reason why cultured salmon often enter fresh water later in the season than wild fish. During spawning, cultured female salmon from fish farms make fewer nests, tend to breed for a shorter period of time, are poorer at nest covering, and retain greater amounts of unspawned eggs than wild females. Cultured male salmon from fish farms exhibit less combat and display behaviour, have greater difficulty in acquiring access to mates, show less quivering and courting behaviour, and have lower reproductive success than wild males. However, cultured male salmon are more involved in prolonged, reciprocal fights than wild males and are, therefore, more often wounded. The reproductive success of cultured salmon increases with the time the fish have lived in nature before maturing sexually; for cultured females released in nature at the smolt stage, reproductive success is similar to that of wild females. The relative reproductive success of cultured males is smaller than that of corresponding females. Within both sexes of cultured and wild salmon, competitive spawning ability increases with body size. As a phenotypic response to increased growth rate during the first year of life, cultured salmon tend to have smaller sized but more numerous eggs than wild fish of the same size. Offspring of cultured salmon are more generally aggressive, more risk prone, and have a higher growth rate than wild offspring. Consequently, their survival rate in nature may be lower.
Kostow 2004	Steelhead	The results suggest that modified selection begins immediately in the first generation of a new hatchery stock and may provide a mechanism for genetic change. Naturally produced smolts had average smolt-to-adult survivals of 5–6%, whereas both hatchery stocks had average survivals over the 5 years of about 1% (differences between natural and hatchery fish significant at $P < 0.001$). 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.

Kostow and Zhou 2006	Steelhead	The authors investigated the effect of a hatchery summer steelhead program on the productivity of a wild winter steelhead population in the Clackamas River, Oregon. They used Ricker and Beverton–Holt stock–recruitment models that incorporated species interaction variables to demonstrate that when high numbers of hatchery summer steelhead adults were present the production of wild winter steelhead smolts and adults was significantly decreased. They found that large releases of hatchery smolts also contributed to the decrease in wild adult productivity. Averaged over the results of the models, a 50% decline in the productivity parameter (the number of recruits per spawner at low densities) and a 22% decline in the maximum number of recruits produced in the basin were observed when high numbers of hatchery fish were present. We concluded that over the duration of the hatchery program, the number of hatchery steelhead in the upper Clackamas River basin regularly caused the total number of steelhead to exceed carrying capacity, triggering density-dependent mechanisms that impacted the wild population. The number of smolts and adults in the wild winter steelhead population declined until critically low levels were reached in the 1990s. Hatchery fish were removed from the system in 2000, and early results indicate that the declining trends have reversed. Although the system [the particulars of Clackamas] was unique, it's likely the impacts they detected are not restricted to the Clackamas River basin. Similar density-dependent ecological effects could occur in any hatchery program that causes basin carrying capacity to be exceeded, whether or not interbreeding effects also occur. Competitive interactions between wild steelhead, adult hatchery steelhead, and the naturally produced offspring of hatchery steelhead must be added to the list of concerns about the effect of hatchery programs on wild populations. Managers generally need to avoid management strategies that allow hatchery adults to enter natural production areas in excess of basin carrying capacity within systems containing wild populations. This recommendation is valid if wild populations are to be protected from impacts, regardless of the purpose of the hatchery program or of expectations of hatchery fish reproductive success.
Kostow et al. 2003	Steelhead	Hatchery summer steelhead reproductive success was relatively poor. The authors 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 (36–53% 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 adults were observed, suggesting high mortality of the naturally produced smolts following emigration. Counts at the dam demonstrated that hatchery summer steelhead predominated on natural spawning grounds throughout the 24-year hatchery program. The data support the conclusion that hatchery summer steelhead adults and their offspring contribute to wild winter steelhead population declines through competition for spawning and rearing habitats.
Lahnsteiner and Jagsch 2005	Brown trout	Authors found significant differences between the populations from the 19th century, the current wild populations, and the hatchery populations in morphometric parameters (mainly shape of pectoral, ventral and anal fins) and the RFLP pattern of mtDNA. They did find the typical phenotypes and genotypes from the 19th century in either of the current populations. This phenotypic and genotypic replacement was considered to be due to anthropogenic activities (stocking). There exist several highly differentiated wild populations with specific phenotype and genotype which conservation is valuable under aspects of maintaining biodiversity.

