Northwest Power and Conservation Council

October 28, 2010

MEMORANDUM

TO: Council Members

FROM: Tony Grover

SUBJECT: **Columbia River Intertribal Fish Commission Presentation on Hatchery Science and Policy Developments**

Bill Bosch, Yakama Indian Nation, representing the Columbia River Inter-Tribal Fish Commission, will present empirical data in support of supplementation science. Paul Lumley, Executive Director, CRITFC, will discuss policy issues related to salmon and steelhead hatcheries. Both will share perspectives on current hatchery review processes now underway.

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Empirical Data in Support of Supplementation Science

Yakama Nation Fisheries
Columbia River Inter-Tribal Fish Commission

Bill Bosch – YN/YKFP

Regional Assessment of Supplementation Project (1992)

“Supplementation is the use of artificial propagation in an attempt to maintain or increase natural production while maintaining the long term fitness of the target population, and keeping the ecological and genetic impacts on nontarget populations within specified limits”.

Purpose: Present Information Relevant to Three Questions

1. Can supplementation maintain or increase natural production?

2. Can supplementation hatcheries be managed to maintain the long-term fitness of wild/natural populations?

3. If there are negative hatchery effects, are they reversible?

Hatchery Programs are needed because:

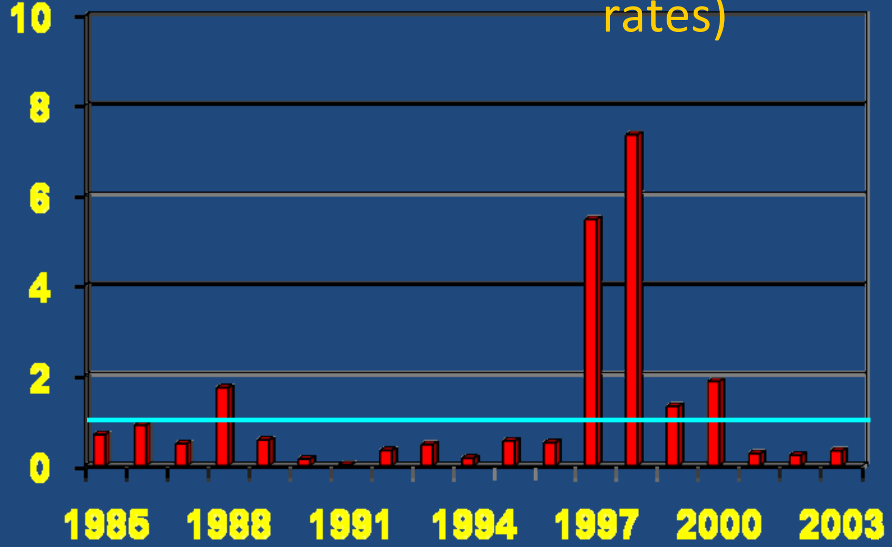
- 8 or more dams continue to diminish survival and limit passage to and from "usual and accustomed" fishing areas, and

- Population growth and incumbent development needs continue to put pressure on shared habitat and water resources

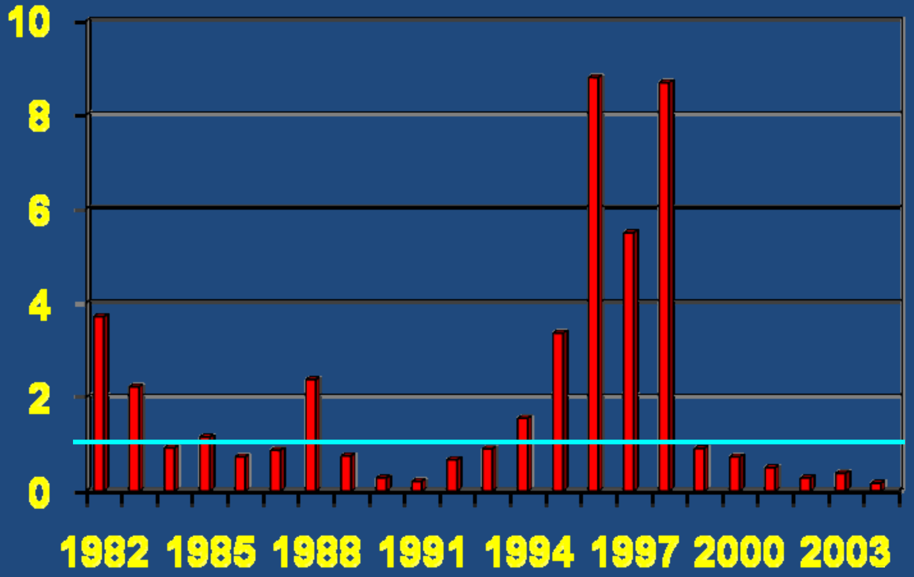
Meaning that …

Natural-Origin Stocks are not Replacing Themselves

(Adult-to-Adult return rates)



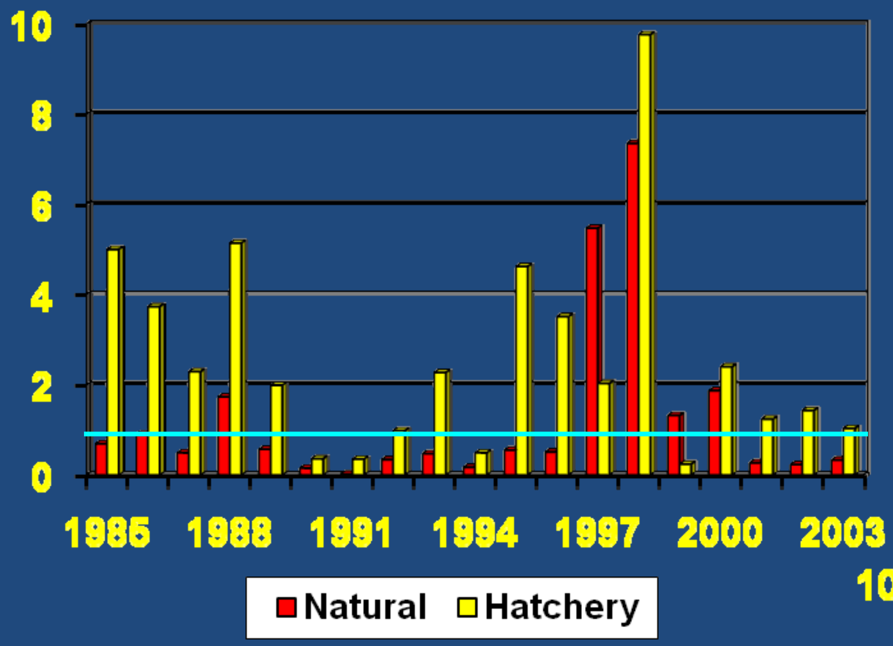
Tucannon River Sp. Chin.: 14 of 19 years at or below replacement



Yakima River Sp. Chin.: 15 of 23 years at or below replacement

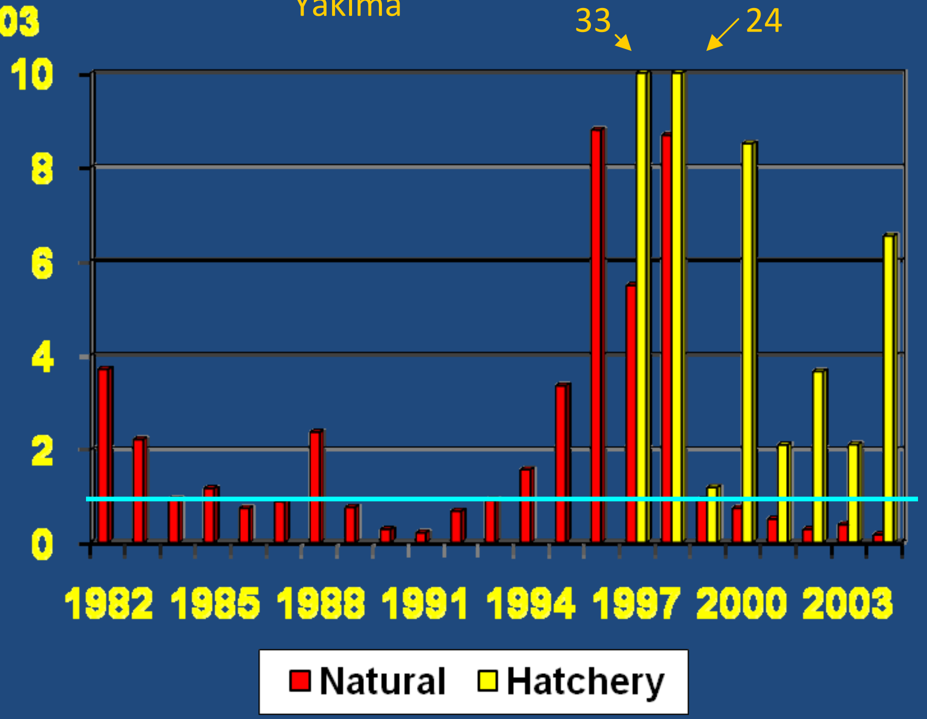
How do Hatchery Programs help?

Spring Chinook Return-per-Spawner Rates



Tucannon

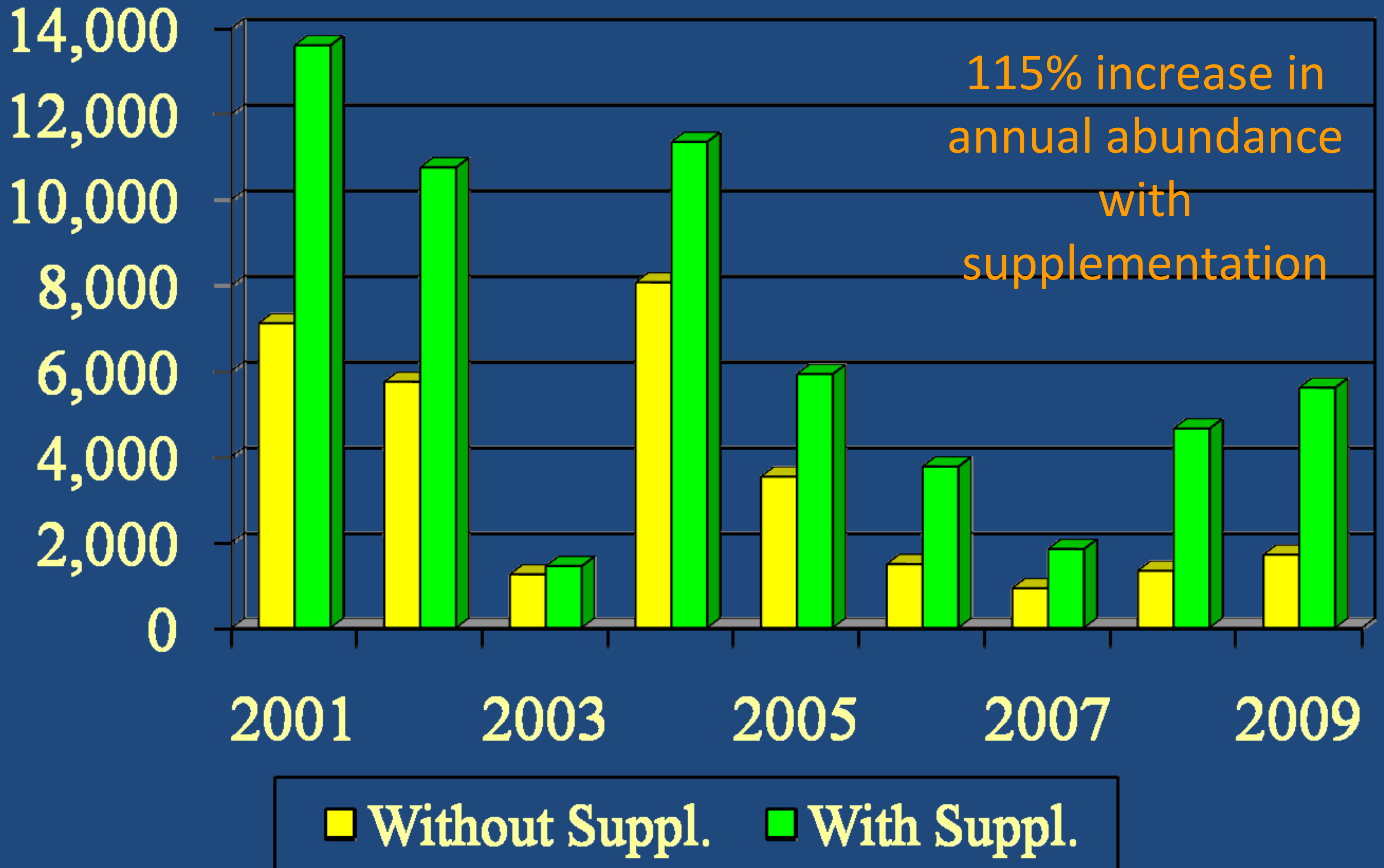
Yakima



"In many ways the hatchery program has helped conserve the natural population by returning adults to spawn in the river"

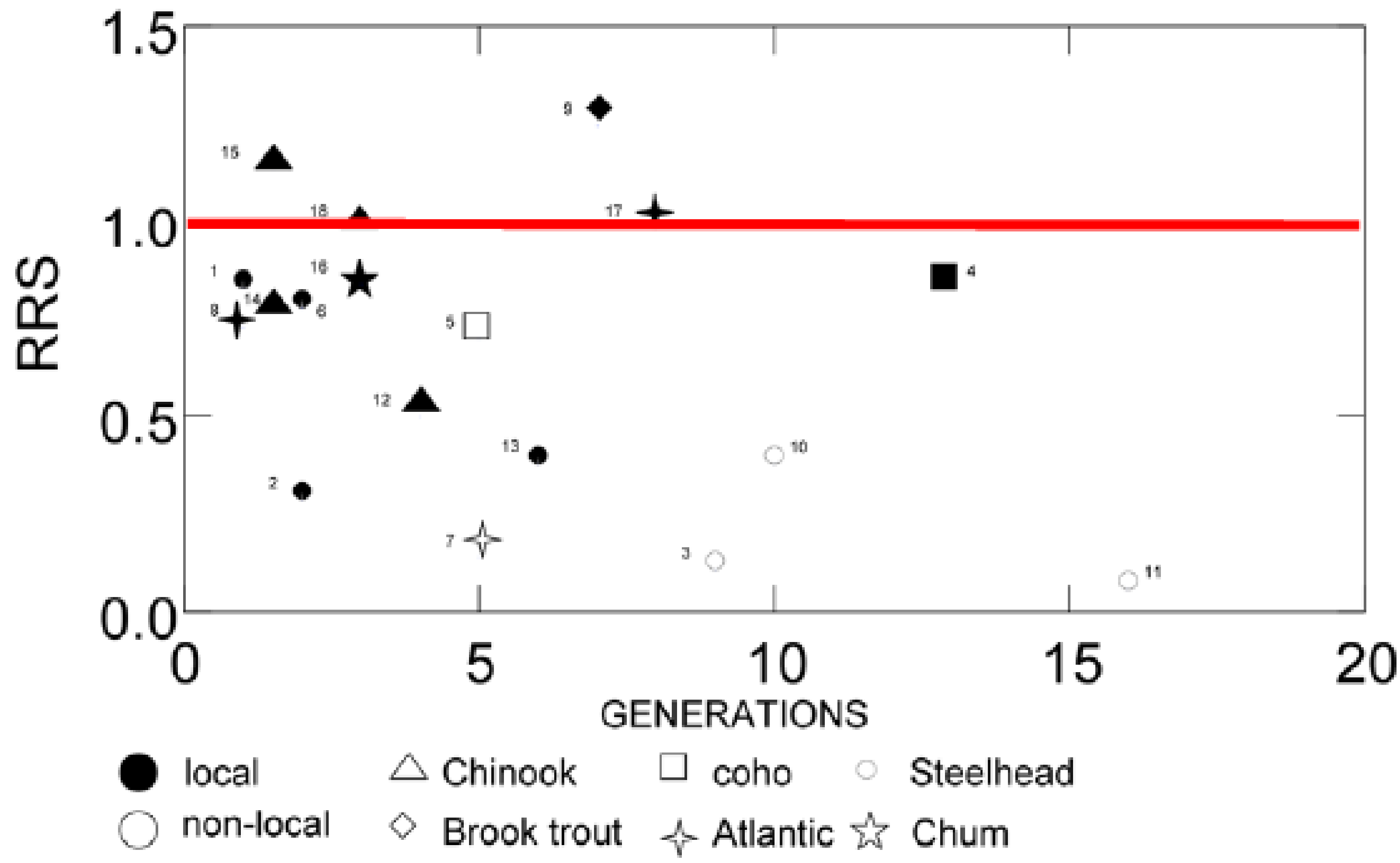
Gallinat and Ross, WDFW,
2007 Annual Report

Upper Yakima Spring Chinook
Age 4 Returns with and without Supplementation

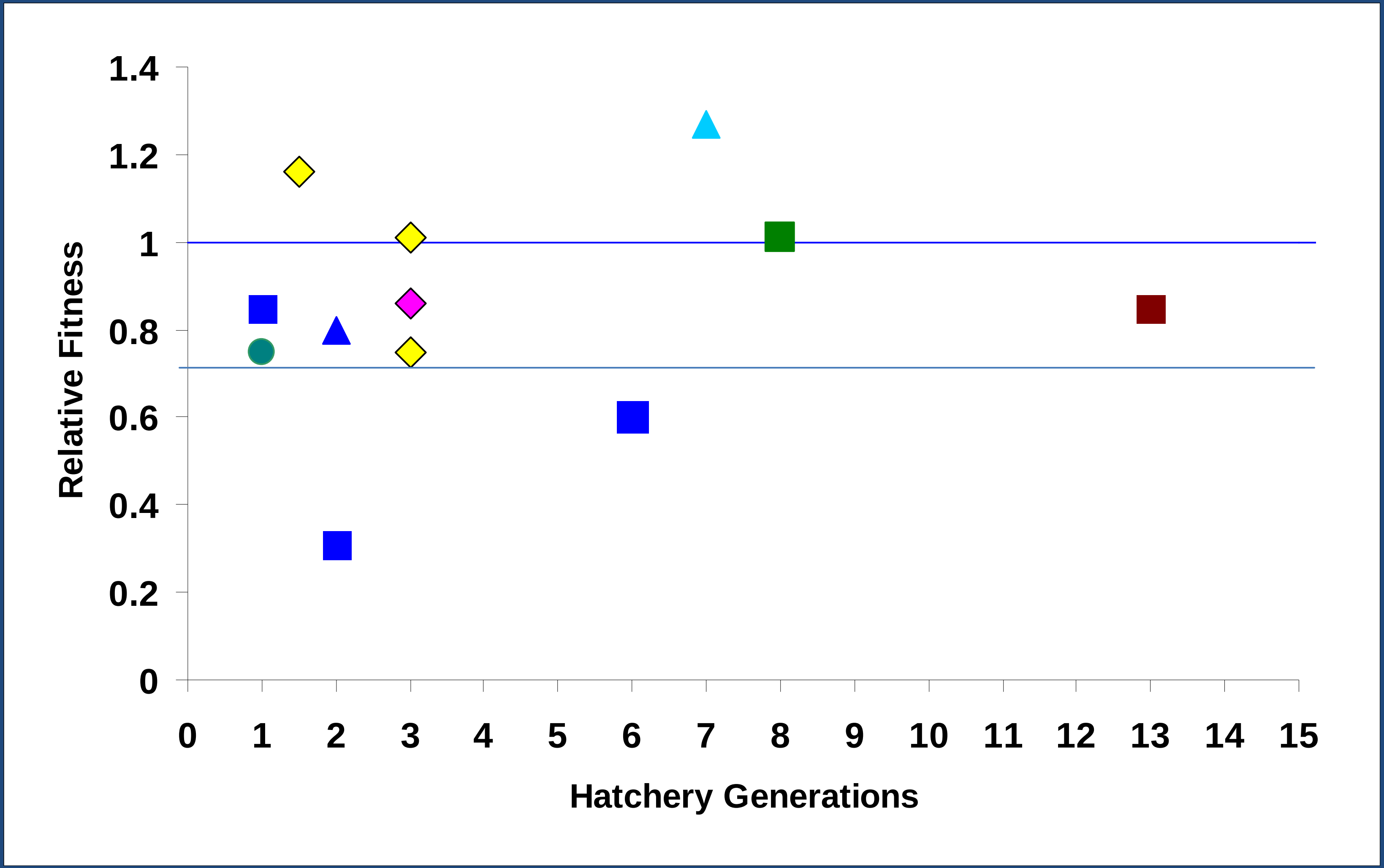


Emerging Trends in Hatchery-Origin Reproductive Success

How general is low hatchery fitness?



