Appendix D

Introgression Analysis_10-22-15

SAN JOAQUIN RIVER RESTORATION PROGRAM

JULY 2018

San Joaquin River Introgression Analysis

Introduction

A major goal of the San Joaquin River Restoration Program (Program) is to restore spring Chinook and fall Chinook salmon to the mainstem of the San Joaquin River below Friant Dam. Historically, the two races of Chinook salmon spawned in different portions of the basin and at different times. This spatial and temporal separation of the two Chinook races ensured that hybridization (i.e., genetic introgression) rates were low. Under restoration conditions, both spring Chinook and fall Chinook will spawn in the same river reaches, thereby increasing the probability that the hybridization rate will increase. Hybridization can reduce population genetic diversity, which may lead to decreased fitness, productivity, and survival, and alteration of run timing.

The purpose of this analysis is to develop a suite of Chinook restoration alternatives that could reduce or prevent hybridization between spring and fall Chinook while still achieving the Program's fisheries goals to the greatest extent possible. The alternatives examined are as follows:

- Alternative 1- Spring Chinook Program Only
- Alternative 2- Develop a Chinook Population Adapted to the San Joaquin River
- Alternative 3- Develop a Late Run of Fall Chinook
- Alternative 4- Physical Segregation of Spring and Fall Chinook Spawning Areas

The alternatives reduce hybridization risks using varying levels of human intervention. The simplest approach to reducing the risk of hybridization is to focus on the restoration of a single Chinook run. This is the approach proposed in Alternative 1, wherein spring Chinook restoration is prioritized over fall Chinook. Alternative 2 recognizes that over the long term, life history traits such as run timing are determined by the environment. The most successful run timing strategies will dominate over the long term, and therefore, the system is managed to facilitate this outcome. Alternatives 3 and 4 use a combination of adult management actions (weirs, ladders, adjusted adult run timing) to reduce introgression risks while at the same time attempting to achieve adult production goals for each run more or less simultaneously.

In Appendix A, data from river systems outside of the Central Valley are used to show potential outcomes with respect to hybridization and adult abundance when two Chinook races compete for spawning and rearing habitat[1]. Examples of hybridization in Central Valley Chinook populations can be found here:

https://swfsc.noaa.gov/publications/CR/2008/2008Garza4.pdf

Tomalty et al. (2014) and SJRRP (2014) provide additional perspectives on approaches for reducing hybridization between spring and fall Chinook. The alternatives developed by these authors are similar to the alternatives presented in this report.

Key Assumptions

The key assumptions used to develop the alternatives are described below.

[1] SJRRP fisheries staff are already familiar with introgression problems in the Yuba River and Feather River so this information is not included in this report.

Spawner Abundance Goals

For Chinook salmon, the long term program goal is to achieve a spawning population of 30,000 spring Chinook and 10,000 fall Chinook in the restoration area[2]. Short term and average program goals range from 500-2,500 spawning adults in each run (Table 1). The analysis assumes that the outcome of the alternatives is the long term adult production target for each run and accounts for implications to fisheries management.

Table 1- Short-term, average and long-term adult spring Chinook and fall Chinook production goals for the San Joaquin River Restoration Program.

Category	Time Frame	Adult Production Target
Short Term	<2020	500 spring run and 500 fall run (1,000 total)
Average (5-year average)	2020 – 2024	2,500 spring run and 2,500 fall run (5,000 total)
Long Term (5-year average)	2025-2040	30,000 spring run and 10,000 fall run (40,000 total)*

*The Minimum Floodplain Habitat Area Report has a long-term spawning target of 45,000 adult spring Chinook and 15,000 adult fall Chinook (also see Hanson et al. 2007 http://restoresjr.net/program_library/04-RA_Recommends/2008/tac_all_run_final_2-20-08_1.pdf)

Spring and Fall Chinook Spawn Timing

For this analysis, spring and fall Chinook spawn timing is the key life stage and period of interest. It is at the spawning stage where hybridization of the runs may occur. Expected spawn timing for the two Chinook runs is presented in Table 2 (SJRRP 2007). Hybridization is most likely to occur during October, the period of temporal overlap in spawn timing for the two runs. However, it should be noted that environmental variability in river flow and temperature may result in more or less overlap in spawn timing between runs in some years.

Table 2- San Joaquin River spring Chinook and fall Chinook spawn timing.

Chinook Run	August	September	October	November	December
Spring Run					
Fall Run					

Spawning Habitat

There are approximately 24 miles of potential Chinook spawning habitat in the mainstem San Joaquin River below Friant Dam (ICF 2014)[3]. Spawning habitat is located in reach 1A1 and 1A2 starting just downstream of the dam. Based on adult production goals of 30,000 spring Chinook and 10,000 fall Chinook, the total number of spawners per mile (SPM) of habitat (24 miles) would equal 1,667.

However, habitat modeling using the EDT Model indicated that spring Chinook spawning habitat is primarily limited to the 12.3 miles in reach 1A1 due to water temperature issues (ICF 2014). If this is the

[2] Harvest rates on fall Chinook and spring Chinook have averaged about 60 percent in the recent past. At this harvest rate, adult spring and fall Chinook production from the restoration area will have to be 75,000 and 25,000 fish, respectively, to meet the spawning population goals.

[3] ICF International. 2014. Technical Report: Analysis of Fish Benefits of Reach 2b alternatives of the San Joaquin River. The authors note that the majority of spawning habitat is located in reach 1A1, which is only 12.3 miles long.

case, the number of spawners per mile would equal 2,439. Both estimates (1,667 and 2,439 spawners per mile) are substantially higher than those observed in other systems where introgression has been observed (e.g., Trinity River at 340 spawners per mile and Feather River at 950 spawners per mile).

Prioritization of Spring Chinook for Restoration

The Settlement Agreement for the Program states that:

"…in the event that competition, inadequate spatial or temporal segregation or other factors determined to be beyond the control of the Parties make achieving the Restoration Goal for both spring run and fall run Chinook salmon infeasible, then priority shall be given to restoring self-sustaining populations of wild spring run Chinook salmon."

Therefore, alternatives that prioritize spring Chinook over fall Chinook are assumed to be consistent with the Settlement Agreement.

Use of Hatcheries

The Settlement Agreement, the Fish Management Plan (FMP) (SJRRP 2010) and Hatchery Genetic Management Plan (HGMP) (Karrigan et al. 2010) envision that hatchery production will be reduced over time as natural origin adult abundance increases:

1. FMP Objective – Within 10 years of reintroduction, less than 15 percent of the Chinook salmon population should be of hatchery origin.[4]
2. Settlement Agreement – Beyond the use of trap-and-haul and hatcheries to facilitate reintroduction, the restoration administrator shall only recommend the use of trap-and-haul and hatcheries for operations essential to protect fish from dropping below a low level risk of extirpation.

Based on these two statements, it is assumed that the Chinook restoration alternatives, at least for the short-term (10 years), can rely on both hatchery production and trap-and-haul systems to reduce hybridization rates.

Hybridization Criterion

The Spring-Run Chinook Salmon Genetic Management Plan established a 5 percent criterion for hybridization (Baerwald et al. 2011). The criterion was set to maintain phenotypic integrity (primarily run timing) for the two runs. The authors actually recommended that the introgression (hybridization) rate should be maintained well below 5 percent, and if possible prevented completely. The 2015 Segregation Protocol sets 2 percent as one of the criteria that would be used as a trigger to test the feasibility of using a segregation weir to maintain spawning separation of the two runs (SJRRP 2015).

Implicit in the introgression criterion is that hybridization has deleterious impacts which will imperil the achievement of Chinook population goals or at best has no biological benefit.

More detail on, and justification for, fish management, population and habitat goals for the Program can be found in the Fish Management Plan (SJRRP 2010).

[4] The 15 percent value includes strays from other hatcheries.

Hybridization Effects

In Appendix A, data from five non-Central Valley river systems are used to show potential outcomes with respect to hybridization and adult abundance when two Chinook runs compete for the same spawning and rearing habitat. These river systems are similar to Central Valley rivers in that fish distribution and abundance are affected by both dams and hatchery operations within and outside of the basin.

The key findings of the analysis are:

1. Data indicate that when spring Chinook and fall Chinook are forced to spawn in the same reach, fall Chinook appear to dominate with respect to total fish abundance.
2. For the Lewis and Cowlitz Rivers, spring Chinook comprise 2 to 11 percent of the total Chinook natural spawning populations. The sustainability of the spring Chinook population in each river system is deemed questionable without the continued input of hatchery origin (HOR) spring Chinook adults.
3. Genetic analyses conducted in the Trinity River, Puntledge River and White River show that hybridization can and does occur between spring and fall Chinook, summer and fall Chinook, and tule and upriver bright Chinook.
4. Although run timing of the two races (spring and fall) varies, it appears there is sufficient overlap in spawn timing that hybridization is observed in multiple river basins.
5. Hybridization rates appear to increase as the spawning season progresses. This is to be expected as there is generally some overlap in spawn timing between later arriving spring Chinook and earlier arriving fall Chinook.
6. Although hybridization may result in the production of juvenile offspring, these juveniles may or may not produce returning adults.

The possible effects that various levels of hybridization may have on Chinook fitness and abundance are presented in Table 3. This data is based on the analytical approach used by the Hatchery Scientific Review Group (HSRG) to determine the effects hatchery-origin fish may have on the population fitness and abundance of natural-origin fish in the Pacific Northwest (HSRG 2014). The analysis indicates that population fitness and adult abundance decreases as the introgression rate increases. The California HSRG (2012a) and Tomalty et al. (2014) were also concerned that introgression between hatchery and natural-origin fish or between fall and spring Chinook is likely to reduce or alter population performance.

Table 3- Expected change in natural origin adult Chinook abundance for introgression rates ranging from 0 to 10 percent. The analysis is based on a Beverton-Holt productivity of 4.0 and capacity of 41,000.

Introgression Rate	Fitness	Adult Abundance	Percent Change in Abundance
0%	100%	30,743	0%
2%	85%	24,686	-20%
3%	76%	20,986	-32%
4%	68%	17,814	-42%
5%	62%	15,195	-51%
6%	57%	13,049	-58%
10%	30%	10,250	-67%

Tomalty et al. (2014) examined the causes and consequences of hybridization of Chinook runs in the San Joaquin River and provided the following observations:

- Hybridization is defined as the mating and production of offspring by individuals from genetically distinct groups, be they species or genetically divergent populations within a single species.
- Central Valley Chinook salmon are an excellent example of a group that faces genetic diversity loss and population structure collapse, in part from hybridization.
- For the San Joaquin, overlap in migration spawn timing and lack of spatial separation between runs will likely create conditions that encourage introgression.
- Introgression will almost certainly lead to the loss of distinct fall run and spring run phenotypes and/or genotypes.
- Introgression may lead to a hybrid storm where phenotypes are lost and the population consists primarily of hybrids.
- Or, run-timing phenotypes may be preserved, but the genetic distinction between runs may be lost.

Alternative Approaches to Reduce Introgression

Four alternative approaches to reducing or preventing hybridization between spring and fall Chinook were developed in this analysis. A description of each alternative is provided in this section of the report.

Alternative 1- Prioritize Spring Chinook Restoration

The simplest way to eliminate hybridization between spring Chinook and fall Chinook in the San Joaquin River is to restore only one Chinook run at a time. The approach taken to achieve the objectives in Alternative 1 is summarized here:

- Only spring run Chinook would be allowed to spawn in the restoration area until the average adult natural origin (NOR) spawner goal of 5,000 adults is achieved[5]. Fall Chinook would be prevented from entering the spawning area using weirs and/or a fish ladder located downstream of the spawning area[6]. Preventing fall Chinook from entering the area would ensure that the hybridization criterion is met[7].
- When the spawning goal of 5,000 spring Chinook NORs is reached, managers would have the option to allow adult fall Chinook access to the spawning reaches. The number of fall Chinook adults released to the river would not exceed 2 percent of the spring Chinook spawning escapement. The restriction guarantees that the hybridization rate is maintained at less than 2 percent (SJRRP 2015). Studies would be undertaken to determine the temporal and spatial overlap of spring and fall Chinook spawners as well as the level of hybridization. Spring Chinook hatchery production would be terminated with the achievement of the 5,000 average NOR spawner goal. This action achieves the objective of reducing hatchery production over time (although this may not occur within the 10-year time frame).
- Spring Chinook hatchery facilities may be converted to rear fall Chinook. The objective of the fall Chinook hatchery Program would be to develop a hatchery stock of fall Chinook adapted to the San Joaquin River. Over time the number of hatchery origin (HOR) and NOR fall Chinook allowed to spawn naturally would be increased until the 2 percent introgression criterion is reached. Genetic analyses of either juvenile or adult migrants would be implemented to determine the introgression rate[8].

Alternative 1 Selection Rationale

The rationale used to select and implement Alternative 1 is described below.

Hybridization level must be maintained below 2 percent

It is assumed that the 2 percent criterion is scientifically defensible and necessary to maintain distinct spring and fall run Chinook populations.

Spatial and temporal overlap in spawn timing/location for the two runs will be such that the 2 percent hybridization criterion cannot be achieved.

The data in Table 2 show that spring and fall Chinook spawning location and timing overlap. Given the limited amount of spawning habitat (24 miles) and long term spawning objectives for spring Chinook (30,000) and fall Chinook (10,000) it would appear unlikely that the hybridization criterion (<2 percent) could be achieved without the use of a segregation weir (or other forms of active adult management). The use of a weir would also reduce the amount of spawning habitat available to later arriving fall Chinook, possibly resulting in lower egg survival due to redd superimposition (see Alternative 3 for a more detailed discussion). This in turn decreases the probability that long term population objectives for the fall run can be achieved.

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[5] For this alternative, the 2,500 spawner goal for each run was combined to establish the 5,000 spawner objective used in the analysis.

[6] Adult passage facilities could be included in the proposed juvenile collection/transport system to prevent adult fall Chinook from entering spawning areas.

[7] There is some risk that fall Chinook jacks could get past a weir and spawn with spring Chinook adults; therefore the risk of introgression is dependent on the effectiveness of the physical barrier.

[8] It may also be possible to sample redds (eggs) to determine genetic make-up of the parents.

Spring Chinook goals may be prioritized over those of fall Chinook

The Settlement Agreement states that if:

"…inadequate spatial or temporal segregation or other factors determined to be beyond the control of the Parties make achieving the Restoration Goal for both spring run and fall run Chinook salmon infeasible, then priority shall be given to restoring self-sustaining populations of wild spring run Chinook salmon."

In Alternative 1, it is assumed that spatial and temporal segregation is either not physically possible, too expensive, or that the use of a structure to separate the two runs would reduce the probability of achieving adult abundance targets for one or both runs.

Spring and fall Chinook long-term spawner abundance goals are realistic

The spring Chinook and fall Chinook spawner escapement goals for the Program are 30,000 and 10,000 adults, respectively. Assuming that 24 miles of spawning habitat are available, the combined escapement goal for spring Chinook and fall Chinook is 1,667 spawners per mile.

Upon achievement of the adult spawner goals, spawner density for the San Joaquin River (1,667 spawners per mile) would be much higher than that observed for the Feather River (~950 per mile) and Trinity River (~340 per mile). Even at these lower spawner densities, hybridization of spring and fall Chinook has occurred in both rivers[9] (CA HSRG 2012a and CA HSRG 2012b). Thus, attempts to prevent hybridization at the start of the restoration Program would eventually be overwhelmed by the large numbers of fish expected in the future.

If Alternative 1 is selected, it is assumed that Chinook spawner goals are likely to be achieved and that this will result in severe competition for spawning habitat between the two races.

Alternative 2- Develop a Chinook Population Adapted to the San Joaquin River

The objective in Alternative 2 is to produce a self-sustaining Chinook population that is locally adapted to the environmental conditions present in the San Joaquin River. Tomalty et al. (2014) developed a similar approach, which they defined as Passive Reintroduction. Success of the Program would not be based on adult run timing but instead on total Chinook production and its sustainability. As noted by Tomalty et al., and the data presented in Appendix A from other river systems, the resulting run will likely be dominated by fall Chinook (Figure 1).

[9] It is recognized that spawner densities vary by reach in these two systems, with more fish generally spawning closer to the hatchery. For this analysis it is assumed that average spawner density can be used as an indicator of hybridization risk (Painter et al. 1977).

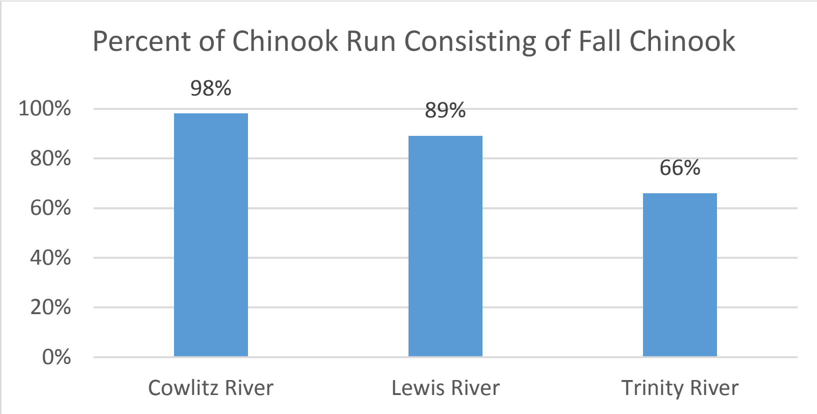

Figure 1- Fall Chinook percentage of total spawner escapement of spring and fall Chinook in the Cowlitz River, Lewis River and Trinity River

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The Program would be implemented in four phases. These phases are similar to those proposed by the HSRG for salmon conservation programs (HSRG 2014, Table 4). Management triggers based on adult run size and composition (natural or hatchery) would be used to move the Program from one phase to the next[10].

Table 4- Biological phases of restoration and objectives for different ecosystem conditions (HSRG 2014).

Biological Phases	Ecosystem Conditions	Objectives
Preservation	Low population abundance; habitat unable to support self-sustaining population; ecosystem changes pose immediate threat of extinction.	Prevent extinction; retain genetic diversity and identity of existing population.
Re-colonization	Underutilized habitat available through restoration and improved access.	Re-populate suitable habitat from pre-spawning to smolt outmigration (all life stages).
Local Adaptation	Habitat capable of supporting abundances that minimize risk of extinction as well as tribal harvest needs; prevent loss of genetic diversity; and promote life history diversity.	Meet and exceed minimum viable spawner abundance for natural-origin spawners; increase fitness, reproductive success and life history diversity through local adaptation.
Full Restoration	Habitat restored and protected to allow full expression of abundance, productivity, life-history diversity, and spatial distribution.	Maintain viable population based on all viable salmonid population (VSP) attributes using long-term adaptive management.

[10] A similar phased approach for the program was described in Hanson et al. (2007). http://restoresjr.net/program_library/04-RA_Recommends/2007/final_tac_recommendations.pdf

Phase 1- Development of a Locally Adapted Hatchery Population

Hatchery facilities would be used to rear and then release spring and fall Chinook juveniles to the San Joaquin River[11]. Adult fish returning from these juvenile releases (and any natural production) would be prioritized for broodstock. The Program would continue to import spring Chinook broodstock from other hatcheries/streams in years when adult returns are insufficient to meet hatchery production targets.

This phase of the Program would continue until adult returns are sufficient to meet broodstock needs. Once this criterion has been achieved, broodstock will no longer be imported from other hatcheries/streams and the Program will move to Phase 2- re-colonization.

Phase 2- Re-colonization

In Phase 2, returning hatchery adults in excess of broodstock needs are released to spawn naturally. A portion of the resulting adult returns of natural origin fish would be incorporated into the hatchery broodstock. This action begins the development of an integrated type hatchery program as defined by the HSRG:

*A hatchery program is an **Integrated Type** if the intent is for the natural environment to drive the adaptation and fitness of a composite population of fish that spawns both in a hatchery and in the wild* (HSRG et al. 2004a).

The hatchery program becomes the genetic repository for the population over time. Such a repository is needed because it is expected that environmental conditions (e.g., poor marine conditions, drought) may be such that natural returns alone are insufficient to safeguard genetic resources over time.

No restrictions would be placed on the number or origin (HOR or NOR) of the fish released to spawn naturally.

This phase ends when the average spawner escapement target of 5,000 adults (HOR + NOR) is achieved[12].

Phase 3- Local Adaptation

In Phase 3, the hatchery program is operated consistent with HSRG guidelines for an integrated type program. In order for the natural environment to drive local adaptation, the proportion of the broodstock consisting of natural origin spawners (pNOB) must be greater than the proportion of hatchery origin fish spawning naturally (pHOS). The larger the ratio of pNOB/(pNOB+pHOS), the greater the influence the natural environment has on the selection process. The HSRG refers to this ratio as the proportionate natural influence (PNI) (HSRG et al. 2004a).

The number of hatchery fish allowed to spawn naturally would be controlled to achieve the target PNI level identified by fisheries managers. HORs in excess of broodstock or natural escapement needs would be harvested or removed from the system using trapping facilities or other means. However, the effectiveness of this action would be dependent on the ability to identify the large number of hatchery fish from other programs that stray into the restoration area. Currently, only 25 percent of the hatchery fish released from most Central Valley hatchery programs are marked (CA HSRG 2012b). Unmarked hatchery fish would not be readily distinguishable from naturally produced San Joaquin River fish.

[11] The fish used in the program would come from the Feather River hatchery and other populations as determined by program managers.
[12] The target or trigger could be based on a single year return or an average of multiple years.

Phase 3 would be terminated when natural escapement reaches the average abundance objective of 5,000 fish. The difference between the 5,000 adult abundance criterion in Phase 2 and Phase 3 is that in Phase 3 only NORs count when determining if the criterion is met. A return of 5,000 NORs is considered evidence that the run is likely self-sustaining.

The Program would return to Phase 2 if the 5-year average NOR abundance is less than 500 fish.

Phase 4- Full Restoration

When the 5,000 NOR escapement criterion is achieved, the hatchery program would be suspended. It may be reinstated if NOR abundance falls below a 5-year average of 500 adults. This action would ensure that the population does not reach demographic levels that may decrease population diversity or result in extirpation[13].

Whether or not the long-term spawner objective (40,000 spring/fall Chinook) is achieved would depend on habitat conditions within and outside of the San Joaquin River system.

Alternative 2 Selection Rationale

The rationale used to select and implement Alternative 2 is described below.

<u>Life-history diversity is determined by the environment</u>

The selection of Alternative 2 recognizes that over time the life histories expressed by the population will ultimately be determined by the environment. Achievement of the Program's natural abundance goal is deemed more likely if the population is allowed to naturally adapt to its environment rather than being continually shaped through human intervention.

<u>Hatchery production is a temporary measure</u>

The Settlement Agreement, FMP and HGMP for the Program recommend that hatchery production be terminated at some point in the future. If hatchery production ends, hatchery influence on run timing will cease and the natural population will, over time, develop a life history best suited for survival in the San Joaquin River. In Alternative 2, this outcome is allowed to happen at the beginning rather than at the end of the restoration process.

Alternative 3- Develop a late run of fall Chinook

The objective of Alternative 3 is to achieve adult Chinook abundance objectives using spring Chinook and a run of fall/winter Chinook with non-overlapping spawn timing. Fall Chinook would not be allowed into the spawning areas until spring Chinook spawning has ceased (mid-October to early November). Fall Chinook would be prevented from entering the spawning area by constructing a physical barrier (weir, ladder etc.) in a downstream reach. Once spring Chinook spawning is complete the barrier would be removed and fall Chinook would be allowed to pass upstream to spawn[14].

Delaying fall Chinook spawning until after the spring Chinook spawning season should be an effective method for ensuring that the 2 percent hybridization criterion is achieved. However, there is still the risk that late run fall Chinook would dig up (i.e., superimpose upon) spring Chinook redds, thereby reducing

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[13] The use of hatchery production to prevent extirpation is consistent with the Settlement Agreement (see page 70 of 80 (Exhibit D).

[14] Another approach would be to first develop a hatchery fall Chinook population with a spawn timing later than November 1st. Once this hatchery population has been determined to be sustainable, adults or fry could be released to the river.

spring Chinook egg survival[15]. The level of reduced egg survival would depend on run size and degree of overlap in spawning habitat selection between the two races. For example, data collected on the Feather River in the late 1960s showed that Chinook egg survival rates decreased as spawner escapement increased (Figure 2)[16,17]. Researchers on the Tuolumne River found similar results for Chinook and noted that fish preference for higher quality spawning areas oversaturates those areas as run size increases and results in lower egg survival and resulting juvenile recruitment (EA 1997)[18,19].

Spawning overlap between races may be reduced due to the difference in San Joaquin River flow before and after November 1 in Dry to Wet years (Table 5). River flows in early November (11/1 to 11/10) are twice those present in September and October. The higher November flows will alter water velocity and water depth, two factors that influence Chinook spawning location (YRDP 2013)[20]. Differences in water velocity and depth could cause fall Chinook to spawn in locations other than those selected by spring Chinook[21] (at least until flows are again reduced in mid-November). In addition, if fall Chinook do spawn during this 10-day period in November the decrease in river flows planned for the rest of the month could result in redd desiccation and egg loss. This same outcome could occur for spring Chinook in other water year types as a similar drop in river flow is observed from August through December.

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[15] See the following web link for a good description of superimposition: http://www.yubaaccordrmt.com/Presentations/2013%20Yuba%20River%20Accord%20Symposium/Presentation%206%20Massa%20New%20Developments%20%286-12-2013%29.pdf

[16] In 2009 and 2010, superimposition rates for Chinook averaged 12.5% (see Yuba web site above).

[17] McNeil (1964) found a 33 percent, 50 percent and 67 percent decrease in potential egg deposition when female pink salmon ranged from 1 to 3 fish per meter squared, respectively.

[18] Additionally, for the period 1991-2009 redd superimposition on the Mokelumne River averaged 10.6 percent (Bilski and Rible 2011).

[19] Schmit et al. (2013) estimated that 19 percent of spring Chinook redds were superimposed upon by later arriving summer Chinook.

[20] YRDP 2013 data showed that between 69-77 percent of Chinook redd location were predicted based on water depth and velocity and stream bed substrate. These data indicate that flow manipulation may be a method to influence redd location and reduce competition for spawning sites.

[21] A decrease in flow from 700 cfs to 350 cfs has the potential to dewater redds. Wetted stream width values at each flow should be confirmed to determine possibility of redd desiccation.

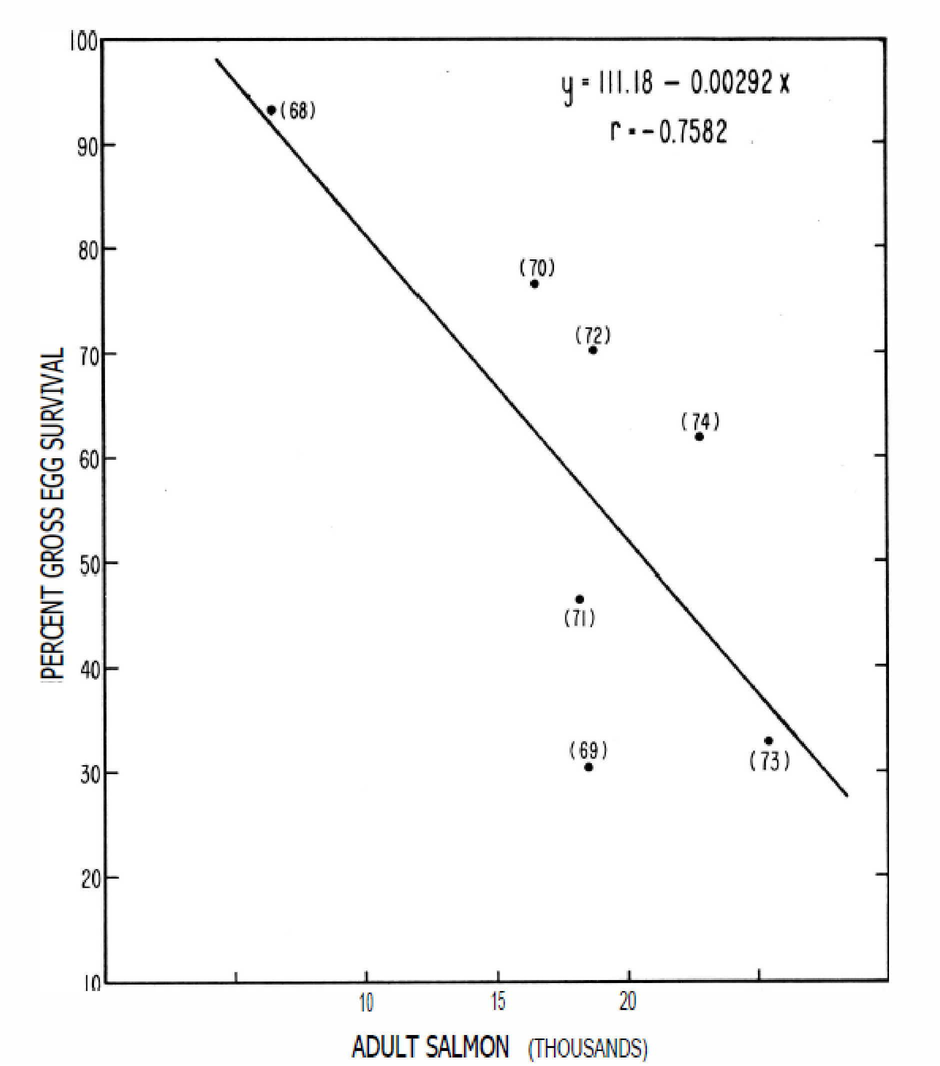

Figure 2- Relationship between Chinook egg survival and spawning escapement in the Feather River (1968-1974) (reproduced from Painter et al. 1977).

Stream temperatures in the months of August, September and October may also affect the level of egg mortality that may occur due to fall Chinook disturbance of spring Chinook redds. Higher stream temperatures result in earlier fry emergence timing. Stream temperatures from August through October could result in some fry emerging from the gravel prior to November 1. If this occurs, fall Chinook spawning effects on spring Chinook redds would be reduced as eggs/fry would not be present[22].

Finally, egg losses due to superimposition may not be an issue if the quantity of fry/juvenile rearing habitat is what actually limits population abundance (e.g., egg capacity is greater than fry rearing capacity).

In Alternative 3, hatchery production of each race would cease when NOR abundance exceeds 5,000 fish.

[22] An emergence timing analysis would need to be completed to confirm such an assumption.

Table 5- Expected San Joaquin River flow (cfs) by date and water year type.

Date	Water Year Type[23] and Discharge (cfs)					
	Critical Low	Critical High	Dry	Normal Dry	Normal Wet	Wet
10/1-10/31	160	160	350	350	350	350
11/1-11/6	130	400	700	700	700	700
11/7-11/10	120	120	700	700	700	700
11/11-12/31	120	120	350	350	350	350
1/1-2/28	100	110	350	350	350	350
3/1-3/15	130	500	500	500	500	500
3/16-3/31	130	1500	1500	1500	1500	1500
4/1-4/15	150	200	350	2500	2500	2500
4/16-4/30	150	200	350	350	4000	4000
5/1-6/30	190	215	350	350	350	2000
7/1-8/31	230	255	350	350	350	350
9/1-9/30	210	260	350	350	350	350

Source: FMP 2010- Appendix E

*Red cells indicate flow reduction that may result in redd desiccation or alteration of fish spawning location.

Alternative 3 Selection Rationale

The rationale used to select Alternative 3 is similar to Alternative 1 as the only difference between them is timing. Alternative 1 achieves the 2 percent hybridization criterion by delaying (measured in years) fall Chinook reintroduction until the spring Chinook adult abundance target is met. In contrast, Alternative 3 delays (within each year) fall Chinook access to the spawning area until after spring Chinook have spawned.

An additional factor considered in selecting Alternative 3 is that superimposition by fall Chinook on spring Chinook redds is likely and should be prevented. The validity of this assumption is dependent on whether or not the 40,000 adult spawner target is a realistic outcome of the restoration Program. In Alternative 3 it is assumed that this long term abundance target will be met. Under this assumption, the average superimposition rate expected could be estimated by dividing the average fall Chinook adult escapement target by the average spring Chinook adult escapement target:

10,000 fall/ 30,000 spring = 33 percent

The 33 percent value assumes that each fall Chinook spawner eliminates one spring Chinook redd. However, data collected on the Yuba River shows that the actual rate of superimposition should be calculated based on disturbance of the egg pocket (YRDP 2013). The Yuba River researchers found that ~45 percent of the egg pockets in redds that had undergone superimposition were affected. Applying 45 percent as a correction factor for egg pocket impacts results in an expected superimposition rate of

[23] The wettest 20% of the 83-year period of record is classified as “Wet.” In order of descending wetness, the next 30% of years are classified as “Normal-Wet,” the next 30% of years are classified as “Normal-Dry,” and the next 15% of years are classified as “Dry.” The remaining 5% of years are classified as “critical.” A subset of the critical years, those with less than 400,000 acre-feet (TAF) of unimpaired runoff, are classified as “Critical-Low”; the remaining critical years are classified as “Critical-High.”

14.85 percent (33% * 45%). The actual rate would vary based on differences in run size between the two races, with higher possible impacts occurring when fall Chinook run size exceeds that of spring Chinook.

Alternative 4- Physical Segregation of Spring Chinook and Fall Chinook Spawning Areas

Under Alternative 4 a segregation weir would be placed in the stream channel to prevent the two runs from spawning in the same area (SJRRP 2014). The weir picket spacing would be narrow enough that both Chinook jacks and adults could not spawn upstream of the weir, thereby ensuring that the 2 percent hybridization criterion is achieved.

The weir would be placed such that 75 percent of the available spawning habitat is located upstream of the weir. The 75 percent value was selected based on the assumption the proportion of habitat reserved for each run should be equal to the percent each race composes of the total adult abundance goal[24].

For spring Chinook the proportion of habitat needed was calculated as follows:

30,000 spring/ (30,000 spring + 10,000 fall) = 75 percent

Spring Chinook adults would be collected at a downstream location, transported and released above the weir. Stream temperatures in reaches upstream of the weir will be closer to optimal levels for spring Chinook adult holding and spawning requirements than downstream reaches (SJRRP 2014).[25] Reserving the best habitat for spring Chinook is consistent with the Settlement Agreement that allows for the prioritization of spring Chinook over fall Chinook. However, limiting fall Chinook spawning to possibly poorer quality habitat may reduce their survival and the probability that adult production goals can be achieved[26].

As was the case with Alternative 3, hatchery production (by race) would be terminated when NOR abundance reaches 5,000.

Alternative 4 Selection Rationale

The rationale for selecting Alternative 4 for implementation is based on the following assumptions:

1) A weir, or other physical barrier, can be built such that it prevents > 98 percent of fall Chinook adults and jacks from passing upstream of its location (achieves the 2 percent hybridization criteria).
2) The cost associated with barrier construction and long term operation is acceptable.
3) Restricting fall Chinook to a smaller portion of the spawning area will not affect achievement of adult abundance targets or the possible loss in fish production is an acceptable risk.
4) Fall Chinook superimposition on spring Chinook redds results in unacceptable mortality rates for spring Chinook.

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[24] The EDT model for the basin could be used to determine total spawning habitat in each reach. Weir location would be located at the point (river mile) where spawning habitat is sufficient for 10,000 to 15,000 redds.

[25] Water temperature averages 15.5 degree C for 4.1 miles downstream of Friant Dam (RM 268) in August and 5.1 miles downstream of this same point in September through October. SJRRP 2014 states that habitat conditions are still ideal at river mile 261.2.

[26] The EDT model could be used to determine the likely effect on fall Chinook production.

Discussion

A primary goal of the SJRRP is to restore spring Chinook and fall Chinook salmon to the mainstem of the San Joaquin River below Friant Dam. Historically, the two races of Chinook spawned in different portions of the basin and at different times. This spatial and temporal separation of the two runs ensured that hybridization (i.e., genetic introgression) rates were low. Under restoration conditions, both spring Chinook and fall Chinook will spawn in the same river reaches, thereby increasing the probability that the hybridization rate will increase. Hybridization of the two runs can reduce population genetic diversity which may lead to decreased fitness, productivity and survival.

The alternatives developed in this analysis reduce hybridization risks using varying levels of human intervention and control. The simplest approach to reducing the risk of hybridization is to focus on the restoration of a single Chinook run. This is the approach proposed in Alternative 1, wherein spring Chinook restoration is prioritized over fall Chinook. Alternatives 3 and 4 use a combination of adult management actions (weirs, ladders, adjusted adult run timing) to reduce hybridization risks while at the same time attempting to achieve adult production goals for each run more or less simultaneously. Alternative 2 recognizes that over the long term, life history traits such as run timing are determined by the environment and manages the system accordingly.

Ultimately the selection of a preferred alternative will be based on its ability to achieve Program goals. Thus, the first step in the selection process would be to confirm the Program goals and their management priority. The analysis assumes that the long term goal of producing 30,000 spring Chinook and 10,000 fall Chinook spawners is achievable[27]. At these adult escapement levels, competition for the 24 miles of potential spawning habitat will be intense. Competition for spawning habitat will be even higher if it is assumed that quality spawning habitat for spring Chinook is limited to the 12.3 miles of reach 1A1 as forecasted by the EDT Model (ICF 2014). Hybridization and redd superimposition rates are likely to be high without the implementation of adult management actions. However, if the habitat is only capable of producing the average adult abundance target of 5,000 Chinook, hybridization and redd superimposition may not occur or could be reduced through such actions as river flow management. Thus, the alternative selected for implementation would be heavily dependent on expected long term production for each Chinook run.

The Settlement Agreement states that it may be possible to prioritize spring Chinook restoration over that of fall Chinook. Fisheries managers should confirm this assumption because focusing on restoring a single run of fish to the project area virtually eliminates hybridization and redd superimposition concerns posed by fall Chinook. However, it should be noted that 30,000 spring Chinook spawning in 24 miles (or 12.3 miles as forecast by EDT) of stream may still result in some superimposition of redds. Spring Chinook are expected to spawn from August through October, therefore spring Chinook spawning later in the season may dig up redds constructed by earlier spawners.

The role hatcheries will play, and over what time frame, should also be confirmed as this could affect the achievement of Program goals and the level of hybridization risk incurred. Data from other river systems indicate that where both runs compete for spawning habitat, spring Chinook run timing is likely maintained by the hatchery program. Without constant input of hatchery spring Chinook, natural production tends to be dominated by fall Chinook in these rivers. This outcome is not surprising given

[27] The abundance goal(s) is a 5-year average; therefore adult returns in some years are expected to be even greater than 40,000 total adults.

that the runs are restricted to reaches that were historically used for spawning by fall Chinook and not spring Chinook.

Managers are concerned that later spawning fall Chinook will dig up spring Chinook redds, thereby reducing spring Chinook egg survival. The analysis indicates that if the long term adult abundance goal is achieved (40,000) the superimposition rate could be about 15 percent. This value was calculated based on a simple relationship between spawner abundance goals for each run, not on the total amount of available spawning habitat. In reality, the superimposition rate will vary based on the difference in yearly spawner abundance, overlap in spawn timing/spawning location, amount of spawning habitat available, fry emergence timing, and environmental conditions such as river flow and temperature. A model, similar to the one developed for the Tuolumne River, could be used to estimate superimposition rates over a range of conditions (EA 1997). The need for such a model would be dependent on the alternative selected for implementation, which in turn is highly dependent on whether the long term adult abundance goal is realistic.

Finally, the large number of hatchery strays from other programs pose substantial risk to the achievement of Program population goals and complicate basin fish management (Kormos et al. 2012). Currently, only 25 percent of the hatchery fish from most Central Valley Chinook hatchery programs are marked (CA HSRG 2012b), which means that 75 percent of the strays entering the restoration area are not readily distinguishable from naturally produced Program fish. Both the CA HSRG and Pacific Northwest HSRG have concluded that hatchery fish from these segregated hatchery programs, if allowed to spawn naturally, will likely reduce the fitness of natural populations.

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Appendix A: Examples of Chinook Hybridization from Non-Central Valley River Systems

The Lewis, Cowlitz and Trinity Rivers are systems where dams have resulted in spring Chinook and fall Chinook having to compete for spawning habitat in the river reach below a dam. These rivers provide examples of possible outcomes with respect to the abundance and potential hybridization of the two Chinook races competing for spawning and rearing habitat in the San Joaquin River below Friant Dam.

In addition to the above examples, information on summer/fall Chinook hybridization for the Puntledge River, and White River systems are also presented as additional case studies.

Lewis River-Washington

In the Lewis River (Washington), fall Chinook and spring Chinook both spawn primarily in the 19.2 mile reach extending from Merwin Dam to the river's mouth. However, the vast majority of spawning occurs in the 4-mile reach near the dam. The number of spring and fall Chinook spawning in the Lewis River is provided in Table 1. The average spawning escapement for Lewis River fall Chinook and spring Chinook is 10,972 and 1,291 (www.streamnet.org), respectively. Over this time period spring Chinook composed on average approximately 11 percent of the total spawning escapement.

Although the two races spawn in the same river reach, spawn timing varies. Spring Chinook spawning occurs from late August through early October. Lewis River fall Chinook are classified as a "bright" stock and spawn from October to January. Thus, there is minimal overlap in spawn timing between the two races. Information is not available to determine the level of genetic introgression that may have occurred between spring and fall Chinook.

Hatchery fall Chinook are not released into the Lewis River. There is, however, a substantial spring Chinook hatchery program that releases 1.33 million fish each year (www.hatcheryreform.us). Adult strays from this program spawn naturally in the lower Lewis River and comprise approximately 40% of the total natural spring Chinook spawning population. Broodstock for the program are selected based on run timing back to the hatchery. In general, broodstock collection starts in April, peaks in May and continues through July.

It is not known if the constant input of hatchery spring Chinook adults to the natural spawning population is the factor responsible for maintaining spring Chinook run timing or if the natural population can maintain itself without this input.

Table 1. Lewis River spring and fall Chinook natural spawning escapement 1980-2011 (www.streamnet.org).

Year	Fall Chinook	Spring Chinook	% Spring Chinook
1980	13,839	992	7%
1981	19,297	324	2%
1982	8,370	986	11%
1983	13,540	732	5%
1984	7,132	1,565	18%

Year	Fall Chinook	Spring Chinook	% Spring Chinook
1985	7,491	512	6%
1986	11,983	1,875	14%
1987	12,935	6,850	35%
1988	12,052	5,267	30%
1989	21,199	3,483	14%
1990	17,506	1,345	7%
1991	9,066	1,607	15%
1992	6,307	1,254	17%
1993	7,025	1,412	17%
1994	9,939	475	5%
1995	9,718	270	3%
1996	13,971	493	3%
1997	8,670	410	5%
1998	5,929	211	3%
1999	3,184	240	7%
2000	9,820	439	4%
2001	13,886	642	4%
2002	16,380	483	3%
2003	18,505	679	4%
2004	15,342	494	3%
2005	10,668	393	4%
2006	11,890	7,530	39%
2007	3,468	48	1%
2008	5,200	25	0%
2009	6,916	58	1%
2010	10,558	157	1%
2011	9,302	45	0%
Average	10,972	1,291	11%

Cowlitz River-Washington

Cowlitz River spring and fall Chinook spawn in the lower Cowlitz River (Washington) from RM 50.4 to the river's confluence with the Columbia River. The majority of spawning occurs in the upper 15 miles of this reach. Spring Chinook and fall Chinook spawning naturally in the Lower Cowlitz River has averaged 3,778 and 150 fish, respectively (Table 2). Spring Chinook constitute 2 percent of the total number of natural Chinook spawners.

Spring Chinook spawn timing ranges from August through early October. In contrast, fall Chinook (tule stock) spawn from late September to mid-November. Thus, there is substantial overlap in spawn timing between the two races. Information is not available to determine the level of genetic introgression that may have occurred between spring and fall Chinook in the Cowlitz River.

The Cowlitz Salmon Hatchery produces both spring Chinook and fall Chinook. Historically, 1.3 million spring Chinook yearlings and ~5 million fall Chinook subyearling were released annually. Hatchery fish make up ~40 percent of the total natural Chinook spawning population for both races[28]. The Hatchery Scientific Review Group (HSRG) concluded in 2009 that spring Chinook[29] in the lower Cowlitz River were not sustainable and were likely present because of the constant input of hatchery-origin fish (www.hatcheryreform.us)[30].

The hatchery uses adult run timing as the primary method for selecting broodstock for the spring Chinook and fall Chinook hatchery programs. The use of run timing to select broodstock ensures that the adult run timing of each race does not change substantially over time.

Trinity River-California

Fall and spring Chinook both spawn in the river reach below Lewiston Dam (RM 110) on the Trinity River. The majority of spawning takes place in the 11 km section just below the dam. From 2000-2008 the average adult fall Chinook and spring Chinook natural spawning escapement in the Trinity River was 24,312 and 12,665, respectively (http://cahatcheryreview.com). On average, spring Chinook composed approximately 34% of the total Chinook natural spawning population (Table 3).

The Trinity River Salmon Hatchery produces both spring Chinook and fall Chinook. Historically, 1.5 million spring Chinook and 2.9 million fall Chinook juveniles were released annually to the Trinity River. Hatchery fish make up ~50 percent of the total natural Chinook spawning population of both races. As is the case with most hatcheries, adult run timing back to the hatchery is used to select the broodstock used for each program.

Table 2. Cowlitz River spring and fall Chinook spawning escapement 1980-2011 (www.streamnet.org).

Year	Fall Chinook	Spring Chinook	% Spring Chinook
1980	2,418	31	0.6%
1981	3,991	157	2.0%
1982	3,024	70	1.2%
1983	3,654	25	0.3%
1984	2,577	14	0.3%
1985	4,300	105	1.2%
1986	3,388	492	7.3%
1987	5,930	19	0.2%
1988	7,700	49	0.3%
1989	7,220	121	0.8%
1990	2,698	42	0.8%
1991	2,567	135	2.6%
1992	2,489	13	0.3%
1993	2,218	22	0.5%
1994	2,512	8	0.2%
1995	2,231	65	1.5%

[28] In recent years, the proportion of hatchery fall Chinook fish spawning naturally has decreased to 20 percent due to changes in hatchery release numbers and better identification of hatchery fish (i.e. 100 percent marking).
[29] http://www.hatcheryreform.us/hrp_downloads/reports/columbia_river/system-wide/4_appendix_e_population_reports/lower_col-cowlitz_spring_chinook_01-31-09.pdf
[30] http://www.hatcheryreform.us/hrp_downloads/reports/columbia_river/system-wide/4_appendix_e_population_reports/lower_col-cowlitz_fall_chinook_01-31-09.pdf

Year	Fall Chinook	Spring Chinook	% Spring Chinook
1996	1,602	2	0.1%
1997	2,710	18	0.3%
1998	2,108	94	2.2%
1999	997	50	2.5%
2000	2,363	2	0.0%
2001	4,652	32	0.3%
2002	13,514	0	0.0%
2003	10,048	16	0.1%
2004	4,466	84	0.9%
2005	2,870	15	0.3%
2006	2,944	35	0.6%
2007	1,847	0	0.0%
2008	1,828	14	0.4%
2009	2,602	22	0.4%
2010	3,734	13	0.2%
2011	3,685	3,034	41.2%
Average	3,778	150	2.0%

Table 3. Trinity River spring and fall Chinook spawning escapement 2000-2008 (http://cahatcheryreview.com)

Year	Fall Chinook	Spring Chinook	% Spring Chinook
2000	27,015	12,084	31%
2001	37,162	11,503	24%
2002	13,044	25,551	66%
2003	32,109	31,116	49%
2004	15,710	8,695	36%
2005	13,569	6,974	34%
2006	22,918	3,633	14%
2007	39,820	8,234	17%
2008	17,464	6,191	26%
Average	24,312	12,665	34%

Trinity River spring Chinook and fall Chinook spawn from September through late November and early November-December, respectively. In 2008, spawning surveys indicated that spring and fall Chinook spawning overlapped from mid-November to mid-December (Sinnen et al. 2010)[31].

Genetic analysis of Trinity River fall and spring Chinook indicate that substantial hybridization of the two races has occurred (Kinziger et al. 2008 and Malakauskas 2007). Malakauskas (2007) inferred from the data collected that hybridization has however been stable for three to four generations. The author also noted that simulation modeling conducted by others indicated:

[31] The overlap was based on the recovery of Coded-Wire-Tagged fall and spring Chinook.

"…under ideal conditions (taxa of equal proportions, taxa have same fitness, random mating), hybridization will lead to the extinction of a population in as few as three generations. However, as noted above, there are currently no indications that the Trinity Chinook salmon runs will homogenize due to hybridization. In fact, it appears that the hybrid zone has been stable over the last 12 years."

The author hypothesized that for the Trinity River:

"…the hybrid zone is maintained by some combination of three factors: selection pressures on the salmon from the ecology of the river, assortative mating practiced by Trinity River Hatchery personnel, and continued dispersal into the hybrid zone as a result of flow changes in the middle of the spawning season. To judge the relative importance of each of these three factors, future studies that are able to isolate and test these factors separately are needed."

The large number of hatchery fish spawning naturally in the Trinity River may also cause some additional genetic problems. Kinziger et al. (2007) concluded that a spawning population containing a large proportion of hatchery fish results in no genetic differentiation between the hatchery and natural components of the population. Their data suggested that in river reaches immediately below hatcheries, low potential exists for the development of wild stocks that are well adapted to natural riverine conditions.

The HSRG has established criteria for determining what constitutes a "large proportion" of hatchery fish spawning naturally (HSRG et al. 2004a). For hatcheries operated as integrated type[32] the HSRG recommends that the proportion of natural influence (PNI) should exceed 0.67 (rounded to 0.70) for populations with high biological value. PNI is calculated as:

PNI = pNOB/(pHOS+pNOB)

Where:

pNOB = proportion of hatchery broodstock consisting of natural origin fish

pHOS = proportion of hatchery fish in the natural spawning escapement

Regardless of PNI, they also recommend that pHOS not exceed 30 percent for integrated programs. For segregated[33] hatchery programs, the HSRG recommended that pHOS not exceed 5 percent (HSRG et al. 2004b)[34].

[32] A hatchery program is an **Integrated Type** if the intent is for the natural environment to drive the adaptation and fitness of a composite population of fish that spawns both in a hatchery and in the wild.

[33] Hatchery programs are classified as **segregated** if the hatchery population is propagated as a genetically discrete or segregated population relative to naturally spawning populations. The principal goal of a segregated broodstock program is to create a new, hatchery-adapted population to meet co-manager needs for harvest or other purposes.

[34] The California HSRG recommends (provisional) a pHOS less than 5 percent for populations that are not integrated with the target program http://cahatcheryreview.com/wp-content/uploads/2012/08/CA%20Hatchery%20Review%20Report%20Final%207-31-12.pdf

Puntledge River-Vancouver Island British Columbia

The Puntledge River system has both summer-run and fall-run Chinook salmon. It is suspected that the two stocks originated from the same population but now the summer-run is genetically distinct from the fall-run.

In the mid-2000s a salmon genetics study was undertaken at the Puntledge Hatchery (Guimond and Withler 2009). The authors found that of the Chinook sampled, 1-31 percent were hybridized (mixed) summer/fall Chinook. The number of mixed fish observed increased during the spawning season progressed suggesting that mixed fish have an intermediate run timing between summer and fall Chinook (Figure 1). The authors hypothesized that the mixed fish are the result of historical hybridization between the two stocks through natural paring on the spawning grounds or unintentional pairing at the hatchery.

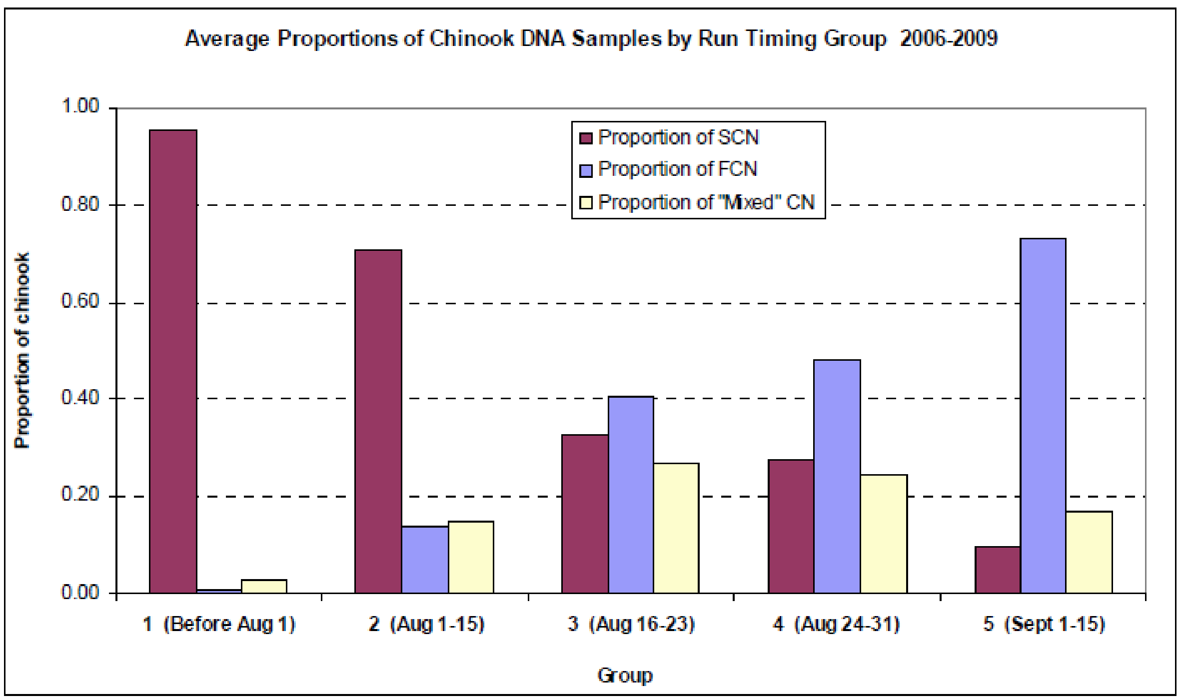

Figure 1. Proportion of summer Chinook (SCN), fall Chinook (FCN) and summer/fall ("Mixed" CN) adults by date for the Puntledge River DNA analyses (reproduced from Withler et al. 2012).

In their 2010 report, Guimond and Withler (2010) concluded that the relatively low rate of summer/fall hybridization may have been the result of reduced fitness of the mixed stock or to a propensity for both summer and fall Chinook spawning naturally to spawn with a mate of the same race.

To test the latter theory, a spawning behavior study was implemented in Jack Creek. The initial results of the study indicated that there seemed to be a weak affinity for fish to spawn with members of the same race. DNA sampling of emergent fry from summer and fall Chinook placed into a spawning channel indicated that salmon showed no preference in choosing a mate of the same race. However, resulting progeny production was positively correlated with male length (larger males produced more progeny) (Withler et al. 2012).

The authors of the spawning behavior study concluded that:

"If the primary goal is to rebuild a self-sustaining summer-run Chinook population to historic escapement levels, the results of the two trials underscore the importance of developing and implementing strategies in the hatchery and in the wild that will increase the separation in the run timings of the two ecotypes in order to reduce the introgression of summer Chinook genes into the fall Chinook population (and vice versa)."

White Salmon River-Washington State

Smith and Engle (2011) examined the interaction between upriver "brights" and tule fall Chinook salmon spawning in the White Salmon River. Although in the past these two Chinook races did not spawn in the same area, hatchery practices have resulted in an overlap in spawn timing and location. Based on genetic analysis, the authors found that between 4.3% and 15.0% of the migrating juveniles were hybrids (brights X tule) and that these hybrids did not produce returning adults.

Conclusions

The following conclusions can be drawn from the four examples:

1. Data collected in the Lewis River, Cowlitz River, and Trinity River indicate that when spring Chinook and fall Chinook are forced to spawn in the same reach, fall Chinook appear to dominate with regard to total fish abundance. However, because large numbers of hatchery fish spawn naturally in these systems, the proportion each race would contribute to the total Chinook population without constant hatchery input of adults is not known.
2. For the Lewis River and Cowlitz River, spring Chinook make up between 2-11 percent of the total Chinook abundance. The sustainability of the spring Chinook population in each river system is questionable without the continued input of hatchery origin adults.
3. Genetic analyses conducted in the Trinity River and Puntledge River systems show that hybridization can and does occur between spring and fall Chinook, and summer and fall Chinook.
4. Although run timing of the two races (spring/fall) varies, it appears there is sufficient overlap in spawn timing to allow for some hybridization.
5. Hatchery broodstock selection is based primarily on run timing back to the hatchery. This approach ensures that the adult run timing between races is maintained.
6. Because hatchery spring Chinook make up a large proportion of the natural spawning population, they may be maintaining the spring Chinook run timing for the combined natural and hatchery population.
7. Hybridization rate appears to increase as the Chinook spawning season progresses. This is to be expected as there is generally some overlap in spawn timing between the early arriving spring Chinook and later arriving fall Chinook.

8. Although hybridization may result in the production of juvenile offspring, these juveniles may or may not produce any returning adults.
9. Studies indicated that larger males produce more progeny than smaller males. It may be hypothesized that if the size of males from one race is larger than the other, hybridization rates may increase.
10. Natural spawning populations with high pHOS values will likely prevent the development of wild stocks that are well adapted to natural riverine conditions.

Appendix B: Comments Received on August 2015, Draft Report.

San Joaquin River Restoration Program: Comments on August 2015 Draft San Joaquin River Introgression Analysis

Commenter Affiliation Date	Statement in Draft Report	Comment
Tom Johnson RA, 10/5/15	---	Detail needed on river temperature and the potential for substantial thermal barriers as a factor for run separation
	---	Consider management techniques such as flow timing to extend or reduce thermal barriers rather than a physical barrier; the Restoration Flow Guidelines provide flexibility for adjusting flow release patterns to support management objectives.
	---	Provide additional discussion of how temperature management may be a key factor in the implementation of Alt 3.
Monty Schmidtt NRDC 10/8/15	General comments	Analysis ….” does not take into account some key existing information, conditions and limitations. For example, developing an alternative that would require hatchery production of both fall and spring run fish would exceed the current planned capacity of the new facility.”
		“A major factor for introgression is overlap of spawning. This analysis essentially identifies October as the only month of overlap. Something that is missing from the alternatives is a more adaptable approach that looks at how the two populations could be managed over time as their numbers grew. Perhaps a segregation weir is only needed to prevent introgression but not redd supper imposition. A more nuanced approach to the issue is needed.”
	Historically, the two races of Chinook salmon spawned in different portions of the basin and at different times.	Is this true? Spatially perhaps they were more segregated but was there overlap? Temporally, spawning for the two runs would likely have overlapped.
	…….in Alternative 1, wherein spring	This is a misleading characterization of

Commenter Affiliation Date	Statement in Draft Report	Comment
	Chinook restoration is prioritized over fall Chinook.	Alternative 1 since each alternative prioritizes Spring run. This alternative would be more aptly described as a spring run only scenario.
	Habitat modeling using the EDT Model indicated that spring Chinook spawning habitat is primarily limited to the 12.3 miles in reach 1A1 due to water temperature issues (ICF 2014).	If this number is used for planning purposes it should be carefully reviewed for legitimacy. The EDT model is not deemed by some to be a very accurate tool.
	"…in the event that competition, inadequate spatial or temporal segregation or other factors determined to be beyond the control of the Parties make achieving the Restoration Goal for both spring run and fall run Chinook salmon infeasible, then priority shall be given to restoring self-sustaining populations of wild spring run Chinook salmon." Therefore, alternatives that prioritize spring Chinook over fall Chinook are assumed to be consistent with the Settlement Agreement	An important part of this quote is the qualifier "…beyond the control of the Parties…" which clarifies that priority will be given to spring run if nothing else can be done to advance both populations. It would be incorrect to interpret this as being a blanket excuse for all prioritization.
	Data indicate that when spring Chinook and fall Chinook are forced to spawn in the same reach, fall Chinook appear to dominate with respect to total fish abundance.	This is a statement that is repeated in this report several times but may not be correctly applied to the Upper San Joaquin. Historically, spring run populations were significantly greater than fall run. This was likely due to the spring run timing being better adapted to the USJR including temperature and distance. Some of those conditions continue to exist and therefore it should not be assumed that fall run would naturally dominate as seen elsewhere.
	Tomalty et al. (2014) examined the causes and consequences of hybridization of Chinook runs in the San Joaquin River……	It seems like Tomalty et al. 2014 examined the likely causes and potential consequences for the Upper SJR
	Introgression will almost certainly lead to the loss of distinct fall run and spring run phenotypes and/or genotypes.	2%,5%? Seems like there is a level of introgression that happened historically and there is some level that could occur in the future that would not be significant.
	Alternative approaches to reduce introgression	The alternatives that were developed have provided some extreme bookends that are informative, but the likely solution is

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		something that borrows from some or all four. It would be helpful to refine these coarse alternatives to combine attributes.
	Alternative 1: The simplest way to eliminate hybridization between spring Chinook and fall Chinook in the San Joaquin River is to restore only one Chinook run at a time.	This may not be so simple as described here. The Hills Ferry Barrier has been used for decades to exclude fall run from the system with poor success. Creating a 100% effective barrier could be extremely difficult and have unintended consequences on other native fish. This alternative would be inconsistent with the Settlement unless there is clear evidence that it is "…beyond the control of the Parties…" to implement other actions including the three other alternatives. If this alternative is continued for further consideration, then the ability to implement a 100% effective barrier should be explored and discussed.
	Hybridization level must be maintained below 2 percent	Seems like this is a key variable that needs to be discussed to determine what the maximum allowable hybridization level should be.
	….it would appear unlikely that the hybridization criterion (<2 percent) could be achieved without the use of a segregation weir (or other forms of active adult management). The use of a weir would also reduce the amount of spawning habitat available to later arriving fall Chinook, possibly resulting in lower egg survival due to redd superimposition.	With a month of overlap in spawning, a weir could be used to prevent introgression. A separate question is whether there is a need to maintain a barrier to prevent redd superimposition. See general comment #2
	In Alternative 1, it is assumed that spatial and temporal segregation is either not physically possible, too expensive, or that the use of a structure to separate the two runs would reduce the probability of achieving adult abundance targets for one or both runs	It has not yet been determined what would meet the definition on being "beyond the control of the Parties" and would suggest not speculating here beyond that doing so is not physically possible. Cost is subjective and there has been no discussion of whether to eliminate one run at the expense of achieving the long term goal.
	If Alternative 1 is selected, it is assumed that Chinook spawner goals are likely to be achieved and that this will result in severe competition for spawning habitat between	This seems speculative because an option could be to segregate spawning areas.

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	the two races	
	Alt 2- develop a Chinook population adapted to the SJR	Rather than see this as an alternative, I wish that this analysis explored the fact that adaptation will occur under all the alternatives and how to manage that fact in a way that helps achieve multiple runs.
	As noted by Tomalty et al., and the data presented in Appendix A from other river systems, the resulting run will likely be dominated by fall Chinook.	As per previous comment, the USJR was dominated by spring run historically and therefore what has happened elsewhere may not prove to be the case here.
	Phase 1: Hatchery facilities would be used to rear and then release spring and fall Chinook juveniles to the San Joaquin River	This is not currently envisioned as part of the capacity of the conservation hatchery. It would seem that there might be other ways of achieving this objective of creating two runs adapted to conditions on the USJR.
	This phase [Phase 1]of the Program would continue until adult returns are sufficient to meet broodstock needs	The current production at the hatchery for spring run uses something like eggs from 50 adults. In other words such a phase might not take long or might be met with actions taken to-date
	Alt 3: Develop a late run of fall Chinook	This might occur anyway as the fish adapt to condition in the USJR, especially with the narrow window for juvenile emergence and outmigration before temperatures become lethal. As part of this alternatives analysis, it would be helpful to assess whether experts believe that this will occur anyway as part of any alternative.
	Spawning overlap between races may be reduced due to the difference in San Joaquin River flow before and after November 1 in Dry to Wet years (Table 5). [*remainder of lengthy paragraph can be found under Alternative 3 discussion*.]	This is a very helpful discussion and raises the question of whether there are other flow related actions that we can do to achieve our goals to separate the two runs. This would be good to explore further in the revision of this analysis.
	Stream temperatures in the months of August, September and October may also affect the level of egg mortality that may occur due to fall Chinook disturbance of spring Chinook redds. Higher stream temperatures result in earlier fry emergence timing. Stream temperatures from August through October could result in some fry emerging from the gravel prior	These are important factors that could substantially shift the potential for introgression. It would be helpful to assess the likelihood and degree to which these factors might impact introgression.

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	to November 1. If this occurs, fall Chinook spawning effects on spring Chinook redds would be reduced as eggs/fry would not be present[35]. Finally, egg losses due to superimposition may not be an issue if the quantity of fry/juvenile rearing habitat is what actually limits population abundance (e.g., egg capacity is greater than fry rearing capacity).	
	Yuba River researchers found that ~45 percent of the egg pockets in redds that had undergone superimposition were affected. Applying 45 percent as a correction factor for egg pocket impacts results in an expected superimposition rate of 14.85 percent (33% * 45%).	This is a thought provoking calculation. Another variable (among others) would be the number of spring run redds that would have already emerged before the late arriving fall run would spawn. A good question is what level of superimposition is acceptable. Another important aspect is the time when this will become a problem – is it right away or in 5 years, 20yrs at what assumed population levels. If this is not a problem for 10 years, that makes a big difference in terms of implementation.
	For spring Chinook the proportion of habitat needed was calculated as follows: 30,000 spring/ (30,000 spring + 10,000 fall) = 75% Spring Chinook adults would be collected at a downstream location, transported and released above the weir	See comment above regarding refining the understanding and assumed level of concern regarding redd superimposition. Is this in the near term or after fish passage barriers are resolved (e.g. Mendota dam)?

[35] An emergence timing analysis would need to be completed to confirm such an assumption.