Leider et al. 1990	Steelhead	Substantial differences were found in the relative ability of naturally produced offspring of hatchery and wild steelhead to survive in stream conditions. Throughout their various lifestages, natural offspring of transplanted hatchery steelhead survived less well than those of the local wild stock. Reporductive success of hatchery fish (defined as the ability of naturally spawning hatchery steelhead to produce offspring relative to the ability of wild steelhead) decreased from 0.750-0.788 at the subyearling stage, to 0.308-0.310 at the smolt stage, to 0.108-0.129 at the adult stage. However, the hatchery stock was not locally derived and so part of the poorer survival for the naturally produced hatchery population could have been due to maladaptation to the recipient stream resulting from an "out of basin stock," not just due to maladaptation caused by long term artificial and domestic selection.
Levin et al. 2001	Chinook salmon	The authors used a 25 year time series of outmigrant and adult return return data at Lower Granite Dam and the Oyster Condition Index (a measure of ocean conditions) to examine the relationship between hatchery production, survival, and ocean conditions. They demonstrated a strong, negative relationship between the survival of chinook salmon and the number of hatchery fish released during years of poor ocean conditions. The results suggest that endangered species, like Snake River spring chinook salmon, experience density dependent mortality even though their populations are at historic lows. Because ocean conditions have become unfavorable in recent years, increased mortality of wild salmon associated with high densities of hatchery fish may become more prevalent. As a result, industrial scale hatcheries will probably become an increased threat to wild salmon.
Lynch and O'Hely 2001	Salmonids (not specified)	Domestication selection (adaptation to the captive environment) poses a particularly serious problem because it promotes fixations of alleles that are deleterious in nature, thereby resulting in a permanent load that cannot be purged once the supplementation program is truncated. The 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 transformations that can eventually lead to natural populations that are no longer capable of sustaining themselves.
Marchetti and Nevitt 2003	Rainbow trout	Using rainbow trout, Oncorhynchus mykiss, as a model, the authors measured eight regions of the salmonid brain to examine differences between wild and hatchery reared fish. Using multiple analysis of covariance (MANCOVA), analysis of covariance (ANCOVA) and discriminant function analysis (DFA), they found that the brains of hatchery reared fish are relatively smaller in several critical measures than their wild counterparts. The work suggested a mechanistic basis [changes in the brain] for the observed vulnerability of hatchery fish to predation and their general low survival upon release into the wild.

McGinnity et al. 2003	Atlantic salmon	The high level of escapes from Atlantic salmon farms, up to two million fishes per year in the North Atlantic, has raised concern about the potential impact on wild populations. THe authors report on a two generation experiment examining the estimated lifetime successes, relative to wild natives, of farm, F1 and F2 hybrids and BC1 backcrosses to wild and farm salmon. Offspring of farm and 'hybrids' (i.e. all F1, F2 and BC1 groups) showed reduced survival compared with wild salmon but grew faster as juveniles and displaced wild parr, which as a group were significantly smaller. Where suitable habitat for these emigrant parr is absent, this competition would result in reduced wild smolt production. In the experimental conditions, where emigrants survived downstream, the relative estimated lifetime success ranged from 2% (farm) to 89% (BC1 wild) of that of wild salmon, indicating additive genetic variation for survival. Wild salmon primarily returned to fresh water after one sea winter (1SW) but farm and 'hybrids' produced proportionately more 2SW salmon. However, lower overall survival means that this would result in reduced recruitment despite increased 2SW fecundity. Farm salmon consistently show the lowest freshwater and marine survival in all cohorts. There is no evidence for hybrid vigour, with F1 and BC1 hybrids being intermediate between wild and farm salmon in survival, growth and parr maturity. There is clear evidence of outbreeding depression in the F2 hybrids, as might be expected from a breakdown of coadapted sets of alleles following recombination of parental chromosomes. This demonstrates that interaction of farm with wild salmon results in lowered fitness, with repeated escapes causing cumulative fitness depression and potentially an extinction vortex in vulnerable populations.