Evidence of Hatchery-Origin Reproductive Success: RRS Studies using locally derived brood sources



Colors and shapes denote different species and life stages

Competing Hypotheses: Ford et al. 2006

Smolt production 1940-1955: ~28,000

↓

Smolt production 2002-2003: ~15,000-19,000

Hatchery effects

OR

Habitat effects?

Steelhead Study Issues: Mackey et al. 2001

"In Washington State, the approach to management of wild and hatchery steelhead trout *Oncorhynchus mykiss* has been to separate the timing of return and spawning by the two groups through selective breeding for early timing in hatchery fish."

Other Steelhead Study Issues

- wild/natural fish migrate to sea after 1 to 3 years in freshwater

- nearly all steelhead hatcheries operate to produce age-1 smolts

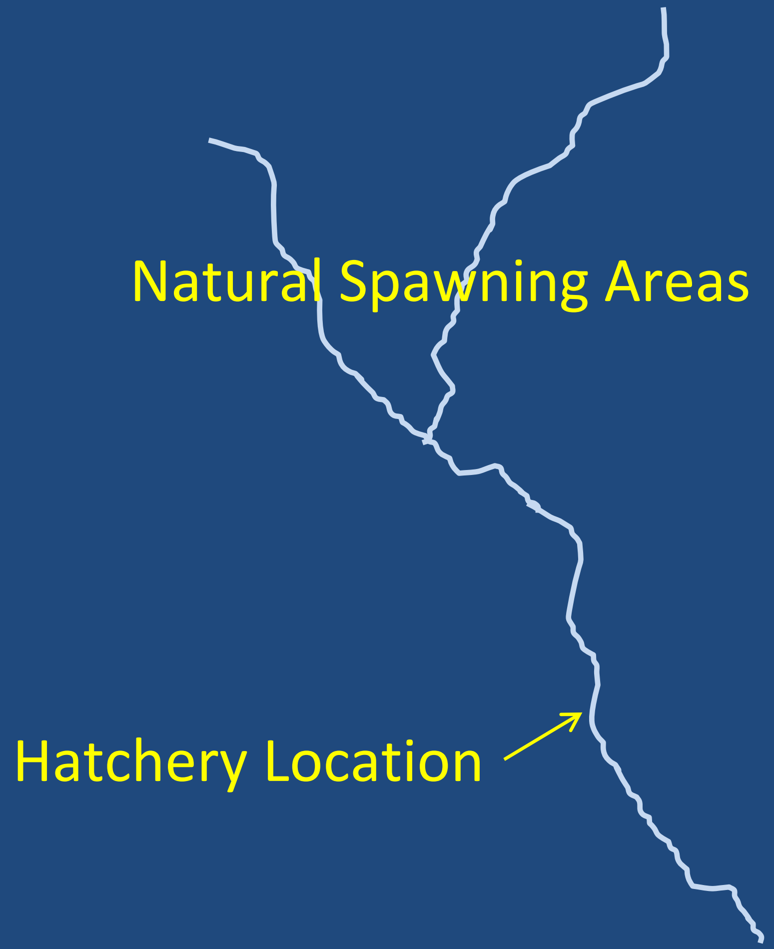
- unique winter and summer populations

- inadvertent hatchery hybrids?

Other Study Issues

- rearing and release locations

- density dependence



Tribal Management Practices aka Hatchery Reform / Best Management Practices

- random, representative broodstock selection
- local broodstock
- use natural broodstock if possible
- factorial mating to maintain diversity
- low rearing densities
- underwater feeders and cover to encourage natural behavior
- intensive disease monitoring
- acclimation sites in natural spawning areas
- state-of-the-art marking strategies for M&E
- test different rearing/release strategies to increase survival

Behavior and Breeding Success of Wild and First-Generation Hatchery Male Spring Chinook Salmon Spawning in an Artificial Stream

S.L. Schroder, C.M. Knudsen, T.N. Pearsons, T.W. Kassler, S.F. Young, E.P. Beall and D.E. Fast

Transactions of the American Fisheries Society, 139:989-1003

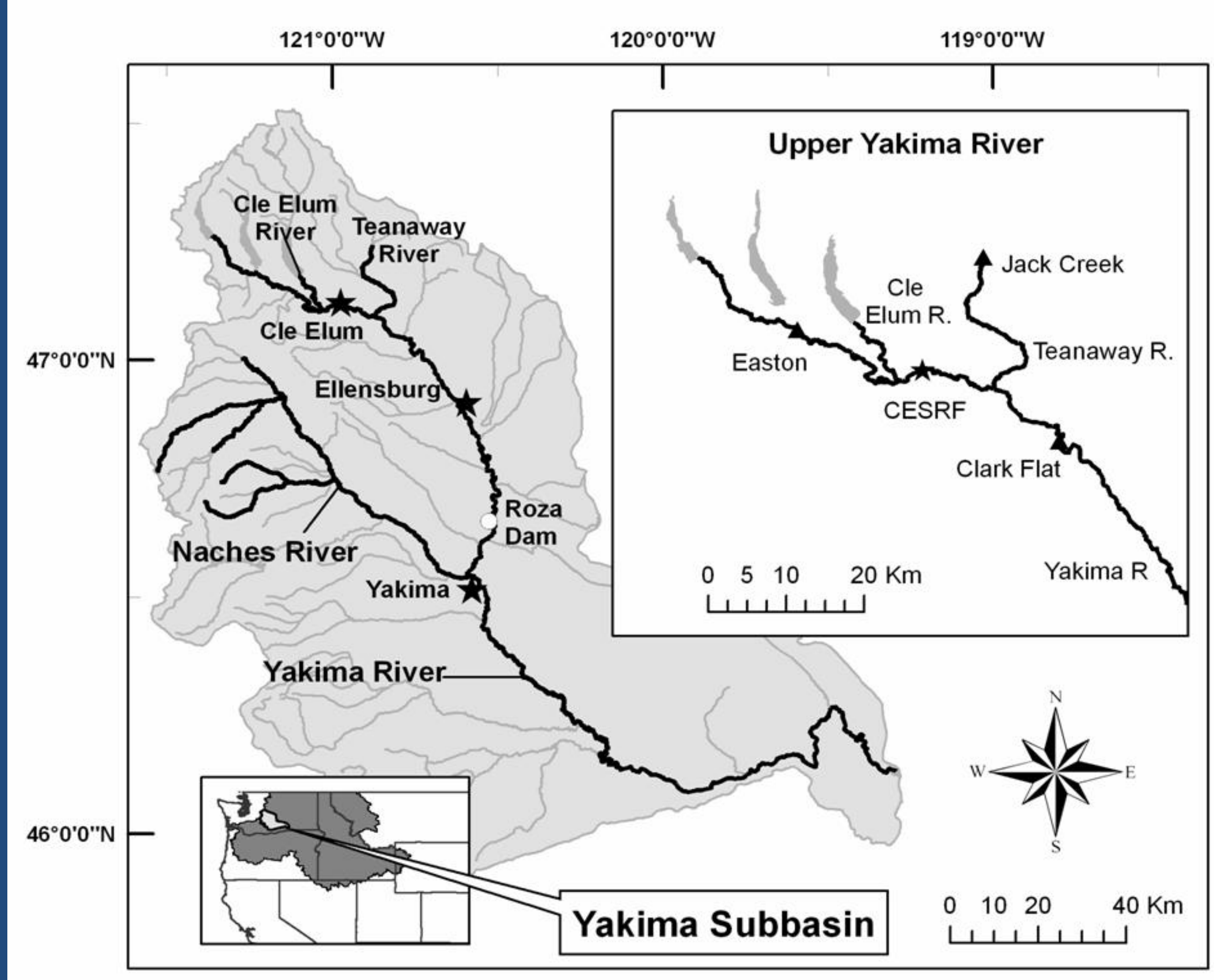
"Pedigree analyses based on DNA showed that hatchery and wild males had comparable breeding success values."

Breeding Success of Wild and First-Generation Hatchery Female Spring Chinook Salmon Spawning in an Artificial Stream

S.L. Schroder, C.M. Knudsen, T.N. Pearsons, T.W. Kassler, S.F. Young, C.A. Busack, and D.E. Fast

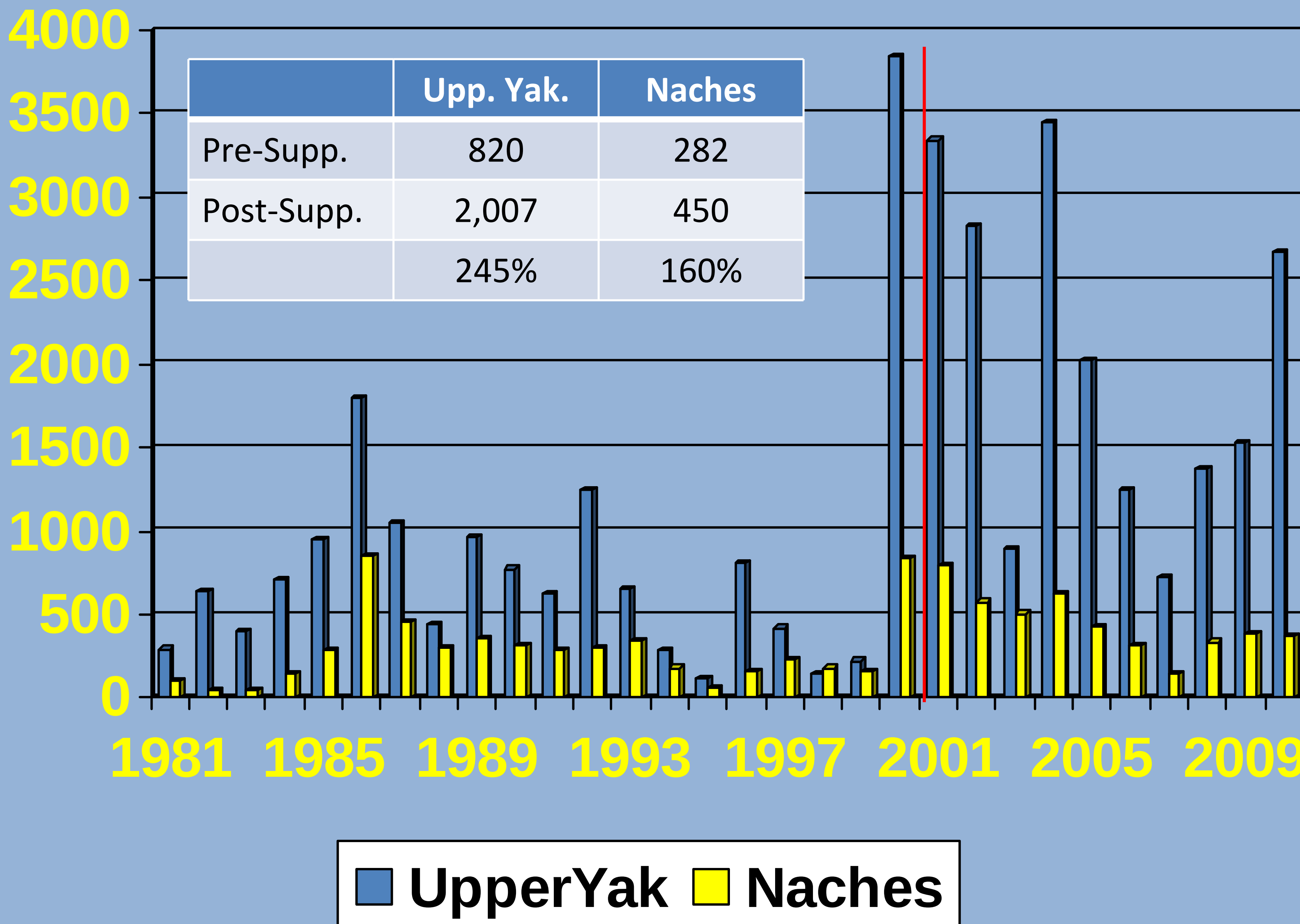
Transactions of the American Fisheries Society, 137:1475-1489

"No differences were detected in the egg deposition rates of wild and hatchery females. 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."



1997	2001	2005	2009	2013
1st Brood	Integrated HxW spawning in the wild	Integrated F1 progeny return	Integrated F2 progeny return	

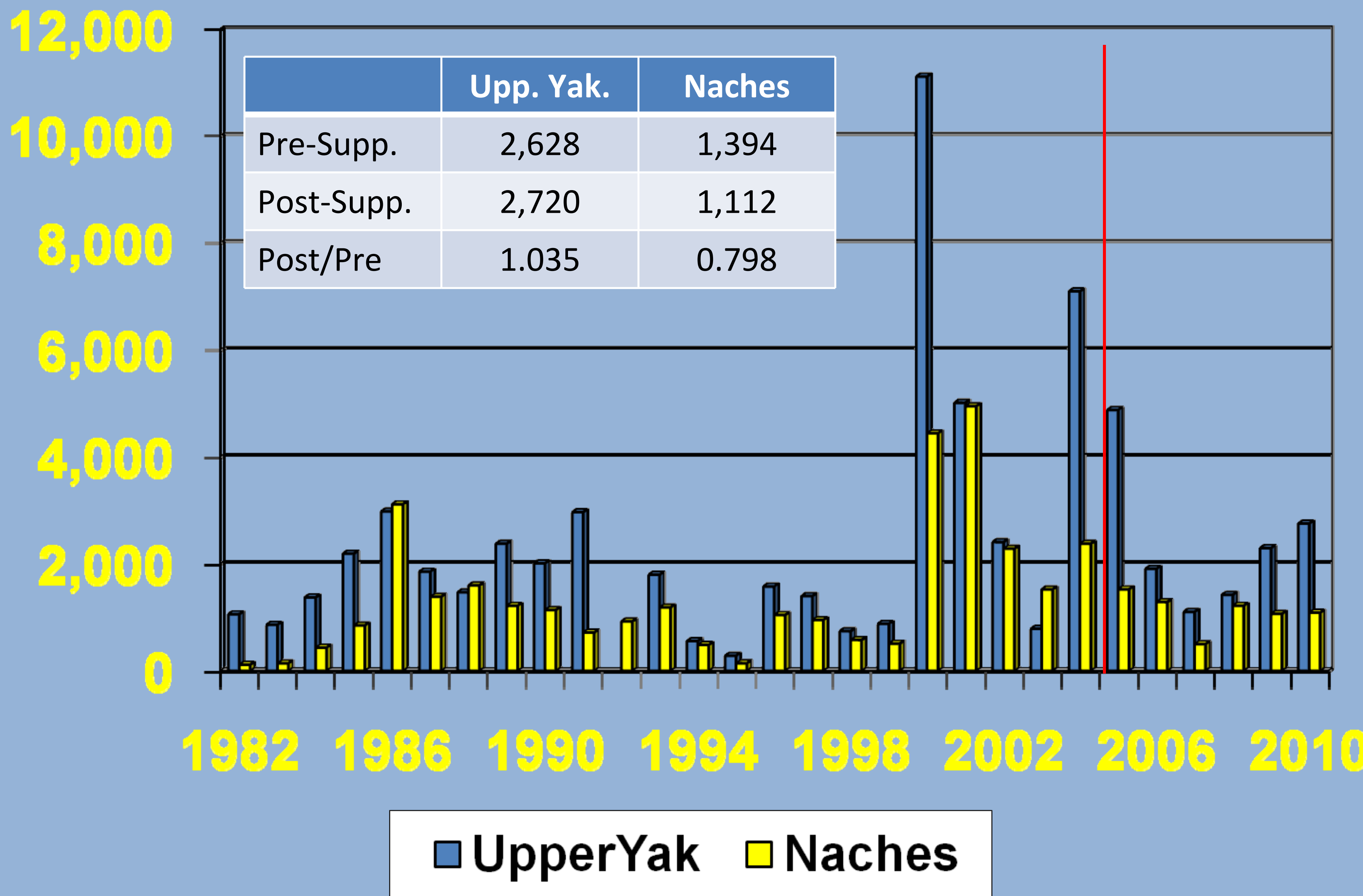
Upper Yakima vs Naches Redds, 1981-2010



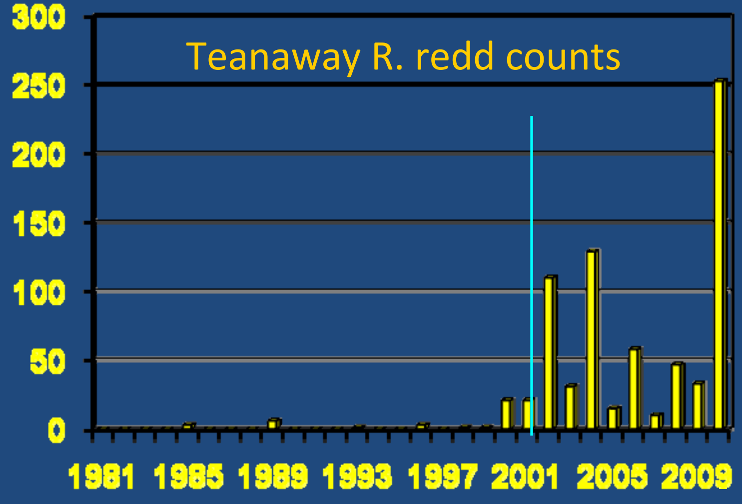
	Upp. Yak.	Naches
Pre-Supp.	820	282
Post-Supp.	2,007	450
	245%	160%

