Reference Document: Upper Klamath River Coho Salmon Workshop Considerations for Genetic Conservation and Artificial Propagation

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Abundance of coho salmon in the Shasta River has declined precipitously. All recent spawning cohorts have collapsed to well under 100 adult returns (adult abundance estimates for 2008=30, 2009=9, 2010=44; D. Chesney and M. Knechtle, 2011, Klamath River Project Draft Report, CA DFG), many of which are hatchery-origin strays. Further, all recent spawning runs have failed to produce enough juveniles to replace themselves under typical marine survival conditions. With uncertainties about the genetic status of the Shasta River population and the capacity of habitat in the Shasta River to produce fish, the path forward for recovery and management of coho salmon in the Shasta River is not clear. The Upper Klamath River Coho Salmon Workshop was organized by a group local stakeholders, state and federal agency fisheries managers and regulatory personnel to share the best available information on the current status of the Shasta River salmon population, its habitat, abundance, and genetic composition; and to explore options available for supplementation to assist in the recovery of the Shasta River coho salmon population. There is evidence that other coho salmon populations in the Upper Klamath are on a similar trajectory to the Shasta population, so information and strategies shared at this conference have implications beyond the Shasta River. Moreover, the Shasta River population doesn't stand alone; it interacts with neighboring hatchery and wild populations, so simultaneous consideration of the entire upper Klamath River Basin is required.

This document is a record of the workshop proceedings. The initial summary section is not intended to include all of the detailed information presented, but to encapsulate the main points as they are relevant to the purposes of the workshop (see below) and provide a brief science-based synthesis. For more detailed information, abstracts and slides from all of the presentations are included as an appendix. Note that this document is not intended to be a plan for future supplementation efforts on the Shasta, but a reference as the groups involved decide on the best course of action.

Purposes of the workshop:

1) To review existing information regarding the genetic diversity of Shasta River wild fish, Iron Gate Hatchery coho brood stock, and nearby populations of coho (including Upper Klamath and Scott River populations);
2) To assess the degree of consensus, if any, regarding appropriate brood stock source(s) for any coho supplementation plan that may be implemented in the Shasta River
3) To evaluate various coho salmon supplementation techniques for application in the Shasta River.

The summary is organized into sections roughly corresponding to the purposes, with the addition of introductory sections that review the information presented on the current status of the population and its habitat and the coho salmon stock at Iron Gate Hatchery and a final section that synthesizes all of the sections to address the overarching question of whether supplementation is justified for the Shasta River coho salmon population.

Organization:

1. Shasta River coho salmon population and habitat status
2. Coho salmon and Iron Gate Hatchery
3. Genetic status of the upper Klamath River coho salmon populations
4. Supplementation techniques and potential broodstock sources
5. Is supplementation justified?

1. Shasta River coho salmon population and habitat status

The Shasta River is unusual habitat for coho salmon within the threatened Southern Oregon/Northern California Coast coho salmon Evolutionary Significant Unit (SONCC coho ESU). The warm summer temperatures, low precipitation, and lack of forested land cover in the valley at the headwaters of the Shasta are very different from the cool, shaded forests that typify juvenile coho rearing habitat in coastal streams. However, springs in the upper Shasta River produce cool water year-round, providing a summer refuge to heat-intolerant coho salmon while the nutrient-rich spring water supports massive populations of invertebrate prey for juvenile coho. Further, these spring-fed habitats are not subject to the extreme winter floods that challenge coastal coho populations. This habitat in the Shasta likely supported substantial production of coho salmon historically (Snyder 1931, Brown and Moyle 1991).

While potential for coho salmon production in the Shasta River may be substantial, it has not been realized in recent years due to alterations of the habitat and water flow in the upper Shasta, its tributaries, and downstream in the mainstem Klamath River. In the Shasta River, reduced flows due to irrigation, loss of in-stream and riparian vegetation, and increased channel width have increased heat gain so that cool-water habitat suitable for coho salmon is limited to areas immediately adjacent to spring outflows. Further, very low spring and summer flows during the irrigation season (in concert with high temperatures) restrict movement of juvenile salmon seeking patches of suitable habitat and interfere with migration of salmon smolts downstream out of the Shasta River, leading to high mortality.

Recent and ongoing habitat restoration projects have yielded substantial improvements to the habitat in the Shasta River and its tributaries, especially on the Big Springs property acquired by The Nature Conservancy. Fencing and re-vegetation of riparian and in-stream habitat, along with a cooler, wetter summer in 2011, have contributed to larger areas of suitable thermal habitat for coho. Work is ongoing to improve water management to maintain flows during critical periods for salmon dispersal and migration.