Mclean et al. 2003	Steelhead	Hatchery steelhead spawning in the wild had markedly lower reproductive success than native wild steelhead. In two seperate years, wild females produced 9 and 42 times as many adult offspring per capita as did hatchery females that spawned in the wild. The wild seteelhead population met replacement requirments, (3.7-6.7 adult offspring per female) but the hatchery stock did not (< 0.5 adults per female). The survival difference was greatest in the freshwater environment (i.e., production of smolts), but survival at sea favored hatchery fish in one year and wild fish in the other. Authors postulated that poor performance of hathcery fish may have been a consequence of spawning too early in the winter (original broodstock was selected for early returns) generations of inadvertent artificial selection, or both.
Mclean et al. 2004	Steelhead	The authors used eight microsatellite loci to create allele frequency profiles for baseline hatchery and wild populations and assigned the smolt (age 2) offspring of this parental generation to a population of origin. Adults originating from a generalized hatchery stock artificially selected for early return and spawning date were successful at reproducing in Forks Creek,Washington. Although hatchery females (N = 90 and 73 in the two consecutive years of the study) produced offspring that survived to emigrate as smolts, they produced only 4.4–7.0% the number produced per wild female (N = 11 and 10).

Mclean et al. 2005	Steelhead	Authors examined the mating system for steelhead at Forks Creek Hatchery in Washington and investigated factors affecting selection of individual steelhead for spawning by hatchery staff. Despite efforts by the staff not to spawn selectively, data on steelhead spawned over seven years revealed selection for large adult body size and early reproductive timing and a tendency for size assortive mating (i.e., large with large). Selection on size was related to selection on reproductive timing because early returning fish tended to be larger than those returning later. Lack of selection in the hatchery for breeding-associated traits results in captive-bred fish with poor reproductive success in the wild as a consequence of inappropriate spawning behavior. Conservation hatcheries that intend to produce self-sustaining populations that can maintain themselves through natural production will be ineffective until natural mechanisms of mate choice can be incorporated into spawning protocols.
Meffe, G.K. 1992	Salmonids (not specified)	A mangement strategy that has a centerpiece of artificial propagation and restocking of species that have declined as the result of environmental degredation and overexploitation, without correcting the causes of decline, is not facing the biological reality. 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 causes of decline, but it may exacerbate the problemand accelerate the extinction process. There are at least six reasons why the current use of hatcheries in salmonid management is counter productive and should be reconsidered: 1) data demonstrate that hatcheries are not solving the problem-salmon continue to decline despite decades of hatchery production; 2) hatcheries are costly to operate and divert resources from other efforts like habitat restoration; 3) hatcheries are not sustainable in the long-term, requiring continual input of money and energy; 4) hatcheries are a genetically unsound approach to management that can adversely affect wild populations; 5) hatchery production leads to an increase in the harvest of wild fish; 6) hatcheries conceal from the public the truth of wild salmon declines.
Mesa 1991	Cutthroat trout	The results support the hypothesis that excessive expenditure of energy for unnecessary aggression, use of fast-flowing water, or other purposes contributes to poor survival of hatchery fish after they are stocked in streams. Poor survival would reduce the efficacy of using hatchery stocks to supplement wild production. Author compared feeding, aggressive behavior, and spatial distribution of differently ranked individuals of hatchery and wild coastal cutthroat trout Oncorhynchus clarki clarki in an artificial stream. Both hatchery and wild groups established stable dominance hierarchies that seemed be based on size differences. Hatchery and wild fish within a hierarchical rank fed at similar rates. Hatchery fish were more aggressive than their wild conspecifics, irrespective of rank. Dominant hatchery fish were evenly distributed in pools and riffles, whereas dominant wild fish were three times more often in pools than in riffles. In both groups, socially intermediate fish were almost evenly distributed between pools and riffles, and subordinate fish spent most of their time in pools. average, hatchery fish spent 57% of their time in pools and 43% in riffles, whereas wild fish spent 71% of their time in pools and 29% in riffles.