Upper Yakima vs Naches Natural-Origin Returns, 1982-2010

	Upp. Yak.	Naches
Pre-Supp.	2,628	1,394
Post-Supp.	2,720	1,112
Post/Pre	1.035	0.798

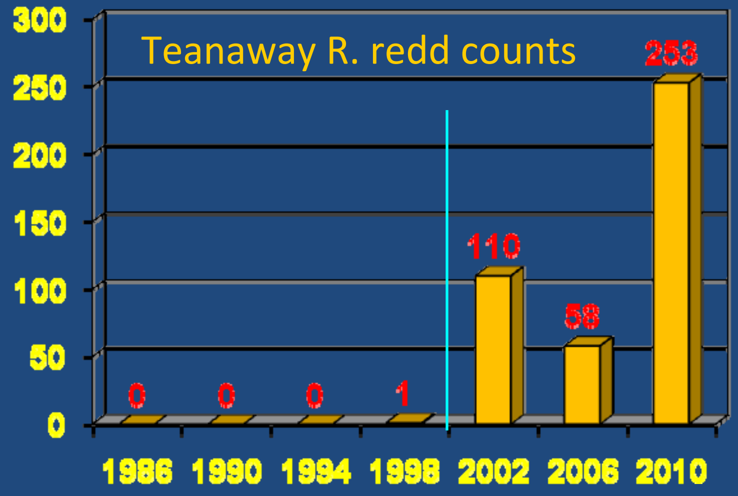


Evidence of Hatchery-Origin Reproductive Success: Teanaway R. Spring Chinook



- pre-supplementation average: 3
- post-supplementation average: 76

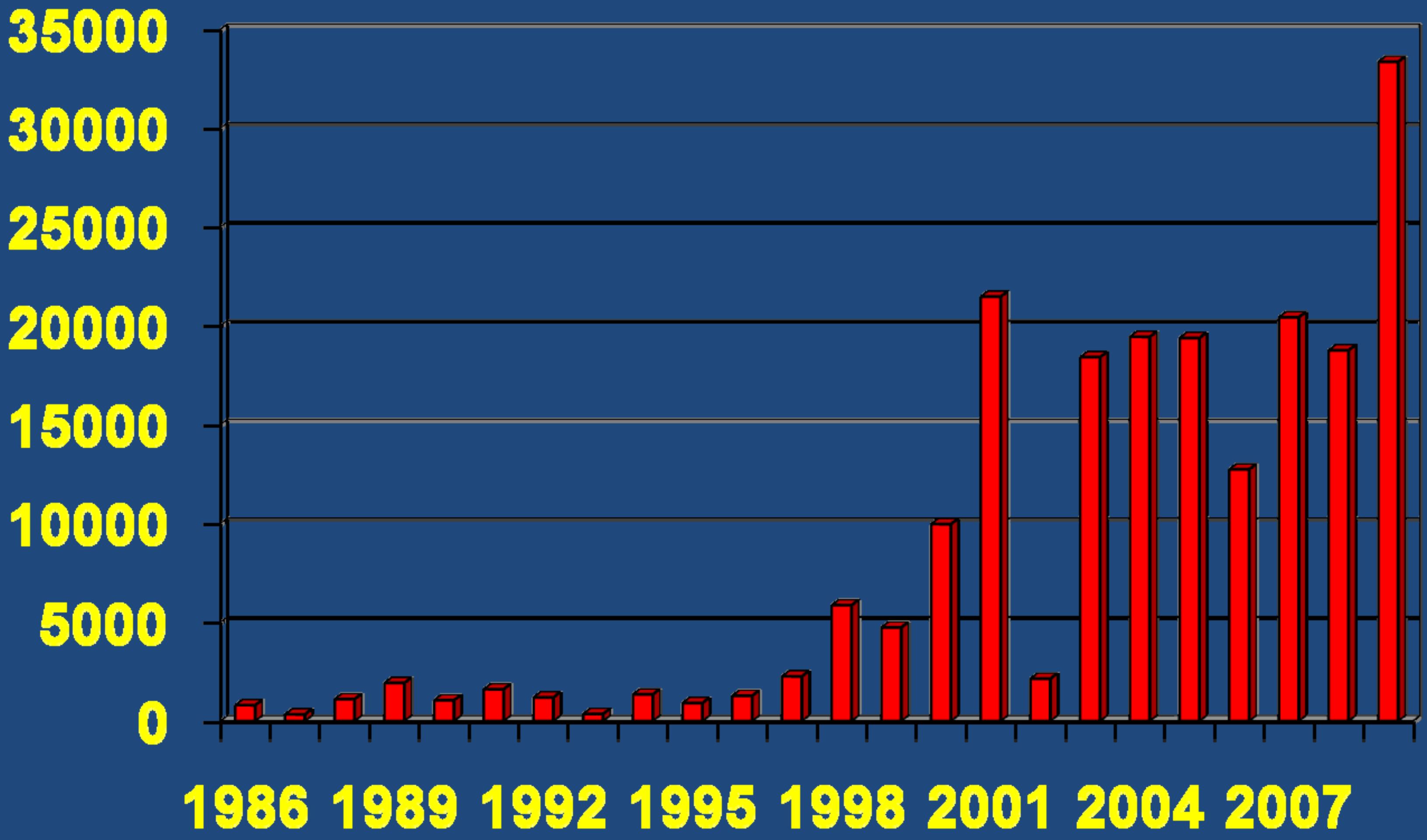
Let's look at one 4-year brood cycle:



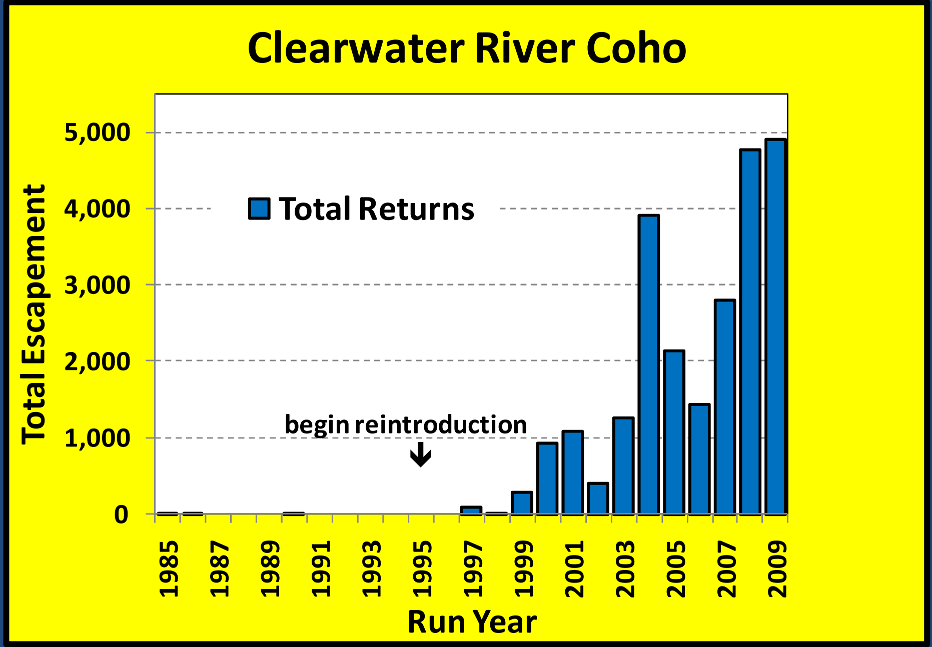
- 1st HO returns in 2002
- 17-fold increase in % of NO carcasses from 2002 to 2006
- Parents were NO, progeny are NO

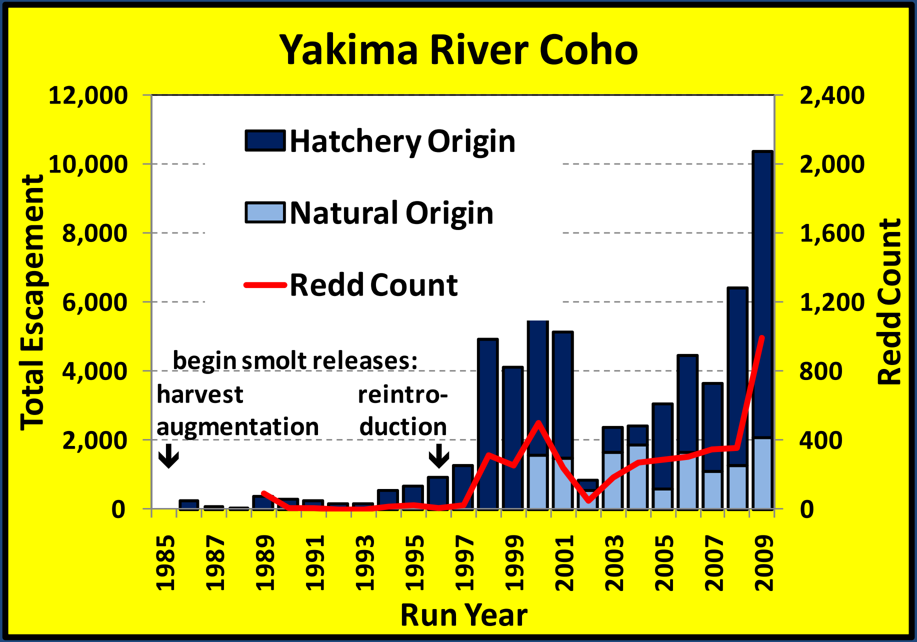
McNary Dam Adult Coho Counts, 1986-2009

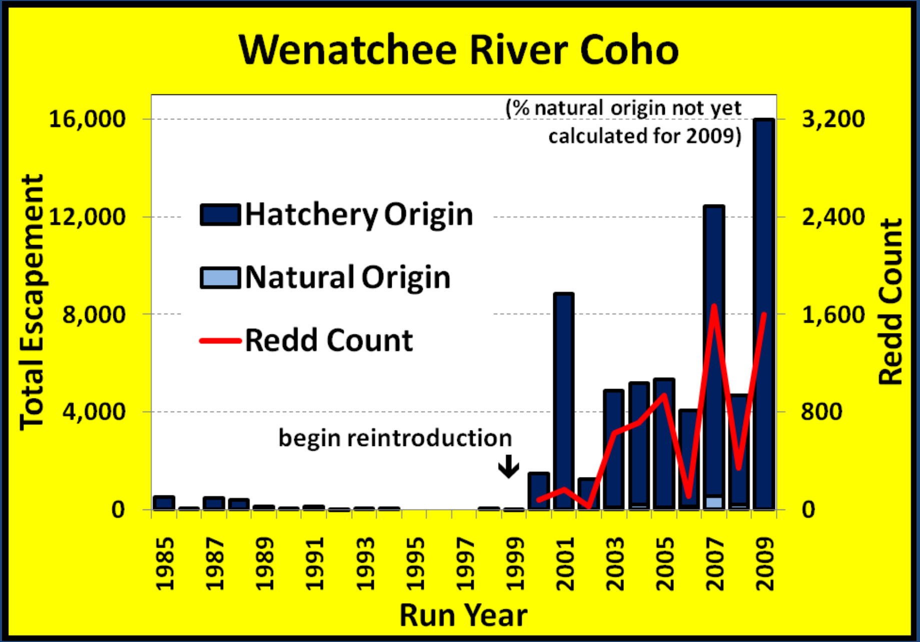
Includes fish destined to Yakima, Snake, and Upper Columbia



Tribal Coho Reintroduction







Evaluating the Feasibility of Reestablishing a Coho Salmon Population in the Yakima River, Washington

W.J. Bosch, T.H. Newsome, J.L. Dunnigan,
J.D. Hubble, D. Neeley, D.T. Lind, D.E. Fast, L.L. Lamebull, and J.W. Blodgett

North American Journal of Fisheries Management 27:198-214

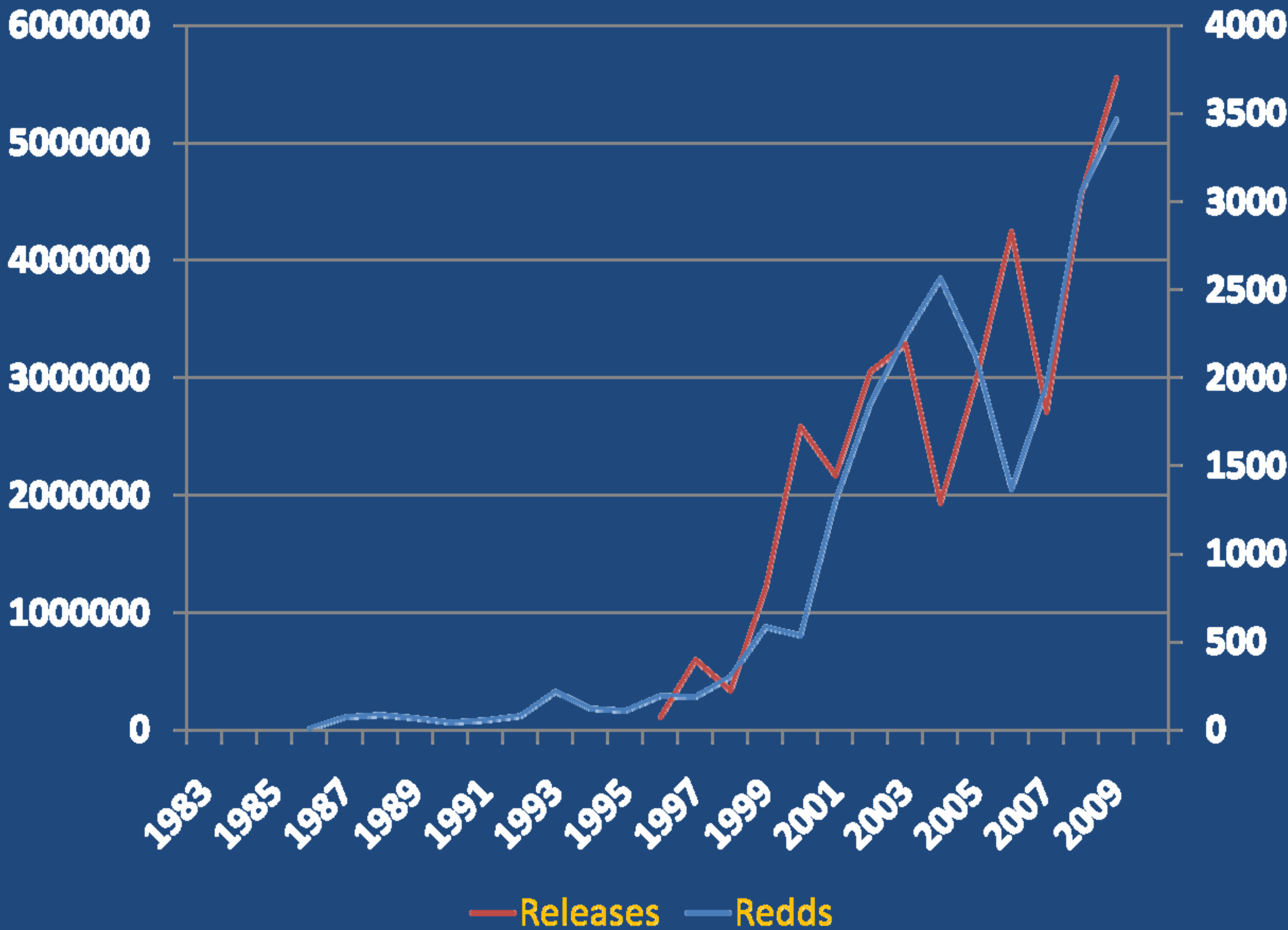
"We conclude that hatchery-origin coho, with a legacy of as many as 10 to 30 generations of hatchery influence, demonstrated their ability to reestablish a naturalized population after as few as 3 to 5 generations of outplanting in the wild."

Evidence of Hatchery-Origin Reproductive Success: Willamette Falls Coho

- not native
- first hatchery-origin releases in 1952
- intensive stocking program from 1964-1974
- Thirteen different hatcheries and variety of stocks used for program

- **hatchery-origin releases stopped in 1998**
- **2009 adult count : 25,300**
- **Projected 2010 adult count : > 30,000**
- **30,000 NO spawners in just 4 generations!!**

Snake River Fall Chinook – Correlation of Supplementation Releases with Redds in recent years.