What is not clear in the Shasta River is whether the current low recruitment is simply a result of the low number of adults spawning or whether the habitat capacity and productivity limits the population.

Average marine survival in recent years for Shasta fish is estimated at 3.3%. Given this survival rate, freshwater production amounting to 30 smolts for each spawning adult is required to sustain the population. Average freshwater production in the Shasta estimated over recent years is 18 smolts per adult, much less than the 30 required to prevent a population decline. Other factors may have contributed to the decline, but the data indicates that current freshwater production in the Shasta is likely too low to sustain a population.

Synthesis: There are at least three categories of causes for low coho salmon freshwater production in the Shasta River, all with different implications for management and supplementation (ignoring genetic issues for now- see Section 2 below).

1. Low productivity could be due to depensatory effects (negative effects of small population size on population growth), such as inbreeding, difficulty finding mates, and elevated losses due to predators. If depensation is limiting productivity, supplementation could have a substantial positive effect on population size and growth rate.
2. The current habitat could be at its capacity because there is not enough space in suitable habitat or resources to produce additional smolts (Scheuerell et al. 2006). If the habitat is at capacity, supplementation would have no beneficial effect (additional individuals would just be lost because there is no habitat available to support them) and, at worst, could reduce production (if increased competition for limited space could have detrimental effects on all fish, or if lower-fitness hatchery origin fish replaced natural origin fish).
3. The habitat could have a low productivity but not be at capacity (Scheuerell et al. 2006)- for example if fry have poor survival during late spring early summer because most perish before they find a suitable thermal refuge. In this case, supplementation could have a small positive effect on population size, but would be very inefficient because, like the natural stock, most additional fish would perish. The population would continue to decline after supplementation if the cause of low productivity were not rectified.

Note that these three general causes are in no way mutually exclusive and all could be constraining production in any given year. A fourth possibility, discussed below, is that low productivity is due to low fitness in nature of the current Shasta River stock, due to genetic influences of IGH strays.

At present, there is not sufficient information to identify the specific causes of low production for the Shasta River coho salmon population and whether they are associated with depensation, capacity, or productivity. Further, given that habitat conditions can change substantially depending on annual temperatures and precipitation, and coho abundance varies widely across cohorts, the same factors may not be limiting from one year to the next. Two lines of evidence- the incredibly high growth rates of juvenile coho in the spring habitats in the Upper Shasta and the fact that there is no indication that production rates are depressed for the one remaining cohort with appreciable numbers- both suggest that there is likely capacity for more juvenile production. However that capacity is not useful if productivity is limited by habitat required for other life stages (e.g. migration) to levels too low for the population to persist.

2. Coho salmon and Iron Gate Hatchery

Iron Gate Hatchery (IGH) initiated operations in the mid-1960s to mitigate for habitat loss associated with dam construction. The founding IGH coho salmon stock originated from Trinity River Hatchery and a variety of stocks from outside sources were propagated at IGH until 1970. Since this time only local stock has been spawned at IGH. Iron Gate Hatchery releases 75,000 yearling coho salmon and 100% of releases are marked, but concurrently releases millions of Chinook salmon and therefore (theoretically) has the capacity to expand production of coho salmon

The draft Hatchery and Genetic Management Plan calls for IGH to serve as a tool to aid in recovery and conservation of coho salmon. The plan calls for an integrated program that simultaneously considers population components that spawn in the wild and in a hatchery. Under such a program the natural environment is to drive adaptation and fitness. This goal has been set in response to a growing literature that indicates hatchery stocks can have dramatically lower fitness than wild stocks in natural areas and that the effects can carry-over to wild-born descendants of hatchery parents.

The proportion of natural influence, or PNI, is the standard metric for determining the extent to which the natural environment drives adaptation in integrated hatchery programs. Using a quantitative genetic model, and a few simplifying assumptions, it is generally thought that PNI depends almost entirely on the extent of migration between the wild and hatchery populations. PNI is expressed mathematically as: PNI = pNOB/(pNOB + pHOS), where pNOB is the proportion of natural-origin fish in the hatchery broodstock and pHOS is the proportion of hatchery-origin fish on the spawning grounds. Higher PNI values indicate natural environments are driving adaptation whereas lower values suggest a strong role for hatchery domestication selection. For natural environment to drive adaptation it is recommended that PNI exceed 0.5. To ensure high levels of natural dominance in stocks of biological significance PNI should be greater than 0.7.

The pNOB for coho salmon at IGH has varied dramatically through time. From 1997-03 volitional entries to IGH were spawned and during this period pNOB ranged from 0.06 to 0.44. From 2004 to 2009 NOAA and CDFG entered into an agreement that resulted in reduction of pNOB to 0.03-0.15. In 2010 and 2011 pNOB was 0.12 and 0.25, respectively, owing to deliberate efforts increase pNOB by hatchery staff. The future target for pNOB at IGH is 0.20-0.50.