Miller 1954	Cutthroat trout	Author presumed that low survivability of hatchery fish was due to the absence of natural selection at early stages in the life history. Pond-rearert fish exhibited very low survival over the first (0 to 4.9 percent) and second (0 to 3.1 percent) winter. Survival was largely independent of age. Transplanted wild trout showed survival of 46.0 to 29.0 percent to the second and third summers, respectively. Stream-reared hatchery fish gave an intermediate value (17.2 percent to the second summer). All lots of trout lost weight for some 30, or 40 days when superimposed on a resident population. This loss was more severe and was regained more slowly in pond-reared trout than in transplanted wild trout.

Nickelson 2003	Coho salmon	An index of productivity based on the density-independent rate of reproduction of wild coho salmon (Oncorhynchus kisutch) in 12 Oregon coastal river basins and two lake basins was negatively correlated with the average number of hatchery coho salmon smolts released in each basin. The index of productivity was not significantly correlated with the average proportion of hatchery coho salmon in each naturally spawning population or with habitat quality. 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 a volitional release strategy or a strategy that employs smaller release groups spread temporally. An unexpected result was the lack of a relationship between habitat quality and productivity of wild populations.
Nickelson et al. 1986	Coho salmon	Hatchery coho salmon failed to rebuild coho salmon populations in stocked streams. The authors evaluated the effectiveness of using hatchery coho salmon presmolts to rebuild wild populations in Oregon coastal streams. Juvenile and adult populations were monitored in 15 stocked and 15 unstocked streams from 1980 to 1985. During the summers following the planting presmolts, the number of juveniles per meter of pool surface area was higher in the stocked streams than in the unstocked streams. However, during two years when the estimates of abundance were made seperately for wild and hatchery juveniles, wild juveniles were significantly less abundant in the stocked streams. Adult returns were not significantly different between the stocked and unstocked streams but returns tended to be earlier in the stocked streams. Despite the lack of difference in the adult returns, the resulting densities of juveniles in the stocked streams were significantly lower than those in the unstocked streams. The authors concluded that premature spawning by hatchery coho salmon was responsible for the the failure of hatchcery coho salmon to rebuild populaitons as [freshets] high flows likely reduced spawning success.
Reisenbichler and McIntyre 1977	Steelhead	Relative growth and survival of offspring from matings of hatchery and wild steelhead on the Deschutes R. were measured to determine is hatchery fish are genetically different from wild fish in traits that can affectt the stock-recruitment relationship of wild populations. Sections of four natural streams and a hatchery pond were stocked with genetically marked offspring from hathcery x hatchery, hatchery x wild and wild x wild parents. In streams wild x wild progeny had the highest survival and hatchcery x wild progeny had the highest growth rate when sig. differences were found; in the hatchery pond, hatchery x hatchery progeny had the highest survival and growth rates [this may suggest hatchery fish are better adapted to life in the hatchery than in natural settings]. The hatchery fish were genetically different from wild fish and the obseerved 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 only wild spawners. Length data from the creeks indicated that there were genetic differences between the offspring of the various matings that survived one year of full exposure to natural selection. If these and other genetic differences persist until the offspring of hatchery and wild fish return as adults, there will be an additional effect on the wild population with the expected result being a reduction in the overall reproductive success of the wild population.

Reisenbichler and Rubin 1999	Salmonids (not specified)	The authors reviewed publications and studies in progress and determined that there is 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. Substantial declines in fitness for natural propagation are clearly undesireable for both conservation and the economic efficiency of supplementation.
Reisenbichler et al. 1992	Steelhead	Steelhead Oncorhynchus mykiss from various sites between the Columbia River and the Mad River, California, were genetically characterized at 10 protein-coding loci or pairs of loci by starch gel electrophoresis. Fish from coastal streams differed from fish east of the Cascade Mountains and from fish of the Willamette River (a tributary of the Columbia River, west of the Cascade Mountains). Coastal Steelhead from the northern part of the study area differed from those in the southern part. Genetic differentiation within and among drainages was not statistically significant; however, gene diversity analysis and the life history of Steelhead suggested that fish from different drainages should be considered as separate populations. Genetic variation among fish in separate drainages was similar to that reported in northwestern Washington and less than that reported in British Columbia. Allele frequencies varied significantly among year-classes. Genetic variation within samples accounted for 98.3% of the total genetic variation observed in this study. Most hatchery populations differed from wild populations, suggesting that conservation of genetic diversity among and within wild populations could be facilitated by altering hatchery programs. It is desirable to ameliorate or avoid the possible causes of reduced genetic variability both within and between populations) because such reduction may decrease the productivity of a species and increase the likelihood that the species will become extinct.