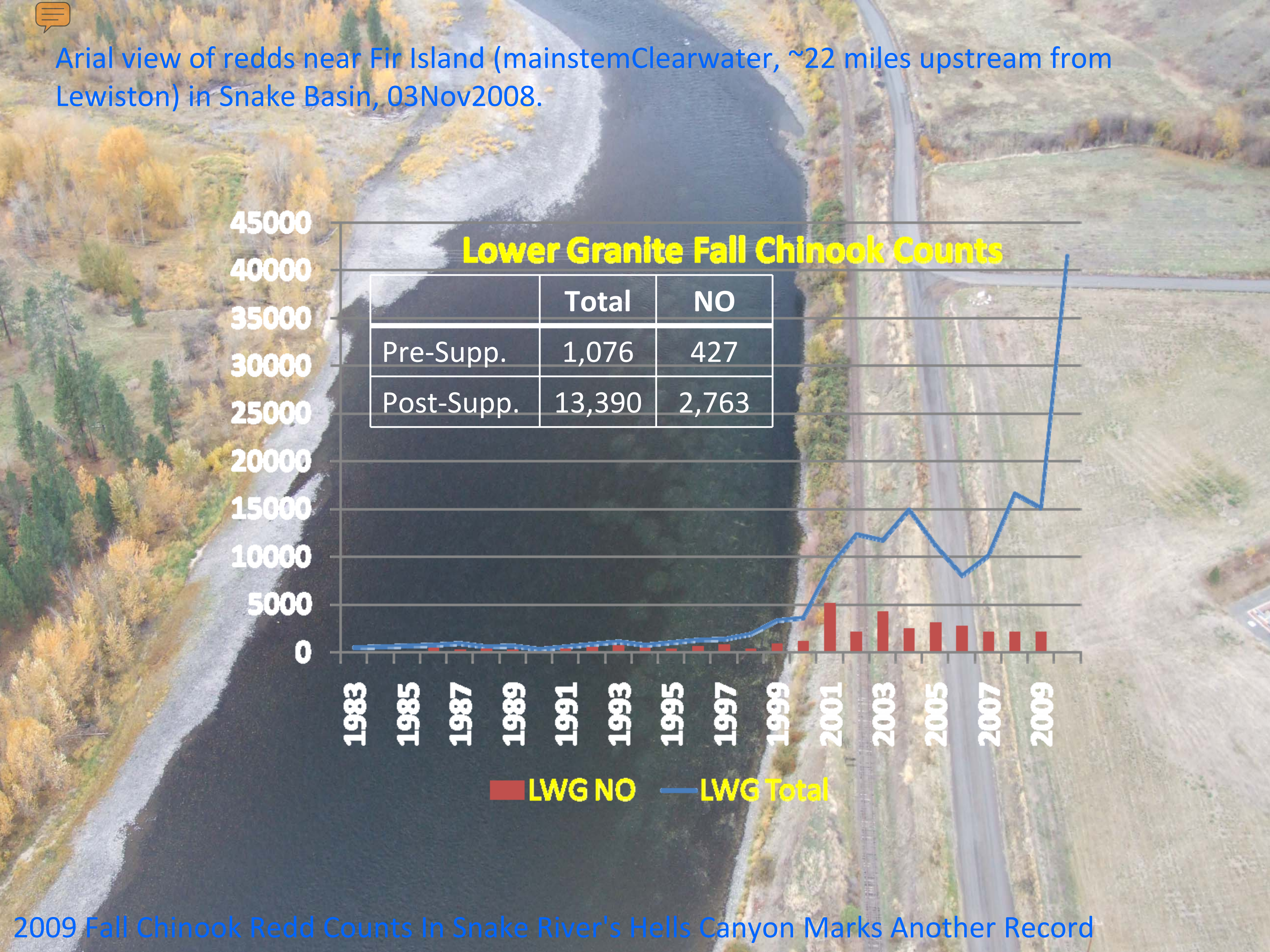
Hatchery Supplementation Success and the Juvenile Life-History of Wild-Reared Fall Chinook Salmon in the Lower Snake River, Idaho.

J.M. Plumb, C.M. Moffitt, and W.P. Connor.

AFS poster presentation, national meeting, Nashville, TN, Sept. 2009.

"The increased release of hatchery juveniles into the river was strongly ($P<0.0001$) related to the increase in redds. This increase in redds was, in turn, strongly related ($P<0.0001$) to an increase in CPUE of wild juveniles in the rearing areas. This study documents the success of hatchery supplementation with a known-origin stock to restore a wild population."

Arial view of redds near Fir Island (mainstemClearwater, ~22 miles upstream from Lewiston) in Snake Basin, 03Nov2008.



	Total	NO
Pre-Supp.	1,076	427
Post-Supp.	13,390	2,763

2009 Fall Chinook Redd Counts In Snake River's Hells Canyon Marks Another Record

Answers to Three Questions

1. Can supplementation maintain or increase natural production?

Yes – At least 11 recent studies support this

2. Can supplementation hatcheries be managed to maintain the long-term fitness of wild/natural populations?

Yes – At least 25 publications or studies support this

3. If there are negative hatchery effects, are they reversible?

Yes – At least 5 publications or studies support this

For more Information:

Bibliography in Support of Supplementation Science

www.ykfp.org

www.critfc.org

Bibliography in Support of Supplementation Science

Compiled by:
Yakama Nation Fisheries – Yakima Klickitat Fisheries Project
Columbia River Inter-Tribal Fish Commission

Draft, November 3, 2010

Purpose: The primary purpose of this bibliography is to present publications or studies that support the theory that supplementation (as defined by RASP 1992) techniques can be used to maintain or increase natural production, while maintaining the long-term fitness of the wild and native salmonid populations and keeping adverse genetic and ecological impacts within acceptable limits.

Note: The term "abstract" is used here to denote an abstract as published by the authors. The term "synopsis" is used when compilers of this bibliography summarized publications, often using sentences taken directly from the publications.

1) Can supplementation maintain or increase natural production?

Araki, H., W. R. Ardren, E. Olsen, B. Cooper, and M. S. Blouin. 2007. Reproductive success of captive-bred steelhead trout in the wild: evaluation of three hatchery programs in the Hood River. Conservation Biology 21 (1), 181-190.

Abstract: Population supplementation programs that release captive-bred offspring into the wild to boost the size of endangered populations are now in place for many species. The use of hatcheries for supplementing salmonid populations has become particularly popular. Nevertheless, whether such programs actually increase the size of wild populations remains unclear, and predictions that supplementation fish drag down the fitness of wild fish remain untested. To address these issues, we performed DNA-based parentage analyses on almost complete samples of anadromous steelhead (*Oncorhynchus mykiss*) in the Hood River in Oregon (U.S.A.). Steelhead from a supplementation hatchery (reared in a supplementation hatchery and then allowed to spawn naturally in the wild) had reproductive success indistinguishable from that of wild fish. In contrast, fish from a traditional hatchery (nonlocal origin, multiple generations in hatcheries) breeding in the same river showed significantly lower fitness than wild fish. In addition, crosses between wild fish and supplementation fish were as reproductively successful as those between wild parents. Thus, there was no sign that supplementation fish drag down the fitness of wild fish by breeding with them for a single generation. On the other hand, crosses between hatchery fish of either type (traditional or supplementation) were less fit than expected, suggesting a possible interaction effect. These are the first data to show that a supplementation program with native brood stock can provide a single-generation boost to the size of a natural steelhead population without obvious short-term fitness costs. The long-term effects of population supplementation remain untested.

Baumsteiger, J., D. M. Hand, D. E. Olson, R. Spateholts, G. FitzGerald, and W. R. Ardren. 2008. Use of Parentage analysis to Determine Reproductive Success of Hatchery-Origin Spring Chinook Salmon Outplanted into Shitike Creek, Oregon. North American Journal of Fisheries Management, 28:1472-1485.

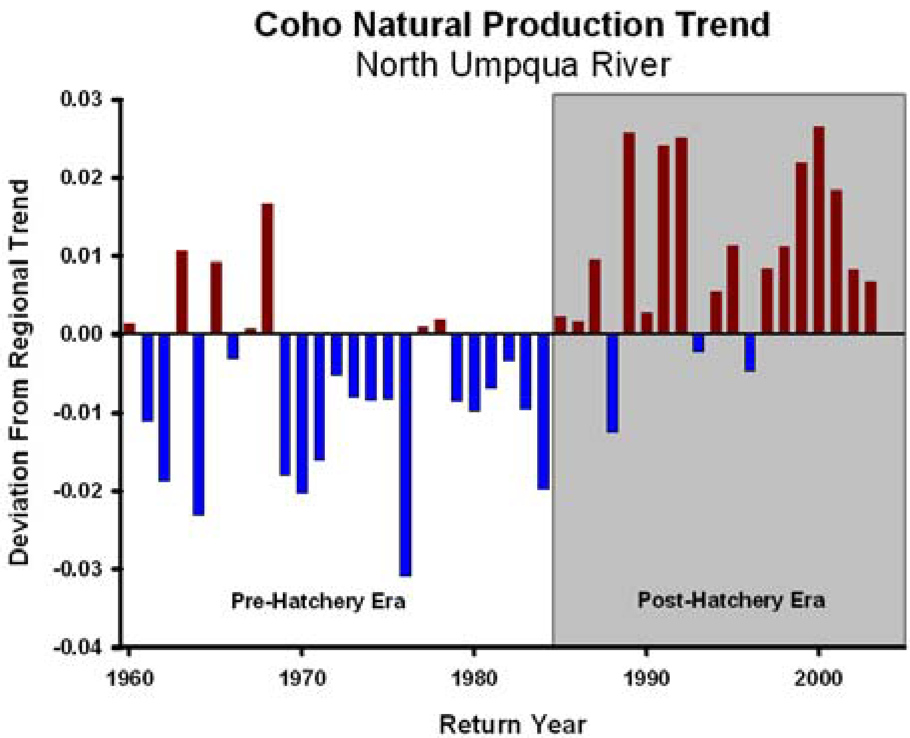
Abstract: Removal of fish passage barriers provides Pacific salmon *Oncorhynchus* spp. and steelhead *O. mykiss* the opportunity to recolonize previously accessible habitat, though the time scale of natural recolonization may not be sufficient for management or conservation goals. One strategy for accelerating recolonization is to outplant hatchery-origin adults into newly restored habitats. In this paper, we describe how genetic parentage analysis was used to determine the reproductive success of adult stream-type spring Chinook salmon *O. tshawytscha* taken from two localized hatchery stocks and outplanted into a stream. We defined reproductive success as the production of migratory juveniles. In 2002 and 2003, 83 and 265 adult hatchery salmon, respectively, were outplanted into Shitike Creek, Oregon, a tributary to the Deschutes River. Using 11 microsatellite markers, 799 and 827 migratory juveniles from the two brood years were genotyped and matched back to potential outplanted parents using genetic parentage analyses. Successful spawning of outplant–outplant, outplant–wild, and wild–wild fish occurred in Shitike Creek in both years. Adults outplanted in 2002 showed far fewer matches (18%) to sampled juveniles than those from 2003 (88%). Additionally, only 1% of juveniles had both parents identified as outplants in 2002, compared with almost 61% in 2003. Differences in the number of females outplanted each year appeared to account for the differential productivity. The number of offspring attributed to an individual outplant was variable, ranging from 1 to more than 10. Multiple outplant × outplant matings were identified for each sex as males mated with up to seven females and females mated with up to four males. This study shows that, under the right conditions, outplanted adult hatchery fish taken from localized hatchery stocks can contribute to the overall juvenile production in a natural stream.

Berejikian, B. A., T. Johnson, R.S. Endicott, and J. Lee-Waltermire. 2008. Increases in Steelhead Redd Abundance Resulting from Two Conservation Hatchery Strategies in the Hamma Hamma River, WA. Canadian Journal of Fisheries and Aquatic Sciences, 65:754-764.

Abstract: Conservation hatcheries for anadromous salmonids that aim to increase production and minimizing genetic, ecological, and demographic risks have not been experimentally tested for their ability to increase number of adults spawning in the natural environment. The conservation hatchery program for steelhead (i.e., sea-run rainbow trout, *Oncorhynchus mykiss*) evaluated in this study caused an increase in the number of redds in the supplemented Hamma Hamma River compared with the presupplementation period. Three control populations (nonsupplemented) either remained stable or declined over the same period. The increase in redds from hatchery-produced spawners did not reduce the redd production from natural-origin spawners. The strategy of rearing and releasing adult steelhead accounted for the greatest proportion of redd abundance increases. Environmentally induced differences in spawn timing between the adult release group and anadromous adults of hatchery and natural origin may explain why the adult release group and anadromous adults assortatively formed pairing combinations on the spawning grounds. Although captively reared adults produced the majority of redds in years they were released in substantial numbers, uncertainty regarding the relative reproductive success of this strategy suggests caution in recommending one strategy over the other. A demographic boost to the naturally spawning population was effected while managing to minimize negative ecological consequences.

Cramer, S. P., N. K. Ackerman, and J. B. Lando. 2005. Viability of Oregon Coastal Coho: Comments on Oregon's 2005 Assessment. Report to Oregon Forest Industries Council and Douglas County. S.P. Cramer & Associates, Inc. Gresham, OR.

Synopsis: Review of data set dating back to 1958. Hatchery fish were virtually non-existent in the North Umpqua for the first 24 years of data, 1958-1981, and composed an average 76% of natural spawners after 1982. The North Umpqua showed a highly significant increase in natural production after 1982. Since 1985, when substantial returns from naturally spawning hatchery coho began, the trend in natural production of coho from the North Umpqua consistently out-performed the regional trend in natural production (see figure). This difference clearly indicates that hatchery fish were successfully reproducing and having a detectable positive influence on natural production.

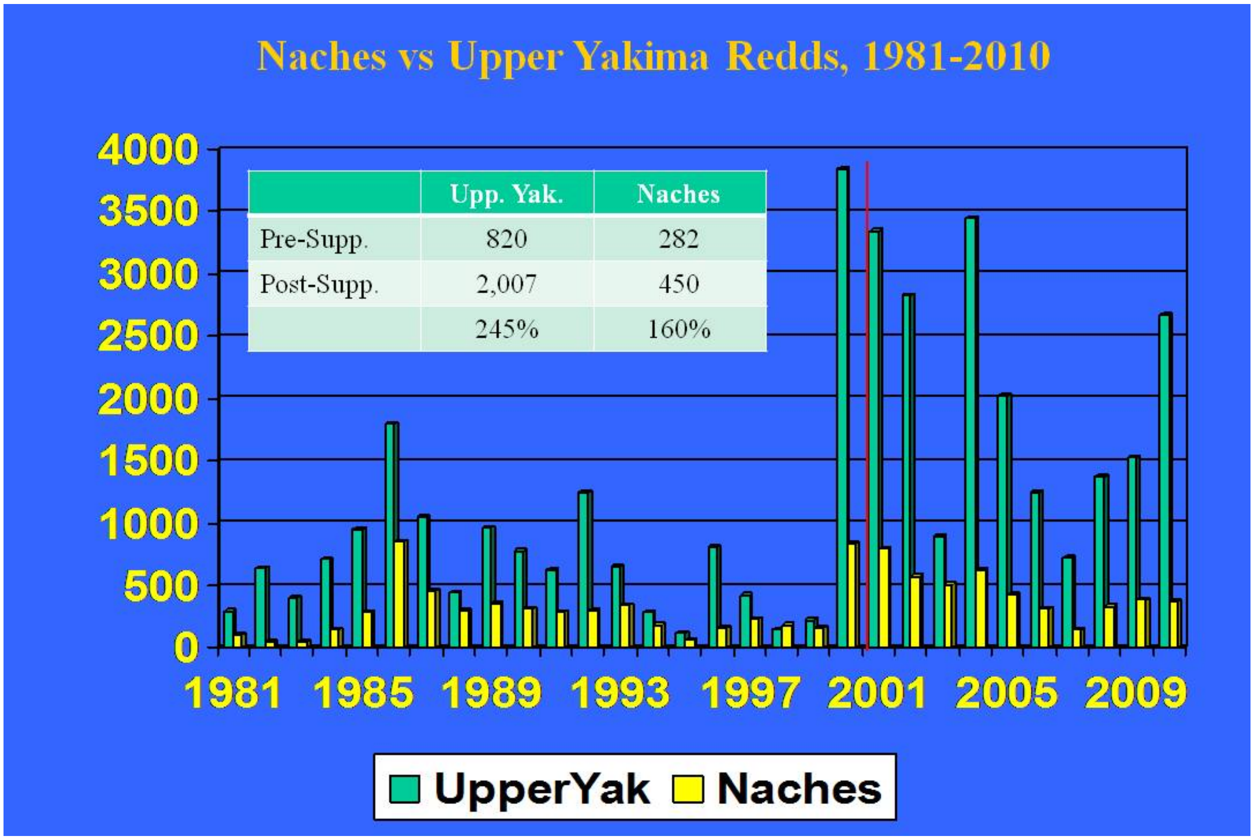


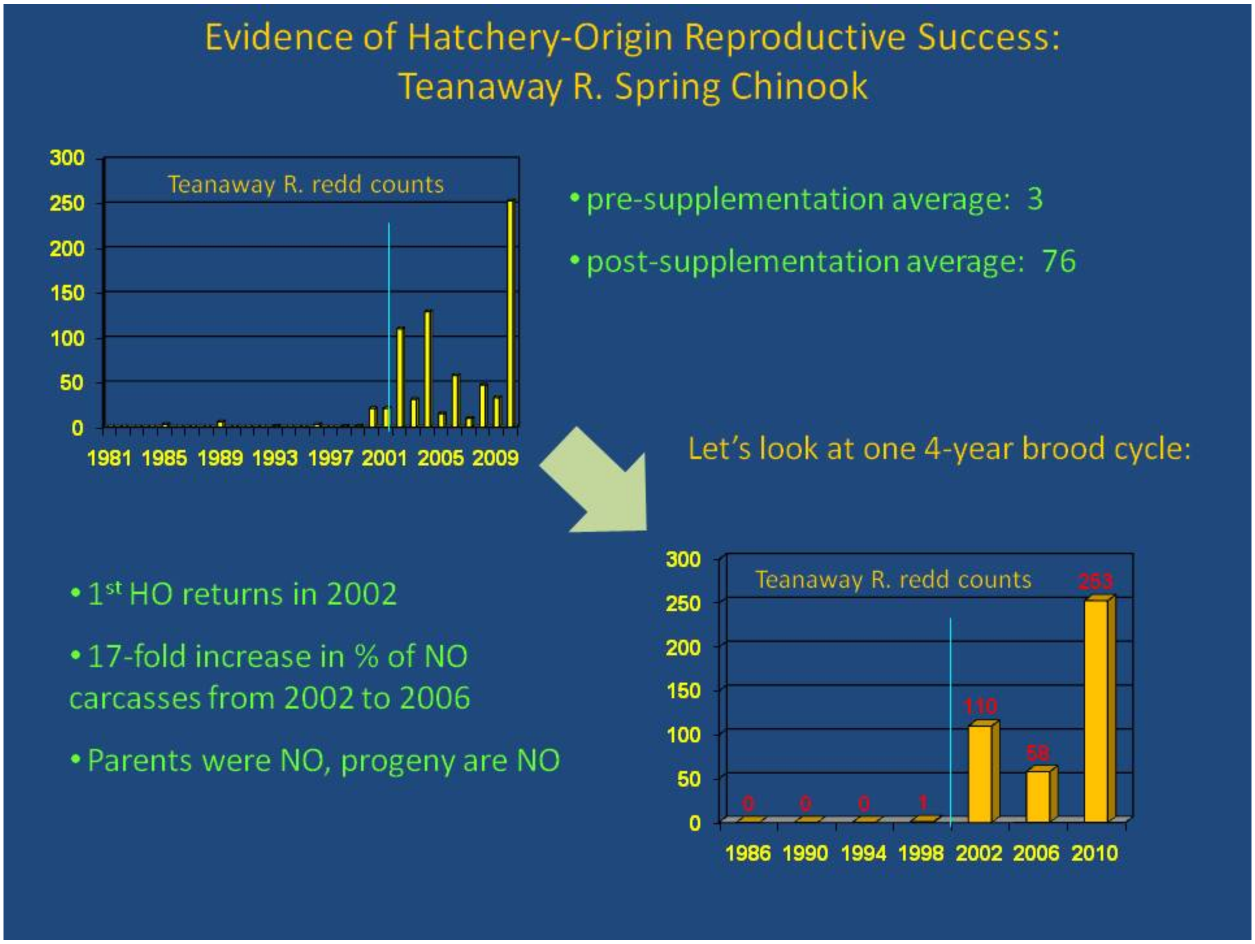
Kassler, T. W., D. K. Hawkins, and J. M. Tipping. 2008. Summer-Run Hatchery Steelhead Have Naturalized in the South Fork Skykomish River, Washington. Transactions of the American Fisheries Society 137:763-771.

