Juvenile Spring-Run Chinook Salmon Production and Emigration in the San Joaquin River Restoration Area

2017–18 Monitoring and Analysis

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Self-Certification of Peer Review

This proposal has been peer reviewed by the following two individuals, at least one of whom is from outside my work group:

Name	Affiliation	Phone Number

I certify that, to my best knowledge, these two individuals are qualified to review this work, and that they have peer reviewed this proposal.

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PI Signature

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1.0 Introduction

In 1988, a coalition of environmental groups, led by the Natural Resources Defense Council (NRDC), filed a lawsuit challenging the renewal of long-term water service contracts between the United States and the Central Valley Project Friant Division Long-Term Contractors. After more than 18 years of litigation of this lawsuit, known as NRDC et al. vs. Rodgers et al., 2006, a stipulation of the settlement (Settlement) was reached. The Settlement establishes two primary goals: (1) Restoration—to restore and maintain fish populations in "good condition" in the mainstem San Joaquin River (SJR) below Friant Dam to the confluence of the Merced River, including naturally reproducing and self-sustaining populations of salmon and other fish and (2) Water Management—to reduce or avoid adverse water supply impacts on all of the Friant Division long-term contractors that may result from the Interim and Restoration Flows provided for in the Settlement.

The Settlement, though, does not define the process for restoring and maintaining fish populations. The Fisheries Framework was developed to provide a criterion for goals and objectives relating to this process (SJRRP 2018). It identifies stressors and provides a plan for reducing these stressors to produce self-sustaining populations of fall-run and spring-run Chinook Salmon in the Restoration Area. Rotary screw trap (RST) monitoring of juvenile salmon allows evaluation of these criteria identified in the Fisheries Framework.

Juvenile migration success has been posited as a limiting factor for sustaining spring-run and fall-run Chinook Salmon (*Oncorhynchus tshawytscha*) in the Restoration Area (SJRRP 2018). Since salmon have been extirpated from the area following the construction of Friant Dam in the 1940s, limited data are available regarding juvenile Chinook Salmon emigration, timing, and survival prior to recent reintroduction efforts (e.g., adult trap and haul, juvenile releases, and broodstock releases). Prior juvenile tracking and monitoring efforts were limited to fall-run Chinook Salmon (Hueth et al. 2017; Sutphin et al. 2018). California Department of Fish and Wildlife have released spring-run adult broodstock into Reach 1 following rearing efforts at the Interim Salmon Conservation and Rearing Facility (hereafter, referred to as SCARF) located in Friant, California. Following adult spawning in fall 2017, downstream juvenile presence, distribution, and numbers were monitored late 2017–late spring/early summer 2018.

Data collected through these activities provides baseline information regarding juvenile spring-run Chinook Salmon and will assist management in comparing current conditions against criteria in the Fisheries Framework. In turn, this will help to determine whether future restoration efforts are appropriate or need to be re-evaluated to meet the conditions of the Settlement.

1.1 Objectives

The following objectives are intended to provide data regarding the juvenile life stage of spring-run Chinook Salmon following redd emergence. Efforts herein will help to gauge how current river conditions support juvenile spring-run Chinook Salmon in the Restoration Area. Information from the following objectives will assist SJRRP management with decisions regarding continued restoration activities. The objectives are:

1) Estimate production of juvenile spring-run Chinook Salmon from the spawning grounds in Reach 1.
2) Evaluate survival of juvenile spring-run Chinook Salmon through the Restoration Area.
3) Identify factors that may influence Objectives 1–2 (e.g., flow, temperature, fish size).

2.0 Materials and Methods

2.1 Study Sites and Schedule

Rotary screw traps are frequently used to monitor juvenile salmon movements and estimate production (Thedinga et al. 1994; Volkhardt et al. 2007; Pilger et al. 2019). Rotary screw traps (2.4-m diameter) were placed at four locations in Reach 1 (Figure 1) and 2 of the Restoration Area: downstream from Friant Dam (Friant; near river mile [RM] 266), Owl Hollow (RM 259), Highway 99 (Hwy 99; RM 243), and San Mateo crossing (RM 212). Screw trap placement was contingent upon site accessibility and suitability as well as redd locations in the river. Proper trap operation requires adequate water depth to allow unimpeded rotation of the RST cone and enough flow to physically rotate the cone. Traps were placed in the thalweg to maximize the volume of water sampled. For production estimates, ideal placement of RSTs is at the downstream extent of the spawning area (Volkhardt et al. 2007); screw traps interspersed between redds allow for estimates of survival and site-specific production rates within the spawning area. During fall 2017 survey efforts, 13 spring-run Chinook Salmon redds were detected (McKenzie et al. 2018). Nine of these were upstream of the Friant RST, another three upstream of the Owl Hollow RST, and one upstream of the Hwy 41 Bridge. The Hwy 99 RST was placed downstream of all observed redds. The RST at San Mateo Crossing was so placed because this location provided the greatest distance from Hwy 99 to allow survival estimates while being upstream of significant impediments to fish movement (i.e., Mendota Dam and Sack Dam). Monitoring during this period was from December 2017–June 2018. Monitoring efforts at respective RST locations ceased based on either a factor of catch or temperature, or combination thereof. Fishing periods for each trap are identified in Table 1.

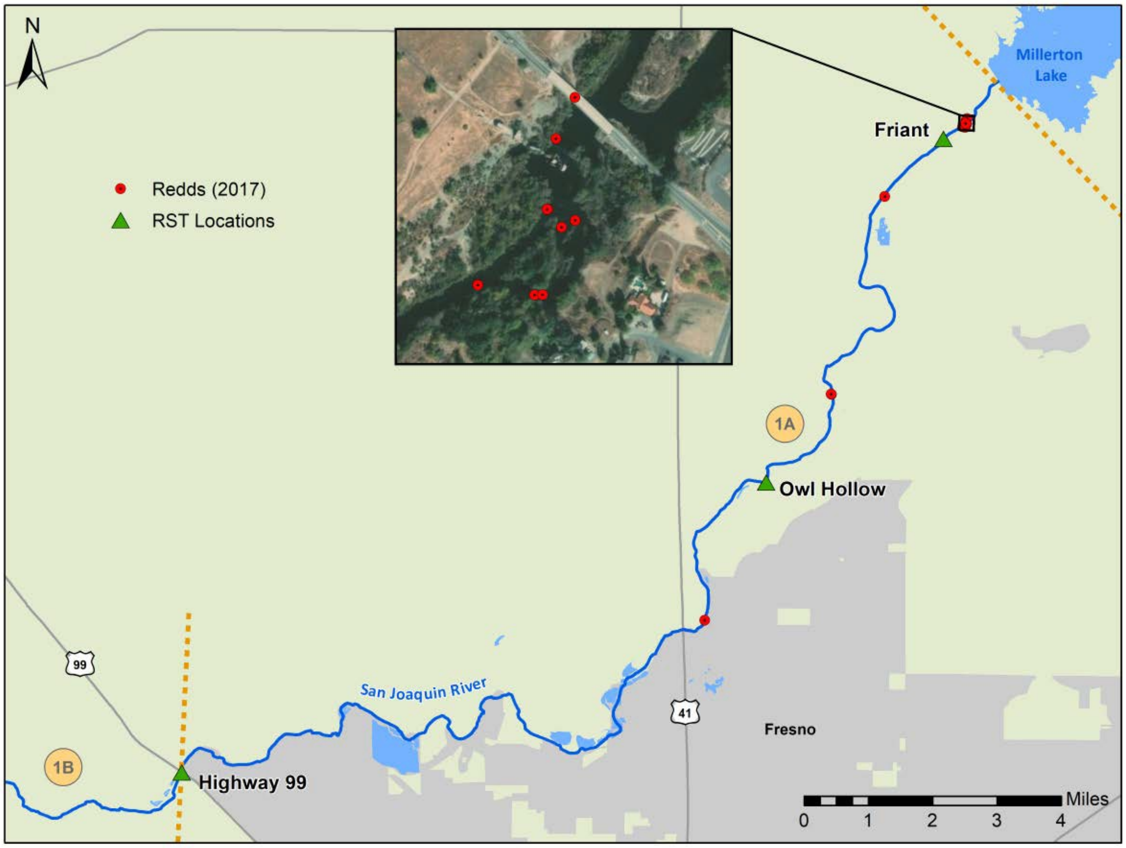

Figure 1.—Recorded salmon redds and rotary screw trap locations (San Mateo rotary screw trap in Reach 2 not shown).

Table 1.—Installation and removal dates for rotary screw trap (RST) locations during 2017–18 sampling season.

RST Site:	Installation:	Removal:
Friant	12/1/2017	3/14/2018
Owl Hollow	12/3/2017	6/26/2018
Hwy 99	12/1/2017	6/27/2018
San Mateo	12/14/2017	5/22/2018

2.2 Trap Placement and Operation

At all but the San Mateo location, each RST was secured with a 13-mm (1/2-in.) wire rope affixed high enough above the water surface to allow for recreational river usage (e.g., kayakers, fishermen). Affixed to the highline was a snatch block that permitted lateral positioning of the RST for optimal operation. The RST was attached to the snatch block with two 10-mm (3/8-in.) wire ropes—one connected to the front of each RST pontoon. Two additional 10 mm (3/8 in.) wire ropes connected to the snatch block were secured on either side to the high line using wire rope clips that prevented lateral movement after the RST was suitably located. These also allowed for repositioning the screw trap from the shoreline after loosening the clamps from each side. Buoys and lights placed up and downstream of each RST alerted recreationalists to its presence. Figure 2 illustrates the installed Friant RST in operation. Site conditions at the San Mateo RST location were such that the trap could be located adjacent to the river margin, allowing the wire ropes to be situated at water level on only one side of the river (no high line needed).

Figure 2.—Friant rotary screw trap attached to high line wire rope via snatch block and smaller diameter wire ropes (made apparent to recreationalists using pink flagging).

Following installation, traps were lowered into the fishing position. They were checked daily for proper operation and to remove captured fish. Site conditions were recorded, including trap operation (i.e., rotating or not), rotation count (via magnetic counter attached to the base of the cone), water velocity at the mouth of the RST, temperature, dissolved oxygen, and turbidity. Debris loads were categorically annotated (low, medium, high) based on the percentage of the live well filled with debris, and subsequently cleared. Traps were scrubbed as necessary to remove accumulated algae/debris. Captured fish were enumerated and processed (see *Fish Processing* below) and released downstream of the RST. When any of the RSTs could not be checked in a 24-hour period (e.g., flood releases exceeding safe operation), personnel raised and secured the cone in the non-fishing position until safe operation could resume.