Rhodes and Quinn 1998	Coho salmon	Authors used aquarium experiments evaluate competition between hatchery and wild coho salmon. Prior residents dominated intruders of the same size but intruders with a 6% length advantage were equally matched against prior residents. Prior winning experience (distinct from individual recognition) also strongly influenced competitive success and overcame a prior residence effect. Coho salmon reared in a hatchery dominated sized matched fish from the same parental population reared in a stream. Hatchery-reared salmon also dominated naturally spawned salmon, even whne the wild salmon were prior residents. The combined effects of greater size and rearing experience of hatchery produced salmon were sufficient to overcome the prior residence advantage of a wild salmon. Efforts to rehabilitate salmonid populations must take into account behavioral interactions if displacement of wild fish is to be prevented
Saisa et al. 2003	Atlantic salmon	Statistically significant changes in allele frequencies were common in the hatchery stocks (F = 0.029, for Iijoki), but not in the wild Teno stock, which was temporally very stable (F = 0.007). Allelic richness decreased statistically significantly (24.8%) in the Oulujoki broodstock, from 62.1 to 46.7 alleles at nine loci. On average, there were 9.7 fewer alleles (15.7%) in the contemporary broodstocks than in the corresponding historical stocks. The mean heterozygosity was 6.6% lower in the contemporary Oulujoki broodstock, but remained unchanged in the Iijoki broodstock.

Small et al. 2004	Coho salmon	Significant heterogeneity in genotype frequencies was detected between wild-spawning coho salmon from the upper North Fork (NF) Nooksack River and hatchery-strain coho salmon from the Nooksack River (descendants of primarily Nooksack River broodstock). Little difference in genotype frequencies was detected between wild-spawning coho salmon from the Samish River and hatchery-strain coho salmon from the Nooksack River. The 13- locus suite provided high resolution: in assignment tests over 85% of wild-spawning coho salmon from the upper NF Nooksack River were assigned to source. Wild-spawning coho salmon collected below hatcheries in the Nooksack River and 50% of wild-spawning Samish River coho salmon were assigned to hatchery collections. The genetic divergence of wild-spawning coho salmon in the upper NF Nooksack River is remarkable given the extensive stocking history and proximity of a hatchery. Authors suggest that these upper river fish are native coho salmon and that wild spawners in the lower Nooksack and Samish River are descendants of hatchery productions. This divergence was attributed to earlier run timing in upper NF Nooksack River wild spawners, availability of extensive spawning and rearing habitat upstream of a hatchery in the upper NF Nooksack River, and a longer stocking history in the Samish River.
Sweeting et al. 2003	Coho salmon	Through estimates derived from fin clip and coded wire tag data collected from commercial and sport fisheries, research surveys, and examination of the microstructure of otoliths extracted from juvenile coho salmon collected during marine surveys, authors determined that the percentage of hatchery-reared coho salmon Oncorhynchus kisutch in the Strait of Georgia, British Columbia, increased from nearly 0% in the early 1970s to more than 70% by 2001. Authors suggested that at the beginning of the hatchery program, increases of hatchery coho salmon being released relative to the wild coho salmon production was responsible for the increasing percentage of hatchery fish in the Strait of Georgia. A decline in wild smolt production probably occurred in the early 1990s as a result of declining marine survival and high exploitation rates. This decline was not matched by decreased hatchery releases. So, the percentage of hatchery coho salmon in the Strait of Georgia population increased in the mid-1990s even though there was only a relatively small increasing trend in hatchery releases compared with the 1970s and early 1980s.At the beginning of the hatchery program in the early 1970s, it was believed that the abundance of coho salmon could be rebuilt and wild stocks supplemented by adding more smolts to the ocean than would be produced naturally in rivers and streams so there was no policy that protected wild coho salmon. But hatchery fish replaced rather than augmented natural populations. Authors suggested that clear that strategies are needed for the management of both hatchery and wild coho salmon and that any enhancement program requires clear policies for both the wild and the enhanced stocks.