Abstract: Evaluation of natural-origin, hatchery-origin, and unmarked steelhead *Oncorhynchus mykiss* from the Skykomish River drainage basin, Washington, was conducted to determine the source of unmarked steelhead that return to Sunset Falls (South Fork Skykomish River). One possible source is the large number of steelhead stocked into the Skykomish River basin from Reiter Ponds Hatchery; this hatchery stock was founded with fish from Skamania Hatchery in the Washougal River system, Washington. A microsatellite DNA analysis of 10 loci was used to evaluate unmarked samples in comparison with natural-origin samples from the North Fork Skykomish River and hatchery-origin samples from Reiter Ponds Hatchery. Results of the analyses provide evidence that the unmarked steelhead collected at Sunset Falls are more closely related to Reiter Ponds Hatchery fish than to natural-origin fish from the North Fork Skykomish River. There is evidence that unmarked steelhead at Sunset Falls are also mixing with natural-origin North Fork Skykomish River fish but to a lesser degree than with Reiter Ponds Hatchery fish. This study documents that Skamania Hatchery-origin steelhead have naturally produced offspring that are returning to spawn in a northern Puget Sound river basin.

May, D., D. Larsen, M. Moser, D. Fast, M. Johnston, and A. Dittman. 2007. Spatial patterns of Yakima River spring Chinook spawning before and after supplementation. AFS poster presentation, national meeting, San Francisco, CA, Sept. 2007.

Synopsis (updated by compilers to include data from 2007-2010): Redd survey totals for the upper Yakima R. and Naches R. (1981 to 2010) indicated that the number of spawners increased for both populations during the post-supplementation period (2001-2010) but the average number of redds increased 245% in the upper Yakima vs. 160% for the unsupplemented Naches River (see figure below). These results suggest that supplementation increased the number of spawners in the upper Yakima beyond the natural increases associated with improved ocean survival. The number of redds and natural origin spawners has increased in the targeted Teanaway River indicating this approach may be successful for reintroduction of salmonids into underutilized habitat (2nd figure below).





McLean, M.L., P.T. Lofy, and J.D.M. Schwartz. 2006. Successful natural production of hatchery spring chinook salmon: A lesson from Lookingglass Creek in Eastern Oregon. Oregon Chapter AFS Meeting Presentation, March 3, 2006.

Synopsis: Reintroduction of a non-endemic hatchery spring Chinook stock from Rapid River (RR) was evaluated and various survival parameters were compared with an endemic stock from Lookingglass Creek (LCE) and other naturally produced fish from the Grand Ronde River (GRR) or other Columbia Basin tributaries (CSR). "There was no significant difference in mean adults-per-redd among the RR, LCE, or CSR. There was no significant difference in mean juveniles-per-redd between RR, LCE, and GRR. Progeny-per-parent ratios for RR were not significantly different than those estimated for GRR."

Phillips, J.L., J. Ory and A. Talbot. 2000. Anadromous salmonid recovery in the Umatilla River Basin, Oregon: A case study. Journal of the American Water Resources Association, Vol. 36, no. 6, pp. 1287-1308. Dec 2000.

Synopsis: The mean adult-to-adult return rate of hatchery-reared steelhead exceeded replacement and that of the naturally-spawning population. Although the smolt-to-adult survival rates of hatchery-reared fish fluctuate, salmonid escapement has increased in recent years, permitting steelhead and spring chinook harvest. Enumeration of potential spawners and observed redds reveals an increase in natural production of all supplemented species.

Plumb, J.M., C.M. Moffitt, and W.P. Connor. 2009. Hatchery Supplementation Success and the Juvenile Life-History of Wild-Reared Fall Chinook Salmon in the Lower Snake River, Idaho. AFS poster presentation, national meeting, Nashville, TN, Sept. 2009.

Synopsis: Since 1998, a fall Chinook supplementation program has been conducted in the Snake River Basin with brood captured from fish passage facilities and Lyons Ferry State Fish Hatchery. In association with hatchery releases, abundance of the wild spawning population has increased substantially. The increased release of hatchery juveniles into the river was strongly ($P<0.0001$) related to the increase in redds 3 years later. This increase in redds was, in turn, strongly related ($P<0.0001$) to an increase in CPUE of wild juveniles in the rearing areas. This study documents the success of hatchery supplementation with a known-origin stock to restore a wild population.

Steffensen, K.D., L.A. Powell, and J.D. Koch. 2010. Assessment of Hatchery-Reared Pallid Sturgeon Survival in the Lower Missouri River. North American Journal of Fisheries Management 30:671-678.

Abstract: The population of pallid sturgeon *Scaphirhynchus albus* in the lower Missouri River between Gavins Point Dam (river kilometer [rkm] 1,305.2) and the confluence with the Mississippi River (rkm 0.0) remains imperiled, little to no natural recruitment occurring. Artificial propagation and subsequent population augmentation (i.e., stocking) may be the only viable option for maintaining pallid sturgeon populations in the lower Missouri River in the near term. Because relatively little is known about the ability of hatchery-reared pallid sturgeon to survive, the objective of this study was to quantify survival estimates for hatchery-reared pallid sturgeon stocked into the lower Missouri River. We used stock–recapture data collected from 1994 to 2008 to derive survival estimates based on the Cormack–Jolly–Seber model within program MARK. Since 1994, a total of 78,244 hatchery-reared pallid sturgeon have been released and 1% of these have been recaptured. Recapture numbers by size at stocking were as follows: 48 age 0, 730 age 1, and 38 older than age 1. Stocked age-0 hatchery-reared pallid sturgeon had an estimated apparent survival rate of 0.051 (SE = 0.008), compared with 0.686 (SE = 0.117) for age-1 fish and 0.922 (SE = 0.015) for fish older than age 1. Our analysis confirms that hatchery-reared pallid sturgeon can survive in the wild and contribute to the overall population of this species.

Van Doornik, D.M., B.A. Berejikian, L.A. Campbell, and E.C. Volk. 2010. The effect of a supplementation program on the genetic and life history characteristics of an *Oncorhynchus mykiss* population. Canadian Journal of Fisheries and Aquatic Sciences, 67(9): 1449-1458.

Abstract: Conservation hatcheries, which supplement natural populations by removing adults or embryos from the natural environment and rearing and releasing parr, smolts, or adults back into their natal or ancestral streams, are increasingly being used to avoid extinction of localized populations of Pacific salmonids. We collected data before and during a steelhead (*Oncorhynchus mykiss*) supplementation program to investigate the effect that the program has had on the population's genetic diversity and effective population size and any changes to an important life history trait (residency or anadromy). We found that supplementation did not cause substantial changes in the genetic diversity or effective size of the population, most likely because a large proportion of all of the steelhead redds in the river each year were sampled to create the supplementation broodstock. Our data also showed that the captively reared fish released as adults successfully produced parr. Furthermore, we found that during supplementation, there was an increase in the proportion of *O. mykiss* with anadromous ancestry vs. resident ancestry.

2) Can supplementation hatcheries be managed to maintain the long-term fitness of wild/natural populations?

Araki, H. 2008. Hatchery Stocking for Restoring Wild Populations: A Genetic Evaluation of the Reproductive Success of Hatchery Fish vs. Wild Fish. Pp. 153-167 in K. Tsukamoto, T. Kawamura, T. Takeuchi, T. D. Beard, Jr. and M. J. Kaiser, eds. *Fisheries for Global Welfare and Environment, 5th World Fisheries Congress*.

Abstract: Potential impacts of hatchery programs on wild populations have long been discussed, and of particular interest is the reproductive success of hatchery born fish in natural environments. Here I summarize our recent studies, in which DNA fingerprinting and genetic parentage analyses were used to estimate adult-to-adult reproductive fitness of steelhead trout (*Oncorhynchus mykiss*) in the Hood River, Oregon (USA). We found: (1) Hatchery fish left fewer adult offspring per parent than wild fish, but supplementation hatchery fish (from local, wild broodstock; H_{supp}) left larger numbers of offspring than traditional hatchery fish (from nonlocal, multi-generation hatchery broodstock; H_{trad}); (2) The reproductive fitness of H_{supp} declined unexpectedly fast (~40% per generation) when H_{supp} were reused as broodstock in a hatchery, suggesting that the negative effects of hatchery rearing are cumulative and heritable; (3) Effective population size was mainly restricted by variance in reproductive success among individuals, rather than by biased sex ratio and temporal fluctuation of population sizes; (4) H_{trad} showed particularly large variance in reproductive success, indicating another negative effect of traditional programs. Our case studies suggest that using local, wild broodstock reduces negative effects of hatchery rearing, but the repeated use of H_{supp} as broodstock should be minimized for efficient supplementation.

Berejikian, B. A., E.P. Tezak, T.A. Flagg, A.L. LaRae, E. Kummerow, and C.V.W. Mahnken. 2000. Social dominance, growth, and habitat use of age-0 steelhead (*Oncorhynchus mykiss*) grown in enriched and conventional hatchery rearing environments. Canadian Journal of Fisheries and Aquatic Sciences, 57:628-636.

Abstract: This study investigated whether culturing age-0 steelhead (*Oncorhynchus mykiss*) in habitat-enriched rearing tanks, containing a combination of in-water structure, underwater feeders, and overhead cover, affected competitive ability and habitat use compared with juveniles cultured in more conventional vessels. In laboratory tests, steelhead juveniles grown in the enriched tanks socially dominated size-matched competitors grown in conventional tanks. When both treatments were introduced into separate sections of a quasi-natural stream, no differences in growth were found between them. However, when intermixed, fish reared in the enriched tanks grew at a higher rate than conventionally reared competitors, suggesting greater competitive ability of juveniles grown in the enriched tanks. Visual isolation and defensible food resources in combination in the enriched tanks were considered as the primary factors causing the observed competitive asymmetries. Steelhead juveniles from the two rearing environments exhibited very similar use of woody structure in the quasi-natural stream, both in the presence and in the absence of mutual competition. Rearing steelhead in more naturalistic environments could result in hatchery fish that behave and integrate into the postrelease (natural) environment in a manner more similar to wild fish.

Berejikian, B. A., D. M. Van Doornik, J. A. Scheurer, R. Bush. 2009. Reproductive behavior and relative reproductive success of natural - and - hatchery - origin Hood Canal summer chum slamon (*Oncorhynchus keta*). Canadian Journal of Fisheries and Aquatic Sciences, 66:781-789.

Abstract: Estimates of the relative fitness of hatchery- and natural-origin salmon can help determine the value of hatchery stocks in contributing to recovery efforts. This study compared the adult to fry reproductive success of natural-origin summer chum salmon (*Oncorhynchus keta*) with that of first- to third-generation hatchery-origin salmon in an experiment that included four replicate breeding groups. Hatchery- and natural-origin chum salmon exhibited similar reproductive success. Hatchery- and natural-origin males obtained similar access to nesting females, and females of both types exhibited similar breeding behaviors and durations. Male body size was positively correlated with access to nesting females and reproductive success. The estimates of relative reproductive success (hatchery/natural = 0.83) in this study were similar to those in other studies of other anadromous salmonids in which the hatchery population was founded from the local natural population and much higher than those in studies that evaluated the lifetime relative reproductive success of nonlocal hatchery populations.

Brockmark, S., and J.I. Johnsson. 2010. Reduced hatchery rearing density increases social dominance, postrelease growth, and survival in brown trout (*Salmo trutta*). Canadian Journal of Fisheries and Aquatic Sciences, 67(2):288-295.

Synopsis: Hatchery fish reared for conservation or supplementation often have difficulties adapting to natural conditions, resulting in poor performance in the wild. In a standard hatchery, fish are confined at high densities, which creates a social environment different from that experienced after release. Here we investigated how rearing density influences social dominance, postrelease growth, and survival in brown trout (*Salmo trutta*). Fish were reared at three density treatments: conventional hatchery density, half of conventional hatchery density, and natural density. Four months after hatching, dominance status was determined, and 36 fish from each treatment were released into an enclosed stream and recaptured after 36 days. Trout reared at natural density had higher dominance status and grew faster, both in the hatchery and in the natural stream, than trout from higher densities. Moreover, trout reared at natural density were twice as likely to survive in the stream as trout from higher densities. These novel results suggest that more natural rearing densities would facilitate the development of adaptive behaviour in hatchery salmonids and, thereby, their contribution to natural production.

Clarke, L.R., M.W. Flesher, T.A. Whitesel, G.R. Vonderohe, and R.W. Carmichael. 2010. Postrelease Performance of Acclimated and Directly Released Hatchery Summer Steelhead into Oregon Tributaries of the Snake River. North American Journal of Fisheries Management 30: 1098-1109.

Abstract: In a study using 14 paired-release groups over 10 release years, we compared the performance of hatchery summer steelhead *Oncorhynchus mykiss* that were acclimated as smolts (AC) for 16–57 d before release into ponds supplied with ambient stream water with that of fish trucked from the hatchery and directly released (DR) into Spring, Deer, and Little Sheep creeks in northeastern Oregon. After releasing the fish into streams, we monitored out-migration travel times and survival to Lower Granite Dam (LGD) on the Snake River using freeze brand marks or implanted passive integrated transponder tags in a subsample of each release group. Across all release groups, travel time was significantly slower for AC fish (34.7 d) than for DR fish (31.8 d), though there was no significant difference in survival probability to LGD. We used recoveries of coded wire tags to estimate smolt-to-adult survival (SAS) and a stray rate index (SRI) for the AC and DR strategies. Across all release groups, SAS was 33% higher and SRI 42% lower for AC steelhead. At each release site acclimation increased average SAS by at least 11% and decreased SRI by at least 16.5%. We found a significant, negative linear relationship between travel time to LGD and SAS;

however, there was no significant relationship between survival to LGD and SAS, which implies that judgments about the success or failure of a novel rearing or release strategy should not be made based on out-migration survival. Acclimating juvenile steelhead produced significantly higher SAS and lower SRI in the hatchery program we evaluated.

Cuenco, M. L., T. W. H. Backman, and P. R. Mundy. 1993. The use of supplementation to aid in natural stock restoration. Pages 269-293 in J. G. Cloud and G. H. Thorgaard, editors. Genetic conservation of salmonid fishes. Plenum Press, New York.

Synopsis: Defines supplementation and the parameters of a successful supplementation program. Note that this document was published by tribal scientists long before hatchery reform became popular and widely advocated. Many of the recommendations in this publication are being used in studies contained in this bibliography.

Dahl, J., E. Pettersson, J. Dannewitz, T. Järvi, and A-C Löf. 2006. No difference in survival, growth and morphology between offspring of wild-born, hatchery and hybrid brown trout (*Salmo trutta*). Ecology of Freshwater Fish 15:388-397.

Abstract: We studied survival, growth and morphological characters in the offspring of native hatchery and wild-born anadromous brown trout (*Salmo trutta*) and their hybrids (wild-born female × hatchery male and wild-born male × hatchery female) in a 1-year field experiment. We also conducted laboratory studies where we examined social interactions between the offspring of the same hatchery and wild-born trout. All offspring were raised in a hatchery and nose tagged before being released into the stream. In total, 1125 individuals were released into the stream (1999) and a total of 614 individuals were recovered (2000). We found no differences in growth and survival between the offspring of hatchery, wild-born and hybrid trout. Morphology was also similar among groups, where only 38% females and 36% males were classified into the right category, which were only 12% better than random classification. In the laboratory experiment, we compared only the offspring of hatchery and wild-born trout with respect to growth, dominance, aggressiveness, feeding and activity. We found small differences between the offspring of hatchery and wild-born fish with respect to growth but this effect was not found in the field experiment. Our result suggests that the offspring of hatchery trout and hybrids between hatchery and wild-born trout performed equally well to the offspring of wild-born trout.

Dannewitz, J., E. Petersson, T. Prestegaard, and T. Jarvi. 2003. Effects of sea-ranching and family background on fitness traits in brown trout *Salmo trutta* reared under near-natural conditions. Journal of Applied Ecology 40:241-250.

Summary (Author's words taken directly from publication):
1. Many threatened populations of salmonids depend on supplemental releases of hatchery-produced fish. Laboratory studies suggest that altered selection regimes in the hatchery may result in evolutionary changes of traits connected to fitness. Such changes can have profound effects on the performance of the hatchery fish following release in the natural environment, and may also affect the genetic characteristics of locally adapted wild populations. However, surprisingly few studies have looked at the ability of hatchery fish to compete with wild conspecifics under natural conditions.
2. We studied growth, survival and life-history adoption of a wild and a multigeneration sea-ranched strain of brown trout *Salmo trutta* in a semi-natural stream. The fish were planted in the stream as eyed eggs and their family and strain origins were later revealed by microsatellite markers.