2.3 Fish Processing

Fish were removed daily during RST checks. All captured fish were typically identified to species and recorded. Bycatch were enumerated and measured to total length (TL; nearest mm). In cases where large numbers of any one species were captured, a subsample of 20 fish were measured for length, and the remaining fish counted. In some cases, small fish (e.g., young-of-year *Micropterus* and cyprinid spp.) were identified to family or genus. Bycatch were not discussed within the body of this report, but data are available in Appendix A. An abundance of lamprey were also captured during the 2017–18 field season. While not the primary focus of this document, additional information regarding lamprey capture and timing is presented in Appendix B.

Wild salmon, determined by presence of adipose fin and lack of identifying marks (i.e., photonic tag, coded wire tag), were anesthetized in a solution of 40–60 mg/L MS-222 (tricaine methanesulfonate) before processing. They were measured for fork length (FL) and TL (mm), weighed (nearest 0.1 g), and a tissue sample was collected from the caudal fin for genetic analysis. Salmon were classified as yolk-sac fry, fry, parr, smolt, or yearling based on criteria in Volkhardt et al. (2005); Cramer Fish Sciences (CFS 2014) provides a Smolt Index Protocol that further elaborates of this differentiation and the rotary screw trap protocol (USFWS 2008) includes a visual representation of fish within each age class. Anesthetized fish were allowed recovery time in a bucket of fresh water prior to release. After processing, bycatch and salmon were released downstream of the RST. Salmon were carried in the recovery bucket approximately 30 meters downstream of traps before release, with the aim of ensuring such fish were not recaptured at the same location.

2.4 Efficiency Tests

Efficiency tests were completed for each RST. Since only thirteen redds were detected in 2017 (McKenzie et al. 2018), catch rates of wild salmon were anticipated to be insufficient to conduct efficiency tests following the CAMP protocol (USFWS 2008). For that reason, hatchery fish (spring-run Chinook Salmon, reared at the SCARF were used to conduct efficiency tests. All hatchery fish were coded wire tagged before being available for efficiency tests, and fish were required to be a minimum of 55 mm FL for coded wire tagging. Resultantly, efficiency tests could not commence until late January during the 2017–18 season.

Efficiency tests were typically conducted at each RST location every 1–2 weeks. Total fish available for all efficiency tests were limited to 40,000, restricting the total number of releases during the field season. For each trap, 8–10 groups of 1,000 fish were released through late April 2018. Calibration protocols for estimating production of salmon in the Central Valley indicate that enough of fish be used so trap efficiency estimates would not be altered by more than five percent for each additional salmon captured (USFWS 2008). Additionally, because anticipated capture rates were not known, 1,000 fish (nominally) per efficiency test were released to ensure enough recaptured fish for estimating trap efficiency. The intent of these staged releases was to evaluate individual trap efficiency with varying fish sizes and environmental conditions during the sampling season (Carlson et al. 1998; Volkhardt et al. 2007). The Friant RST was removed March 14 resulting from low efficiency estimates and catch rates of wild fish. However, fish were still released at this location as a metric to estimate downstream movement and survival.

Groups of test fish were marked with photonic tagging solution (NEWWEST Technologies, LLC., Santa Rosa, CA). Replicate groups were uniquely colored and marked (Figure 3). By varying the color and fin combinations across traps and release date, staff could ascribe recaptured fish to specific releases. A subsample of 100 test fish/replicate were measured (fork length, mm; weight, g) to describe morphometrics of each release group. Fish were size-graded prior to marking, and the size variation was limited to no more than 10–15 mm for each release group. Test fish were typically given a 96-h recovery period prior to release.

Figure 3.—Example of hatchery-reared, photonically-tagged spring-run Chinook Salmon *(Oncorhynchus tshawytscha*) used for rotary screw trap efficiency tests.

Fish were released upstream of the RSTs, with the intent to allow fish to distribute across the river as they typically would, but near enough where other factors (e.g., predation) would not affect the number making it to the location of the RST—generally, this is recommended as 400–800 m upstream of the RST (USFWS 2008). Additionally, fish were subdivided into groups and released over an hour's duration at varying locations across a single transect perpendicular to the flow, to limit schooling of the entire batch. It is suggested that releases be staged across the diel period to incorporate any temporal bias of typical migration times (Volkhardt et al. 2005; USFWS 2008). However, Tattam et al. (2013) found a significant difference in the estimate of efficiency between fish released during daylight hours and naturally migrating fish, but not between fish released during civil twilight and naturally migrating fish. Therefore, releases for efficiency tests occurred in the late afternoon/early evening, typically the hour preceding sunset.

Rotary screw traps were checked two hours following each release to limit overcrowding in the live wells overnight. For salmon with an observable photonic mark, staff recorded the location/color of the mark. In the event of the photonic mark fading beyond recognition, a missing (clipped) adipose fin indicated hatchery origin. This information was recorded but these fish were not included in overall production estimates. Following initial efficiency testing, all salmon subsequently captured the remainder of the field season were checked for the presence of a photonic mark. The remainder of the processing and release procedures were similar to those for wild salmon and are outlined in the *Fish Processing* section above (though photonically marked salmon were not fin clipped for genetic analysis).

2.5 Analyses

Genetic Analyses—The Southwest Fisheries Science Center Santa Cruz Laboratory received 816 tissue samples from juvenile Chinook Salmon captured in RSTs from the San Joaquin River. Using standard laboratory protocols, DNA was extracted, and individuals genotyped with the set of 96 single-nucleotide polymorphism (SNP) markers that has been employed throughout the project to date. Importantly, this set of loci has been used to genotype all SCARF broodstock individuals, their progenitors at the Feather River Hatchery, and a comprehensive baseline of Central Valley and other Chinook Salmon populations. This allows both parentage-based analyses as well as stock identification and traditional population genetic analyses.

Analysis of these samples proceeded incrementally. Duplicate genotypes, analogous to recaptures in a mark-recapture framework, were first identified. Data were analyzed to evaluate potential growth rates of these recaptured fish. With respect to all tissue samples collected, it was determined that some of the captured salmon were not offspring of the spring-run broodstock released into the system. An attempt was made to assign these juvenile fish to multiple pools of adults, both those known in the system, and others potentially contributing offspring to juvenile production—potential parents included fall-run adults that had been transported and released into the Restoration Area, SCARF captive broodstock adults, and broodstock from the Feather River Hatchery (the source of SCARF broodstock and their siblings). For juveniles sampled in the RSTs that were not assigned to two parents, an alternative analysis technique was employed (COLONY software; Jones and Wang 2010) that allows for identification of single parents, when only one has been sampled, and the *de novo* assembly of full-sibling groups by inferring the genotypes of unsampled parents.

Rotary Screw Trap Efficiency and Production—Trap efficiency is based on the ratio of captured, marked fish, to the total number of released, marked fish. These ratios, combined with the capture of wild fish, can be used to determine the total number of naturally produced fish moving past each RST. Under the constraints of RST efficiency evaluations, several assumptions were made (Volkhardt et al. 2007; USFWS 2008):

- hatchery fish are representative of wild fish, both in size and behavior
- marked fish behave no differently than unmarked fish, all fish have equal probability of capture
- marked fish remain readily identifiable
- all released fish move downstream and have an equal opportunity to encounter downstream RSTs
- rotary screw trap efficiency is constant within each efficiency interval
- the population is closed

Production over time was estimated using the daily catch of spring-run Chinook Salmon and RST efficiency at each trap location. The following stratified mark-recovery approach for the use of a single partial capture trap, from Carlson et al. (1998), and further outlined in Volkhardt et al. (2007) and the CAMP protocol (USFWS 2008), was used to estimate production and associated variance for each efficiency interval:

$$\hat{n}_i = \frac{u_i(M_i + 1)}{m_i + 1}$$

$$v(\hat{n}_i) = \frac{(M_i + 1)(u_i + m_i + 1)(M_i - m_i)u_i}{(m_i + 1)^2(m_i + 2)}$$

where $\hat{n}_i$ is the estimated production in interval i, u_i is the unmarked fish in interval i, M_i is the number of marked fish released in interval i, and m_i is the number of marked fish recaptured in the corresponding RST during interval i. Interval i constitutes the period between one efficiency release group and the next. Prior to the first release, and following the last, the nearest efficiency estimate was used to estimate fish production during such periods. For example, the first efficiency release at Hwy 99 was January 29, 2018. Trap efficiency calculated at this interval was used to estimate production of wild fish from trap installation until the next efficiency release on February 5, 2018.

At each RST, total production and the associated variance over the sampling season is the sum across all efficiency release periods:

$$\hat{N} = \sum_{i=1}^{n} \hat{n}_i$$

$$V(\hat{N}) = \sum_{i=1}^{n} v(\hat{n}_i)$$

In every efficiency interval at Owl Hollow, survival estimates of fish released at the Friant RST exceeded 100 percent—in the most extreme instance, by a factor of 30 (see following section for description of survival analyses). This suggested Owl Hollow RST efficiency estimates were unreliable and biased low. It’s likely the release location selected for marked efficiency fish violated the assumptions of efficiency testing—fish did not distribute in a manner consistent with fish from upstream locations, fish did not move downstream beyond the trap, the selected location was in an area that promoted predation, etc.

Some logical reasoning led us to re-evaluate the method for determining RST efficiency at Owl Hollow. One could deduce that increasing the distance of the release location to the RST would expose fish to a higher potential for predation or other obstacles that could limit fish from reaching the target location. Resultantly, one would expect to see lower survival rates (and lower efficiency rates) for fish released at upstream RST locations. Therefore, any contradiction to this would suggest a biased-low efficiency estimate, and higher efficiency estimates for fish released at upstream locations (i.e., a greater distance from the RST) as compared to those released at a more proximate location, but having a lower trap efficiency estimate, would be more accurate. Following this reasoning, and to provide a more accurate assessment of RST efficiency at Owl Hollow, fish released at the Friant location were used in lieu of those originally released at the Owl Hollow location. This resulted in an increase in trap efficiency estimates compared to Owl Hollow-released fish.

Survival—Survival was estimated using the recapture of marked fish between RSTs. The reliability of these estimates is dependent upon the assumption that hatchery and wild fish behave in the same manner. The total number of marked fish from each efficiency test, released at Friant and Owl Hollow, and surviving to the Hwy 99 RST, is estimated as the sum product, $\Sigma({}^{1}/_{e_i})\, m_{ij},$ using the following matrices:

$$\begin{bmatrix} e_1 \\ e_2 \\ \vdots \\ e_i \end{bmatrix} \begin{bmatrix} m_{11} & m_{12} & \cdots & m_{1j} \\ m_{21} & m_{22} & \cdots & m_{2j} \\ \vdots & \ddots & \ddots & \vdots \\ m_{i1} & m_{i2} & \cdots & m_{ij} \end{bmatrix},$$

where e_i is the efficiency of the Hwy 99 RST during interval i, m_{ij} is the number of marked fish from the upstream efficiency group j (either from Friant or Owl Hollow release), captured in the i^{th} interval. Survival for each marked release is then estimated using:

$$\frac{\left[\Sigma({}^{1}/_{e_i})\, m_{ij}\right]}{M_j}$$

where M_j is the total number of marked fish, M, released in group j. Survival to Hwy 99 is presented as the average of these estimates from respective release location.