Tymchuck et al.	Coho salmon	Multiple generations of pure and hybrid families were generated for coho salmon O. kisutch, including pure farm (D), pure native (Ch; a natural strain propagated by wild and hatchery production), F1 and F2 hybrids, and F1 3 wild backcross (BCh) genotypes. The family groups were reared in the laboratory under controlled conditions as (1) individual genotypic groups, (2) mixed groups under culture conditions, and (3) mixed groups under enriched (seminatural) conditions. The growth of the fish was tracked until smoltification. There was a significant genotype effect on growth performance (mass and length), with rankings as follows: D . F2 . F1 . BCh . Ch. This ranking remained the same in all three rearing environments. Behavioral differences were observed among the families, the fast-growing domesticated families showing a reduced antipredator response relative to the slow-growing wild families. Based on this data, the effect of a single small introgression of farm alleles into a wild population would be diluted with repeated backcrosses in the absence of selection, and little phenotypic effect would be detectable after two or more generations. In contrast, escapes of large numbers of farmed individuals into small populations, or repeated escapes of moderate numbers over several generations, would have an impact on the phenotype of the receiving population. The critical question, as yet unanswered, is whether natural selection can restore wild-population genetic structures from such introgressed populations.
Unwin 1996	Chinook salmon	This study clearly demonstrated that fry-to-adult survival rates for hatchery produced chinook salmon fell well short of what would be expected given their great size advantage over naturally produced fry. While survival rates for hatchery fish were four times higher than those of naturally produced fish, they were extremely poor relative to their size at release. Survival rates for hatchery and naturally produced fish were positively correlated, suggested that recruitment of both stocks is controlled by common influences in the marine environment, likely during the first winter at sea. Stock-recruitment analysis for the natural population showed little tendancy for recruitment to increase with stock size, suggesting that marine3 survival rates may be density dependent. The reasons for the poor survival of hatchery fish were somewhat unclear, but the results provide a case study in which hatchery fish appear to have a poorer "fitness to survive" than naturally produced fish.
Unwin and Glova 1997	Chinook salmon	Chinook salmon runs in New Zealand exhibited significant changes in life history traits following supplementation releases of hatchery reared juveniles. Total run strength did not decline but the proportion of naturally produced fish returning to spawn fell to 34%. Attempts to segregate hatchery and natural spawners were not successful. A variety of life history traits showed significant trends over time, all of which were linked to the increasing presence of hathcery fish. Hatchery males were smaller at ages 2 and 3 than naturally produced males and more often matured as jacks, producing an 86 mm decrease in fork length over a 28 year period. Run timing was shifted earlier and there was evidence of a declining incidence of stream-type adults [commonly called spring run in PNW, but they do not segregate in New Zealand]. Prior to hatchery releases, ocean type fry out number stream-type fry by 2:1 at the time of hatching but experienced much higher mortality as a result of their small size at ocean entry. Hatchery rearing for 8-12 months therefore greatly increased the survival of ocena type fry, but would likely be less beneficial to stream-type fry. By differentially affecting survival rates in this way, hatchery rearing selected for ocean type fish and 2 year olds (ocean type fish are more likely to return as 2 year olds).

Vasemagi et al 2005	Atlantic salmon	While many studies have reported a loss of genetic diversity in hatchery stocks, the authors found more genetic variation within two hatchery stocks than in wild populations of Gulf of Finland. However, they suggested that distinct ecological conditions, the presence of alleles not found in hatchery stocks and moderate genetic differentiation (FST=0.083–0.115) among the wild populations as well as between the wild and hatchery stocks (FST=0.055–0.187) justify conservation efforts of the last remaining wild salmon populations of Gulf of Finland.