3. In the first experiment, in which the experimental fish originated from a full-sib mating design, there were strong family effects on both growth and survival over the first growth season. In the second experiment, in which the experimental fish originated from a half-sib mating design, there were significant male and female effects on growth parameters but not on survival over the first growth season.
4. When family and male–female effects were accounted for, there were no differences between wild and sea-ranched trout in body size and condition factor after the first growth season, or in survival up to this stage. Nor was there any difference between the groups in the proportions that metamorphosed into the migratory smolt phase at 1 year of age.
5. Synthesis and applications. Our results suggest that wild-born trout of sea-ranched origin can successfully compete with trout of wild origin under semi-natural conditions. This indicates that the impact of hatchery selection on the performance of sea-ranched fish in the wild may not be as pronounced as previously thought. It is suggested that for salmonid populations that depend on supplemental stocking, more effort should be paid to minimizing negative environmental effects during hatchery rearing. The observed differences in fitness characters between families suggest that family effects should be taken into account in stocking programmes because the amount of genetic variation maintained within populations is related to the variance in family performance.

Dittman, A. H., D. May, D. A. Larsen, M. L. Moser, M. Johnston, and D. Fast. 2010. Homing and spawning site selection by supplemented hatchery- and natural-origin Yakima River spring Chinook salmon. Transactions of the American Fisheries Society 139:1014-1028.

Synopsis: This paper examined the homing patterns of supplemented Yakima River spring Chinook salmon releases from satellite acclimation facilities. The data indicated that supplementation increased the spatial range of spawning in the upper Yakima River. Natural- and hatchery-origin fish displayed similar spawning distributions within the upper Yakima Basin. Like their natural-origin counterparts, hatchery-origin fish demonstrated the ability to seek optimum spawning locations. This occurred especially in the absence of acceptable spawning conditions in their area of acclimation and release.

Eldridge, W.H. and K. Killebrew. 2008. Genetic diversity over multiple generations of supplementation: an example from Chinook salmon using microsatellite and demographic data. Conservation Genetics 9:13-28.

Abstract: We examined demographic data and microsatellite loci in a supplemented population of Chinook salmon (*Oncorhynchus tshawytscha*) seeking evidence of changes in genetic diversity or for reduction of the effective size (*Ne*) arising from supplementation (i.e., the Ryman-Laikre effect). A supplementation program in the North Fork Stillaguamish River (Washington State, USA) was intended to increase abundance (*N*) and maintain genetic diversity in the depressed population. Since supplementation expanded in 1986, about 9% of the population has been randomly collected for broodstock. The resulting progeny are released into the wild and comprised 10–60% of all returning adults. Genotypic data were obtained at 14 microsatellite loci from adult samples collected in four years between 1985 and 2001; these data indicated that the allelic richness and expected heterozygosity did not significantly change during this period and that genetic diversity in the captive and wild progeny was similar. The inbreeding and variance Ne estimated from adult escapement between 1974 and 2004 were different for the same generation, but the ratios of effective size to census size were very similar and decreased following supplementation. The variance *Ne* by the temporal method increased over time, but it is difficult to draw conclusions because of necessary assumptions made during the calculations. Based on these results we conclude that: (1) genetic diversity has been maintained over multiple generations of supplementation; (2) supplementation has not contributed to a loss of genetic diversity; and (3) monitoring genetic effects of supplementation is not straightforward, but it can be useful to look at both demographic and genetic data simultaneously.

Fraser, D. J. 2008. How well can captive breeding programs conserve biodiversity? A review of salmonids. Evolutionary Applications, 1:535-586.

Synopsis: Review of existing literature relevant to genetic diversity and fitness issues in captive breeding and supplementation programs. Empirical and theoretical studies both suggest that most salmonid captive breeding programs can maintain genetic diversity over several captive generations. The apparent low N_e in some captive broodstocks might easily be avoided through the use of procedures that reduce genetic and other risks associated with captive breeding programs such as using local brood sources and minimizing generations in captivity. Many of the poorest performances of hatchery fish relative to wild fish involved nonlocal hatchery strains that had been in captivity for greater than five generations or that had undergone intentional artificial selection. There is little long-term evidence regarding whether captive-reared salmonids can or cannot be reintroduced as self-sustaining populations. There are numerous examples of the ability of salmonids to evolve rapidly in the wild over several generations. Certainly, then, the possibility exists that a reintroduced population based on captive- reared fish could re-adapt to the wild environment under a similar timeframe. There is only very limited empirical research to suggest that maintaining several small isolated populations with periodic mixing may be more effective at reducing losses of genetic diversity and fitness than maintaining a single large population.

Hedrick, P.W., D. Hedgecock, S. Hamelberg, and S.J. Croci. 2000. The impact of supplementation in winter-run chinook salmon on effective population size. Journal of Heredity, 91(2): 112-116.

Abstract: Supplementation of young raised at a protected site, such as a hatchery, may influence the effective population size of an endangered species. A supplementation program for the endangered winter-run chinook salmon from the Sacramento River, California, has been releasing fish since 1991. A breeding protocol, instituted in 1992, seeks to maximize the effective population size from the captive spawners by equaling their contributions to the released progeny. As a result, the releases in 1994 and 1995 appear not to have decreased the overall effective population size and may have increased it somewhat. However, mistaken use of non-winter-run chinook spawners resulted in artificial crosses between runs with fish on Battle Creek, the site of the hatchery, resulted in limiting the contribution of the released fish to the target mainstem population. Rapid genetic analysis of captured spawners and a new rearing facility on the Sacramento River should alleviate these problems and their negative effect on the effective population size in future years.

Hedrick, P.W., V.K. Rashbrook, and D. Hedgecock. 2000. Effective population size of winter-run chinook salmon based on microsatellite analysis of returning spawners. Canadian Journal of Fisheries and Aquatic Sciences, 57(12): 2368–2373.

Abstract: We previously estimated the predicted effective population size for the endangered winter-run chinook salmon, *Oncorhynchus tshawytscha*, based on a number of assumptions, including random survival and return of released fish. Here we present data from actual returning spawners, identified to family by microsatellite loci, and calculate the observed effective population size. In 1994 and 1995, the observed effective population sizes were 93.6 and 78.2% of predicted values, respectively, suggesting that the numbers of returning fish were very close to random expectations in 1994 and less close to random in 1995. The ratio of the effective population size to the adult number, Ne/N, was greater than unity for 1994 and approximately 0.5 in 1995. The high ratio in 1994 reflects the success of the breeding protocol to equalize individual contributions and near random returns, while the lower number in 1995 appears to be the result of both less successful equalization and less close to random returns in that year. These findings provide an optimistic outlook for the success of this supplementation program and suggest that the overall effective population size has not been greatly reduced, since returning spawners represent a broad sample of parents and not fish from only a few families.

Heggenes, J., M. Beere, P. Tamkee, and E. B. Taylor. 2006. Genetic diversity in steelhead before and after conservation hatchery operation in a coastal, boreal river. Transactions of the American Fisheries Society 135:251-267.

Abstract: The objectives of this study were to (1) investigate the genetic diversity of wild steelhead populations in the river before hatchery stocking and (2) assess the potential genetic impacts of interbreeding of returning hatchery adult fish with wild spawners over almost 20 years of large-scale hatchery operation. The level of population subdivision among Kitimat River samples was low (0.004) and not significantly different from 0. 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). Our data, however, did indicate a slight but significant reduction in allelic richness after hatchery stocking. Pairwise tests for genetic differentiation among samples from different yearclasses were nonsignificant. We conclude 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.

HSRG. 2005. Hatchery Scientific Review Group. Hatchery Reform in Washington State: Principles and Emerging Issues. Fisheries. Volume 30, Number 6. June 2005.

Synopsis: Makes recommendations for reforming hatchery operations to better meet goals of supporting sustainable fisheries and assisting with the conservation of natural populations. Many of the recommendations proposed by the HSRG were documented by Cuenco et al. in 1993 and are being used in studies contained in this bibliography.

Johnson, S.L., J.H. Power, D.R. Wilson, and J. Ray. 2010. A Comparison of the Survival and Migratory Behavior of Hatchery-Reared and Naturally Reared Steelhead Smolts in the Alsea River and Estuary, Oregon, using Acoustic Telemetry. North American Journal of Fisheries Management 30:55-71.

Abstract: We tracked three groups of steelhead *Oncorhynchus mykiss* smolts implanted with acoustic transmitters to determine whether the degree of hatchery domestication or the juvenile rearing environment (hatchery raceway versus natural stream) influenced migration timing and survival in the Alsea River and estuary, Oregon. Two groups consisted of age-1 smolts reared in concrete raceways. One hatchery-reared group (traditional brood group) was derived from the traditional Alsea River broodstock initially developed in the 1950s. The second hatchery-reared group (new brood group) was derived from naturally reared Alsea River adult steelhead that were captured and spawned at the hatchery beginning in the winter of 2000–2001. The third group (naturally reared group) consisted of age-2 naturally reared smolts captured in a downstream migrant trap located in a tributary stream near the hatchery. We placed transmitters in 74 traditional brood smolts, 76 new brood smolts, and 72 naturally reared smolts. Thirty-one acoustic receivers were located throughout the Alsea River and estuary and in the ocean offshore of the river mouth to monitor smolt movement. Neither the degree of hatchery domestication nor the juvenile rearing environment (hatchery raceway versus natural stream) appeared to influence the number of steelhead smolts that successfully migrated to the ocean. We found no significant difference between groups in their survival to the head of tide or to the mouth of the estuary. Most smolts from all three groups were detected at the head of tide (87% of fish from the traditional brood group, 78% from the new brood group, and 84% from the naturally reared group). However, survival was poor in the lower estuary for all three groups; we estimated that only 37% of the traditional brood group, 45% of the new brood group, and 47% of the naturally reared group survived to the ocean. The timing of migration through the river was highly variable in all three groups, and we found no significant differences in the rate of downstream movement from the release site to the head of tide. Mean residence time within the estuary was similar for all groups, although smolts from the naturally reared group showed less variability in estuary residence time than hatchery-reared smolts.

Kassler, T.W. and C.A. Dean. 2010. Genetic Analysis of Natural-origin Spring Chinook and Comparison to Spring Chinook from an Integrated Supplementation Program and Captive Broodstock Program in the Tucannon River. Report to BPA, Project No. 2000-019-00, Contract Number 40744. WDFW, Olympia, WA.

Abstract: A collection of natural-origin spring Chinook from 1986 was compared to samples from two spawner groups (supplementation program and in-river spawners), and to collections of hatchery- and natural-origin from the Tucannon River. Samples from the captive brood program at the Tucannon River Hatchery were also compared. A microsatellite DNA analysis was conducted to determine if there have been any changes to the genetic diversity of spring Chinook in the Tucannon River. The measures of genetic diversity (heterozygosity and allelic richness) revealed similar levels within each spawner group and collection based on origin over time. Assessment of within population diversity indicates that the spawner groups and collections by origin have not undergone a loss of diversity and are not represented by family groups. We did detect that collections of the captive brood are not within Hardy-Weinberg proportions and have significant linkage disequilibrium as a possible result of using equal numbers of individuals from two brood years that are differentiated. The collection of captive brood progeny returns in 2008; however is within expected proportions and indicates there has not been a genetic change to the spawner group collection or collections by origin. The pairwise F_{ST} values identify the variation between any two groups is approximately 1.0% or less indicating the differences among the groups is small. Factorial correspondence analysis identifies similarity among collections that are separated by four years and represent the genetic differences among primary brood years and not genetic changes to the natural-origin collection from 1986. The combination of all the results demonstrates that the genetic diversity of spring Chinook in the Tucannon River has not significantly changed as a result of the supplementation or captive brood programs.

Knudsen, C.M., S.L. Schroder, C. Busack, M.V. Johnston, T.N. Pearsons, and C.R. Strom. 2008. Comparison of Female Reproductive Traits and Progeny of First-Generation Hatchery and Wild Upper Yakima River Spring Chinook Salmon. Transactions of the American Fisheries Society 137:1433-1445.

Abstract: Hatchery and wild female spring Chinook salmon *Oncorhynchus tshawytscha* from the upper Yakima River were compared to determine whether their reproductive traits had diverged after a single generation of artificial propagation. Fecundity, relative fecundity, individual egg mass, and total gamete mass were all significantly correlated with body length, while reproductive effort (gonadosomatic index) was not. Regressions of trait versus body length often differed significantly among brood years. Hatchery spring Chinook salmon were significantly smaller than wild females over the four brood years examined. After brood year and body length (when necessary) were accounted for, wild females had an average of 8.8% more total gamete mass, 0.8% more individual egg mass, 7.7% greater fecundity, and 0.8% greater reproductive effort than hatchery females. Relative fecundity (the number of eggs per centimeter of body length) was on average 1.3% greater in hatchery females. We also compared body size at yolk absorption and egg-to-fry survival of the progeny from hatchery-by-hatchery and wild-by-wild matings. After differences in egg size were accounted for, hatchery fry were on average 1.0% heavier than wild fry. Egg-to-fry survival rates varied among years, with no consistent difference between hatchery and wild fry. The relationships between reproductive traits and body length were not significantly altered by a single generation of hatchery exposure. However, because hatchery females had smaller body sizes, the distributions of linked traits, such as total gamete mass and fecundity, differed by as much as 0.6 SD, probably resulting in some fitness loss. Our data support the idea that a single generation of state-of-the-art conservation hatchery propagation can produce fish with reproductive traits similar to those of wild fish, given comparable body size.

Lacroix, G.L. 2008. Influence of origin on migration and survival of Atlantic salmon (*Salmo salar*) in the Bay of Fundy, Canada. Canadian Journal of Fisheries and Aquatic Sciences 65:2063-2079.

Synopsis: Atlantic salmon smolts of wild and hatchery origin were tagged with ultrasonic transmitters and monitored at successive arrays of submerged receivers during migration from five watersheds in three regions of the Bay of Fundy, Canada. The early marine survival of migrating Atlantic salmon was estimated by monitoring their migration in estuarine and coastal habitats. Except in cases where hatchery fish were purposely forced to migrate later than their wild counterparts, the migration success did not differ significantly between groups of wild and hatchery smolts for rivers where both were simultaneously monitored. The responses of hatchery fish to delays in release indicated that synchronizing the readiness and release time of hatchery smolts to the timing of wild smolt runs may be crucial to successful management of the depleted or endangered salmon populations being sustained by hatchery programs in the Bay of Fundy.

Loomis, D. W., G. R. Moyer, M. Banks, and J. Muck. 2006. Umpqua Coho Genetic Pedigree Project: CHIP-ping Forward with Assessing Reproductive Success of Supplemental Fish Releases. Oregon Chapter AFS Meeting Presentation, March 1, 2006.

Synopsis: In progress (study overview available here). The first F1 generation from this coho study returned in 2004. Preliminary results show no statistical differences in smolt-to-adult returns or relative reproductive success for hatchery-by-hatchery (derived from local wild stock) compared to wild-by-wild matings and releases. Complete project results are expected to be available in 2011.

Monzyk, F.R., B.C. Jonasson, T.L. Hoffnagle, P.J. Keniry, R.W. Carmichael, and P.J. Cleary. 2009. Migration Characteristics of Hatchery and Natural Spring Chinook Salmon Smolts from the Grande Ronde River Basin, Oregon, to Lower Granite Dam on the Snake River. Transactions of the American Fisheries Society 138: 1093-1108.

Abstract: We investigated the patterns of travel time and survival of hatchery and natural smolts fitted with passive integrated transponder (PIT) tags through specific reaches of the migration corridor during the 2000–2006 migration years for two populations originating in the Grande Ronde River basin (Lostine River and Catherine Creek). For both populations, median travel times for natural smolts were significantly longer in the upper reaches of the migration corridor but shorter in the lower reaches than for their hatchery counterparts. Also, among both hatchery and natural smolts, smaller individuals spent more time in the upper reaches, presumably feeding to attain a larger size before continuing their migration. Within populations, both hatchery and natural smolts showed similar patterns of survival through the reaches of the migration corridor above Lower Granite Dam. Size-selective mortality was evident for hatchery and natural smolts from both populations, especially in the upper reaches, larger individuals experiencing higher survival.

Moyer, G.R., J.D. Rousey, and M.A. Cantrell. 2009. Genetic Evaluation of a Conservation Hatchery Program for Reintroduction of Sicklefin Redhorse *Moxostoma* sp. in the Tuckasegee River, North Carolina. North American Journal of Fisheries Management 29: 1438-1443.

Abstract: Restoration and reintroduction efforts for the sicklefin redhorse *Moxostoma* sp. have been initiated by state, tribal, and federal agencies owing to the limited geographic distribution of this species and threats associated with the physical alteration of its habitat. A critical component of a successful reintroduction is that the source and recipient populations have similar genetic resources and life history patterns. We used 10 microsatellite loci to estimate and compare indices of genetic diversity between the Little Tennessee River population of wild adults and the hatchery broodstock being used for initial reintroduction efforts. We also compared relatedness values for the broodstock used for restoration efforts. There were no significant differences between hatchery broodstock and wild adults with respect to average gene diversity, but the average number of alleles for each brood year was significantly less than that for wild adults. While this trend persisted when the 2007 and 2008 brood years (combined) were compared with wild adults, the reduction was not significant. Finally, all hatchery crosses were among unrelated individuals. Our results highlight the importance of using genetic information to assist restoration and reintroduction efforts.

Pearsons, T. N. and G. M. Temple. 2007. Impacts of Early Stages of Salmon Supplementation and Reintroduction Programs on Three Trout Species. North American Journal of Fisheries Management 27:1-20.