At IGH pNOB can be directly prescribed, however the ability to control pHOS in natural areas depends upon the geographic context considered. In Bogus Creek future plans call for placement of a weir near its confluence with the Klamath River which would allow control of pHOS. Due to the presence of weirs, similar opportunities exist on the Shasta and Scott rivers. In contrast, controlling pHOS on the mainstem Klamath River presents logistical problems owing to the large size of the river.

Estimates of pHOS for Bogus Creek between 2004 and 2011 ranged 0.24 to 0.75 and estimates for pHOS in the Shasta River from 2007 to 2011 ranged 0.02 to 0.71. Large fractions of hatchery-origin fish in wild spawning areas in some years combined with low to moderate levels of pNOB at IGH, suggest low levels of wild adaptation in Bogus Creek and Shasta River coho salmon populations. In contrast, no IGH coho salmon have been recovered at Scott River in recent surveys (to the authors knowledge) suggesting strong potential for retention of local and wild adaptation at this location.

The future target for PNI for the upper Klamath basin coho salmon is 0.50. There appears to be three major obstacles to reaching this PNI target. First, relatively low numbers of natural-origin individuals volitionally enter IGH in some years and thus it will likely be difficult to attain pNOB targets without collections from wild areas. Weirs provide convenient facilities to collect natural-origin fish in the event that pNOB targets cannot be met at IGH. Second, there is no clear mechanism for controlling pHOS for the coho population spawning on the mainstem Klamath River. Third, IGH currently releases surplus coho salmon not required to reach mitigation goals back to the Klamath River. This new policy was initiated in 2010. Prior to this period excess coho salmon at IGH were culled. New protocols were instituted to provide demographic support for depleted wild stocks but may pose problems for attaining PNI targets by boosting pHOS in natural areas.

Concerns over inbreeding of coho salmon at IGH have arisen owing to low numbers in some years. For example, in 2009 a total of 20 females were spawned at IGH. Starting in 2010 a program was implemented to minimize inbreeding among coho salmon spawned at IGH. Genetic analyses are conducted to estimate relatedness among the hatchery broodstock prior to spawning. A spawning matrix is generated that lists the relatedness between each female and all potential male partners. Candidate males with relatedness coefficients ≥0.25 (greater than half siblings) are deemed too closely related to be spawned. The remaining males are ranked according to relatedness and those least related to the target female are deemed the best match for inbreeding avoidance.

Five additional items with respect to the IGH coho salmon program merit mention. First, historically no jacks were spawned at IGH. Given that almost all coho salmon spawn at age three, this has resulted in the cessation of gene flow between brood years. Future plans call for spawning jacks at IGH at a rate equivalent to their abundance at IGH, a procedure which should restore gene flow between brood years. Second, one to one mating between males and females are planned for the future. This procedure will decrease variance in family size, a factor shown to be responsible for major reductions in genetic effective population size of steelhead. Third, out-of-basin fish, such as the occasional stray from Trinity River Hatchery or the Rogue River, will be not be spawned at IGH. This policy seemingly thwarts natural gene flow processes and prevents introduction of genetic diversity from outside sources. Fourth, studies of the life history of wild and hatchery populations are being considered in response to evidence that suggests that hatchery coho salmon spawn earlier (early-November to early-December) than populations from the wild areas (later in December). Lastly, the IGH Hatchery and Genetic Management Plan has language that allows for stocking of IGH reared coho salmon directly into natural areas such as Shasta or Scott rivers.

Synthesis: Coho salmon produced at IGH in the recent past are potentially inbred (few spawners) and likely subject to domestication selection (low pNOB). Both factors would tend to reduce the fitness of hatchery-origin fish in the wild. Further, IGH fish have clearly been straying into the Shasta River and locations within the upper Klamath Basin with exception of the Scott River. The influence of this hatchery strain is one further potential explanation for the low productivity of the Shasta population (see Section 1 above), as observed in other salmon species and populations that mix with hatchery fish (Chilcote et al. 2011). If hatchery influence has reduced production potential of the Shasta River stock, supplementation has limited potential to increase production of coho salmon in the short term unless fish with higher fitness in the wild than the current hatchery or Shasta River strain are used.