Emigration Timing and Production—Water quality data were paired with average FL (of wild fish) and production estimates at Hwy 99 to evaluate factors influencing timing of downstream migration and production in Reach 1. Flow data were downloaded from the California Data Exchange Center (CDEC; http://cdec.water.ca.gov/). Data from the Highway 41 flow sensor were used for comparison since this location is somewhat central between RSTs in Reach 1. Temperature and turbidity data were collected daily during RST checks. Production estimates and corresponding data were grouped into 4-day blocks—daily production estimates were quite variable. Additionally, flow pulses were often sporadic but tended to return to pre-pulse levels within a few days. Daily production estimates could also have been affected by deviations in daily timing of RST checks. Four-day blocks tended to be an ideal balance between capturing fluctuations in daily catch without overlapping flow pulses. The average turbidity, flow, temperature, and fish size were calculated for the corresponding production blocks. The data set was also trimmed to coincide with the first and last occurrence of salmon capture at Hwy 99.

Spearman Rank Order Correlation was used to identify collinearity among the independent variables—photoperiod (date), average flow, turbidity, temperature, and average FL (size) of fish. Of these variables, size and temperature had a significant ($p < 0.05$) and strong correlation ($r = 0.93$ for both variables) to photoperiod. Additionally, size and temperature also had a strong correlation to one another ($r = 0.83$). Turbidity had a significant ($p < 0.05$) and moderate correlation to date and flow ($r = 0.55$ and $r = 0.47$, respectively). Fish lengths were not always ascribed to genetic samples, and due to the collinearity between size, temperature, and photoperiod, size was excluded from additional analyses. Because of the strong correlation between photoperiod and temperature ($r = 0.93$), and since the correlation between turbidity and photoperiod was less strongly correlated than turbidity and temperature ($r = 0.55$ vs. $r = 0.60$), photoperiod but not temperature was included in further analyses.

Data were then evaluated for outliers using Tukey's method since it is relatively robust to extreme values (Hoaglin et al. 1986; Kannan et al. 2015). After removing outliers, multiple linear regression was used to evaluate the significance of date, flow, and turbidity on production. When necessary to meet the assumptions of normality, production data were transformed using the natural log of $(xx + 1)$, where xx is the 4-day production estimate for the corresponding period. Analyses were completed in SigmaPlot (Systat Software Inc., San Jose, California); alpha values were set at 0.05 for all analyses.

To evaluate trends in travel speed with respect to flow conditions in Reach 1, the median travel time for each marked-efficiency group from Friant and Owl Hollow to Hwy 99 was calculated. These calculations relied on the recapture of fish released from upstream locations. However, fish from any given group were often recaptured throughout the remainder of the sampling season, spanning multiple efficiency intervals. Trap efficiency at Hwy 99 and the total number of fish captured from each unique efficiency release were combined to estimate total daily fish from each unique group passing this location—the median travel time was derived after estimating this number. Total distance from release site to Hwy 99 was divided by the time between release and recapture, providing travel speed (RM/day). The median travel speed for each release group was plotted as a function of river miles/day by release date and flow at time of release.

3.0 Results

Genetics—Following tissue sample evaluation, it was determined several groups of juvenile Chinook Salmon were present during 2017–18 sampling: broodstock-produced progeny, escapement-produced progeny, SCARF escapees, and fall-run salmon. Additionally, several individual tissue samples suggested some instances of hybridization between fall-run/spring-run salmon as well.

Regarding duplicate genotypes identified, a total of 21 individuals were sampled twice, with an intervening time span of 0–159 days. All but two fish were resampled at a downstream location. However, length data were incomplete, so growth rates could not be determined. Seventeen fish were labeled as “yearling” in the field, based on capture size. Of these 17 fish, 13 were assigned to fall-run trap-and-haul parents—10 to a single, large full-sibling family and the other three as singletons (no other siblings sampled). Additionally, there were also two fish not labeled as yearlings, but ultimately assigned to the large sibship (totaling 12). Of the four remaining ‘yearlings’, three were assigned to SCARF parents (likely juveniles used to test trap efficiency or escapees from the facility) and the last appeared to have one SCARF parent and one unknown parent.

The majority of RST juveniles were expected to be the offspring of SCARF-reared spring-run adults released into the habitat for natural spawning (broodstock). However, upon initial analysis, only 84 juveniles were assigned to known pairs of broodstock fish from May and August; they were distributed into 16 families ranging from 1–25 full siblings. A total of 368 juveniles were assigned to SCARF parents that were not part of the broodstock fish released into Reach 1. These juveniles were distributed in 110 families ranging from 1–21 full siblings and were determined to likely be fish used to test trap efficiency or escapees from the facility (SCARF escapees).

COLONY assigned three additional fish to three distinct pairs of SCARF broodstock parents and two additional fish to a family with a fall-run trap-and-haul father and a SCARF broodstock mother. COLONY assigned 79 juveniles to a SCARF broodstock father and an unknown mother (distributed in 17 families, from 1 to12 full-sibs) and assigned another 35 juveniles to an unknown father and a SCARF broodstock mother (distributed in 14 families, from 1 to 10 full-sibs). Finally, 226 juveniles were assigned to two unknown parents. Over all three groups with assignments to unknown parents, COLONY inferred 28 unsampled male parents and 21 unsampled female parents. This is likely a modest over-estimate, as Colony tends to over split full sibling families when data is limited.

Finally, genetic assignment to the stock identification reference (baseline) database and a Bayesian clustering algorithm both indicated that the juveniles not assigning to two sampled parents all belonged to the Central Valley Chinook Salmon fall-run/Feather River spring-run metapopulation. Furthermore, genotyping at proprietary markers in the run-timing associated locus GREB1L, revealed that 284 of these fish were homozygous for the spring-run allele, while 12 fish were heterozygous spring/fall and 42 fish were homozygous for the fall-run allele. As for the origin of the unassigned fish, we suggest a combination of potential sources, including but not limited to, program fish whose parents were not genotyped successfully, natural spawners that entered the Restoration Area through artificial waterways, and intentional releases of non-program juveniles (Classroom Aquarium Education Program, *see following subsection*).

Rotary Screw Trap Monitoring—A total of 904 Chinook Salmon were captured across the four RSTs during the 2017–18 field season (Table 2). Based on genetic analyses, 386 of these were wild spring-run Chinook Salmon—of these 202 were genetically identified as broodstock progeny, while 184 were determined progeny of adult spring-run salmon that had likely made it into Reach 1 during high flow conditions in early 2017. The remaining fish comprised 371 SCARF escapees, 58 fall-run Chinook Salmon, and 89 were undetermined. Of the fall-run Chinook Salmon captured, fifteen were yearlings—

eleven at Hwy 99 (four in December and seven in late March) and four at the Owl Hollow RST (three in December and one in late March). Several of these were identified as precocious males—sexually mature yearlings, maturing without seaward migration (Larsen 2004); these fish were also identified as offspring of fall-run fish transported to Reach 1 during 2016 Fall-run Chinook-Salmon Trap and Haul efforts. The remaining fall-run salmon were likely from fish released into Reach 1 as part of an educational outreach program, the Classroom Aquarium Education Program (https://wildlife.ca.gov/CAEP), where classrooms hatch fry from eggs at the eyed-stage and subsequently release these fish following yolk-sac absorption. Since these fall-run Chinook Salmon were not related to the production of spring-run Chinook Salmon, they have been omitted from production and survival estimates. Of the 89 "undetermined" fish, most (n = 63) were a result of not collecting tissue samples during the first day of rotary screw trap operation at Friant. The remainder were from the few early days of trapping where samples of fry were subsampled, or later in the sampling season for various reasons (e.g., fish escaped prior to tissue collection, lost tissue sample post-collection). Additionally, tissue samples from two fish had no assigned genotype after genetic analyses. One of these had sibling pairs identified as spring-run progeny. Therefore, this fish was also assigned to the spring-run grouping. The other fish had no siblings identified; however, its size at capture (88mm FL on May 15, 2017) suggested it was likely a fall-run fish and was classified as such (Figure 4).

Table 2.—Total Chinook Salmon (*Oncorhynchus tshawytscha*) captured during 2017–18 rotary screw trap operation in Reach 1 of the San Joaquin River Restoration Area. Italicized numbers indicate total fish, by subgrouping, captured within fall and spring-run groups.

	Friant	Owl Hollow	Hwy 99	San Mateo	Totals:
Spring-run	148	129	94	15	386
Broodstock	*74*	*74*	*48*	*6*	*202*
Escapement	*74*	*55*	*46*	*9*	*184*
SCARF escapees	0	135	215	21	371
Fall-run	2	19	36	1	58
Classroom Fish	*2*	*15*	*25*	*1*	*43*
Yearling	*0*	*4*	*11*	*0*	*15*
#N/A	73	10	5	1	89

Early in the sampling season, fry were predominately captured at upstream locations (Friant and Owl Hollow; Figure 5). Fry capture was greatest upon initiation of trap operation in early December; capture rates decreased through mid-January. Thereafter, most wild fish captured were either parr or smolt. Mid- to late-March, the catch rate at the Hwy 99 RST exceeded that of the other traps. The Friant RST was removed early March due to low capture and efficiency rates.