Vincent 1960	Brook trout	Three stocks of brook trout, domestic, wild, and first generation reroved from wild stock, were tested and observed for effects of domestication. The domestic stock had been selectively bred for 90 years, whereas the wild stock came from an isolated lake in the Adirondack Mountains. After 1 year under these hatchery conditions the domestic fish were 5.2 inches in length and the wild, 3.6 inches. Throughout the rearing domestic stock were tamer and exhibited less fright than wild-stock fish. Laboratory tests showed that wild stock could stand a greater concentration of accumulated metabolites, that they could endure higher water temperature, and that domestic stock had a surface response whereby they moved to the surface of a rearing trough or a tall aquarium. Domestic fish also lacked the desire to conceal themselves. Stamina tests conducted by swimming 1,522 fish individually until exhausted in a small trough showed that the wild stock had greater stamina throughout the size range tested. Survival trials in a small stream and a pond indicated that wild fish experienced less mortality and had growth rate similar to or better than domestic fish in both habitats. After 73 days in the small stream 20 percent of the domestic and 33 percent of the wild stock survived. Domestic fish grew 0.34 inches and wild fish, 0.48 inches. Survival was 43 percent for the domestic and 65 percent for the wild after 108 days in a pond, while length increase was 2.6 inches for the domestic and 2.5 inches for the wild stock. The domestic increased more in weight. After being in a pond for nearly 4 months, the domestic stock had acquired little wariness.
Wessel et al. 2006	Chinook salmon	The results suggest that the differences observed between lines are largely genetic in origin and may be a result of the divergence of the hatchery stock from the founding wild stock. Family of origin had a significant effect on body morphology. Body morphology differed significantly between juvenile hatchery Chinook salmon Oncorhynchus tshawytscha that have experienced five generations of hatchery culture and juveniles derived from the wild founding stock and cultured in the same environment. All lines tested were raised in a similar hatchery environment. Thin-plate spline analysis was used to characterize the morphometric variation among these lines of fish. Hatchery fish had a more compressed body, a narrower head, shorter maxillae, and a longer and narrower caudal peduncle than wild fish. Canonical discriminant analysis was able to correctly classify 88% of hatchery fish and 90% of wild fish. Second-generation hybrids of the two lines were morphologically intermediate to but significantly different from both the hatchery and wild lines, and they appeared to be more similar to the wild line.
Yokota et al. 2003	Salmonids (not specified)	Loss of within-population genetic diversity by genetic drift is related to stocking. In order to reduce it, selective use of wild-born individuals for hatchery broodstock is proposed by the authors. The authors used numerical simulations to analyze how five different broodstock collection strategies would result in genetic drift under different proportions of hatchery fish spawning in the wild. Results indicated that using only wild fish is effective in slowing the process of genetic simplification by drift when the relative hatchery contribution, r, is large [when there are a lot of hatchery fish spawning in the wild]. Results from the analysis were less sensitive to an incresing of the proportion of hatchery fish in the broodstock as the effective population size in the hatchery increased.

Zaporozhets and Zaporozhets 2004	Salmonids (not specified)	In the Paratunka River, east Kamchatka, up to 20 million juveniles have been released from Paratunsky Hatchery annually since 1993. Not only have consequent ‘‘replacement’’ of wild chum salmon stock with hatchery chum been shown, but mass straying of hatchery chum salmon to natural spawning grounds as well. The dominance of hatchery chum salmon in the middle and lower reaches of the river has been observed almost every year. Moreover, according to the authors' data, there is a valid negative correlation between the volume of juvenile release from Paratunsky Hatchery and adult returns. Studies of interactions among salmon of different origins have indicated that natural populations have been replaced in particular rivers by hatchery reared fish, due to the practice of abundant juvenile hatchery releases and extensive poaching in spawning grounds. A negative aspect of interactions between hatchery and wild fish is the spread of infections and the reduction of biological variations [genetic and phenotypic variation] in mixed [hatchery and wild] populations. Regular releases of chum salmon reared in Japanese hatcheries to overfill the North Pacific have been confirmed in the course of complex studies. As a result, the Japanese hatchery chum salmon, a principal consumer of forage resource, has not only been excluding the stocks of other origin, but gets sacrificed itself under the pressures of high competition density.

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