Abstract: Salmon supplementation and reintroduction programs have the potential to negatively impact other valued fish taxa that are not the targets of enhancement (nontarget taxa [NTT]). Impacts of the supplementation of spring Chinook salmon *Oncorhynchus tshawytscha* and the reintroduction of coho salmon *O. kisutch* (hereafter supplementation) on populations of rainbow trout *O. mykiss*, steelhead (anadromous rainbow trout), cutthroat trout *O. clarkii*, and bull trout *Salvelinus confluentus* were evaluated after 5 years of stocking approximately 1 million yearling smolts in the upper Yakima River basin between 1999 and 2003. Field methods included backpack electrofishing and snorkeling in tributaries and drift-boat electrofishing in the main stem. We used three sequential steps in our evaluation: (1) we determined whether spatial overlap occurred between supplemented fish and NTT; (2) if overlap occurred, we determined whether a change in abundance, size, or biomass occurred during supplementation; and (3) if a change occurred, we determined whether the change could be reasonably attributed to supplementation. Salmon rarely overlapped cutthroat trout or bull trout in tributaries, but some overlap with cutthroat trout occurred in relatively high elevations of the main stem and considerable overlap with rainbow trout occurred in tributaries and the main stem. Except in steelhead, the lower 90% confidence limit (CL) of abundance, size, and biomass was above the containment objective for NTT that overlapped significantly with salmon. We used rainbow trout as an analog for steelhead. The lower 90% CL of rainbow trout abundance and size in tributaries and the main stem and biomass in the main stem was below the containment objective for steelhead. However, comparisons of rainbow trout abundance, size, and biomass between tributaries and main-stem sections with relatively high and low salmon abundances revealed that the change was probably not the result of supplementation (before–after control–impact paired site analysis: $P > 0.05$). Our data indicate that early stages of salmon supplementation have not impacted trout species in the upper Yakima River basin beyond predetermined containment objectives.

Schroder, S. L., C. M. Knudsen, T. N. Pearsons, T. W. Kassler, S. F. Young, C. A. Busack, and D. E. Fast. 2008. Breeding Success of Wild and First-Generation Hatchery Female Spring Chinook Salmon Spawning in an Artificial Stream. Transactions of the American Fisheries Society, 137:1475-1489.

Abstract: First generation hatchery and wild spring Chinook salmon from the upper Yakima River, Washington State were placed into an artificial stream and allowed to spawn. Seven independent test groups were placed into the stream from 2001 through 2005. No differences were detected in the egg deposition rates of wild and hatchery females. 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. Body size did not affect the ability of females to spawn or the survival of their deposited eggs. How long a female lived was positively related to her breeding success but female origin did not affect longevity. The density of females spawning in portions of the stream affected both egg deposition and egg-to-fry survival. No difference, however, was found in the overall distribution patterns of the two types of females. Other studies that have examined the effects of a single generation of hatchery culture on upper Yakima River Chinook have disclosed similar low-level effects on adult and juvenile traits. The cumulative impact of such differences will need to be considered when hatcheries are used to restore depressed populations of salmon.

Schroder, S. L., C. M. Knudsen, T. N. Pearsons, T. W. Kassler, S. F. Young, E.P. Beall, and D. E. Fast. 2010. Behavior and Breeding Success of Wild and First-Generation Hatchery Male Spring Chinook Salmon Spawning in an Artificial Stream. Transactions of the American Fisheries Society, 139:989-1003.

Abstract: Spring Chinook salmon *Oncorhynchus tshawytscha* native to the upper Yakima River, Washington, were placed into an artificial stream to evaluate the effect of a single generation of hatchery culture on their spawning behavior and ability to produce offspring. From 2001 to 2005, seven independent test groups containing wild and hatchery fish were placed into the stream. The effects of body weight, spawning ground longevity, attack frequency, social dominance, courting frequency, and mate number on breeding success in hatchery and wild males were evaluated. Differences in male agonism due to male origin were found. Wild males exhibited higher attack rates and greater social dominance than did hatchery males. However, the observed inequalities in agonism and dominance appeared to be largely caused by differences in body weight between the two types of males: wild males were, on average, 9% heavier than hatchery males. Wild and hatchery males did not differ in the frequency of courting behaviors or in the number of mates. Pedigree analyses based on DNA showed that hatchery and wild males had comparable breeding success values. Consequently, a single generation of hatchery exposure appeared to have a low effect on spring Chinook salmon male breeding success in our experimental setting.

Sharma, R, G. Morishima, S. Wang, A. Talbot, and L. Gilbertson. 2006. An evaluation of the Clearwater River supplementation program in western Washington. Canadian Journal of Fisheries and Aquatic Sciences, 63(2): 423-437.

Synopsis: After three generations of study, an integrated coho supplementation program in a Washington coastal stream documented no empirical evidence that the program negatively affected the fitness of the target population. This study demonstrates that a supplementation (hatchery) program, in this case following new and innovative operational protocols, can produce smolts that have nearly the same survival rate to adults as that of wild smolts and can result in more adult coho returning to the Clearwater basin. This benefit appears possible without short-term adverse impacts to either intrinsic productivity or the number of naturally produced smolts.

Sharpe, C.S., P.L. Hulett, C.W. Wagemann, M.P. Small and A.R. Marshall. 2010. Natural Reproductive Success of First-generation Hatchery Steelhead Spawning in the Kalama River: A Progress Report. Washington Department of Fish and Wildlife, Fish Program, Fish Science Division. (http://wdfw.wa.gov/publications/00969/wdfw00969.pdf)

Synopsis: The goal of the Kalama research program is to identify and empirically quantify risks imposed by hatchery programs on natural production of anadromous salmonids, and identify strategies to manage those risks. Studies of steelhead genetics, ecology, and life history have been ongoing in the Kalama River since the mid-1970's. A primary objective of Kalama research work has been to assess the relative reproductive performance and contribution of hatchery and wild steelhead spawning in the wild. We did not detect a difference in reproductive success of the wild broodstock hatchery spawners: the proportions of offspring from Hatchery × Hatchery (HH), Hatchery × Wild (HW), and Wild × Wild (WW) spawners closely approximated the proportions expected under the null hypothesis with reproductive success of hatchery spawners equal to that of wild spawners. Reproductive success of first-generation wild broodstock hatchery fish appeared to be similar to that of wild fish in the first replicate of our experiment. The outcome is in agreement with initial results from a similar reproductive success study on the Hood River, Oregon (Araki et al. 2006), where first generation wild-broodstock winter-run steelhead appeared to be as reproductively competent as the wild fish from which they were derived (but see Araki et al. 2007 and Araki et al. 2008). Because we present results from only the first of three replicates the results should be considered preliminary.

Small, M.P., K. Currens, T.H. Johnson, A.E. Frye, and J.F. Von Bargen. 2009. Impacts of supplementation: genetic diversity in supplemented and unsupplemented populations of summer chum salmon (*Oncorhynchus keta*) in Puget Sound (Washington, USA). Canadian Journal of Fisheries and Aquatic Sciences, 66:1216-1229.

Abstract: In supplementation programs, hatcheries employ wild-origin fish as brood stock and their offspring are allowed into wild spawning areas. Resource managers use supplementation to support imperiled salmonid populations, seeking to increase census size and possibly effective population size (Ne), while minimizing risks of genetic diversity loss and domestication from hatchery intervention. Here we document impacts of 5–10 years of supplementation on threatened summer-run chum salmon (*Oncorhynchus keta*) in Hood Canal (HC) and Strait of Juan de Fuca (SJF) in Washington State and compare them genetically with unsupplemented summer- and fall-run chum salmon from HC and South Puget Sound. Microsatellite allele frequencies identified four run-timing and geographic groups. HC and SJF summer chum salmon genetic relationships followed a metapopulation pattern of isolation by distance, similar to patterns prior to supplementation, suggesting that supplementation minimally impacted population structure. In most supplemented subpopulations, we detected no effects on diversity and Ne, but high variance in individual pairwise relatedness values indicated over-representation of family groups. In two subpopulations, hatchery impacts (decreased diversity and lower Ne) were confounded with extreme bottlenecks. Rebounds in census sizes in all subpopulations suggest that general survivorship has improved and that possible hatchery effects on genetic diversity will be overcome.

3) If there are negative hatchery effects, are they reversible?

Bosch, W. J., T. H. Newsome, J. L. Dunnigan, J. D. Hubble, D. Neeley, D. T. Lind, D. E. Fast, L. L. Lamebull, and J. W. Blodgett. 2007. Evaluating the Feasibility of Reestablishing a Coho Salmon Population in the Yakima River, Washington. North American Journal of Fisheries Management 27:198-214.

Abstract: Historical returns of coho salmon to the Yakima River Basin were estimated to range from 45,000 to 100,000 fish annually but declined to zero by the 1980s after decades of overexploitation of fishery, water, and habitat resources. In 1996 the Yakama Nation and cooperators initiated a project to determine the feasibility of reestablishing a naturally spawning coho population in the Yakima River. The Yakima coho project explored whether successful recolonization was feasible when multi-generational, hatchery-reared coho were reintroduced to native habitats. After 10-20 years of outplanting, we compared data for adult returns of known natural- and hatchery-origin coho. We found that natural-origin coho returned at a significantly larger size than hatchery-origin coho. Mean egg mass and mean egg size of natural-origin females were greater than those of hatchery-origin females, though the differences were statistically significant for only one of three sample years. Natural-origin adults returned (2 to 9 days) and spawned (5 days) later than their hatchery-origin counterparts. Preliminary indices of smolt-to-adult survival for natural-origin coho were 3.5 to 17.0 times survival indices of hatchery-origin coho. The number of coho returning to historical native spawning habitats in upriver areas generally increased. Spawning surveys demonstrated the existence of robust and sustainable spawning aggregates in various locations in the basin. Hatchery releases from local brood source parents had significantly higher smolt-to-smolt survival than releases from out-of-basin hatchery broodstock, but some of these observed differences in survival could have been due in part to differences in smolt size. We conclude that hatchery-origin coho, with a legacy of as many as 10 to 30 generations of hatchery-influence, demonstrated their ability to reestablish a naturalized population after as few as 3 to 5 generations of outplanting in the wild.
Note that natural-origin coho adult returns to spawning areas above Willamette Falls confirm these results. After decades of outplanting hatchery-origin coho from multiple hatcheries including Oregon coastal hatcheries, releases above Willamette Falls were terminated in 1998. Now, 3-4 coho generations after hatchery-origin releases were terminated, adult coho returns to Willamette Falls numbered 25,300 in 2009 and will likely exceed 30,000 in 2010.

Conover, D. O., S. B. Munch, and S. A. Arnott. 2009. Reversal of evolutionary downsizing caused by selective harvest of large fish. Proceedings of the Royal Society B. doi:10.1098/rspb.2009.0003.

Synopsis: Evolutionary responses to the long-term exploitation of individuals from a population may include reduced growth rate, age at maturation, body size and productivity. Theoretical models suggest that these genetic changes may be slow or impossible to reverse but rigorous empirical evidence is lacking. Here, we provide the first empirical demonstration of a genetically based reversal of fishing-induced evolution. We subjected six populations of silverside fish (*Menidia*

menidia) to three forms of size-selective fishing for five generations, thereby generating twofold differences among populations in mean weight and yield (biomass) at harvest. This was followed by an additional five generations during which size-selective harvest was halted. We found that evolutionary changes were reversible. Populations evolving smaller body size when subjected to size-selective fishing displayed a slow but significant increase in size when fishing ceased. Neither phenotypic variance in size nor juvenile survival was reduced by the initial period of selective fishing, suggesting that sufficient genetic variation remained to allow recovery. These results show that populations have an intrinsic capacity to recover genetically from harmful evolutionary changes caused by fishing, even without extrinsic factors that reverse the selection gradient.

Doyle, R.M., R. Perez-Enriquez, M. Takagi, and N. Taniguchi. 2001. Selective recovery of founder genetic diversity in aquacultural broodstocks and captive, endangered fish populations. Genetica 111:291-304.

Abstract: Hatchery broodstocks used for genetic conservation or aquaculture may represent their ancestral gene pools rather poorly. This is especially likely when the fish that found a broodstock are close relatives of each other. We re-analysed microsatellite data from a breeding experiment on red sea bream to demonstrate how lost genetic variation might be recovered when gene frequencies have been distorted by consanguineous founders in a hatchery. A minimal-kinship criterion based on a relatedness estimator was used to select subsets of breeders which represented the maximum number of founder lineages (i.e., carried the fewest identical copies of ancestral genes). UPGMA clustering of Nei"s genetic distances grouped these selected subsets with the parental gene pool, rather than with the entire, highly drifted offspring generation. The selected subsets also captured much of the expected heterozygosity and allelic diversity of the parental gene pool. Independent pedigree data on the same fish showed that the selected subsets had more contributing parents and more founder equivalents than random subsets of the same size. The estimated mean coancestry was lower in the selected subsets, meaning that inbreeding in subsequent generations would be lower if they were used as breeders. The procedure appears suitable for reducing the genetic distortion due to consanguineous and over-represented founders of a hatchery gene pool.

Fraser, D. J. 2008. How well can captive breeding programs conserve biodiversity? A review of salmonids. Evolutionary Applications, 1:535-586.

Tymchuk, W. E., C. Biagi, R. Withler, and R. H. Devlin. 2006. Growth and behavioral consequences of introgression of a domesticated aquaculture genotype into a native strain of coho salmon. Transactions of the American Fisheries Society 135:442-455.

Abstract: Selective breeding for enhanced growth in Pacific salmon *Oncorhynchus* spp. and other fish typically involves use of the largest mature individuals to breed for future generations of aquaculture broodstock. Owing to an altered selection regime, faster-growing fish may not be as adapted to the natural environment as wild fish. To increase understanding of the genetic changes underlying selection for enhanced growth that results in phenotypic differentiation of farmed from wild Pacific 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), F_1 and F_2 hybrids, and F_1 × wild backcross (B_{Ch}) 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: $D > F_2 > F_1 > B_{Ch} > Ch$.

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. Expression of the phenotypic differences in the hybrids and backcrosses, together with the results from a joint-scale analysis on line means, suggests that additive genetic effects contribute significantly to the divergence between the fast- and slow-growing strains. As phenotypic differences between strains are largely a consequence of additive gene action, the phenotypic effects of domestication are largely diluted within two generations of backcrossing to wild salmon. Knowledge of the genetic changes responsible for altered growth rates is crucial to our ability to predict the consequences of introgression of domestic strains into wild populations of salmon.

4) Are hatchery effects genetically based?

Beacham, T. D. 2010. Revisiting Trends in the Evolution of Egg Size in Hatchery-Enhanced Populations of Chinook Salmon from British Columbia. Transactions of the American Fisheries Society, 139: 579-585.

Synopsis: Hatchery enhancement has been reported to result in an increase in egg size in coho salmon *Oncorhynchus kisutch* and a decline in egg size in Chinook salmon *O. tshawytscha*. Egg size may be directly influenced by selection, a larger egg size evolving as a consequence of hatchery incubation. Alternatively, a smaller egg size could evolve as a correlated response to fecundity selection, and a unidirectional change in egg size over time may reflect selection and an underlying genetic change in the population. To address this question, temporal trends in egg size were investigated for two hatchery-enhanced populations of Chinook salmon from Vancouver Island, British Columbia. After the effect of female length variation was removed by standardizing egg sizes to a female of common length (the overall mean for each population), there was no temporal trend in egg size from the 1970s to 2008 for any of the hatchery-enhanced populations evaluated. These results do not support a previous report of genetically based declines in egg size in hatchery-enhanced Chinook salmon populations from this region.

Mackey, G., J.E. McLean, and T.P.Quinn. 2001. Comparisons of Run Timing, Spatial Distribution, and Length of Wild and Newly Established Hatchery Populations of Steelhead in Forks Creek, Washington. North American Journal of Fisheries Management 21: 717-724.

Synopsis: In Washington State, the approach to management of wild and hatchery steelhead trout *Oncorhynchus mykiss* has been to separate the timing of return and spawning by the two groups through selective breeding for early timing in hatchery fish. However, overlap in timing and spatial distribution could permit genetic and ecological interactions. To evaluate this management approach, we compared the timing, spatial distribution, and size of adult steelhead in the wild and newly established hatchery populations of Forks Creek, Washington. Hatchery fish tended to return and spawn about 3 months before wild fish but there was some temporal overlap. Radio-tracking indicated that the spatial distributions of the populations overlapped considerably, permitting interbreeding and ecological interactions. However, the hatchery fish tended to stay closer to the hatchery, consistent with olfactory imprinting on the hatchery's water supply. Wild females were larger than hatchery females (median fork lengths were 670 and 644 mm, respectively), and wild males and females varied more in length than did hatchery fish of the same sex. In the first year in which naturally spawned offspring of hatchery fish might have returned, we observed a marked increase in early-returning unmarked (i.e., naturally spawned) adults, suggesting that some hatchery fish spawned successfully in the creek.

5) Background / Additional Reading

Bosch, W. J. 2004. The promise of hatchery-reared fish and hatchery methodologies as tools for rebuilding Columbia Basin salmon runs: Yakima Basin overview. American Fisheries Society Symposium 44:151-160.

Synopsis: Overview of Yakima Basin Projects and why supplementation is necessary.

Brannon, E. L., D. F. Amend, M. A. Cronin, J. E. Lannon, S. LaPatra, W. J. McNeil, R. E. Noble, C. E. Smith, A. J. Talbot, G. A. Wedemeyer, and H. Westers. 2004. The controversy about salmon hatcheries. Fisheries 29(9): 12-30.

Synopsis: Reviews literature that has been often cited to show the negative effects of hatcheries and explains how poor experimental designs or the use of inappropriate (e.g., non-local origin, multiple generations in hatcheries) hatchery stocks contributed to the negative results reported in these papers. Documents many examples where fish from traditional hatcheries have spawned successfully and done well under natural conditions.

Columbia River Inter-Tribal Fish Commission. 1995. WY-KAN-USH-MI WA-KISH-WIT Spirit of the Salmon. The Columbia River Anadromous Fish Restoration Plan, Vol. I and II. Portland, Oregon.

Columbia River Inter-Tribal Fish Commission. 2000. WY-KAN-USH-MI WA-KISH-WIT Spirit of the Salmon. The Columbia River Anadromous Fish Restoration Plan Update, Vol. I and II. Portland, Oregon.

Dompier, D. W. 2005. The Fight of the Salmon People: Blending Tribal Tradition with Modern Science to Save Sacred Fish. Xlibris Corporation, www.Xlibris.com.

Gallinat, M. P., and L. A. Ross. 2008. Tucannon River Spring Chinook Salmon Hatchery Evaluation Program, 2007 Annual Report. WDFW, Olympia, WA.