3. Genetic status of the upper Klamath River coho salmon population

Two coho salmon evolutionary significant units (ESUs) are recognized in California. Coho salmon populations south of Punta Gorda, California are assigned to the Central California Coast (CCC) ESU and those populations distributed between Cape Blanco, Oregon, and Punta Gorda, California are in the southern Oregon/Northern California coast (SONCC) ESU. Under the US Endangered Species Act the CCC is considered endangered whereas the SONCC has threatened status. The upper Klamath River, including coho salmon from Scott River, Shasta River, Bogus Creek, the Klamath River mainstem and Iron Gate Hatchery are within the SONCC ESU. The upper Klamath River coho salmon populations represent a modest portion of the entire geographic range of the SONCC ESU.

Coastwide evaluations of genetic structure within coho salmon reveal that genetic divergence is strongly related to geography, presumably as a consequence of the homing tendencies of this species. Owing to the importance of geography, genetic structure in coho salmon is hierarchically structured with progressively lower levels of genetic differentiation as the spatial scale becomes smaller. The largest levels of genetic divergence within California are between the geographically separated SONCC and CCC ESUs. In tree-based analyses, the Klamath River basin is a divergent fork within the SONCC, differentiated from all other populations within the ESU. Within the Klamath River drainage, the Trinity and Klamath systems are genetically differentiated, consistent with the geographic separation between these regions, representing the finest scale of strong genetic and geographic based structuring in the Klamath River basin.

In fine-scale analysis of genetic differentiation among populations in the upper Klamath River basin, the Scott River population exhibits differentiation from individuals returning to the Shasta River, Bogus Creek, and Iron Gate Hatchery. This finding is consistent with current monitoring (clip identification of recovered adults), which has not detected an influence of IGH coho in the Scott River. Thus, field and genetic data both support the assertion that a unique genetic lineage exists within the Scott River and that this lineage likely exhibits adaptive characteristics of a wild stock.

In contrast, there is appreciable genetic evidence indicating substantial gene flow between Iron Gate Hatchery, Bogus Creek and Shasta River, indicating that these populations represent a single metapopulation connected by migration. Tagging studies further corroborate this assertion by showing that large numbers of IGH coho salmon stray from the hatchery, particularly into Bogus Creek, but also into the Shasta River (Shasta River pHOS from 0.02 to 0.71 between 2007 and 2011). Thus, there is no evidence of genetically diverged lineages within the Shasta River, or that this population possesses specialized genetic variation or unique adaptations.

Instead, genetic analyses indicate a dominance of temporal structuring among populations in the extreme upper end of the Klamath River basin (minus Scott River), likely brought about by hatchery management practices. Tree-based and Bayesian methods both show marked divergence among brood cycle cycles at Iron Gate Hatchery and that this divergence exceeds levels of divergence between geographically separate locations. For example, genetic divergence between brood cycles from Iron Gate Hatchery (2007 and 2010 vs. 2005, 2008, and 2011 vs. 2006 and 2009) exceeds levels of divergence between rivers. The predominate three year life cycle of coho salmon combined with the limit use of jacks (two year olds) at Iron Gate Hatchery until 2010 is the most likely factor responsible for this pattern. Thus temporal structuring is result of recent management practices at Iron Gate Hatchery rather than natural genetic structuring patterns expected for coho salmon.

Synthesis: Available genetic evidence indicates that the fish currently spawning and rearing in the Shasta River do not represent a reservoir of unique genetic information, but instead are similar to other populations of coho salmon in the upper Klamath River Basin (e.g., Bogus Creek, IGH or mainstem Klamath River). There is evidence for substantial genetic and demographic connectivity among populations in the upper Klamath River Basin (IGH, Bogus Creek, and Shasta River). In contrast, the Scott River population exhibits appreciable divergence from those populations in upper Klamath River Basin (IGH, Bogus Creek, and Shasta River).

4. Supplementation techniques and potential broodstock sources

Many supplementation programs have been implemented for coho salmon populations throughout their range, as well as for other salmon species. A variety of approaches and techniques for supplementation exist. Conservation and restoration oriented supplementation programs are fundamentally different from hatchery production programs that focus on the ongoing production of large quantities of fish to maintain harvest opportunities. The goal for conservation hatcheries is generally to prevent extinction of a local stock and boost abundance of natural-origin fish, while avoiding any negative effects by minimizing the fitness difference between the hatchery and natural origin stocks. This approach is inherently a short-term fix, with hatcheries operating only until the factors that caused the population to decline are corrected.