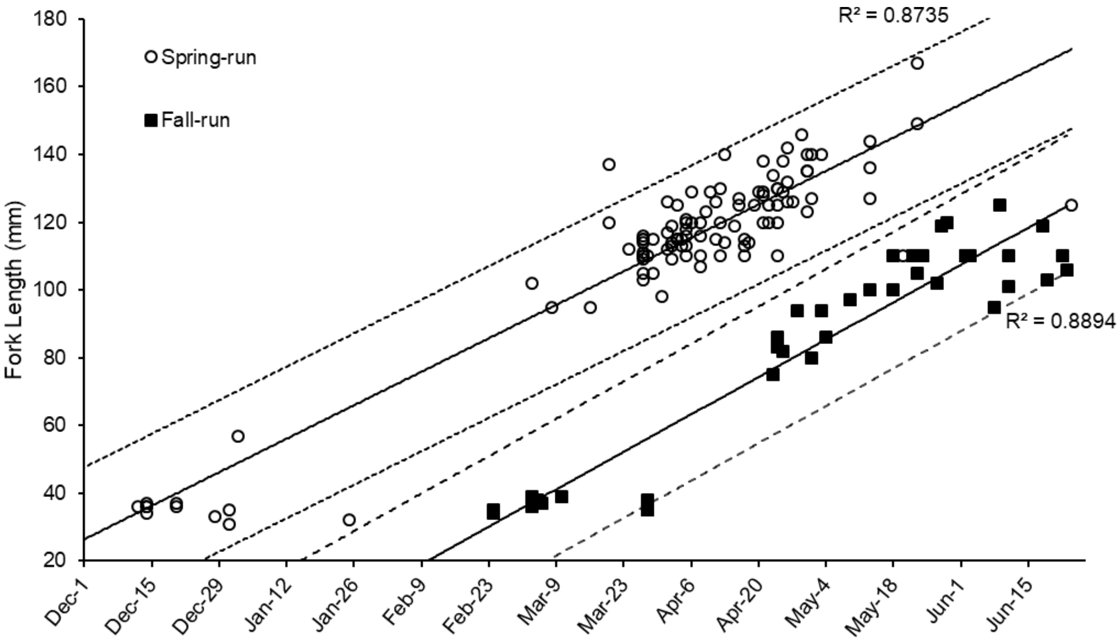

Figure 4.—Logarithmic trendline (solid line) and ±99 percent confidence interval (dotted line) based on size at capture of genetically identified spring-run (circles) and fall-run (squares) Chinook Salmon (*Oncorhynchus tshawytscha*) captured during the 2017–18 sampling season.

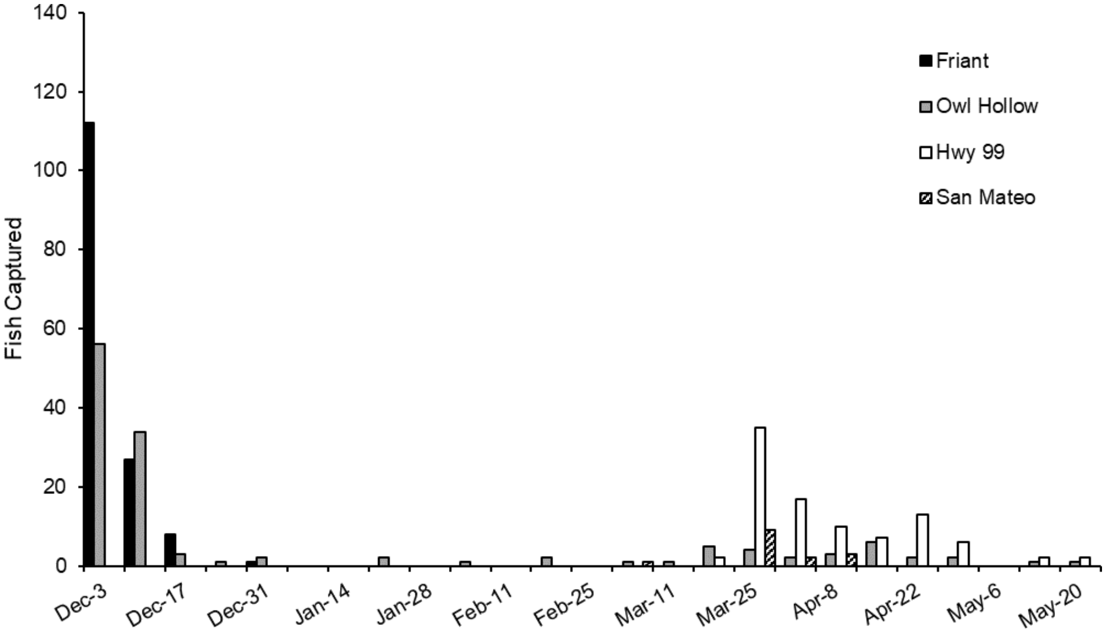

Figure 5.—Wild salmon captured (7-day blocks from listed date) at rotary screw traps installed in Reach 1 of the San Joaquin River Restoration Area.

Rotary Screw Trap Efficiency and Production—Average RST efficiency at Friant was 0.7±1.2 percent (±95 percent confidence interval [CI]). Trap efficiency for Owl Hollow was 3.3±2.3 percent (±95 percent CI), when using Owl Hollow-released fish (see

Materials and Methods: Analyses). After using Friant-released fish to estimate trap efficiency, this estimate increased to 14.0±4.4 percent (±95 percent CI). Hwy 99 efficiency was 19.1±5.8 percent (±95 percent CI) and San Mateo RST efficiency was 4.7±3.5 percent (±95 percent CI).

Production was calculated specifically for spring-run salmon encountered during RST operations. Captured fall-run salmon were excluded from these analyses. Hybrid salmon (spring-run/fall-run genotypes) were limited in number. These fish were included in the spring-run production estimates since these fish likely had at least one spring-run parent and were produced during the same period. Hatchery fish (SCARF escapees) were also excluded from production analyses.

Production of spring-run salmon at the Owl Hollow RST was 1,090±225 (±95 percent CI) and production at Hwy 99 was 575±115 (±95 percent CI; Figure 6). At Owl Hollow, broodstock progeny production was 618±155 (±95 percent CI), and escapement progeny production was 472±131 (±95 percent CI). Broodstock progeny production at Hwy 99 was 286±78 (±95 percent CI), while escapement progeny production was 288±81 (±95 percent CI). Cumulative production estimates at these two locations are presented in Figure 7. Because of the low and variable efficiency estimates at the Friant and San Mateo RSTs, production and survival could not be reliably estimated at these locations. We suspect the Friant RST location suffered from similar issues as the release location of Owl Hollow. However, without marked fish releases further upstream with which to compare, such a determination was not possible. With regards to the San Mateo RST—unlike using Friant-released fish to estimate the efficiency of the Owl Hollow RST, insufficient Hwy 99 efficiency fish were captured at San Mateo to either attribute the trap as having low efficiency, or to suggest a problem existed with the release location. Inconsistent trap operation could also have contributed to these issues. At times, flows at the San Mateo crossing were often below recommended thresholds for RST rotation (Volkhardt et al. 2007; USFWS 2008). While the RST did rotate, revolutions were often noticeably lower than at other locations. Resultantly, no estimates of production or survival were calculated at these locations; only quantitative data with respect to timing and total captured fish are further discussed. Efficiency estimates for each interval at the four RST locations are presented in Appendix C.

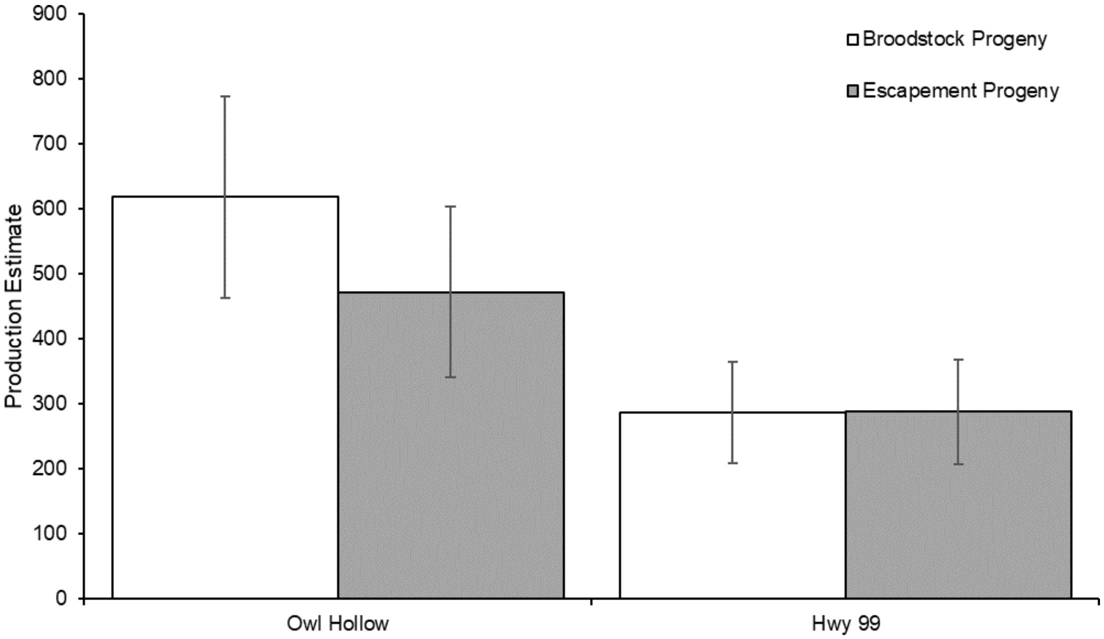

Figure 6.—Production estimates (±95 percent confidence interval) for spring-run Chinook Salmon (*Oncorhynchus tshawytscha*) at two rotary screw traps in Reach 1 of the San Joaquin River Restoration Area.

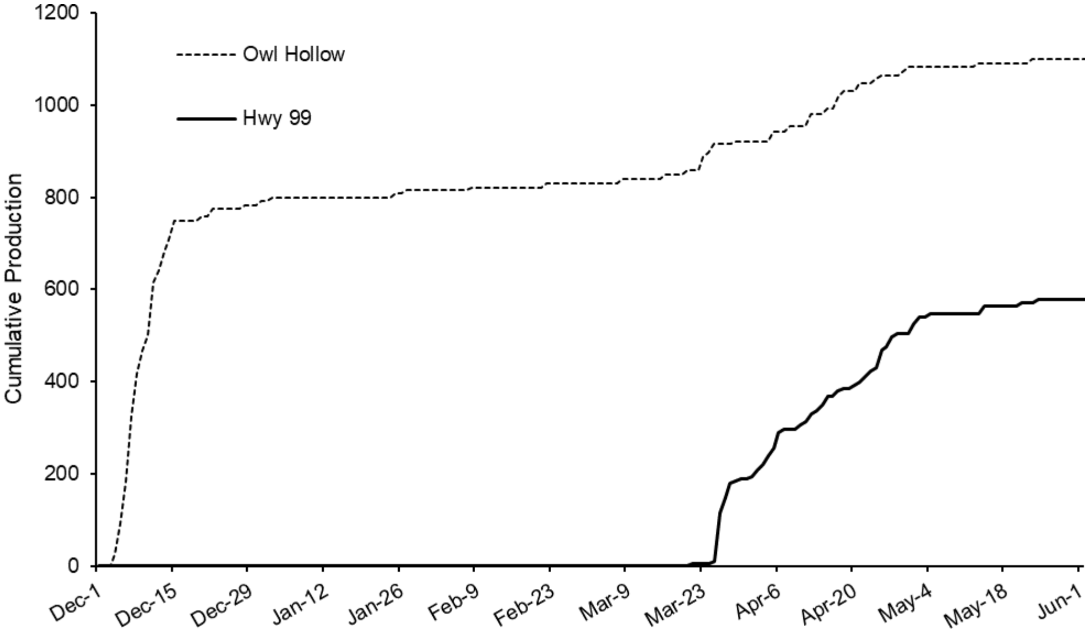

Figure 7.—Cumulative production of wild Chinook Salmon (*Oncorhynchus tshawytscha*) at rotary screw traps in Reach 1 of the San Joaquin River Restoration Area.

Survival Between Rotary Screw Traps—The approach for estimating survival relied on the recapture of marked fish at downstream RSTs, standardized to RST efficiency at the time of recapture. Due to the low precision of some intervals of RST efficiency estimates, survival estimates for some release groups exceeded 100 percent. In such instances, a maximum value of 100 percent was recorded. Estimates of survival for marked fish from Friant to Hwy 99 averaged 67.4±20.0 percent (±95 percent CI). Survival of marked fish released at Owl Hollow to Hwy 99 averaged 74.4±15.5 percent (±95 percent CI).

Emigration Timing and Production—Production at Hwy 99 and flow are depicted in Figure 8. Of note is the large flow pulse on March 23. This was a natural pulse produced largely by flows from Little Dry Creek near RM 261 (~916 CFS). Previous pulses were typically the result of releases from Friant Dam. Concurrent with this natural pulse was an increase in turbidity an order of magnitude higher than observed at baseline and pulse flows from Friant Dam releases. Beginning with a spike in production following this pulse, production rates at Hwy 99 continued to stay higher than the previous period, and eventually plateaued in late May (Figure 7). The first wild spring-run Chinook Salmon was captured at Hwy 99 on March 20; the last was captured May 23. Nearly all (98.9 percent) of the wild spring-run salmon moving past Hwy 99 did so following this pulse.

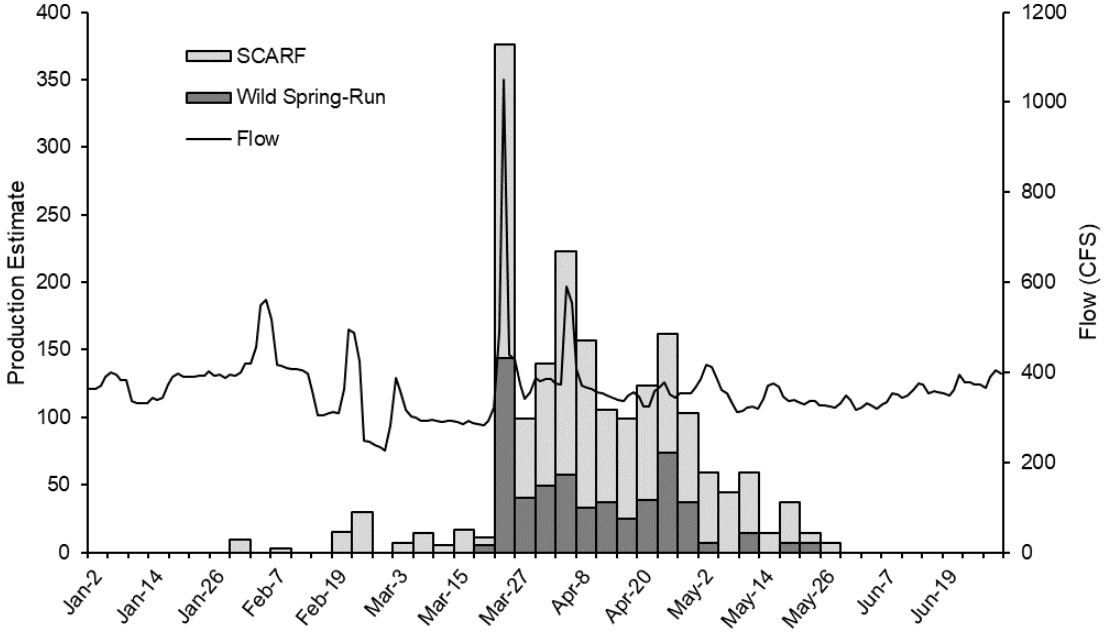

Figure 8.—Downstream movement (via production estimates) of spring-run Chinook Salmon (*Oncorhynchus tshawytscha;* left vertical axis; for a 4-day interval following the listed date) during 2017–18 field season at Highway 99, with respect to average daily flow (CFS, measured at Highway 41; right vertical axis). Wild fish (dark gray) are composed of broodstock and escapement progeny while escapees from the Salmon Conservation and Rearing Facility (SCARF) comprise the fish indicated by the light grey.

Multiple linear regression indicated turbidity was the predominate factor predicting production levels at Hwy 99 for broodstock progeny ($p = 0.03$; Figure 9). Interestingly, turbidity was also correlated with SCARF fish estimates at Hwy 99 ($p < 0.001$); however, no individual variables were statistically significant indicators of production for the entire grouping of wild spring-run fish (broodstock and escapement progeny), nor for escapement progeny alone. This may have been a factor of the limited data points available for analysis (N= 11) of escapement progeny and the more truncated period of escapement progeny detection when compared to broodstock progeny—broodstock progeny were captured March 20–May 23 at Hwy 99 while escapement progeny were only captured March 24–May 3.

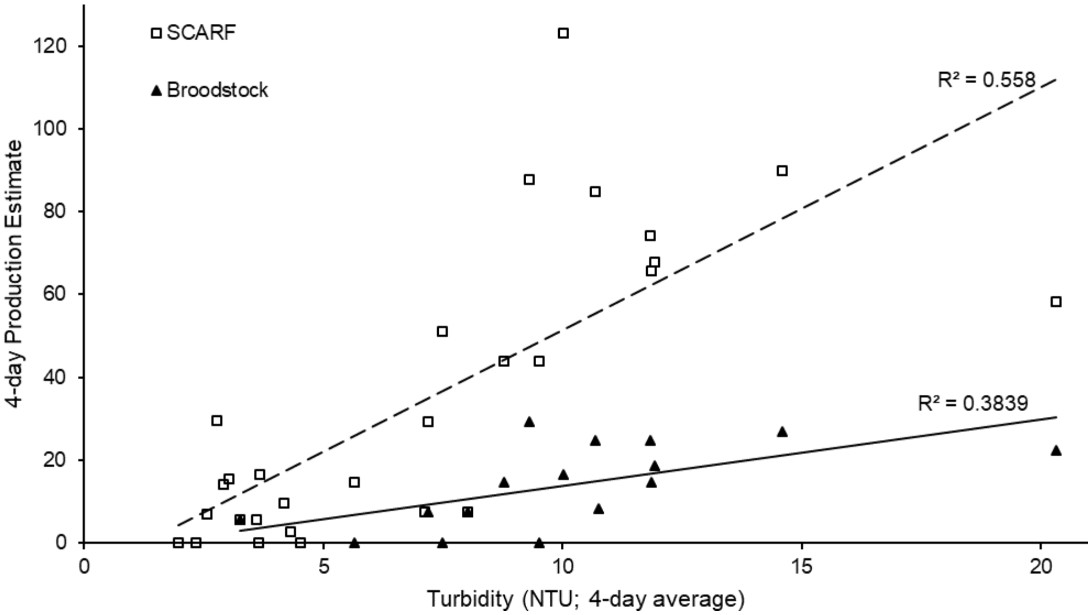

Figure 9.—Four-day production estimates and average turbidity (NTU) for broodstock progeny Chinook Salmon (*Oncorhynchus tshawytscha*; triangles and solid regression line) and Salmon Conservation and Rearing Facility (SCARF) salmon (squares and dashed regression line) at the Highway 99 rotary screw trap during the 2017–18 sampling season.

Travel speed of each release group (marked-efficiency releases) was evaluated from the period of release until the point of recapture, with respect to flow, and is presented in Figure 10. The accuracy of these estimates was limited by the frequency of daily RST checks (every 24h). Nonetheless, travel speed was the most rapid with initial release groups. However, for groups released between February 28 and April 2, travel speed was slower than for other release groups. No correlation was observed between travel speed and flow during this time. Groups with faster median travel speeds tended to have an initial proportion of fish moving quickly downstream, and the remainder holding for a period before being recaptured at downstream locations. However, the groups with slower median travel speeds tended to hold for a period, before recapture—with few to no fish moving downstream immediately and subsequently recaptured.

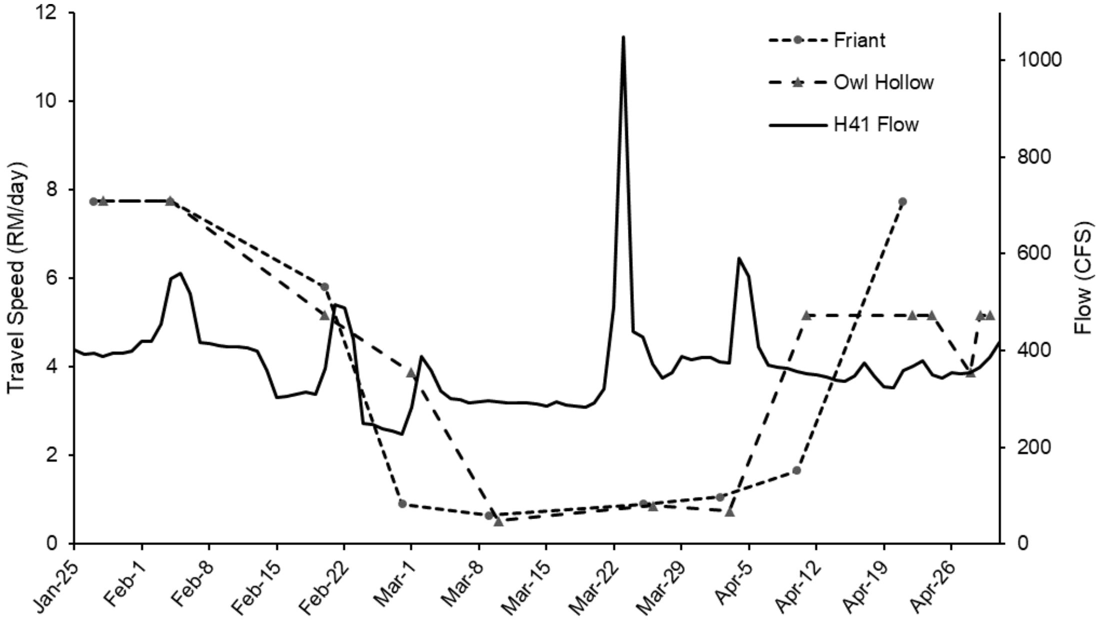

Figure 10.—Median travel speed (river miles [RM]/day; left vertical axis), by efficiency release group (adjusted by rotary screw trap efficiency), from release site to Highway 99 and associated average daily flows (CFS; right vertical axis) measured at Highway 41.

4.0 Discussion

Early in the season, fry were predominately captured at upstream RSTs. Very few were recovered at the Hwy 99 RST. As the sampling season progressed, fewer fish were captured at upstream RSTs and a greater proportion of smolts were captured at the Hwy 99 RST. All of the spring-run production at Hwy 99 occurred within a two-month period from mid-March to mid-May. Conversely, about 82 percent of the estimated production at Owl Hollow occurred prior to this period, and about 74 percent of the fish captured at Owl Hollow were collected prior to December 31, 2017. Most of the fish captured at Owl Hollow, particularly earlier in the sampling season, were fry. Conversely, smolts were most frequently encountered at Hwy 99. This suggests fry move downstream shortly after emergence but are rearing between Owl Hollow and Hwy 99 prior to smoltification and emigration.

Smoltification is the physiological processes that prepare salmon for seaward migration (Baggerman 1960) and is a complex interaction of the individual and environmental parameters, often correlated to photoperiod (Komourdjian et al. 1976) and temperature (Roper and Scarnecchia 1999). Achord et al. (2007) suggest that growth and development influence emigration, finding that larger fish emigrate earlier than smaller fish; reaching sufficient body size is necessary for smoltification (Dickhoff et al. 1997). Furthermore, Roper and Scarnecchia (1999) describe a positive relationship between stream temperatures and size with respect to emigration, as Chinook Salmon in Oregon tended to migrate earlier in years where spring temperatures were higher. In addition to the physiological processes that influence smoltification and subsequent migration, it has been suggested that increased springtime flows may promote seaward migration by juvenile salmon (Scheuerell et al. 2009). We observed high emigration following a natural pulse that was concurrent with higher turbidity rates. It was interesting to note that artificial pulses from Friant Dam did not result in the same increase in turbidity as the natural one from Little Dry Creek. Our analyses indicated turbidity, but not flow, was a significant predictor of emigration/production for broodstock progeny. It is likely that a combination of variables, including factors influencing smoltification as well as environmental parameters such as increased flow and turbidity prompted emigration.

While date (photoperiod) was not a significant factor for estimating production in the analyses described herein, a seasonal trend, nonetheless, is apparent in the data (see Figure 7 and 8). Lunar phase has also been suggested as a contributing factor for emigration rates (Roper and Scarnecchia 1999). Production in the Restoration Area peaked and decreased gradually until tapering off in late May. We were reluctant to run any statistical analyses to compare lunar phase with production out of happenstance that the bulk of production occurred during a period coincident with a specific lunar cycle (Figure 11). However, incorporating multiple years of data across future sampling efforts may indicate such a trend.

Of particular note—although no natural returning spring-run adults were recovered, genetic analyses of progeny captured during the 2017–18 sampling season provide evidence of the first volitionally-returning spring-run Chinook Salmon to the Restoration Area. Flows in spring 2017 likely permitted the volitional return of spring-run salmon during high flow periods, when water passing the Chowchilla Bifurcation Structure downstream through the Eastside Bypass could have allowed fish to bypass structures currently inhibiting upstream migration (e.g., Sack Dam, Mendota Dam). These flows diminished during summer 2017, precluding passage for fall-run salmon later that year. Previously mentioned, genetic analyses suggested some hybridization of fall-run and spring-run salmon. Since precocious males were encountered during trapping efforts, and fall flows were insufficient to allow adult fall-run passage through the Restoration Area, it is logical to conclude some of these hybrids may have been progeny of these fall-run precocious males and spring-run salmon. Future monitoring may indicate to what degree such hybridization occurs.

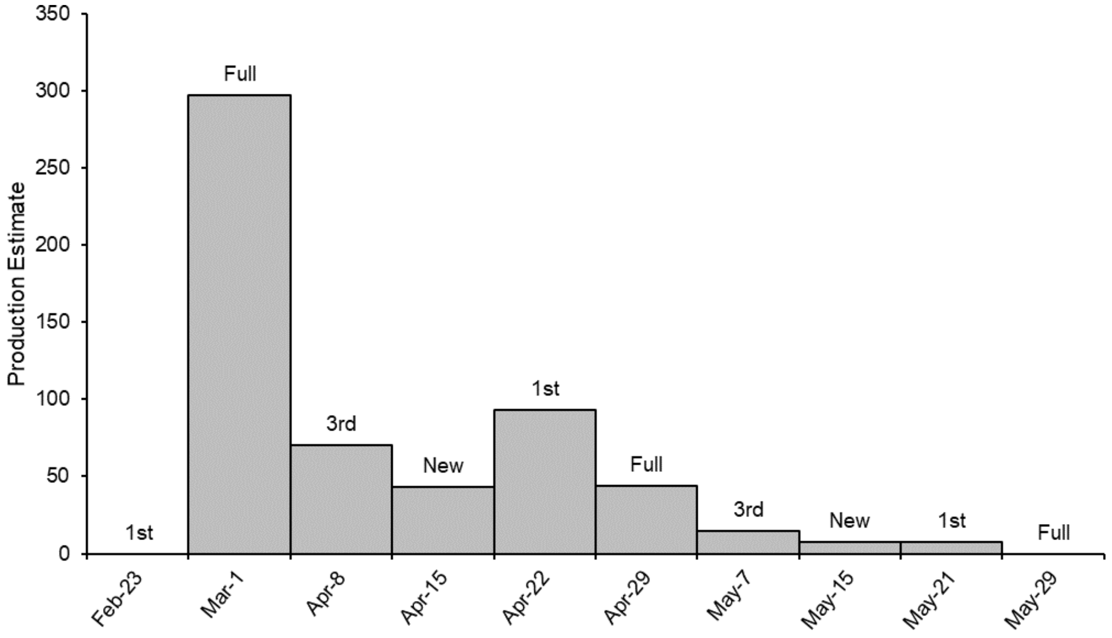

Figure 11.—Production estimates by lunar phase during 2017–18 rotary screw trap sampling in the San Joaquin River Restoration Area.

Considerations—Results of survival and migration speed may be biased because analyses relied on the recapture of marked hatchery fish to determine timing speed, etc. Hatchery fish may not adequately represent the behavior and trends observed in wild fish (Wedemeyer et al. 1980; Volkhardt et al. 2007). Melnychuk et al. (2010) found that, on average, wild fish moved faster than hatchery fish during downstream migrations. The authors suggested stress after release or conditions varying from the hatchery environment as potential contributing factors for this difference. Fish size and growth rates have often been attributed to earlier migration rates (Ewing et al. 1984; Beckman et al. 1998). Marked fish in this study were concurrently smaller than wild fish (Figure 12). If movement and behavior patterns of marked fish are not commensurate with wild fish due to size discrepancies and hatchery origin, results of trap efficiencies, production, and survival may be skewed.

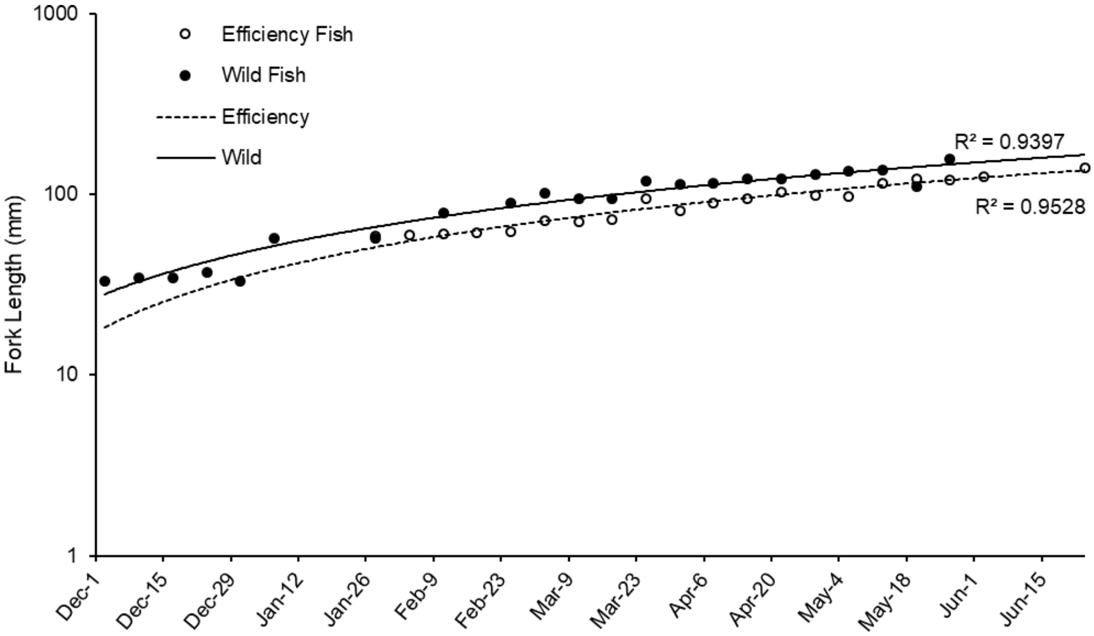

Figure 12.—Average fork length of wild spring-run Chinook Salmon (by week) and recaptured efficiency fish during 2017–18 sampling season. Note the trendline and y-axis are log-scale.

Previous studies have indicated most fish from efficiency releases are typically captured within five days following release (Roper and Scarnecchia 2000). Results herein were consistent with these findings—fish released immediately upstream of RSTs were generally captured shortly thereafter. However, migration times to downstream RST's were much more variable with some fish being captured late into the season, well after release. Photonic tag retention can be quite variable (days to months; Sutphin 2008; CFS 2014). While most recaptured fish were accurately identified, a small proportion (~ 1 percent) could not be positively identified because of tag retention issues. The frequency of occurrence of these fish could affect production and survival estimates. Alternative tagging measures, such as PIT tags could alleviate this issue. The use of PIT tags could also provide a method to evaluate growth rates in the Restoration Area, a criterion identified in the Fisheries Framework (v. 5.1, SJRRP 2018). Management would need to consider whether the increased time/equipment costs of using PIT tags would be offset by the additional data gathered and the reduction in misidentified/unknow tagged fish.

Release location of efficiency fish and RST installation spots need to be addressed during future sampling efforts. It was evident the Owl Hollow release location violated the assumptions for efficiency evaluations since fish released at the upstream Friant location provided a better estimate of trap efficiency than fish released immediately upstream of the Owl Hollow RST. Release locations for efficiency fish at San Mateo should be similarly addressed. During low flow conditions, nearly all SJR water flows through a single culvert at the road crossing at this location. An eddy on either side of the culvert, downstream of the road crossing, may provide flow refuge for fish, particularly when released immediately downstream of the culvert. Moving release locations upstream of the road crossing may encourage a more similar distribution to naturally migrating fish.

That, in turn, may improve trap efficiency estimates. Additionally, trap operation at this location was often subpar, and water velocity was often insufficient to turn the cone for optimal efficiency. If either of these recommendations are not possible, it may be prudent to consider alternative RST locations below Reach 1 in the future. Lack of adequate sampling below the Hwy 99 RST limits survival and production estimates to Reach 1A. Data collected below Hwy 99 is necessary in determining migration patterns and survival in the remainder of the Restoration Area where conditions are generally considered less suitable for salmon.

Conclusions—Based on genetic analyses, 15 broodstock females and 21 escapement females were represented in the captured progeny during the 2017–18 sampling season. Under the assumption that at least one fish from each redd was captured in the RSTs, a total of 36 redds contributed to production estimates. The production estimate at Hwy 99 was 286±78 (±95 percent CI) for broodstock progeny and 288±81 (±95 percent CI) for escapement progeny. The Fisheries Framework (v. 5.1; SJRRP 2018) provides the following target criteria for spring-run Chinook Salmon:

- 50 percent survival of egg to fry
- fry-to-smolt survival rate 5 percent to greater than 70 mm
- passage rate of 70 percent for juveniles >70mm from the spawning grounds to Sack Dam

The average fecundity for hatchery-raised spring-run broodstock was 3,606 (*pers. comm.* P. Adelizi). Due to the lack of data regarding natural returning spring-run salmon, the average fecundity for returning spring-run salmon in the Feather River in 2019 was used as a baseline—this was estimated at 4,368 eggs per female (*pers. comm.* P. Adelizi). Since the majority of fish captured at Hwy 99 were smolts, we can use the total estimated redds in the spawning area as well as production at Hwy 99 to evaluate the first two criteria presented above. Assuming the 15 broodstock redds contained an average of 3,606 eggs and 50% of those successfully reached the fry stage, 27,045 broodstock fry would have produced. Under the 5 percent fry-to-smolt survival criteria, then 1,352 smolts would have been produced. Likewise, for the 21 escapement fish, if each redd contained an average of 4,368 eggs, with a 50 percent egg-to-fry, and 5 percent fry-to-smolt survival, one would expect a production of 2,293 smolts. Under the assumption that production at Hwy 99 represents fry-to-smolt survival, production estimates of 208–364 broodstock progeny and 207–369 escapement progeny suggest the first two criteria are not being achieved.

While further research will be necessary to identify factors that contribute to these low production estimates, survival estimates of marked fish used for efficiency testing may provide some indication. Marked efficiency fish released at Owl Hollow had an estimated survival rate of 74.4±15.5 percent (±95 percent CI) to Hwy 99. Since hatchery fish were required to be a large enough for coded-wire tagging before marking for efficiency releases, survival estimates only included fish exceeding that minimum size—the smallest marked fish released was 49 mm FL; the average size for marked efficiency fish was 73 mm FL. The higher survival estimate of these fish compared to the overall production estimates of wild fish suggests survival may be more problematic between the egg and parr life-stages. Identifying factors contributing to limited survival during these earlier life stages may elucidate areas of improvement necessary to increase production levels observed in the spawning area. Beyond Reach 1, the lack of confidence in providing accurate estimates of production at San Mateo preclude evaluating the passage rate (i.e., survival) downstream of spawning grounds. Improvements in providing accurate estimates of production at RSTs downstream of Hwy 99 will be necessary to evaluate the third criteria previously described.

Future monitoring of spring-run Chinook Salmon will continue to provide metrics of survival and production in the Restoration Area. As methods are refined, the study design can be improved to provide more precise estimates of these values. Future restoration activities involve the construction of bypass structures at Sack Dam and Mendota Dam and will provide access to returning adult salmon to spawning grounds in Reach 1. Interim efforts may also present the opportunity to transport captured adult spring-run salmon to Reach 1, providing increased opportunities for spawning and production. In turn, biologists may be able to take advantage of using wild fish in lieu of hatchery fish to evaluate patterns of movement, seasonal growth rate, and survival.

Moreover, juvenile salmon data collection efforts to date have been in dry and critical water year types when passage through the entire Restoration Area was impossible. Precipitation levels in 2016–17, and the easement for Reclamation to pass water beyond Sack Dam at the Reach 3–4 transition, have connected up- and downstream reaches. If these conditions remain, the potential exists to monitor juvenile salmon passage through the entire Restoration Area. This, in turn, provides the opportunity to collect data pertaining to criteria established in the Fisheries Framework (SJRRP 2018). Evaluating salmon movement and numbers beyond the spawning areas in Reach 1 may provide estimates of survival and identify areas where unacceptable loss rates occur. Such information can be used to guide management decisions regarding future efforts in the Restoration Area.

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6.0 Appendix A: Bycatch

During the 2017–18 field season, 43,905 non-target fish, comprising approximately 30 species were captured in the four rotary screw traps (Table A-1). Of these, 57.2 percent were centrarchids (*Micropterus* and *Lepomis spp.*). The bulk of the centrarchid species captured were juvenile Bluegill (*Lepomis macrochirus*), followed by juvenile black bass species (either Largemouth Bass [*Micropterus salmoides*] or Spotted Bass [*M. puntulatus*], though too small to accurately identify in the field), captured from late March through the remainder of the field season. Lamprey species (Petromyzontidae) comprised 27.3 percent, shad (Clupeidae) 7.7 percent, and another 20 species made up the remaining 7.8 percent of fish captured. Of the 30 species captured, eight were native: Kern Brook Lamprey (*Lampetra hubbsi*), Pacific Lamprey (*Entosphenus tridentatus*), Sacramento Pikeminnow (*Ptychocheilus grandis*), Sacramento Sucker (*Catostomus occidentalis*), Prickly Sculpin (*Cottus asper*), Riffle Sculpin (*C. gulosus*), Threespine Stickleback (*Gasterosteus aculeatus*), and Rainbow Trout *(O. mykiss*).

Table A-1.—Total season bycatch in all rotary screw traps from December 2, 2017–June 27, 2018. Asterisk denotes native species to the San Joaquin River.

Family:	Species:	Common Name:		Season Totals:
Petromyzontidae	*Lampetra Hubbsi*	Kern Brook lamprey	*	74
	Entosphenus tridentatus	Pacific lamprey	*	11,913
	Petromyzontidae spp.	Lamprey spp.	*	14
Centrarchidae	*Pomoxis nigromaculatus*	Black crappie		1,223
	Micropterus spp.	Black bass spp.		9,492
	Micropterus salmoides	Largemouth bass		32
	Micropterus punctulatus	Spotted bass		58
	Lepomis macrochirus	Bluegill		13,614
	Lepomis cyanellus	Green sunfish		215
	Lepomis spp.	Lepomis spp.		1
	Lepomis microlophus	Redear sunfish		443
	Lepomis gulosus	Warmouth		35
Cyprinidae	*Cyprinus carpio*	Common carp		468
	Cyrpinidae spp.	Cyprinid spp.		18
	Pimephales promelas	Fathead minnow		20
	Notemigonus crysoleucas	Golden shiner		870
	Carassius auratus	Goldfish		13
Ictaluridae	*Ptychocheilus grandis*	Sacramento pikeminnow	*	106
	Ameiurus spp.	Bullhead spp.		36
	Ictalurus punctatus	Channel catfish		208
	Ameiurus catus	White catfish		30
Catostomidae	*Catostomus occidentalis*	Sacramento sucker	*	587
Cottidae	*Cottus asper*	Prickly sculpin	*	512
	Cottus gulosus	Riffle sculpin	*	28
	Cottus spp.	Sculpin spp.	*	232
Gasterosteiade	*Gasterosteus aculeatus*	Threespine stickleback	*	185
Salmonidae	*Oncorhynchus mykiss*	Rainbow trout	*	9
Moronidae	*Morone saxatilis*	Striped bass		2
Clupeidae	*Alosa sapidissima*	American Shad		28
	Dorosoma petenense	Threadfin shad		3,358
Atherinopsidae	*Menidia beryllina*	Inland silverside		11
Percidae	*Percina macrolepida*	Bigscale logperch		9
Cobitidae	*Paramisgurnus dabryanus*	Large-scale loach		1
Poeciliidae	*Gambusia affinis*	Mosquitofish		60

7.0 Appendix B: Lamprey Capture Data

A total of 12,016 lamprey, comprising two species were captured during 2017–18 RST monitoring activities. Kern Brook Lamprey (*Lampetra hubbsi*) and Pacific Lamprey (*Entosphenus tridentatus*) were encountered during these efforts. Species were predominately distinguished by eye size, whereby Pacific Lamprey have a proportionately larger eye than Kern Brook Lamprey. A subsample of lamprey, identified using this distinguishing characteristic, were verified with genetic analysis (*unpublished data*). Kern Brook Lamprey is a nonparasitic species that completes its life cycle entirely in freshwater (Vladykov and Kott 1976). Unlike Kern Brook Lamprey, Pacific Lamprey are anadromous with juveniles completing a larval life stage (ammocoete) in freshwater before transformation into macropthalmia and emigrating to the ocean (Beamish and Levings 1991; Moser et al. 2007; Goodman et al. 2015). Adults exhibit a parasitic life history in marine environments, before returning to freshwater, where they typically overwinter and spawn the following year (Beamish 1980; Larsen 1980; Robinson and Bayer 2005).

Adult Pacific Lamprey passage into Reach 1 is likely only feasible in high flow years, when passage through/around instream barriers is possible. Adults captured during the 2017–18 sampling season likely moved up the San Joaquin River into the Restoration Area during spring flood conditions in 2017 which created passable conditions into Reach 1 (Figure B-1). One-hundred thirty adult Pacific Lamprey were captured February–May 2018. Most (~95 percent) of these adults were captured March–April.

In addition to the 130 adult Pacific Lamprey, another 11,886 lamprey were captured during 2017–18 RST sampling. Prior to eye development, differentiation of species at the ammocoete and metamorphosing life-stage can be difficult in the field, so all juvenile lamprey were identified as “unknown lamprey.” Fourteen unknown ammocoetes, 74 Kern Brook Lamprey, and 11,798 juvenile Pacific Lamprey comprised these additional captured lamprey. After hatching, larval Pacific Lamprey (ammocoetes) reside in the substrate for 4–6 years before transforming into macropthalmia and beginning seaward emigration (Beamish and Levings 1991). Since flow conditions permitting adult lamprey passage into Reach 1 were limited, juvenile lamprey captured in the 2017–18 field season were likely 5-year old progeny from adults moving into Reach 1 following flood conditions in 2011 (Figure B-1). Dry conditions 2012–16 likely precluded passage into upstream reaches of the Restoration Area.

In the 2017–18 sampling season, 96 percent (11,403) of the juvenile lamprey were captured during a two-week period in late March/early April (Figure B-2). This coincided with a large pulse flow and increased turbidity rates from Dry Creek (916 CFS contribution near RM 260.6) on March 22–23. Other studies, observing similar trends in lamprey movement, suggest elevated streamflows, combined with the completion of metamorphosis likely play a role in emigration timing (Van de Wetering 1998; Goodman et al. 2015).

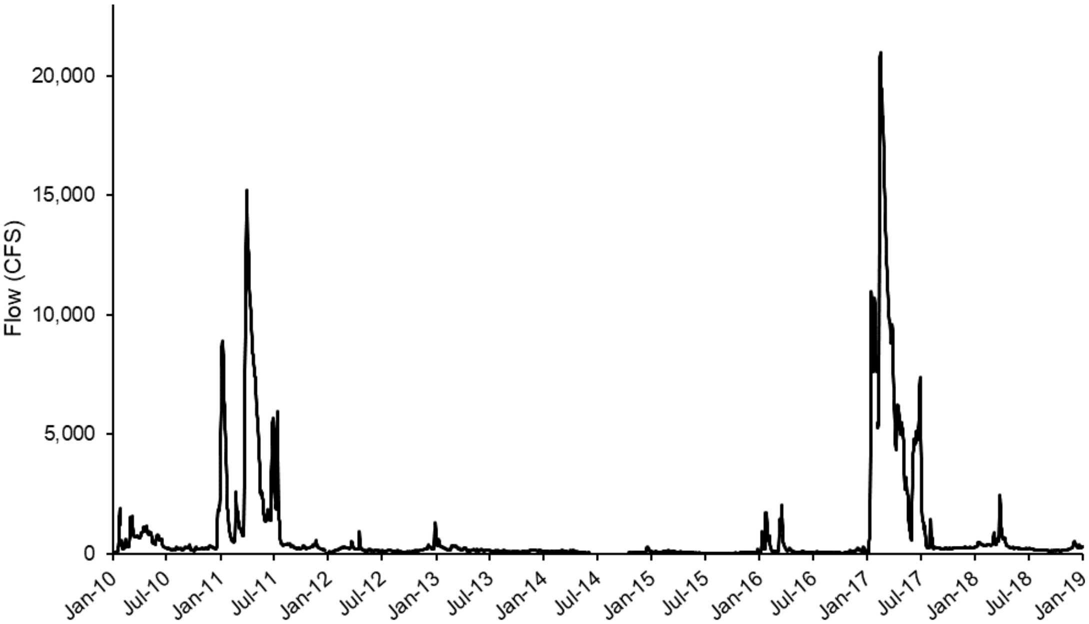

Figure B-1.—Flow in Reach 5 of the San Joaquin River Restoration Area 2010–18. Flow measured at the USGS Freemont Ford gaging station (data downloaded from the California Data Exchange Center).

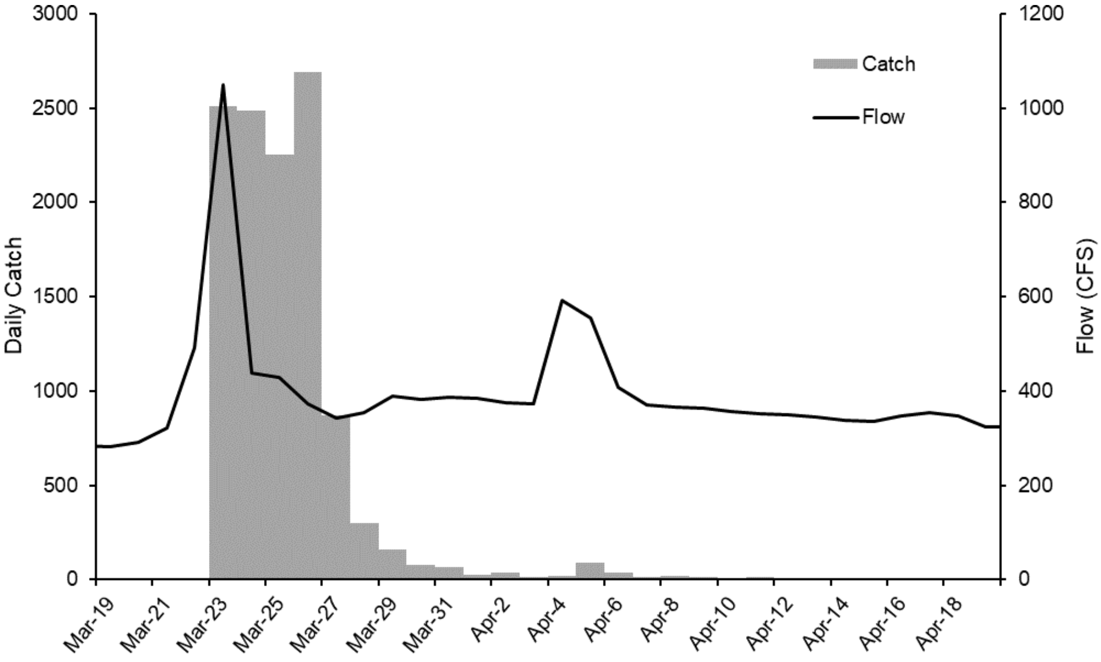

Figure B-2.—Daily catch of Pacific Lamprey (*Entosphenus tridentatus*) in rotary screw traps, and respective flow (daily average; measured at Highway 41) following natural pulse (peak 916 CFS) from Little Dry Creek in Reach 1 of the San Joaquin River Restoration Area.

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8.0 Appendix C: Rotary Screw Trap Efficiency

Table C-1.—Marked efficiency release data for individual release groups during the 2017–18 sampling season. Data includes release group location, size, release date, and total marked fish recaptured within efficiency interval. Also included are the total Salmon Conservation and Rearing Facility (SCARF) escapees and wild spring-run Chinook Salmon (*Oncorhynchus tshawytscha*; subcategorized as either broodstock or escapement progeny) captured during concurrent period.

Release Interval (i):	Capture Site:	# Released (M_i):	Release Date:	Recaptured before next period (m_i):	SCARF (u_i):	Spring-run (u_i):	Broodstock (u_i):	Escapement (u_i):
1	Friant	999	1/27/18	31	0	148	74	74
2	Friant	1000	2/4/18	1	0	0	0	0
3	Friant	1000	2/20/18	0	0	0	0	0
4	Friant	1000	2/28/18	1	0	0	0	0
5	Friant	999	3/9/18	1	0	0	0	0
1	Owl Hollow	1000	1/28/18	63	77	98	57	41
2	Owl Hollow	999	2/4/18	46	7	1	1	0
3	Owl Hollow	1000	2/20/18	123	7	2	1	1
4	Owl Hollow	1000	3/1/18	17	4	1	0	1
5	Owl Hollow	1000	3/10/18	12	9	9	5	4
6	Owl Hollow	1000	3/26/18	4	4	1	0	1
7	Owl Hollow	995	4/3/18	19	9	3	0	3
8	Owl Hollow	1000	4/11/18	9	10	8	6	2
9	Owl Hollow	1000	4/22/18	6	2	2	1	1
10	Owl Hollow	1000	4/28/18	30	6	4	3	1
1	Hwy 99	998	1/29/18	104	1	0	0	0
2	Hwy 99	1000	2/5/18	376	4	0	0	0
3	Hwy 99	999	2/21/18	134	5	0	0	0
4	Hwy 99	1000	3/2/18	285	6	0	0	0
5	Hwy 99	1000	3/11/18	181	47	27	13	14
6	Hwy 99	1000	3/27/18	222	33	20	11	9
7	Hwy 99	1000	4/4/18	121	35	11	3	8
8	Hwy 99	999	4/12/18	161	32	15	11	4
9	Hwy 99	1000	4/23/18	136	52	21	10	11
1	San Mateo	998	1/30/18	115	0	0	0	0
2	San Mateo	995	2/6/18	38	0	0	0	0
3	San Mateo	999	2/22/18	51	0	0	0	0
4	San Mateo	999	3/3/18	5	0	1	0	1
5	San Mateo	999	3/12/18	7	13	9	5	4
6	San Mateo	1000	3/28/18	134	5	1	1	0
7	San Mateo	1000	4/5/18	7	2	4	0	4
8	San Mateo	1000	4/13/18	18	1	0	0	0

Table C-2.—Marked efficiency release groups (Chinook Salmon, *Oncorhynchus tshawytscha*) for evaluating production at Owl Hollow and Highway 99 (Hwy 99) rotary screw trap (RST) locations. Due to the low precision of original marked releases at Owl Hollow, Friant RST-released groups were used to estimate trap efficiency and production at Owl Hollow.

Release Interval (i):	Capture Site:	# Released (M_i):	Release Date:	Recaptured before next period (m_i):	SCARF (u_i):	Spring-run (u_i):	Broodstock (u_i):	Escapement (u_i):
1	Owl Hollow	999	1/27/18	120	77	98	57	41
2	Owl Hollow	1000	2/4/18	291	7	1	1	0
3	Owl Hollow	1000	2/20/18	198	7	2	1	1
4	Owl Hollow	1000	2/28/18	102	3	1	0	1
5	Owl Hollow	999	3/9/18	106	8	6	2	4
6	Owl Hollow	1000	3/25/18	157	4	4	3	1
7	Owl Hollow	999	4/2/18	91	11	3	0	3
8	Owl Hollow	1000	4/10/18	78	10	6	4	2
9	Owl Hollow	887	4/21/18	105	8	8	6	2
1	Hwy 99	998	1/29/18	104	1	0	0	0
2	Hwy 99	1000	2/5/18	376	4	0	0	0
3	Hwy 99	999	2/21/18	134	5	0	0	0
4	Hwy 99	1000	3/2/18	285	6	0	0	0
5	Hwy 99	1000	3/11/18	181	47	27	13	14
6	Hwy 99	1000	3/27/18	222	33	20	11	9
7	Hwy 99	1000	4/4/18	121	35	11	3	8
8	Hwy 99	999	4/12/18	161	32	15	11	4
9	Hwy 99	1000	4/23/18	136	52	21	10	11