Narum, S.R., T.L. Schultz, D.M. Van Doornik, and D. Teel. 2008. Localized genetic structure persists in wild populations of Chinook salmon in the John Day River despite gene flow from outside sources. Transactions of the American Fisheries Society 137:1650-1656.

Abstract: Samples of Chinook salmon *Oncorhynchus tshawytscha* collected from four spawning areas in the John Day River, Oregon (n = 330), were genotyped with 13 microsatellite loci to test for bottlenecks and temporal stability within sites as well as genetic differentiation among sites, and to estimate gene flow from outside populations. Since the John Day River has never been stocked with hatchery-reared fish, this study provided the opportunity to evaluate the genetic integrity and structure of Chinook salmon in a wilderness area amid many hatchery-supported populations in the Columbia River. No tests for bottlenecks (Wilcoxon tests for heterozygosity excess) were significant, and the temporal variation was slight and not significant within any spawning reach except for the collections from the Middle Fork John Day River. Overall, the genetic distance estimates suggest that there are three distinct subpopulations in the John Day River, namely, those in (1) the North Fork John Day River (including Granite Creek), (2) the Middle Fork John Day River, and (3) the upper

main-stem John Day River. These genetic relationships were supported by results from a neighbor-joining dendrogram. Assignment tests indicate that out-of-basin straying occurs throughout the John Day River, the largest percentage of strays going to the North Fork John Day River. Immigration may have acted to avert genetic bottlenecks and maintain genetic diversity in populations with fluctuating census size. Yet the genetic substructure of the Chinook salmon in the John Day River indicates natural reproduction from philopatric individuals, possibly with higher reproductive success than immigrants. The evidence presented here elucidates the balance of philopatry and dispersal acting to maintain genetic diversity and localized structure among the Chinook salmon of the John Day River.

Perrier, C., G. Evanno, J. Belliard, R. Guyomard, and J-L. Baglinière. 2010. Natural recolonization of the Seine River by Atlantic salmon (*Salmo salar*) of multiple origins. Canadian Journal of Fisheries and Aquatic Sciences, 67(1): 1-4.

Abstract: The restoration of previously extinct salmon populations is usually achieved with stocking programmes, but natural recolonization can also occur through the straying of individuals from nearby populations. Here we investigated the origin of Atlantic salmon (*Salmo salar*) that recently recolonized the Seine River (France). The degradation of this river had led to the extinction of the population, but since the 1990s, the water quality has greatly improved. Although no stocking was performed, 162 individual salmon were recently observed by video-counting. Seven fish were sampled for morphological and genetic analyses. These individuals were genotyped at 17 microsatellites markers and their probable source populations were identified using baseline samples from regional and distant populations. Four of the sampled individuals were grilse and three were multi-sea-winter fish. Genetic analyses revealed that the fish partly originated from a nearby stock but also from distant populations, suggesting long-distance straying. This natural recolonization of a large river by strayers from several origins is discussed in terms of population sustainability and management.

References

RASP (Regional Assessment of Supplementation Planning). 1992. Supplementation in the Columbia River Basin, Parts 1-5. Report DOE/BP 01830-11, Bonneville Power Administration.

RIST (Recovery Implementation Science Team). 2009. Hatchery Reform Science. A review of some applications of science to hatchery reform issues. More information on the RIST, as well as an electronic copy of this report, can be found at http://www.nwfsc.noaa.gov/trt/index.cfm.

Bibliography of papers cited in RIST (2009), Figure 4 (see below) and response of tribal scientists (Note: this section is still being developed):

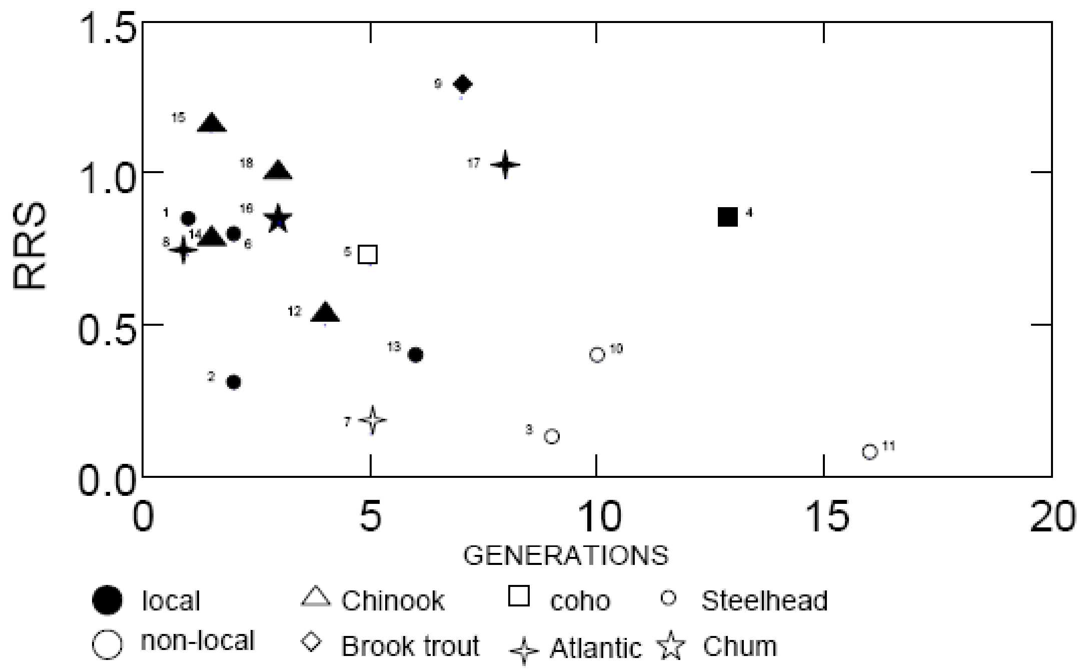


Figure 4 -- Summary of relative fitness estimates by species, broodstock origin, and generations in the hatchery (compiled by Berejikian, NWFSC). 1 - Araki et al. (2007b)), 2 - Araki et al. (2007b), 3 - Leider et al. (1990), 4 - Ford et al. (2006), 5 - Fleming and Gross (1993), 6 - Reisenbichler and McIntyre (1977), 7 - Fleming et al. (2000), 8 - Fleming et al. (1997), 9 - Dannewitz et al. (2003), 10 - Araki et al. (2007a), 11 - Araki et al. (2007a), 12 - Murdoch et al. (2008), 13 - Moran and Waples (2007), 14 - P. Moran (NWFSC, personal communication), 15 - P. Moran (NWFSC, personal communication), 16 – Berejikian et al. (2008), 17 - McGinnity et al. (1997.), 18 – Leth (2005).

Araki, H., B. Cooper, and M. S. Blouin. 2007. Genetic effects of captive breeding cause a rapid, cumulative fitness decline in the wild. Science 318:100-103.

And

Araki, H., B. Cooper, and M. S. Blouin. 2009. Carry-over effect of captive breeding reduces reproductive fitness of wild-born descendants in the wild. Biology Letters, published online 10 June 2009.

Abstract: 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.

Response: This study presents adult-to-adult RRS estimates of naturally spawned steelhead of supplemented vs. wild origin in the Hood River. This paper differs from Araki et al. (2007; Cons. Biol.) by evaluating RRS over three generations rather than only two. The current manuscript is very similar to Araki et al. (2007; Science) with both studies evaluating RRS of wild born steelhead over three generations. A slight difference appears in the analysis groups, with the current paper comparing RRS of wild born fish with captive vs. wild parents, and Araki et al. (2007; Science) comparing RRS of wild born fish from two types of captive reared steelhead. Overall, the premise is fairly redundant with previous papers by these authors, to the point where some text, figures, and tables are nearly identical to earlier literature (Araki et al. 2007a, b). As written, the current manuscript provides only minor advancements relative to previous conclusions, and the methods are greatly lacking appropriate detail. It also appears that further comparisons of RRS could have been made with sample groups from Araki et al. (2007; Science).

Of the work included, the results of RRS are presented in a biased manner to suggest that descendants of captive fish have lower RRS than wild. Specifically, the discussion section glosses over the annual results and focuses only on averages over multiple years to support this claim. However, annual results provided in Table 1 indicate that in only 2 of 18 annual comparisons was RRS of captive fish (either CxC or CxW) significantly less than wild fish (WxW). In most cases (16 of 18) differences in RRS were not significant between groups. Further, in 4 of the 18 comparisons, captive fish had higher RRS than wild fish (but not significant). The annual results much more accurately describe the results of this study than averages that appear to be highly influenced by wide variance in annual RRS.

Deficient methods and limited presentation of results are followed by sweeping conclusions that are not well supported. This topic has important implications and warrants a more complete paper with adequate and detailed analysis methods, full presentation of results, and unbiased discussion.

Ford, M.J., H. Fuss, B. Boelts, E. LaHood, J. Hard, and J. Miller. 2006. Changes in run timing and natural smolt production in a naturally spawning coho salmon (*Oncorhynchus kisutch*) population after 60 years of intensive hatchery supplementation. Canadian Journal of Fisheries and Aquatic Sciences 63:2343-2355.

Abstract: Supplementing natural fish populations with artificially propagated (hatchery) fish is a common practice. In evaluating supplementation, it is important to assess the relative fitness of both hatchery-produced and naturally produced fish when they spawn together in the wild and to evaluate how the absolute fitness of the natural population changes after many generations of supplementation. We evaluated the relative fitness of naturally produced and hatchery-produced coho salmon (*Oncorhynchus kisutch*) in Minter Creek, Washington, USA. We also evaluated long-term changes in natural smolt production in this stream after several decades of intensive hatchery supplementation. Total smolt production was estimated to be 14 660 and 19 415 in 2002 and 2003, respectively, compared with the average value of 28 425 from 1940 to 1955. We found no significant difference in relative fitness between hatchery and natural fish, probably because the natural population consists largely of fish produced from the hatchery a generation or two previously. There has been a long-term trend for adults to return to the stream earlier in the spawning season. We estimated standardized selection differentials on run timing, with results indicating stabilizing selection with an optimum run timing later than the mean contemporary run timing but earlier than the historical mean run timing.

Response: Note the authors found no significant difference in relative fitness between hatchery and natural fish. There is no attempt to explain how other factors (e.g., habitat degradation, changes in water management, etc.-see NOAA 1998 citation below) could explain the decline in smolt production between 1940-1955 and 2002-2003. Earlier run timing could potentially be explained by improper brood representation in hatchery protocols (see Mackey et al. 2001).

E.G. From: National Oceanic and Atmospheric Administration (NOAA). 1998 (on-line). "Population: Distribution, Density and Growth" by Thomas J. Culliton. NOAA's State of the Coast Report. Silver Spring, MD: NOAA. URL:
http://state_of_coast.noaa.gov/bulletins/html/pop_01/pop.html
"Another rapidly developing coastal area is Puget Sound, Washington. In 1940, the area's population totaled 860,000. It has increased by about 400,000 people every 10 years since then. The area is now home to about 3.2 million people. The area's population is expected to increase by another 1.4 million people, reaching 4.6 million in the year 2015. Rural areas are being engulfed by housing and commercial developments. Forests and meadows are being replaced by roads, homes, office buildings and shopping malls. Keeping Puget Sound healthy is a more and more difficult task."

Leider, S.A., P.L. Hulett, J.J. Loch, and M.W. Chilcote. 1990. Electrophoretic comparison of the reproductive success of naturally spawning transplanted and wild steelhead trout through the returning adult stage. Aquaculture 88:239-252.

Abstract: A previous electrophoretic assessment of the natural reproductive success of sympatric transplanted hatchery and wild sumer-run steelhead trout *Oncorhynchus mykiss* (formerly *Salmo gairdneri*) populations was extended to include returns to the adult life history stage. The mean percentage of offspring from naturally spawning hatchery steelhead decreased at successive life history stages from a potential of 85-87% at the egg stage to 42% at the adult stage. In addition, reproductive success of naturally spawning hatchery steelhead compared to wild steelhead decreased from 0.750-0.788 at the subyearling stage to 0.108-0.129 at the adult stage. In freshwater, the period of greatest differential mortality for offspring of hatchery and wild steelhead occurred from the subyearling to smolt stage, suggesting that influences such as predation and competition affected survival of hatchery offspring to a greater extent than did environmental and ecological effects directly associated with differences in parental spawning time. Differential mortality of hatchery offspring also occurred during the smolt to adult phase, and was of a magnitude similar to that for the egg to subyearling phase. Poorer survival for naturally produced offspring of hatchery fish could have been due to long-term artificial and domestication selection in the hatchery population, as well as maladaptation of the transplanted hatchery stock in the recipient stream.

Response:

McGinnity, P., C. Stone, J.B. Taggart, D. Cooke, D. Cotter, R. Hynes, C. McCamley, T. Cross, and A. Ferguson. 1997. Genetic impact of escaped farmed Atlantic salmon (*Salmo salar* L.) on native populations: use of DNA profiling to assess freshwater performance of wild, farmed, and hybrid progeny in a natural river environment. ICES Journal of Marine Science 54:998-1008.

Synopsis: Since Atlantic salmon (*Salmo salar* L.) used for farming are usually genetically different from local wild populations, breeding of escaped farmed salmon potentially results in genetic changes in wild populations. To determine the likelihood and impact of such genetic change, an experiment was undertaken, in a natural spawning tributary of the Burrishoole system in western Ireland, to compare the performance of wild, farmed, and hybrid Atlantic salmon progeny. Juveniles were assigned to family and group parentage by DNA profiling based on composite genotypes at seven minisatellite loci. Survival of the progeny of farmed salmon to the smolt stage was significantly lower than that of wild salmon, with increased mortality being greatest in the period from the eyed egg to the first summer. However, progeny of farmed salmon grew fastest and competitively displaced the smaller native fish downstream. The offspring of farmed salmon showed a reduced incidence of male parr maturity compared with native fish. The latter also showed a greater tendency to migrate as autumn pre-smolts. Growth and performance of hybrids were generally either intermediate or not significantly different from the wild fish. The demonstration that farmed and hybrid progeny can survive in the wild to the smolt stage, taken together with unpublished data that show that these smolts can survive at sea and home to their river of origin, indicates that escaped farmed salmon can produce long-term genetic changes in natural populations. These changes affect both single-locus and high-heritability quantitative traits, e.g. growth, sea age of maturity. While some of these changes may be advantageous from an angling management perspective, they are likely, in specific circumstances, to reduce population fitness and productivity. Full assessment of these changes will require details of marine survival, homing and reproductive performance of the adults together with information on the F_2 generation.

Response:

Moran, P. and R.S. Waples. 2007. Monitor and evaluate the genetic characteristics of supplemented salmon and steelhead. Annual Report to BPA, Project No. 1989-096-00.

Synopsis: The historical role of artificial propagation has typically been enhancement and mitigation; enhancement of existing fisheries or creation of new fishing opportunities and mitigation of habitat loss associated with hydropower. These applications have been, and to some extent remain, highly successful; however, traditional hatchery programs were not designed to sustainably increase natural production, and have generally not been demonstrated to do so. In many cases, artificial propagation can temporarily boost the number of spawners (Waples et al. 2007), but the ability to sustain that boost in the absence of continued hatchery propagation has rarely been demonstrated. Arguably, there are cases where fish have been re-introduced after extirpation of the native population, but the ability use supplementation to produce long-lasting increases in an existing natural population remains largely unproven. The consequences for listed species are unclear, and both theoretical and empirical data suggest that, in some cases at least, hatchery production can actually harm natural populations, putting them at greater, rather than lesser, risk of extinction. In most cases, it is not known how long positive or negative effects might persist, because hatchery production is rarely discontinued. The goal of artificial production in a conservation context is therefore to gain the demographic boost of hatchery production while minimizing whatever genetic risks might be associated with changes in the natural selective regime.

Response:

Murdoch, A.R., T.N. Pearsons, T.W. Maitland, M.J. Ford, and K. Williamson. 2008. Monitoring the reproductive success of naturally spawning hatchery and natural spring Chinook salmon in the Wenatchee River. Annual Report to BPA, Project No. 2003-039-00, Contract No. 00032138.

Abstract: Hatcheries have been increasingly asked to contribute to conserving natural salmon populations, as well as to continue to produce fish to mitigate for lost harvest opportunities. A key biological uncertainty about the effects of hatchery production on natural populations is the degree to which hatchery produced fish can reproduce in the natural environment. In order to help assess the impact (positive or negative) of supplementation of spring Chinook salmon in the Wenatchee River we are using a DNA-based pedigree analysis to (1) directly measure the relative reproductive success of hatchery and natural-origin spring Chinook salmon in the natural environment, and (2) determine the degree to which any differences in reproductive success between hatchery and natural Chinook salmon can be explained by measurable biological characteristics such as run timing, morphology, and reproductive behavior. Both male and female hatchery fish produced far fewer progeny per parent when spawning naturally than did natural-origin fish. Differences in age structure, spawning location, weight, and run timing were responsible for a portion of the difference in fitness between hatchery and natural-origin fish. Male size and age had a large influence on fitness, with older and larger males selectively favored. Male run time had a smaller but still significant effect on fitness, with earlier returning fish favored. Female size had a significant effect on fitness, but the effect was much smaller than the effect of size on male fitness. Spawning location had a significant effect on fitness for both males and females, and for females may largely explain the reduced fitness observed for hatchery fish.

Response:

Reisenbichler, R.R. and J.D. McIntyre. 1977. Genetic Differences in Growth and Survival of Juvenile Hatchery and Wild Steelhead Trout, *Salmo gairdneri*. Journal of Fisheries Resource Board of Canada 34:123-128.

Abstract: Relative growth and survival of offspring from matings of hatchery and wild Deschutes River (Oregon) summer steelhead trout, *Salmo gairdneri*, were measured to determine if hatchery fish differ genetically from wild fish in traits that can affect the stock-recruitment relationship of wild populations. Sections of four natural streams and a hatchery pond were each stocked with genetically marked (lactate dehydrogenase genotypes) eyed eggs or unfed swim-up fry from each of three matings: hatchery x hatchery (HH), hatchery x wild (HW), and wild x wild (WW). In streams, WW fish had the highest survival and HW fish the highest growth rates when significant differences were found in the hatchery pond. HH fish had the highest survival and growth rates. The hatchery fish were genetically different from wild fish and when they interbreed with wild fish may reduce the number of smolts produced. Hatchery procedures can be modified to reduce the genetic differences between hatchery and wild fish.

Response: