Final Technical Memorandum

Potential Fish Benefits associated with Yolo Bypass Salmonid Habitat Restoration and Fish Passage Proposals

Winter Willows, Vic Fazio Yolo Wildlife Area. Photo courtesy of James Scott

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BACKGROUND

This technical memorandum answers questions Yolo County posed in response to state and federal proposals to increase the frequency and duration of Yolo Bypass inundation as part of the Yolo Bypass Salmonid Habitat Restoration and Fish Passage project ("Salmonid Project"). The Salmonid Project is under development to address the Reasonable and Prudent Alternatives (RPA) I.6.1 and I.7 in the National Marine Fisheries Service's (NMFS) Biological Opinion (BiOp) on the Coordinated Long Term Water Operations of the Central Valley Project (CVP) and State Water Project (SWP) for winter-run Chinook salmon, spring-run Chinook salmon, Central Valley steelhead and southern green sturgeon. The U.S. Bureau of Reclamation ("Bureau") and the California Department of Water Resources (DWR) are the lead agencies charged with implementation of the Salmonid Project, which contains two major elements: 1) a fish passage structure to replace the existing Fremont Weir fish ladder scheduled for construction in 2018; and 2) the construction of a structure in the Fremont Weir with operable gates to allow inundation of the Yolo Bypass for floodplain habitat, as well as additional fish passage structures, in 2021. The agencies have already released the Initial Study/Environmental Assessment for the 2018 fish passage structure and are scheduled to release the first draft of the Environmental Impact Statement/Environmental Impact Report (EIS/EIR) for the 2021 operable gates by the end of 2017. Special emphasis was placed on reviewing potential benefits to target fish species from actions proposed in the EIS/EIR for the new operable gates (see Table 1).

Table 1. List of species considered in the EIS/EIR. Federal and state listed threatened and endangered species are noted as "T" and "E".

Species	State Listing	Federal Listing
Central Valley winter-run Chinook	E	E
Central Valley spring-run Chinook	T	E
Central Valley steelhead	--	T
Southern green sturgeon	--	T

INTRODUCTION

Floodplains include those areas adjacent to an active river channel that seasonally flood during high water events. Floodplains support high biodiversity and yet are among the most altered and threatened habitats in the world (Opperman et al. 2010). In the Central Valley, the Yolo Bypass is the largest contiguous floodplain remaining in the Sacramento River basin at 57,000 acres (Howitt et al. 2013). Native fish that evolved to use floodplains, such as Chinook salmon and Sacramento splittail, benefit from relatively high productivity (e.g., chlorophyll a concentration) as compared to altered habitat provided in the channelized mainstem river (Sommer et al. 2004, Jeffres et a. 2008). Existing data also supports the idea that high productivity can result in increased prey availability to higher order consumers on or immediately downstream of floodplain habitat (Sommer et al. 2001a). Additionally, increased food availability and other factors associated with floodplain rearing habitat have been shown to improve juvenile salmonid growth when compared to mainstem river conditions (Sommer et al 2001c, Jeffres et al. 2008). Less understood, however, is how differences in salmonid growth associated with floodplain habitat affect survival (Sommer et al. 2001c, Sommer et al. 2005). Habitat structure associated with floodplains (i.e., density of aquatic vegetation, reduced water velocity, etc.) can also provide refuge to juvenile fishes from predators and high river velocities, which can flush fish downstream into the interior delta. Adults of some species (e.g., splittail) are known to benefit from floodplain inundation, as these species use such habitats for spawning. Uncertainty exists, however, regarding the magnitude of inundation required to achieve significant biological benefits for the fish species targeted by the Salmonid Project.

Growth benefits to fishes associated with floodplain habitat may not increase at a constant rate over time due to bioenergetic trade-offs and changing floodplain conditions. Such trade-offs can occur when growth rates are slowed or reversed due to exceedingly high temperatures or low dissolved oxygen concentration. Sommer et al. (2001c), however, suggested that juvenile salmon may be able to metabolically compensate for increases in water temperature with concomitant increases in prey availability associated with floodplain habitat and, thus, obtain superior growth rates when compared with mainstem conditions. With respect to water temperature, Katz (2012) suggested that juvenile Chinook temperature tolerances may be exceeded during the late spring (late April or May) and trigger floodplain exit. However, the authors found strong evidence that juvenile Chinook salmon permitted to access seasonally inundated floodplain habitat on the Yolo Bypass experienced more rapid growth, substantially improved body condition, and delayed out-migration timing[1]. The authors also suggested that juvenile Chinook salmon experience a superior out-migration route by avoiding the interior Delta. Katz et al. (2013) concluded that in general, even with the anomalous weather patterns during 2013 (the winter of 2013 was one of the driest and warmest on record at the time), water conditions within experimentally inundated rice fields provided excellent growing conditions for

[1] Source of water for the Knaggs Ranch project was the Colusa Basin Drain and is not Sacramento River water as would be the case with an overtopping event at the Fremont Weir.

juvenile Chinook salmon. So, while the quality of water (e.g., water temperature) inundating the floodplain may affect the duration of floodplain use by fishes, there is ample evidence that significant biological benefits are provided to juvenile Chinook salmon by inundated floodplain habitat (Sommer et al. 2001c, Jeffres et al. 2008, Katz 2012, Katz et al. 2013).

Topics & Questions

In 2014, Yolo County identified topics and generated pertinent questions regarding proposed projects to increase inundation in the Yolo Bypass to benefit targeted fish species. This document was generated to address these topics and questions, as well as identify areas of scientific uncertainty. Some of the questions asked and answered in this paper are not relevant to the Salmonid Project, as they pertain to splittail and other species covered by the Bay Delta Conservation Plan. The state and federal government replaced the Bay Delta Conservation Plan in 2016 with California WaterFix and California EcoRestore, neither of which contains the proposals to inundate the Yolo Bypass for floodplain habitat contained in the Bay Delta Conservation Plan. The authors maintained the information about the topics relevant to the Bay Delta Conservation Plan in the event there are future discussions about modifying the Salmonid Project for other species.

1. Abundance of Juvenile Salmon in the Sacramento River

1a. How many juvenile salmon are in the Sacramento River at different times of the year?

1b. Of these fish, how many juvenile salmon can be reasonably expected to access floodplain habitat in the Yolo Bypass under different proposed alternatives? What are the factors that influence their ability to access the floodplain? What is the level of certainty associated with these estimates and what additional research would be necessary to improve that level of certainty?

2. Hatchery Fishes

2a. How many of the fish expected to access the Yolo Bypass floodplain habitat are of hatchery origin?

2b. What is the likelihood that these hatchery fish will reproduce in the wild?

3. Other Floodplains

3a. Is the Yolo Bypass the only floodplain habitat important to fish species of interest in the lower Sacramento River watershed? If not, what other areas are important to fish species of interest (e.g., Sutter Bypass)?

4. Toe Drain Versus Floodplain Habitat

4a. Is floodplain habitat along the Toe Drain in the Yolo Bypass higher or lower quality than other floodplain habitat in the Yolo Bypass, such as the western portion of Knaggs Ranch?

5. Benefits of Flood Timing

5a. What are the benefits of providing floodplain habitat before March 1st for each species of interest? After March 1st? What are the factors that influence level of benefit to fish species of interest, such as temperature? What does the scientific community know about these factors and what information is not available?

5b. How will climate change affect these benefits?

5c. What are the different mechanisms through which splittail spawning success in the Yolo Bypass can be measured, considering that different organizations may define spawning success differently?

5d. Do splittail need 10,000 acres of floodplain habitat to "successfully" spawn (i.e. realized population benefits associated with a smaller inundation footprint) in the Yolo Bypass? Would "success" be possible if splittail floodplain habitat is limited to the lower Yolo Bypass, such as areas in Cache Slough? Are there other opportunities for creation of successful splittail spawning habitat outside of the Yolo Bypass?

5e. How long do juvenile salmonids and splittail need to stay on the Yolo Bypass floodplain to realize significant benefits?

1. ABUNDANCE OF JUVENILE SALMON IN THE SACRAMENTO RIVER

1a: How many juvenile salmon are in the Sacramento River at different times of the year?

The timing and estimate of juvenile salmon abundance occurring throughout the Sacramento River varies inter-annually. Changes in both river flow and water temperature provide cues for juvenile salmon to initiate migration and are dependent on climatic and hydrologic influences (Groot and Margolis 1991). For instance, Del Rosario et al. (2013) found that juvenile winter-run Chinook peak emigration timing in the Sacramento River varied between water type years and found a strong correlation between initial emigration timing and early season high discharge events. Based on rotary screw trap data from Knights Landing (1997-2007), juvenile salmon (all runs) can be found in the Sacramento River from October through July (Roberts et al. 2013). Migration of juvenile salmon past Knights Landing likely occurs in three phases (as in Snider and Titus 2000). Between September 1997 and June 1998, late-fall and winter-run Chinook juveniles produced in the wild and spring-run Chinook dominated Phase 1 (November 16-January 3). Fall-run Chinook dominated Phase 2 (December 28 - March 7), while fall-run Chinook released from Coleman National Fish Hatchery principally comprised Phase 3 (March 8 - June 21) (Snider and Titus 2000).

Rotary screw trap data can provide valuable estimates on the timing of outmigration and catch per unit effort (CPUE) of salmon between different water type years, although uncertainty is introduced into the data as a result of the use of length-at-date criteria to identify runs (see Harvey et al. 2014). Though CPUE is not a direct measure of abundance, it is a valuable tool that standardizes catch (number of salmon) based on the level of effort (time) and is particularly useful when comparing inter-annual data to better understand trends in timing and relative abundance. As such, we examined differences in run timing and CPUE of salmon between years using annual Knights Landing Rotary Screw Trap data. These data describe the relative number of juvenile salmon of different runs based on size criteria (length-at-date) caught at the trap by Julian Week. There are inherent weaknesses, however, associated with run-type identification by length-at-date criteria. Harvey et al. (2014) found extensive fork length overlap between the different Central Valley Chinook races with approximately half of all length-at-date identifications receiving different genetic assignments. In particular, the authors found a very high degree of overlap between fall- and spring-run Chinook, although fork length distributions of all run types overlapped to some extent. This and other work by Merz et al. (2014) suggest the use of length-at-date criteria may significantly under- or over-estimate the contribution of different run types to the total number of out-migrants. Thus, the proportion of different run-types between water years should be viewed with caution.

To estimate how many juvenile salmon are in the Sacramento River at different times of year, we focused on two time steps. First, we examined a snapshot in time using data provided to Yolo County by the California Department of Fish and Wildlife from September 1997 to June 1998 to determine run-type abundance during different times of year in the Sacramento River. This single year analysis focuses on estimates derived from the number of juvenile salmon caught at

Knights Landing (from Snider and Titus 2000) with proportions caught by Julian Week (Roberts et al. 2013, unpublished data). Detailed methods used to estimate abundance of juvenile salmon passing Knights Landing are described in Table 2. Considerable uncertainties are associated with estimating abundance of juvenile salmon from one year of trap data (1997-1998). As such, and to understand patterns over a longer period of time, we also used Knights Land Rotary Screw Trap data from Appendix A in Roberts et al. 2013 (water years 1997-2010). These data describe mean emigration timing during wet, above normal, below normal, and dry water type years and the relative CPUE of total salmon and run-types during 1997-2010. Both analyses should be viewed as an initial effort.

Table 2. Estimates used to calculate total number of fishes moving in the Sacramento River past Knights Landings (Phase 1-3) and number of fish that may have entered Yolo Bypass without and with and operable gate at Fremont Weir, November 1997-June 1998

Chinook Run	Phase 1*	Phase 2	Phase 3	Estimated 1998 Entrainment without gate**	Estimated 1998 Entrainment with gate**
Late Fall	20587.5	25162.5	0	10215.98	12910.65
Winter	45050	61943.75	5631.25	17851.06	25295.58
Spring	16275	4882.5	33092.5	7144.725	11446.75
Fall	1737748	2652353	4755943	1461538	1681043
Subtotals	1819661	2744342	4794667	1496750	1730696
1997-1998 Total number			9358669		

Steps used in calculations:

1. Determined Julian weeks corresponding to each Phase as defined in Snider and Titus 2000.
2. Determined the portion of each run traveling past Knights Landings during each Phase as defined in Roberts et al. 2013, unpublished data of Knights Landing Rotary Screw Trap catches (1997-2007).
3. Used abundance numbers in Snider and Titus 2000 and proportion from Roberts et al. 2013 to estimate numbers of each run migrating during each phase; sum total (~ 9.3 million) became an estimate of the number of fishes found in the Sacramento River from November 1997-June 1998
4. Used proportion of fishes entering Yolo Bypass (without and with operable gate at Fremont Weir; Roberts et al. 2013 *An empirical approach to estimate juvenile salmon entrainment over Fremont Weir*, Fisheries Branch Administrative Report 2013-01, Sacramento) with estimated total abundances to estimate number of fishes entering Yolo Bypass in 1998 WY.
5. Subtracted estimated number of fishes entering Yolo Bypass without operable gate from estimated number fishes entering Yolo Bypass with operable gate to estimate differences between the two scenarios (~234 000 fishes).

Between 1997 and 2010, a total of 613,035 juvenile salmon were collected at the Knights Landing Rotary Screw Trap site over 169,220 hours (3.6 fish/hour). During this period, fall-run Chinook comprised nearly 97% of the entire catch with spring-, winter-, and late-fall-run juveniles comprising the remaining 3% (see Table 3). Annual total catch per unit effort (CPUE) peaked during the 2003 water year (56,049), with the lowest CPUE during 2010 (2,905) (see Figure 1A). Juvenile outmigration varied by water type year with generally greater catch per unit effort of out-migrants on average during wet (n=4, mean=23,722±13,920) and above normal (n=3, mean=33,929±19,680) years and less during below normal (n=2, mean=13,511±15,000), and dry years (n=5, mean=17,149±8553) (Figure 1A and Table 3), although there was significant variability within like water type years. Over all water years, (1997-2011) mean juvenile emigration began on average during week 46 (approximately the second week of November) and ended during week 23 (approximately the second week of June) (see Figure 1B). During this time period, peak emigration generally occurred between weeks 46 and 14 (approximately the first week of April), followed by a second smaller peak during weeks 14 and 23 (Figure 1B). While the length of the total emigration period was similar between years, though somewhat shorter during dry and critical dry years, the magnitude and timing of salmon emigration pulses between water years was different (see Figure 2). For instance, during dry and critically dry years, peak emigration occurred, on average, over three shortened and distinct periods between weeks 49 (mid-December) and week 11 (mid-March). During wet years, peak emigration generally occurred at greater magnitudes and over a sustained period of time between weeks 52 (late-December) and 13 (late March). Differences in emigration timing are likely related to a range of environmental variables, with hydrologic influences likely playing a particularly important role (Del Rosario et al. 2013).

Table 3. Annual catch per unit effort of Central Valley Chinook run-types between 1997 and 2010 at Knights Landing. Percent total composition of each run-type for each year follows CPUE numbers. Water year types: W = wet, AN = Above Normal, D = Dry, BN = Below Normal, C = Critical Dry.

Year	Water Type	Annual Catch Per Unit Effort				
		Total CPUE	**Fall-run**	**Spring-**	**Winter-**	**Late Fall-**
1997	W	37,701	36,815 (97.6)	211 (0.6)	521 (1.4)	154 (0.4)
1998	W	33,504	32,710 (97.6)	297 (0.9)	435 (1.3)	63 (0.2)
1999	W	13,823	13,728 (99.3)	45 (0.3)	30 (0.2)	20 (0.1)
2000	AN	27,381	27,190 (99.3)	48 (0.2)	139 (0.5)	4 (0.01)
2001	D	15,324	14,763 (96.3)	241 (1.6)	297 (1.9)	23 (.15)
2002	D	30,909	29,225 (94.5)	1,135	495 (1.6)	54 (.17)
2003	AN	56,049	54,173 (96.7)	975 (1.7)	886 (1.6)	15 (.03)
2004	BN	24,118	23,201 (96.2)	440 (1.8)	345 (1.4)	132 (0.5)
2005	AN	18,358	16,998 (92.6)	468 (2.5)	746 (4.1)	146 (0.8)
2006	W	9,858	9,432 (95.7)	94 (1.0)	327 (3.3)	5 (0.05)
2007	D	19,066	18,707 (98.1)	138 (0.7)	215 (1.1)	6 (0.03)
2008	C	9,833	9,640 (98)	137 (1.4)	54 (0.5)	2 (0.02)
2009	D	10,613	10,402 (98)	102 (1.0)	68 (0.6)	42 (0.4)
2010	BN	2,905	2,596 (89.4)	168 (5.8)	137 (4.7)	4 (0.13)
Mean		22,103	21,399 (96.8)	321 (1.5)	335 (1.5)	48 (0.2)

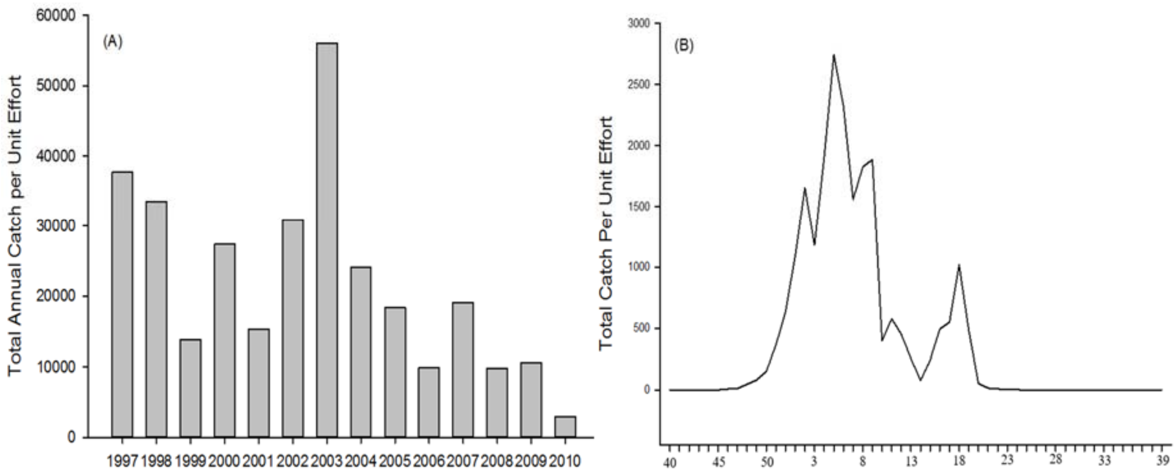

Figure 1. (A) Total annual catch per unit effort at Knights Landing from 1997-2010 and (B) mean emigration timing of all salmon from 1997-2010 at Knights Landing. week 40 corresponds to the beginning of the water year (October 1st).

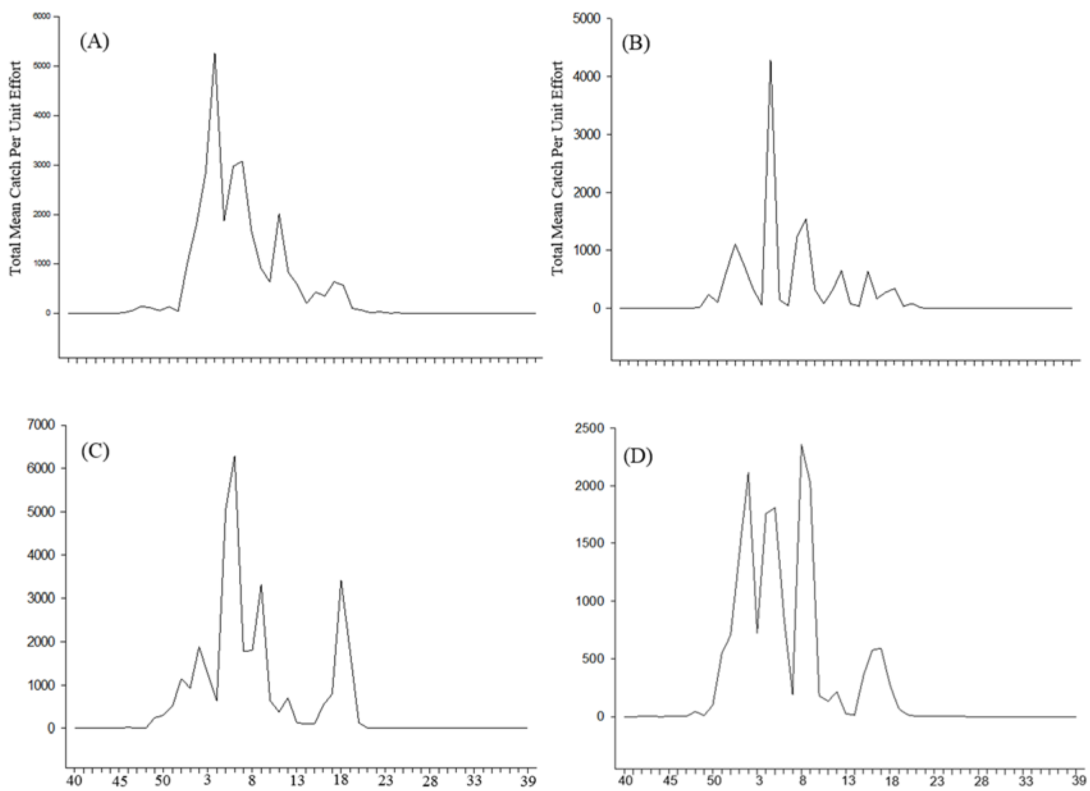

Figure 2. Mean emigration timing (total mean catch per unit effort) over different water years for all run types from 1997-2010 at Knights Landing. Week 40 corresponds to the beginning of the water year (October 1st). (A) Wet years (1997, 1998, 1999, 2006), (B) Above normal years (2000, 2003, 2005), (C) Below normal years (2004, 2010), and (D) Dry and critical dry years (2001, 2002, 2007, 2008, 2009). Note different y-axis scales.

As mentioned previously, estimating juvenile salmon abundance from one year of rotary screw trap data (1997-1998) provides information of limited use. Trap data may be more useful in understanding differences in CPUE and timing between years rather than as a predictive estimate of total abundance. For instance, using a mark recapture study in Alaska, Thedinga et al. (1994) found that trap efficiency ranged between 3% and 24% for steelhead and Chinook salmon, respectively. Trap efficiency is known to be influenced by flow (Gaines and Martin 2002) and turbidity (McKibbin 2012) with fewer fish caught during periods with high flow or low turbidity. In addition, the number of juvenile salmon trapped varies greatly between years (J. Roberts, unpublished data). Likewise, juvenile salmon abundance in the Sacramento River is expected to vary greatly because juvenile abundance reflects the spawning stock size and is affected by the survival of earlier life stages (i.e., incubating eggs, alevin, fry), which can be affected by various environmental conditions, such as water type year, river flow, water temperature, predation, incubation success, and food availability. Finally, Knights Landing trap data could be affected if overflow from the Sacramento River enters the Sutter Bypass (upstream of Knights Landing), providing another migration route to juvenile salmon. In 1998, flows were sufficiently high for fish migrating in the Sacramento River to enter the Sutter Bypass in January (Snider and Titus 2000), so there is considerable uncertainty associated with these estimates.

1b: Of these fish, how many juvenile salmon can be reasonably expected to access floodplain habitat in the Yolo Bypass under different proposed alternatives? What are the factors that influence their ability to access the floodplain? What is the level of certainty associated with these estimates and what additional research would be necessary to improve that level of certainty?

The level of certainty associated with estimates of the number of juvenile salmon that may access floodplain habitat in the Yolo Bypass in any given year, also known as "entrainment," is low due to high variability in juvenile production and survival each year. Acierto et al. (2014) is the first attempt to answer this question, but uncertainties remain regarding estimates of entrainment. For instance, standardized use of rotary screw trap data can provide valuable catch per unit effort numbers among sites and between years for relative comparison, though spatiotemporal variability in capture efficiency often precludes accurate year to year abundance estimates. In general, abundance and entrainment estimates are highly uncertain due to annual variability in discharge and water temperature. The reliability of estimates is most often confounded by changes in trap orientation, changes in the rate of trap rotation, water velocity, and debris accumulation in and around the trap (USFWS 2008). Further, it is difficult to predict how climate change may alter juvenile migration patterns (as in Crozier et al. 2008; Moyle et al. 2013). The level of certainty should be greatly improved by tracking fish movements as juvenile salmon migrate downstream, monitoring the number of fish migrating past Fremont Weir under different conditions and during different water type years, and evaluating the effects of water temperature and flow on run-timing, habitat preferences and selection of migration routes. Some of this is ongoing and will provide important data regarding gate operation at Fremont Weir.

The number of juvenile salmon accessing the Yolo Bypass in any given year will largely depend on the synchrony between migration timing and flow events of sufficient magnitude to overtop

Fremont Weir, flow under the proposed gated channel, or pass through a notch. Roberts et al. (2013) estimated that an operable gate at Fremont Weir could increase the number of juvenile salmon accessing the Yolo Bypass by 185%. The estimate was based on an evaluation of historical Sacramento River discharge at Fremont Weir from 1997-2011 and combined with juvenile salmon emigration data from rotary screw traps at Knights Landing (approximately five miles upstream of Fremont Weir) over the same time period. The authors assumed an even distribution of juvenile Chinook salmon throughout the entire water column and that entrainment was directly proportional to volume of Sacramento River flow overtopping Fremont Weir or moving through an operable gate. Roberts et al. (2013) also based entrainment estimates of different run types on size-at-date criteria and there is considerable uncertainty associated with this method (see Harvey et al. 2014), suggesting that specific run entrainment estimates may be over- or under-estimated. More information is needed regarding the actual distribution of juvenile salmon in the water column, behavioral patterns regarding entrainment, and how the distribution of juvenile Chinook changes in response to different stimuli (i.e., diel behavior, flow events, etc.).