The presentations at the workshop outlined the implementation and evaluation of several supplementation techniques. Brief outlines are included in the summary table below (Table 1). The overall conclusion from the presentations, and the broader literature on salmon supplementation and recovery, is that regardless of the technique the outcome of supplementation attempts is uncertain. If the goal is to increase the natural spawning population, then only way to rigorously evaluate the success of supplementation programs is test for an increase in natural-origin spawners (not total spawners) in the generations after the supplementation program is implemented- clearly a long-term prospect given the 3-year generation time of coho salmon. Further, to confidently determine whether supplementation is the cause of observed changes, such a program requires monitoring of unsupplemented reference sites as a control. This level of evaluation is very rare. Where implemented, these evaluations have often come to the conclusion that supplementation had no positive effect on the abundance of natural-origin fish (see Carmichael presentation) and may have reduced natural production (Chilcote et al. 2011).

It is useful to consider the intensity of a supplementation techniques considered, where intensity is an aggregate measure including monetary costs (personnel and facilities required), biological costs (the potential for hatchery practices to alter life history expression of subsequent recruits), and demographic benefits (degree of enhanced production of recruits that is likely due to by-passing habitat constraints). The supplementation techniques presented at the workshop can be roughly ranked from low to high intensity as follows: adult release (of sea-run adults), egg injection (produced from sea-run adults), juvenile/fry release (produced from sea-run adults), smolt release (produced from sea-run adults), adult release (of captive-reared adults), captive broodstock (offspring release produced from captive-reared adults). Given likely funding and the lack of evidence for a unique local lineage, lower-intensity techniques may be more appropriate if a supplementation program is pursued in the Shasta River.

Table 1. Summary table of presentations on supplementation techniques.

				Evaluation				
Presentation	**Salmon species**	**Broodstock origin**	**Supplementation technique**	**Adults produced?**	**Total spawners increased?**	**Natural origin spawners increased?**	**Reference sites?**	**Notes**
Charlie Lean	Chum, coho	Local natural origin broodstock	Eyed egg injection	Yes	No data	No data	No	Additional benefits: community involvement, low cost.
Larry Lestelle	Coho	Local natural-origin broodstock	Pre-smolt release	Yes	Yes	No	No	No reduction in productivity of natural stock. Habitat at capacity for natural juvenile production.
Thom Johnson	Coho	Local natural origin broodstock (returning supplemental fish used in later years)	Egg, young-of-the-year, and pre-smolt releases	Yes	Yes	Yes (?)	No	Cannot separate the effect of supplementation from effects of concurrent habitat improvements.
Ben White	Coho	Captive-reared broodstock collected as local natural origin juveniles (returning supplemental fish used in later years). Recent outcrossing with fish from nearby streams to reduce inbreeding.	Young-of-the-year and smolt releases.	Yes	Yes	Yes (?)	No	Cannot separate the effect of supplementation from effects of concurrent habitat improvements.
Carlos Garza	Coho	Captive-reared broodstock from nearby streams	Adult release	No data	Yes (in release year)	No data	No	Released adults avoided mating with closely-related individuals.
Rich Carmichael (Grande Ronde)	Chinook	Captive-reared broodstock collected as local natural origin juveniles (compare to conventional hatchery)	Smolt release	Yes	Yes	No	No	Captive broodstock had reduced hatchery performance relative to conventional hatchery fish.
Rich Carmichael (Imnaha)	Chinook	Local natural-origin broodstock crossed with hatchery-origin broodstock (sliding scale of pNOB depending on escapement).	Smolt release	Yes	Yes	No	Yes	Productivity (recruits/spawner) of natural origin spawners has also declined in the supplemented system relative to reference sites. Hatchery practices have changed the life history of hatchery-origin fish.

There is no clear best choice for a broodstock source for a supplementation effort in the Shasta. Our discussion of the potential sources below is broken down according to the life stage considered for release. We briefly outline potential costs and benefits of each source. These lists are not exhaustive, but meant to cover the points raised in discussion at the workshop.