More recent research has focused on the behavior and movement of Chinook salmon in the water column in the Sacramento River near Fremont weir. Using acoustic telemetry, Steel et al. (2016a) found that hatchery juvenile late-fall and winter-run Chinook were not uniform in their use of the channel during outmigration, but that they generally used the outside bend of the Sacramento River near Fremont Weir. The behavior and movement data from this study is being used to further improve resolution on the magnitude and extent of entrainment onto the Yolo Bypass under the different proposed flooding alternatives and will be directly compared with the methods from Roberts et al. (2013). Telemetry results from Steel et al. (2016a and 2016b) are also currently being applied to the Eulerian-Lagrangian-agent method (ELAM), which is being used to model juvenile salmon entrainment onto the Yolo Bypass. ELAM considers both the fluid dynamics associated with potential inundation scenarios and fish behavioral response in an effort to make more robust estimates of entrainment.

The position, size, and run type of juvenile Chinook salmon prior to reaching Fremont Weir may affect their migration route and whether they enter the Bypass via an operable gate. For instance, Steel et al. (2016a) found that hatchery winter-run Chinook migration tracks were farther to the outside of the bend than late-fall-run Chinook over short distances. Tracking of juvenile Chinook salmon near the Delta Cross Channel suggests that both river position and size of individuals can influence migration route selection, although water velocity was the strongest predictor (Steel et al. 2012). Due to size discrepancies, yearling juvenile salmon are better swimmers than sub-yearlings (Groot and Margolis 1991) and, therefore, may access the Bypass at different rates. Larger fish, in general, are also less likely to be entrained involuntarily, suggesting that enhanced swimming performance may aid in preferable route selection or enable yearling juvenile salmon to maneuver through the operable gate more efficiently than sub-yearling juveniles. Conversely, larger individuals may be able to avoid the operable gate all together. Differences in entrainment rates between yearling and subyearling juvenile salmon (or different size classes), however, have not been estimated for the Yolo Bypass and may be of future research interest. Steel et al. (2016a) found that out-migrating late-fall-run juvenile Chinook size classes ranging approximately between 100-180 mm showed little difference in movement, but the direction and movement of smaller individuals (30-70 mm), characteristic of outmigrating juvenile winter-run Chinook, were not studied.

Tracking the movement of juvenile salmon as they approach Fremont Weir should help improve percent entrainment estimates. The lead agencies are currently working on applying two additional methods which should provide further insight on salmonid movement near Fremont Weir. These methods include ELAM (referenced above) and Critical Streakline Analysis. Critical Streakline Analysis examines the spatial distribution and movement of salmon under different velocity conditions through the analysis of acoustic telemetry data and resulting salmonid movement "tracks". Environmental covariates can also be collected in order to statistically assess how individuals are moving under particular environmental conditions.

Until empirical data is available, the Roberts et al. (2013) estimate regarding improved access under an operable gate scenario is valuable. Based on the proportional estimates and abundance estimates discussed under Topic #1, the number of juvenile salmon (including both wild and hatchery fish) estimated to have entered the Yolo Bypass in Water Year 1998 is about 1.5 million juveniles between November 1997 and June 1998 (Table 2). Based on percentages reported in Roberts et al. (2013), an additional 200,000 juvenile salmon may have accessed the Bypass if an operable gate were in place at Fremont Weir during this period (this estimate is specific to the 1997-1998 data). These numbers are illustrative and only provide an estimate, for discussion purposes. As noted, the Department of Water Resources is working with the state and federal fish and wildlife agencies to develop more robust models for estimating the biological benefits associated with an operable gate at the Fremont Weir. While the agencies are unlikely to use the Roberts et al. (2013) methodology in the EIS/EIR, current models (ELAM and Critical Streakline Analysis) will require peer review.

2. HATCHERY FISHES

2a: How many juvenile salmon expected to access the Yolo Bypass floodplain habitat are of hatchery origin?

This section focuses on fall-run Chinook due to the well-documented use of hatcheries to supplant historically diminishing returns throughout the Central Valley. From September 1997-June 1998, about 97% of unmarked salmon and 67% of marked salmon caught at the Knights Landing Rotary Screw Trap were fall-run Chinook (Snider and Titus 2000) (see Table 3 for additional years between 1997-2010). The Central Valley fall-run Chinook population as a whole is now dominated (> 90%) by hatchery produced salmon (Barnett-Johnson 2007, Johnson et al. 2013). If the proportion of juvenile salmon accessing the Yolo Bypass is likewise dominated by fall-run Chinook, then we can estimate that the large majority (> 90%) of juvenile salmon using the Bypass are of hatchery origin. Based on past hatchery release dates, most fall-run Chinook juveniles would migrate through the Bypass between March and June. We also anticipate that individuals of natural origin (i.e. not hatchery produced), despite currently low numbers (including winter- and spring-run), would benefit from improved lateral connectivity associated with a flooded Yolo Bypass. Such habitat may be particularly important to improve runs currently exhibiting extremely low abundances or contributions to overall population dynamics, in addition to improving life history diversity and population resiliency. Of course, such improvements would depend on migration timing coinciding with improved access to the Yolo Bypass and the timing, duration, and magnitude of flooding extent. Recent studies suggest that improving historically important floodplain habitat in the Central Valley vastly improves juvenile Chinook growth and body condition, delays out-migration timing, and may provide a superior out-migration route (Katz et al. 2013, Sommer et al. 2001c, Jeffres et al. 2008).

2b: What is the likelihood that these hatchery fish will reproduce in the wild?

Reproduction of hatchery-origin adult salmon in the wild appears to differ by run type. Such spawning occurs mainly in rivers below hatcheries. While hatchery origin salmon that spawn in the wild often produce large numbers of young, survival of these young appears to be low. Generally, hatchery reared salmonids show a decline in fitness in the wild (Allendorf and Phelps 1980, Ford 2002), which may be due to the selection of maladaptive traits (Christie 2012), competition associated with hatchery reared individuals (see Weber and Fausch 2003), or manipulations of river flows for benefits other than salmon production (P. Moyle, personal communication).

Straying occurs when adult salmon return to spawn in watersheds other than their natal watershed. Straying is a natural part of salmon behavior but is usually less than 10% in wild populations (Groot and Margolis 1991). Releases of hatchery produced juvenile salmon in locations away from the hatchery promote higher rates of straying in returning adults (reviewed in California HSRG 2012) and may have detrimental effects on the ability of a wild populations to cope with changing environmental conditions if the genes from those hatchery-origin adult fish are introduced into the wild population. Straying is thought to be the principal cause of genetic homogenization of Central Valley fall-run Chinook (Williamson and May 2005), making the entire run more susceptible to collapse (Lindley et al. 2009) from both inter-annual variations in environmental cues such as river flows, water temperatures, and other longer-term processes such as climate change.

Fall-run Chinook reproduction in the Mokelumne River was recently studied by Johnson et al. (2013). Upon evaluating the chemical signature of otoliths, Johnson et al. (2013) proposed that 90-99% of fall-run Chinook salmon spawning in the Mokelumne River were of hatchery origin. Similarly, about 86% of spring-run Chinook reared in the Feather River Hatchery between 2004 and 2007 and released in San Pablo Bay strayed when they returned as adults (California HSRG 2012b). Of the groups of Chinook likely to use the Yolo Bypass (see Table 4), we can infer that straying of returning adults is most likely from Coleman National Fish Hatchery releases (both Battle Creek and San Pablo off site releases). Juvenile releases in San Pablo Bay may be particularly problematic. CDFG and NMFS (2001) found that up to 90% of off-site released juveniles strayed upon return as adults and that straying rates and distance of release from the hatchery of origin were positively correlated. Despite juveniles initially being released downstream of the Yolo Bypass, there is a high likelihood that subsequent generations could use the bypass for rearing. However, it is currently impossible to estimate how many of those juvenile progeny will use the Yolo Bypass and subsequently return to the Sacramento River as spawners. Tagging and individual tracking of fishes through their entire life cycle from hatchery rearing through seaward migration to adult spawning could provide valuable estimates of the number of hatchery fish rearing in the Bypass.

Table 4. Run type, percentage marked, and release target, location and month of Central Valley Chinook salmon reared in hatcheries. Two asterisks (**) marks groups most likely to use the Yolo Bypass for rearing, one asterisk marks groups likely to use Yolo Bypass as a migration corridor. FR: fall-run Chinook, SR: spring-run Chinook, LFR: late fall-run Chinook, WR: winter-run Chinook. Note: Livingston Stone National Fish Hatchery is a substation of the Coleman National Fish Hatchery and is operated as a conservation hatchery program to assist in population recover of ESA-listed winter-run Chinook salmon. Source: California HSRG 2012a.

Hatchery Facility	Run	Marked	Release target/year	Release location/month
Nimbus	FR	25%	4,000,000 smolts	San Pabo Bay; mid- May to mid-June
Mokelumne	FR	25%	5,000,000 smolts; 2,000,000 post-smolts	San Pablo Bay & Woodbridge Dam; March to June
Merced	FR	25%	1,000,000 smolts	Var. locations, San Joaquin basin; April to mid-May
Feather	FR	25%	6,000,000 smolts; 2,000,000 post-smolts	Carquinez Straits; April to June
	SR*	100%	2,000,000 smolts	Feather R., Carquinez Straits; April or May
Coleman	FR**	25%	12,000,000 YOY	Battle Creek, San Pablo Bay; April
	LFR*	100%	1,000,000 yearling	Battle Creek
Livingston Stone	WR**	100%	250,000 YOY	Sacramento River; late Jan. to early Feb.

3. OTHER FLOODPLAINS

3a: Is the Yolo Bypass the only floodplain habitat important to fish species of interest in the lower Sacramento River watershed? If not, what other areas are important to the fish species of interest (e.g., Sutter Bypass)?

The Yolo Bypass is the largest floodplain habitat available and is strategically located to encourage alternate routing through the Delta and, thus, provides significant ecological benefits to fish in the lower Sacramento River. However, others have shown that species of concern in this document do use other floodplain type habitats in the Central Valley to complete their lifecycle. For instance, Chinook salmon rear in the Cosumnes River floodplain (Jeffres et al. 2008), Natomas East Main Drainage Canal (Jones and Stokes Assoc. 1999) and Sutter Bypass (Hill and Webber 1999, Ward et al. 2004). Additionally, splittail are known to spawn in floodplain habitats in the lower Cosumnes River, American River, Sutter Bypass, Sacramento River, and lower Tuolumne River (San Joaquin basin; Moyle et al., unpublished report; Moyle et al. 2004). Outside of the Central Valley, splittail are also present in the Napa and Petaluma Rivers (Baerswald et al. 2007) and recent data suggests that these populations overlap with Central Valley splittail during certain years (Feyrer et al. 2015). Sommer et al. (1997) found that larval densities were not statistically different in the Sutter and Yolo Bypasses, suggesting that reproductive success is similar between sites. Furthermore, splittail can successfully spawn along stream banks and in backwaters during small increases in flow (reviewed in Moyle et al. 2004) when the Bypass may not flood. This also suggests that channel margin enhancement projects may strongly benefit splittail.

4. TOE DRAIN VERSUS FLOODPLAIN HABITAT

4a: Is the floodplain habitat along the Toe Drain in the Yolo Bypass higher or lower quality than other floodplain habitat in the Yolo Bypass, such as the western portion of Knaggs Ranch?

The floodplain habitat along the Toe Drain may be of equal quality to other floodplain habitat in the Yolo Bypass, assuming these areas are also seasonally flooded and have similar depth, velocity, and food web characteristics. Toe Drain habitat suitability and juvenile salmon growth is currently being compared to experimental floodplains on Knaggs Ranch, so we anticipate additional information (Katz, personal communication). The Toe Drain may currently be more suitable for some species (e.g., splittail) since they are flooded for longer periods of time (i.e., the Toe Drain is the first to inundate and last to drain), although we anticipate that a range of habitat diversity (floodplain, Toe Drain, etc.) is of particular importance to species of concern. Installing an operable gate at Fremont Weir would allow for the management of floodplain inundation and make a greater area of Yolo Bypass suitable for species such as splittail and juvenile Chinook salmon, depending on water year. Aside from increasing habitat area, bypass inundation will also improve habitat heterogeneity (i.e., shallow, low velocity, high food production) which is expected to benefit species of interest.

One concern regarding floodplain habitat along the Toe Drain is that fish that occur in these areas may be more susceptible to predation. Another concern is the potential for rapid changes in water depth associated with cessation of overtopping of the Fremont Weir under current conditions. The rate of flood recession is presumably important and, if too fast, could contribute to the desiccation of splittail eggs and potentially cause increases in mortality. The proposed operable gate at Fremont Weir would provide more flexibility concerning the management of floodplain inundation (i.e., extent, duration, and timing) and likely improve the chances of realizing biological benefits to fish through an adaptive management framework.

5. BENEFITS OF FLOOD TIMING

5a: What are the benefits of providing floodplain habitat before March 1st, and after March 1st for each species of interest? What are the factors influencing the level of benefit to fish species of interest, such as water temperature? What does the scientific community know about these factors and what information is not available?

Species of interest will benefit from use of the Yolo Bypass in the fall and winter (before March 1st), but juvenile salmon, splittail, sturgeon and lamprey will also benefit from floodplain use after March 1st. However, the magnitude of benefits and how they differ by run timing, size and age of fish has not been evaluated. Further, the area of inundation necessary to achieve the biological goals associated with the BiOp is unknown. The NMFS (2009) OCAP BiOp RPA I.6.1 calls for an initial performance measure of 17,000-20,000 acres of inundation (excluding tidally influenced areas), however, the acreage requirement could be revised if scientific information supports such a change.

Beneficial conditions for growth and survival of individual fish (water temperature, dissolved oxygen, etc.) are expected to last only as long as favorable habitat exists for those species. Currently, favorable habitat is expected to be readily available before March 1st because flooding is more likely and air temperatures are generally cooler, though this may change with the proposed operable gate at Fremont Weir or under different water year type conditions (e.g., cool, wet springs). However, determining the duration of benefits after March 1st is difficult under current and future flood inundation scenarios. Benefits to fish using floodplain habitat are generally governed by numerous abiotic and biotic factors including water quality, temperature, velocity, depth, habitat heterogeneity, prey availability, and predation among others. These factors are expected to vary spatio-temporally and by water type year. As water recedes from the floodplain during late spring, we anticipate that the potential costs of rearing begin to outweigh the benefits, with water temperature, dissolved oxygen content, the potential for stranding, and predation playing increasingly important roles. Jeffres et al. (2008) notes that despite there being tradeoffs between accelerated growth rates and the potential for mortality from poor water quality and possibly stranding, floodplains generally offer a range of habitats enabling juvenile salmon to seek better conditions during tough times.

The magnitude of potential benefits to juvenile salmonids is dependent on floodplain habitat conditions, particularly water temperature and food availability (Railsback and Rose 1999). For instance, Katz et al. (2013) suggested that warmer water temperatures in exceedance of 20°C may have contributed to declines in growth of juvenile Chinook during mid- to late March on experimental floodplains located in the Yolo Bypass. However, the authors suggested that growth was likely sustained prior to this temperature by abundant food resources. Others have suggested that juvenile salmon may be able to sustain or even improve growth under seemingly stressful water temperatures if food is abundant (Bisson 1988). Floodplains are incredibly productive when compared with mainstem river conditions and, thus, juvenile salmonids may be able to metabolically compensate for increases in water temperature to some extent (Sommer et al. 2001). Less clear, however, is our understanding of the magnitude and duration of specific temperature thresholds and how these variables interact with food availability to affect fish growth during late season floodplain inundation.

Temperature, dissolved oxygen concentration, and predation pressure likely become increasingly more stressful to salmonids and potentially other fishes using the floodplain after March 1st as air temperatures increase and flooding depths decrease. Dissolved oxygen concentrations are generally inversely related to water temperature and depth (Allan and Castillo 2007) and are known to exhibit strong seasonal and spatial variability on floodplains (Ahearn et al. 2006). While the Department of Water Resources has an extensive data set of temporal changes in water temperature and dissolved oxygen at specific points within the bypass (i.e, Yolo Bypass at Lisbon), these factors and the potential for predation effects on floodplain fish assemblages have not been extensively spatially monitored during different water years or seasons. Consequently, it is difficult to determine whether suitable conditions end after March 1st or if they persist in certain inundated areas of the Bypass for longer periods. Much of this may depend on water type year with wetter, cooler years providing extended benefits to juvenile salmon. An operable gate at the Fremont Weir allowing freshwater diversion from the Sacramento River into the Bypass may increase the potential for suitable habitat conditions to persist in the Bypass for longer periods than currently and should be the focus of further research efforts.

Monitoring of growth and survival of floodplain fishes and environmental conditions, such as water temperature, dissolved oxygen, prey availability, and potential predation effects is needed to establish the duration of biological benefits that may persist in the Bypass before and after modifications to the Fremont Weir. Monitoring should be extensively implemented (particularly for temperature, dissolved oxygen concentration, and prey availability) throughout the Bypass and collected over multiple water type years to capture spatial (see Ahearn et al. 2006) and temporal variability. A stronger understanding of the effects of predation (both terrestrial and aquatic predators) on juvenile fishes and the interaction between food availability and temperature on fish growth may also be required.

Sommer et al. (2005) estimated juvenile Chinook salmon densities within the Yolo Bypass ranged from 126 to 890 fish per hectare (51 to 360 fish per acre). Based on a density of 300 fish per acre and the abundance estimates from Snider and Titus (2000) (see Topic #1), approximately 6,000 acres of Yolo Bypass floodplain habitat could support all 1.8 million juvenile Chinook salmon estimated to be present in the Sacramento River at Knights Landing. This equates to essentially all of the late-fall-, winter-, and spring-run Chinook migrating from November to December 1997. In comparison, approximately 9,000 and 16,000 acres could support all 2.7 million fishes (wild fall-run Chinook) migrating between December to March and 4.7 million fishes (hatchery fall-run Chinook) migrating between March to June, respectively, in that same water year. If fish can survive at even higher densities, which is suggested by Katz et al. (2013), then they may benefit from even less inundated acreage in the Yolo Bypass. Additionally, not all of these fish would be diverted into the Bypass through an operable gate at Fremont Weir because the large majority of river flow and associated fish would remain in the Sacramento River. Roberts et al. (2013) estimate that up to 38% (late fall-run Chinook in 2006) of some runs may enter the Bypass via an altered Fremont Weir. However, based on 1997-2011 averages, the proportion of fishes entering the Bypass via an operable gate in any given year will more likely range from 13-18% (Roberts et al. 2013). These estimates, however, are speculative because they are based on the proportion of flow moving past Fremont Weir rather than observed numbers.

As discussed under Topic #1, these estimates simply demonstrate that a smaller inundation footprint within the Yolo Bypass has the potential to provide significant biological benefits for covered fish species. Imperative to such estimates is the assumption that habitat availability or acreage and habitat quality are synonymous, which they probably are not, though we anticipate that thousands of acres of inundated floodplain habitat would provide significant habitat heterogeneity for rearing fish. We also note that an improved migration corridor and access to floodplain rearing habitat suggests that future survival rates of salmonids entering the marine stage may also improve with cascading population effects, though this is also dependent on other factors including ocean conditions. Still, we recognize that an operable gate at the Fremont Weir would provide some flexibility in terms of varying potential inundation acreage based on run forecasts. Additional data, modeling, and analysis will be needed to further determine the magnitude of inundation RPA actions must achieve to realize the biological benefits necessary to contribute toward achieving the covered fish species biological goals.

In general, benefits to migratory adults (i.e., salmon, steelhead, sturgeon and lamprey) associated with RPA actions include an alternate route during upstream migration and reduced stranding and migratory delays at Fremont Weir. In addition, adult salmon, sturgeon, and Pacific lamprey fish passage would also improve with the proposed re-design of the fish ladder at Fremont Weir. Such benefits may ultimately improve adult survival to upstream spawning habitat. Conversely, juvenile salmonids are expected to benefit directly from floodplain use during rearing. Juvenile salmonids are better adapted to use shallower, more complex habitats, such as those provided on an inundated floodplain such as the Yolo Bypass, and experience benefits found in Katz (2012), which included more rapid growth, improved body condition, and delayed out-migration timing. Rearing on the Bypass may also provide a superior outmigration route through the Delta (Katz 2012). Splittail will also likely benefit from improved feeding associated with floodplain habitat and spawning over aquatic vegetation in the Bypass (Moyle 2002).

Winter-run Chinook (*Oncorhynchus tshawytscha*) adults typically migrate from January through May, peaking in mid-March (Williams 2006). Juveniles migrate downstream from October to June, with peak numbers at the end April, generally staying upstream of Red Bluff Diversion Dam (Williams 2006, Moyle et al. 2008). Juveniles typically rear 5-10 months before ultimately leaving the Delta (Moyle 2008). Del Rosario et al. (2013) found that the juvenile migration period lasted about eight months, with individuals passing the Red Bluff Diversion Dam in early October and leaving the Delta at Chipps Island in late March through early May. However, there is some uncertainty associated with the length-at-date criteria used to identify winter-run Chinook and the potential to misidentify run-specific stocks (Harvey et al. 2014, Merz et al. 2014). Most juveniles reach the Delta in early winter (Moyle et al. 2008) and outmigration was historically timed to correspond with winter flooding in the Sacramento basin, which provided floodplain habitat for rearing. Juveniles could rear in the Yolo Bypass (when accessible) and much of this could occur prior to March 1st, but juvenile salmonid outmigration may continue through June.

Spring-run Chinook (*O. tshawytscha*) adults spawning migrations typically occur from February through early-July. Adult upstream migration typically peaks in upper Sacramento River tributaries (Butte, Deer, and Mill Creeks) in mid-April to mid-May (Moyle et al. 2008). Adults hold in streams for several months before spawning in fall. Juveniles hatch and subsequently rear in streams through at least the following spring, although there is some variability in emigration timing with individuals also outmigrating as young of year (YOY) and rearing in downstream habitats (Williams 2006). Rotary screw traps at Knights Landing catch juveniles from March to July (J. Roberts, unpublished data; based on length criteria), but hatchery juveniles dominate trap catches in April/May (California HRSG 2013). The relative size of juveniles seems to determine how quickly they migrate to the ocean. Larger juveniles rearing in Sutter Bypass migrate quickly to the ocean (Hill and Webber 1999). Consequently, larger juveniles (i.e., those older than one year) usually migrate after March 1 and are not expected to benefit from Yolo Bypass rearing as much as younger juveniles due to differences in relative size. However, YOY may be more likely to rear for extended periods in Central Valley floodplains such as the Yolo Bypass. Most YOY are expected to migrate through and or rear in the Yolo Bypass before March 1st, but spring-run Chinook rearing has also been documented in April during wetter type water years in similar floodplain habitats, such as the Sutter Bypass (Hill and Weber 1999).

Fall-run Chinook (*O. tshawytscha*) adults typically spawn October to December. Juveniles migrate as fry and smolts in winter and spring. Historically, fall-run Chinook juveniles likely reared in floodplains extensively, benefitting from accelerated growth due to warmer water temperatures and higher prey densities (Sommer et al. 2001c, Jeffres et al. 2008). Today, more than 90% of fall-run adults are considered to be hatchery produced (Barnett-Johnson et al. 2007, Johnson et al. 2013). Naturally-produced (wild) fall-run Chinook have very low survival rates and are largely considered to be the progeny of hatchery-reared adults (Moyle et al., unpublished report). Most wild YOY fry are expected to migrate through the Bypass prior to March 1st, with smolts potentially migrating as late as May or June (Williams 2006).

Late-fall-run Chinook (*O. tshawytscha*) adult migration occurs from November through April (Williams 2006), typically peaking in December and January (Moyle et al. 2008). Size criteria suggest that late-fall-run Chinook juveniles migrate most of the year (Williams 2006), but migration usually peaks in October (Moyle et al. 2008). Most juvenile late-fall-run Chinook likely migrate through the Yolo Bypass before March 1st, with peak smolt migration during October (Moyle et al. 2008).

Central Valley steelhead (anadromous *Oncorhynchus mykiss*) juveniles migrate from the Sacramento-San Joaquin River system from late December to the beginning of May, peaking in mid-March, with a smaller peak in fall. There is generally a lack of evidence to suggest that steelhead require floodplain rearing habitat prior to their marine stage (P. Moyle, personal communication), although Sommer et al. (2001b) noted the presence of a few individuals within the Yolo Bypass. Flooding of the Yolo Bypass is expected to only negligibly benefit Central Valley steelhead juveniles and may only benefit adult steelhead as an alternate migration route through mid-March.

Splittail (*Pogonichthys macrolepidotus*) adults migrate upstream from brackish water (low saline waters) in response to stream flow pulses from November to February (Moyle et al. 2015). Adults will usually spawn from March through April over submerged annual vegetation, although earlier spawning has been observed (Moyle et al. 2004). Juveniles rear in shallower floodplain habitats from March through April and migrate off the floodplain during April and May, as high flows recede. Both adult and juvenile splittail would benefit from flooding of the Yolo Bypass after March 1st. The Yolo Bypass is expected to flood in years when other areas would also be flooded due to high flows, making spawning habitat available in other areas (Sacramento-San Joaquin Delta, Suisun Marsh, Suisun Bay, and Yolo Bypass; see Topic #5). Consequently, spawning habitat is readily available elsewhere in years when the Bypass currently floods. During low water years, flow through an altered Fremont Weir may not be sufficient to cue spawning migration onto the floodplain, though we are unaware of any studies identifying threshold flows that cue such migrations. Consequently, it is uncertain how much splittail will benefit from an operable gate at Fremont Weir. A larger inundation (beyond just the Toe Drain) footprint could provide important rearing habitat for juvenile splittail in the Yolo Bypass. The exact number of acres needed for successful spawning and rearing to achieve biological goals for splittail is unknown.

Little is known about **white sturgeon** (*Acipenser transmontanus)* habitat use in the Central Valley. Prior to spawning, adults begin to move into the lower parts of rivers during winter and then move upstream when flows increase. Spawning occurs in response to increases in flow, typically in late-February to early-June. Spawning in the Sacramento River takes place between Knights Landing and Colusa, although adults historically accessed the Feather River as well, as noted in Moyle (2002). No recent spawning activity has been reported in the Feather River. Spawning takes place in deep water over gravel/rocky substrate (Moyle 2002). Juveniles in the Fraser River use deep water areas (> 5m) with soft sediments and lots of prey (including dipteran flies and mysid shrimp) (Bennett et al. 2005). Harrell and Sommer (2003) suggested that adult sturgeon may use the Yolo Bypass as an alternate migration route and numerous individuals have been rescued at the Fremont Weir due to insufficient flow and lack of passage in recent years. As proposed in RPA I.6.1 and I.7, adult white sturgeon would benefit from Yolo Bypass flooding and the use of the Bypass as an alternate migration route (Harrell and Sommer 2003). In addition, adult white sturgeon passage would benefit from plans to improve the fish ladder at Fremont Weir. Juvenile white sturgeon may also benefit from feeding opportunities on the floodplain after March 1st, but juveniles generally prefer deeper habitat and specific floodplain use of juveniles in the Central Valley (including Yolo Bypass) is unknown.

Green sturgeon (*Acipenser medirostris)* migrate into the Sacramento River to spawn in March to May, generally peaking between May and June (Adams et al. 2002, Heublein et al. 2009), though they are more rare in the Sacramento-San Joaquin drainage than white sturgeon. Adults prefer to migrate in deeper parts of the channel and will hold in deep pools, suggesting that the Yolo Bypass is not considered optimal habitat for adults. Similar to white sturgeon, adult green sturgeon presence has been noted on the Yolo Bypass and numerous individuals have been stranded and subsequently rescued at Fremont Weir (Thomas et al. 2013). Larval green sturgeon have lethal temperature tolerances near summer temperatures in the Sacramento River. YOY sturgeon do best (i.e., bioenegetic performance) under a temperature range between 15-19°C (reviewed in Beamesderfer et al. 2007). Larvae (20-60 mm) migrate downstream between May and August and juveniles can spend 1-4 years in freshwater.

As with adult white sturgeon, adult green sturgeon would benefit from Yolo Bypass flooding if RPA actions provided a viable alternate migration route for adults straying into the Bypass. In addition, adult green sturgeon passage would benefit from plans to improve the fish ladder at Fremont Weir. Juvenile green sturgeon are unlikely to directly benefit from floodplain habitat associated with the Yolo Bypass and there is no evidence of deliberate systematic use of the Yolo Bypass by juvenile green sturgeon (P. Moyle, personal communication).

Little is known about **river lamprey (***Lampetra ayresi)*. They have not been extensively studied in California and the following information is largely based on Moyle (2002). Adults migrate into freshwater in fall and spawn in tributaries in winter or spring. Upon hatching, larval lamprey (ammocoetes) burrow into silt-sand deposits in backwaters that are within the wetted channel. Ammocoete transformation occurs during summer and metamorphosis typically takes 9-10 months. Newly transformed juveniles aggregate just upstream of salt water and enter the ocean in late-spring. Juveniles spend 3-4 months in saltwater. Most of the Yolo Bypass is not considered suitable for ammocoetes because they need perennial water with soft sediments where they can easily burrow. Adults migrating upstream to spawn (before March 1st) and ammocoetes beginning their transformation (after March 1st) may benefit from Yolo Bypass flooding if RPA actions provide a viable alternate migration route.

Adult **Pacific lamprey** (*Entosphenus tridentatus)* spawning migrations begin from early-March to late-June, but migration has also been noted as early as January/February and as late as July (Moyle et al. 2015). Adults use gravel substrates in rivers to build nests and deposit eggs (Moyle 2002). Juvenile metamorphosis and downstream migration is associated with increases in flow in winter and spring. Similar to river lamprey, the Yolo Bypass is not thought to be suitable for ammocoetes because they need perennial water with soft sediments where they can easily burrow. In addition, ammocoetes are filter feeders and, as such, require water velocity to transport food resources (i.e., reduced residence time of water associated with floodplain habitat may affect food capture efficiency). Adults migrating upstream to spawn (before March 1st) and ammocoetes beginning their transformation (after March 1st) may benefit from Yolo Bypass flooding if RPA actions provide a viable alternate migration route.

Delta smelt (*Hypomesus transpacificus)* are mainly found downstream of the Yolo Bypass (Moyle 2002). Spawning success is highest at temperatures 15-20°C (Moyle 2002). Increased mortality is thought to be associated with contaminants, food limitation, predation, water withdrawals, and other environmental factors (Bennett 2005, Hammock et al. 2015, in press). Delta smelt distribution is confined to freshwater and low salinity areas of the San Francisco Estuary. Temperatures over 25°C are lethal to adults, while temperatures above 18°C may increase larval mortality (Moyle 2002). Komoroske et al. (2014), however, found that thermal tolerance shifted with ontogeny and that larval delta smelt were more tolerant of increasing water temperatures than adults. Actual spawning locations are unknown. However, spawning seems to take place between late- February and June, with larvae most abundant from mid-April through May (but are observed from February to mid-July). Spawning in the wild takes place with temperatures between 7-15°C. Delta smelt generally reside in close proximity to the west Delta and Suisun Bay and spawning migrations are initiated by the first winter pulse flow with individuals moving upstream at an average of 3.6 km/day where they generally hold prior to spawning, though variability in spawning behavior is evident (Moyle 2002, Sommer 2011). Copepods are preferred prey of Delta smelt. Delta smelt may benefit indirectly from Yolo Bypass flooding if carbon inputs are sufficient to substantially enhance prey availability in those areas they occupy (as in Schemel et al. 1996 in NHI et al. 2002). Studies suggest, however, that under some conditions bivalve grazing (i.e. from invasive non-native clams) may reverse benefits from increased primary productivity (Greene et al. 2011, Lucas and Thompson 2012) that would otherwise increase delta smelt prey. It is unknown if an increase in the inundation of the Yolo Bypass as a result of RPA actions would increase primary production sufficient to benefit delta smelt and, therefore, additional research is necessary.

Longfin smelt (*Spirinchus thaleichthys)* live in open water bays and channels (Moyle 2002), including areas in the San Francisco Estuary and Delta (CDFG 2009). A few adult longfin smelt have been collected from the Yolo Bypass, most commonly in the winter and spring when flows are low (CDFG 2009). Overall, longfin smelt are rare upstream of Georgiana Slough (CDFG 2009), but have been observed as far upstream as Rio Vista (Moyle 2002). Adults prefer open water with temperatures < 18°C (Moyle 2002). Adults move upstream to spawn over stream substrate or aquatic plants (see Moyle 2002). Most spawning occurs between February and April at temperatures <14.5°C (Moyle 2002). Larvae are most abundant from January to March and are also common in April-July (as in 1989-1990). Juvenile numbers peak in June and July (CDFG 2009). Larvae and juveniles seem to tolerate slightly warmer water, up to approximately 22°C (CDFG 2009). Use of the Bypass and other floodplain habitats by longfin smelt adults and juveniles is minimal (P. Moyle, personal communication). Over a four-year period that examined the use of the Yolo Bypass by native fishes, Sommer et al. (2001) did not note the presence of longfin smelt. Other factors, besides water temperature that influence habitat use by adult and juvenile longfin smelt include prey type and density, predator presence and abundance (including birds and piscivorous fish), dissolved oxygen concentrations, and levels of aquatic toxins (including pesticides).

5b: How will climate change affect these benefits?

The following is a modified excerpt from Moyle et al., unpublished report:

Climate change is already altering fish habitats in California and will continue to do so at an accelerating pace if current trends continue. In general, conditions are declining for native fishes and improving for many alien fishes. For most species of native fish, the predicted outcomes of climate change are likely to accelerate current declines, potentially leading to extinction in the next 50-100 years if nothing is done to offset climatic impacts (Moyle et al. 2013). This section is focused on two major aspects of climate change that affect fish distribution and abundance in California rivers: water temperature and precipitation.

Water Temperature. Water temperatures have been rising in streams for some time and are continuing to rise (Kaushal et al. 2010). In California, there are diverse climate change models to predict future water temperatures, but the more conservative models generally converge on scenarios that assume that within 50–100 years, water temperatures will increase between 1°C–4°C (1.8°F–7.2°F) and 1.5°C–6°C (2.7°F–10.8°F) (Miller et al. 2003, Cayan et al. 2009). Further, annual snowpack in the Sierra Nevada and Cascade mountain ranges is expected to diminish greatly, resulting in stream flows increasingly driven by rainfall events. An increase in the ratio of rain to snow will result in more peak flow events during winter, increased frequency of high flow events (floods), diminished spring pulses, and protracted periods of low (base) flow. In addition, there will be more extended droughts. These conditions will translate into warmer water temperatures at most elevations, reflecting both increases in air temperatures and reduced summer flows. The impacts of climate change on fish are likely to be most severe on cold water species (<18°C–20°C, or 64°F–68°F), especially salmon and trout (Katz et al. 2013). Warming (more days with maximum temperatures > 20°C or > 68°F) of the more freshwater regions of the San Francisco Estuary is regarded as an additional threat to declining endemic species such as delta smelt (Wagner et al. 2011).

Precipitation. Models indicate that precipitation in California will become more variable, with an increase of precipitation falling as rain and less as snow (Cayan et al. 2009). Generally, the total amount of precipitation by 2100 is projected to be less, although the extent of loss is highly uncertain (Cayan et al. 2009). Runoff type streams seem particularly vulnerable to climate change effects with snowmelt streams, in particular, becoming more similar to rain-fed streams. Earlier snowmelt has already resulted in high flow events occurring earlier by an average of 10 to 30 days (Stewart et al. 2005), with annual peak discharges also occurring earlier (Cayan et al. 2009). These changes dramatically affect flows in low-elevation rivers in the Central Valley and are leading to modified reservoir operations (dam releases). Overall, the amount of water carried by streams in California (and the rest of the western United States), will decrease by 10 to 50 percent during drier months, if current trends continue (e.g., Cayan et al. 2001).

There is considerable uncertainty on the effects of climate change on floodplain habitat, particularly in the Central Valley. However, increased water temperature and changes in discharge patterns will broadly affect ecological processes including habitat suitability for cold water species. We can infer that an earlier runoff period (Stewart et al. 2005), broad reductions in snowpack (Hayhoe et al. 2004), and higher magnitude winter peak events (Das et al. 2011) will likely also affect the timing and magnitude of floodplain inundation making the seasonal occurrence of such habitat less predictable. For instance, flooding may occur earlier, but for less sustained periods of time in the Central Valley. This suggests that an operable gate at the bypass and the ability to manipulate flood timing or periods of inundation may be a valuable tool to promote juvenile salmonid rearing and adult passage.

5c: What are the different mechanisms through which splittail spawning success in the Yolo Bypass can be measured, taking into consideration that different organizations will define spawning success differently?

Successful splittail spawning could be measured in a number of different ways, including the number of adults spawning on the floodplain or the number of eggs deposited per acre of inundated floodplain. While such methods would provide some insight on successful reproduction, it is probably more useful to measure juvenile splittail recruitment associated with the Yolo Bypass. The most practical way to measure spawning success is to measure the number of age-0 splittail emigrating off the floodplain during the flood recession using some type of juvenile trap such as a rotary screw trap (e.g., Feyrer et al. 2006) or fyke nets. Such methods would not only provide valuable insight on population recruitment, but also enable evaluation of the benefits of floodplain habitat on juvenile splittail reproduction and rearing.

5d: Do splittail need 10,000 acres of floodplain habitat to spawn successfully in the Yolo Bypass? Would success be possible if splittail floodplain habitat is limited to the lower Yolo Bypass, such as areas in Cache Slough? Are there other opportunities for creation of successful splittail spawning habitat outside of the Yolo Bypass?

Adult splittail generally migrate upstream during late fall and winter and cue off increasing discharge associated with runoff events (Sommer et al. 1997). Their life history is tightly tied to floodplain habitat, as spawning adults require submerged vegetation where eggs can be effectively deposited (Sommer 1997, Moyle 2002, Feyrer et al. 2006). Habitat quantity (i.e., 10,000 acres) is probably not as important as habitat quality (i.e., presence of submerged vegetation, abundant food resources, cover from predators, etc.) and the timing of floodplain inundation and recession. However, the relationship between spawning success, juvenile recruitment, and size of flooded area has not been evaluated. Presumably, there is an optimal area of floodplain inundation required where population benefits are realized, but this likely depends on adult spawning population size, size and fecundity of spawning adults, access to suitable habitat by migrating fish, amount of suitable spawning and larval habitat (annual submerged vegetation), production of food for larvae and juveniles, duration and extent of inundation of suitable rearing habitat, and presence of ‘escape routes’ for juveniles to allow movement off the floodplain and downstream to rearing habitats in places such as Suisun Marsh as inundation recedes (P. Moyle, personal communication). The latter may depend on sufficient production of juveniles to compensate for predation during the outmigration period, though splittail are particularly fecund, which may reduce such threats. Successful spawning is known to occur in other parts of the system (e.g., Sutter Bypass, Cache Slough, Napa River, Cosumnes River) and, thus, splittail are not solely reliant on the Yolo Bypass. For instance, recent work by Feyrer et al. (2015) suggests that splittail populations from the Napa and Petaluma River complex and those from the Central Valley exhibit a metapopulation dynamic where gene flow between populations occurs during periods of heightened freshwater inflow to the delta. Access to floodplain habitat on the Yolo Bypass, however, would likely improve splittail population dynamics, especially during wet periods, because floodplain habitat is generally limited on the Sacramento River. Further research is required regarding the balance between habitat quality, quantity, and timing of inundation. Please refer to Topics # 5, 6 and 7, above, for additional details.

5e: How long do juvenile salmon and splittail need to stay on the Bypass floodplain to realize significant benefits?

We define 'significant benefits' as improved body condition and growth for juvenile salmonids and improved splittail juvenile recruitment rates relative to mainstem river conditions. Sommer et al. (2001b) found that splittail year class strength was stronger when juvenile splittail were able to spawn and rear on the Yolo Bypass for greater than three weeks between March and April. Jeffres (2008) found that after 17 and 20 days, enclosed juvenile salmon on a Cosumnes floodplain showed significant differences in growth when compared with fish reared in the Cosumnes River during 2004 and 2005, respectively. On experimental floodplains at Knaggs Ranch, Katz et al. (2013) found that apparent growth rate (mm/day) was greatest between the third and fourth week of the study, but that growth continued to increase (despite the rate slowing) until the experiment ended between week five and six. Sommer et al. (2005) determined that Yolo Bypass residence times of planted, tagged hatchery Chinook juveniles ranged from 30-56 days between 1998 and 2000. It is probable that a longer event (i.e. >3 weeks) would increase primary and secondary production with cascading benefits to higher order consumers such as juvenile salmonids, though even short inundation periods may provide some ecological benefits to species that use the Bypass (Sommer et al. 2004). There are many interacting factors to consider with such an assumption, however. For instance, the time between initial flooding of the Bypass and subsequent juvenile Chinook emigration to the floodplain appears to be an important consideration. If the inundation period is long enough to catalyze important food web processes (i.e., initial phytoplankton production followed by zooplankton), the duration required to realize significant biological benefits may be shorter than if initial floodplain inundation and juvenile salmon access occur simultaneously or of similar timing (see Schemel et al. 2004 for discussion regarding floodplain inundation and phytoplankton production). In addition, juvenile salmon and splittail floodplain residence time will vary by individual, suggesting that an increased inundation period would benefit larger proportions of respective populations. In all likelihood, the time necessary for juvenile fishes to realize ecological benefits likely varies and is dependent on water type year, flood inundation magnitude, timing, recession rates, residence time, depth, water temperature, and food production.

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