- Adults
    - Hatchery-origin fish that return to IGH
        - Benefits: Fish are readily obtainable. No impact on extant wild populations or availability of NOB for spawning at IGH.
        - Costs: Potentially low fitness in natural areas due to past inbreeding or domestication; hopefully less of an issue with use of inbreeding avoidance measures (e.g., breeding matrix) and increased use of NOB at IGH in future years.
    - Natural-origin fish that return to IGH
        - Benefits: Fish are readily obtainable. Less likely to have reduced fitness due to domestication (and perhaps inbreeding).
        - Costs: Takes fish that would be available to use as NOB as IGH; increasing pNOB at IGH is important because IGH coho salmon stray into many areas within the upper Klamath River (excepting the Scott River). Thus increasing pNOB at IGH has the potential increase wild fitness of the coho population in the upper Klamath (including the Shasta, but not the Scott River).
    - Natural-origin adults collected from the Upper Klamath (e.g. Bogus Creek or mainstem Klamath River)
        - Benefit: Less likely to have reduced fitness in the wild due to hatchery effects but probably only a few generations removed from hatchery influence.
        - Costs: More difficult to obtain fish. Increased pHOSin natural areas may make it more difficult to achieve PNI goals. Reduced spawners in natural areas to provide demographic support. May have an overall negative effect on Upper Klamath coho if production is lower in the Shasta than the source habitat.
    - Natural-origin adults collected from the Scott River
        - Benefits: Least likely to have reduced fitness in natural areas due to hatchery domestication (vs. Shasta River or Mainstem Klamath River).
        - Costs: Difficult to obtain fish. Decreases numbers of coho salmon in the Scott River; a population of conservation concern due to low numbers. May have an overall negative effect on Upper Klamath coho salmon if production is lower in the Shasta than the Scott River.
    - Juveniles collected in the Shasta River and grown to maturity in captivity
        - Benefits: No need for mining of adult returns from elsewhere in the Upper Klamath River basin. Perceived benefit of preserving unique Shasta River lineage, although data do not support this.
        - Costs: Expensive. Potential for inbreeding given small population size, but this issue could be addressed with inbreeding avoidance measures (e.g., breeding matrix). Uncertain need given the strong hatchery component in the parentage of extant Shasta River fish and lack of evidence for genetic unique lineage within the Shasta River.

- Eggs/Fry
    - Produced from a breeding matrix from returns at IGH (mix of hatchery and natural origin fish used as broodstock)
        - Benefits: Fish are easily obtainable. No additional facilities required.
        - Costs: Some potential for reduced fitness due to past hatchery practices; hopefully less of an issue with use inbreeding avoidance measures (e.g,breeding matrix) and increased use of NOB at IGH in future years.
    - Produced from adults that returned to the Shasta
        - Benefits: No need for mining of adult returns from elsewhere in the Upper Klamath River basin. Perceived benefit of preserving unique Shasta River lineage, although data do not support this.
        - Costs: Difficult to obtain fish. If eggs are used, some type of fish culture facility is necessary. Small numbers could lead to inbreeding. Questionable benefit given the hatchery component in the parentage of extant Shasta River fish.
    - Produced from a mix of adults that return to the Shasta and IGH (mix of hatchery and natural origin)
        - Benefits: Perceived benefit of retaining genetic information of Shasta River fish, although data do not support this.
        - Costs: Difficult to obtain fish. Questionable benefit given the hatchery component that already exists in the parentage of extant Shasta River fish.
    - Produced from a mix of natural-origin only adults from the Upper Klamath (including Shasta River, Bogus Creek, IGH, and potentially Scott River)
        - Benefits: Less likely to have reduced fitness due to past hatchery practices (e.g., inbreeding and domestication).
        - Costs: Difficult to obtain fish. Increased pHOS in natural areas. May have an overall negative effect on abundance of Upper Klamath coho salmon if production is lower in the Shasta than the source habitat. If Scott River fish are used, it will decrease numbers of coho salmon in the Scott River; a population of conservation concern due to low numbers.
    - Produced from captive-reared juveniles collected in the Shasta
        - Benefits: No need for mining of adult returns from elsewhere in the Upper Klamath River basin. Perceived benefit of preserving unique Shasta River lineage, although data do not support this.
        - Costs: Expensive. Requires a facility for juvenile to adult rearing, adult spawning, and egg culture. Potential for inbreeding given small population size. Questionable benefit given the hatchery component in the parentage of extant Shasta River fish.
- Juveniles/Smolts
    - In general, costs and benefits of broodstock sources used to produce older juveniles for release are similar to those for eggs and fry, with exceptions noted below.

        - Costs: Extended hatchery-rearing period leads to increased potential for hatchery effects on fitness due to domestication selection and short-term behavioral and life history responses to the hatchery environment.
        - Benefit: Increased survival and growth in the hatchery means that strategies that take fish from the wild are less likely to have a short-term negative effect on abundance of the Upper Klamath coho population compared to adult or egg/fry releases that are subject to habitat constraints in the Shasta River.
    - Transplanted juveniles from rescue operations in the Scott River.
        - Benefits: Of all populations in the Upper Klamath basin (above the Salmon River) confluence, the Scott River receives the fewest IGH strays (none according to field data) and is thus least likely to have reduced fitness due to hatchery effects. Further, inbreeding is likely to be of little concern given the larger population sizes and gene flow across brood years by jacks in natural areas.
        - Costs: Difficult to obtain fish. Possibly depresses abundance of the the Scott (compared to transplanting the fish to rescue locations in the Scott River coho salmon population). Importantly, this action would artificially increase connectivity (gene flow) between populations. Available evidence suggests gene flow between the Scott River and extreme upper portion of the Klamath Basin (e.g., IGH and Shasta River) currently occurs at a low rate.

5. Is supplementation justified?

The workshop participants share the goal of recovery of coho salmon with the Shasta River. Panelists at the workshop concurred that there is little potential for a near-term recovery of a healthy Shasta River coho run without supplementation. The question then is whether supplementation is justified in the near future. The costs are not trivial. Even with the lower-cost methods presented at this workshop (e.g. eyed-egg injection, adult release), supplementation could not occur without a substantial investment of funding in monitoring and evaluation. Further, the genetic evidence presented indicates that there is no need to rush to action to save a unique lineage of biodiversity, but instead the populations within the upper basin should be considered a single unit. The Shasta River may benefit more in the long run from an integrated effort to improve the fitness of the coho population at IGH and the Upper Klamath. From a broader perspective, the Shasta River population represents a small fraction of the entire SONCC ESU, the fundamental unit for conservation under the ESA. If resources invested in Shasta River supplementation would take away from investment elsewhere, the status of other populations in the ESU should be considered before supplementation is attempted in the Shasta River.

As noted in the review of supplementation techniques, there is no certainty that supplementation would yield any benefit in terms of increased natural abundance of coho salmon in the Shasta River. Nonetheless, there are substantial benefits that could come from successful supplementation. The diverse group of stakeholders working together to evaluate options for coho recovery could go a long way toward building greater community investment in coho salmon in the Upper Klamath with the impetus of a successful supplementation program. Such community investment will be required for habitat restoration efforts that will be an essential part of a broader coho recovery effort. Further, if a supplementation effort in the Shasta is designed as an experiment to evaluate specific techniques, the information gained from rigorous evaluation could be invaluable for other coho restoration efforts regardless of whether the initial strategies implemented in the Shasta are successful.

Finally, it is worth noting that straying of IGH fish is a de facto supplementation program already in operation in the Shasta River that will continue into the future. The ongoing decline in abundance of Shasta River coho salmon indicates that supplementation is currently not working as recovery tool in this system. This does not mean that strategic planned supplementation could not help to speed recovery, particularly if higher rates of supplementation could overcome depensation or incorporate fish with higher fitness in the wild than the current IGH strays. However, the failure of this ongoing supplementation suggests that supplementation alone is not sufficient. Work to improve habitat conditions in the Shasta River and the fitness in the wild of fish produced at IGH must continue for successful coho recovery in the Shasta River. Planning should integrate consideration of supplementation with habitat restoration efforts and hatchery practices at IGH, bringing all available tools to bear for coho recovery.

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Appendix- Presentation summaries

Shasta River Juvenile Coho Distribution, Migration and Survival. *Bill Chesney, California Department of Fish and Game.* Overview of coho salmon rearing habitats in the Shasta River including maps and photographs of the Upper Shasta Spring Complex and the downstream Canyon Reach. Results of two seasons of field studies are presented including description of the spatial and temporal aspects of early life history and survival estimates for smolt emigration.

Population Estimates of Adult and Juvenile Coho Salmon in the Scott River, Shasta River and Bogus Creek. *Morgan Knechtle, California Department of Fish and Game*. In addition to descriptions of abundance of smolt and adults, this presentation provides estimates of the proportion of hatchery origin spawners in the Shasta River and Bogus Creek. This latter metric is key for understanding the extent to which an unique and wild adapted form may exist the Shasta River. Further smolt to adult survival estimates are provided.

Population status. *Toz Soto, Karuk Tribe*. Summary of survey efforts for coho salmon in the upper Klamath River, including the study areas and the number of redds, live adults and carcasses detected in these areas. Comparison of spawning timing between upper- and mid-Klamath coho salmon populations is also provided.

Stressors influencing the viability of Shata, Scott, and Upper Klamath SONCC Coho Salmon Populations. *Jim Simondet, National Marine Fisheries Service*. A baseline description of the historical physical and ecological conditions for coho Salmon in the Upper Klamath River Basin. Contemporary stressors that may adversely affect coho salmon are also highlighted (e.g., hydrology, water quality, riparian habitat, habitat complexity, sedimentation, disease, and hatchery impacts).

Actions in the Shasta River. *David Webb, Shasta Valley Resource Conservation District*. Overview of the geology, climate, land ownership, irrigation methods, and ongoing habitat restoration efforts (e.g., fencing, flash-board dam removal) in the Shasta River. Photographs documenting the outcome of habitat restoration efforts.

Thermal diversity and habitat conditions in the Shasta River. *Mike Deas(1) and Carson Jeffres(2). (1) Watercourse Engineering, Inc., and (2) UC Davis Center for Watershed Sciences.* Summary of the importance of thermal diversity for fisheries management and current thermal conditions in the Shasta River basin with particular emphasis upon the Big Springs complex in the upper basin. Also included is a summary of habitat conditions and prey productivity for coho salmon in the Shasta River.

DRAFT Hatchery and Genetic Management Plan (HGMP) for Iron Gate Hatchery Coho Salmon. *Morgan Knechtle, California Department of Fish and Game*. Highlights mitigation role, implementation of the integrated wild and hatchery population program, and conservation role for the Iron Gate Hatchery (IGH) coho salmon program. Changes underway to increase survival and minimize inbreeding at IGH are described. Presentation includes an important summary table describing spawning numbers at IGH (1993-2011) including proportion of natural origin fish used as broodstock and proportion of jacks used as broodstock. Future monitoring and evaluation efforts are also discussed.

Application of conservation genetic principles to salmon recovery. Michael Lacy, California Department of Fish and Game. Overview of conservation principles and their application to potential issues regarding recovery of coho salmon in the Shasta River.

Population Genetic Structure of Coho Salmon in the Klamath River. *John Carlos Garza, Southwest Fisheries Science Center, NOAA*. Description of the population genetic structure of Coho salmon at various hierarchical scales include range-wide, within California, and within the Klamath River drainage. Emphasis is placed upon comparisons among populations in the upper Klamath basin, particularly brood cycles returning to Iron Gate Hatchery. The genetic broodstock management program currently employed at Iron Gate Hatchery is also described.

Overview of the Steps Required to Establish a Supplementation Program. *Michael Lacy, California Department of Fish and Game.* Highlights the historical use of hatcheries to restore salmon stocks, uncertainties regarding these programs, and the role of conservation hatcheries in the recovery of salmon. An overview of specific issues to be addressed prior to, during, and after establishing a conservation hatchery are presented.

Salmon Enhancement in Norton Sound, Alaska. *Charlie Lean, Norton Sound Economic Development Corporation*. Summary of mist incubation and eyed-egg planting efforts aimed to recover depleted salmon stocks. The costs and benefits of the combination of mist incubation and eyed-egg planting in comparison to other techniques are discussed. The modular and portable equipment are described. Labor costs and the means of minimizing water consumption are discussed. Finally, a discussion of the trade-off between the traditional hatchery reared juvenile salmon survival and that of juveniles hatching and rearing in natural habitats is initiated.

Coho supplementation in the Queets River, Washington. *Larry Lestelle, Biostream Environmental*. Summary of supplementation efforts for coho salmon in the Queets River (1989-2002) illustrating that supplementation amplified total abundance of spawners but yielded no increase in the abundance of natural origin fish due to freshwater habitat capacity. Also discusses the benefits of incorporating natural origin fish into hatchery broodstock and complications associated with monitoring performance of a supplementation program.

Supplementation Strategies to Recover Wild Coho Salmon in Snow Creek, WA. *Thom H. Johnson, Point No Point Treaty Council*. Description of a successful coho salmon supplementation program from start to finish including rationale for the approach, experimental design, evaluation methods, and results.

The Russian River Coho Salmon Captive Broodstock Program: Recovery in Progress. *Ben White, Army Corps of Engineers.* Summary of ongoing efforts to restore self-sustaining populations of Coho salmon in the Russian River including a description hatchery procedures and field monitoring efforts.

Coho salmon conservation in the Central California Coast ESU. *John Carlos Garza, Southwest Fisheries Science Center, NOAA*. Synopsis of conservation efforts involving release of captive-raised mature adult coho salmon and summary of ongoing efforts employing this strategy in the Central California Coast ESU.

Implementation and Effectiveness of Captive Broodstock for Conservation of Threatened Spring Chinook Salmon in the Grande Ronde Basin, Oregon. *Richard W. Carmichael, Oregon Department of Fish and Wildlife.* Overview of captive broodstock program for Chinook salmon in the Grande Ronde Basin including descriptions of management goals, monitoring and evaluation procedures, hatchery broodstock strategies and effectiveness of supplementation efforts. Discussion of demographic benefits and alteration of life history under captive broodstock management.

An Assessment of Population Productivity, Abundance and Life History Response to Hatchery Supplementation of Chinook Salmon in the Imnaha River, Oregon. *Richard W. Carmichael, Oregon Department of Fish and Wildlife.* Overview of conservation hatchery program for Chinook salmon in the Imnaha River including descriptions of management goals, monitoring and evaluation procedures, hatchery broodstock strategies and effectiveness of supplementation efforts. A comprehensive evaluation of the supplementation in comparison to reference sites showed no evidence that supplementation increased natural Chinook production.