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

2021–22 Monitoring and Analysis Report

SAN JOAQUIN RIVER
RESTORATION PROGRAM

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Prepared by Jarod Hutcherson[1], Zak Sutphin[1], Jen Giannetta[2], John Carlos Garza[3], and Anthony Clemento[3]

[1]Bureau of Reclamation, Denver Technical Services Center, Fisheries and Wildlife Resources Group, Denver, CO 80225

[2]California Department of Fish and Wildlife, Central Region, San Joaquin Restoration Program, Fresno, CA 93710

[3]NOAA Southwest Fisheries Science Center & UC Santa Cruz Institute of Marine Sciences, Santa Cruz, CA 95060

Self-Certification of Peer Review

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

Name	Affiliation	Phone Number
Meiling Colombano	National Marine Fisheries Service	916-930-3695
O. Towns Burgess	Bureau of Reclamation	916-978-5446

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

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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 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. Resultantly, the Fisheries Framework was developed to provide "a realistic schedule for implementation of the fisheries management actions," while defining goals and objectives towards reestablishing Chinook Salmon (*Oncorhynchus tshawytscha*) in the Restoration Area (San Joaquin River Restoration Program [SJRRP] 2018). Within the Framework, stressors are identified (e.g., predation, water quality, entrainment), and a plan is provided for reducing these stressors. Furthermore, it provides measurable metrics to evaluate progress towards producing self-sustaining populations of fall-run and spring-run Chinook Salmon. The use of rotary screw trap (RST) monitoring allows evaluation of these objectives; specifically, RST monitoring may help identify juvenile passage rate, fry-to-smolt survival, and juvenile production. Evaluation of these objectives using RSTs may also help understand areas within the monitoring locations that may be adversely impacting juvenile salmon survival and emigration success.

Juvenile migration success has been posited as one limited factor for sustaining spring-run and fall-run Chinook Salmon 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, broodstock releases). The 2021–22 season marks the fifth consecutive year of rotary screw trap monitoring for spring-run Chinook Salmon. Prior to that, juvenile tracking and monitoring efforts were limited to fall-run Chinook Salmon (Hueth et al. 2017; Sutphin et al. 2018). While volitional adult salmon passage to spawning grounds in the RA was not possible in spring 2021, two hundred (50 females and 150 males) spring-run adult broodstock were released into Reach 1 following rearing efforts at California Department of Fish and Wildlife's (CDFW) Interim Salmon Conservation and Research Facility (hereafter, referred to as SCARF) located in Friant, California (Demarest et al. 2024). An additional 74 adult salmon (35 females, 29 males, and 10 unknowns) were also released into Reach 1 after capture and transport from Reaches 4–5 during the SJRRP adult spring-run Chinook Salmon Trap and Haul project (Sutphin and Root 2022). Offspring from these spawning adults comprised the juvenile spring-run salmon described herein. Data collected through these activities will continue to provide information regarding juvenile spring-run Chinook Salmon production, emigration timing, survival, and growth, and will assist management understanding current population conditions as well as progress towards meeting those 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

Data collected during RST monitoring provide an estimate of juvenile spring-run Chinook Salmon production, survival, growth and emigration timing from the spawning grounds, and how environmental conditions impact these metrics. Previous years' data can be combined with those collected in this study to evaluate annual trends and fluctuations for juvenile spring-run Chinook Salmon. The following are the target objectives of this study, and will SJRRP management with decisions regarding continued restoration activities and establish a long-term plan for juvenile monitoring:

1) Estimate natural production of juvenile spring-run Chinook Salmon from the spawning grounds in Reach 1.

2) Estimate survival rates of juvenile spring-run Chinook Salmon through the Restoration Area where rotary screw traps are installed and identify sections where higher rates of loss may occur.

3) Evaluate life-stage specific migration timing of juvenile spring-run Chinook Salmon from spawning areas in Reach 1 to downstream areas where rotary screw traps are installed.

4) Identify factors that may influence natural production, survival rates, and migration timing (e.g., flow, temperature, fish size).

5) Genetically determine total spawners contributing to naturally produced progeny captured in rotary screw traps.

6) Determine growth of individuals recaptured in rotary screw traps, identified through genetic analyses or length-at-date analyses.

7) When efforts would not otherwise preclude meeting the above objectives, and when approved by the Restoration Program, opportunistically support additional California fisheries studies by providing data or field samples (e.g., supply fish for pathological analyses for the California-Nevada Fish Health Center, provide lamprey tissue samples for UC Davis to help address population structure and gene flow factors in California).

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; Volhardt et al. 2007; Pilger et al. 2019). Proper trap operation requires adequate water depth (approximately half the depth of the cone diameter, or ~1.2 m deep) to allow unimpeded rotation of the RST cone and sufficient velocity (nominally 0.8–2.0 m/s; Volhardt et al. 2007) to physically rotate the cone. Traps were placed in the thalweg to provide sufficient depth for operation and to maximize the volume of water sampled. For production estimates, ideal placement of RSTs is at the downstream extent of the spawning area (Volhardt et al. 2007); rotary screw traps interspersed between redds allow for estimates of survival and site-specific production rates within the spawning area. Rotary screw traps (2.4-m diameter) were placed at four locations in Reaches 1–2 (Figure 1) of the Restoration Area: Owl Hollow (RM 259), Scout Island (RM 250), Highway 99 (Hwy 99; RM 243), and Gravelly Ford (RM 227). Redd locations were considered for RST placement and installation was contingent upon site accessibility and suitability. During 2021 SJRRP redd and carcass surveys, 32 redds were detected, the majority (97 percent) of which were upstream of the Owl Hollow RST (Demarest et al. 2022). The Scout Island RST is located downstream of an abandoned in-river mine pit that likely affects movement patterns of juvenile salmon in Reach 1. It is also approximately midway between the upstream Owl Hollow RST and downstream Hwy 99 RST. The Hwy 99 RST was placed downstream of all observed spring-run salmon redds (Demarest et al. 2022) and is near the most downstream extent of adult fall-run Chinook Salmon spawning in the Restoration Area (Castle et al. 2016). The Gravelly Ford location was selected for the downstream-most RST placement because catch rates at the previous downstream location of San Mateo suggested few salmon were able to successfully reach this location (Hutcherson et al. 2024). Gravelly Ford is approximately halfway between the Hwy 99 RST location and previously used San Mateo location. Gravelly Ford is ~ 0.4 RM downstream of the start of Reach 1B, so data collected at this location allows estimates of survival through this reach. This location is also downstream of a major irrigation withdrawal: Gravelly Ford—ideally, this location may help indicate whether areas downstream of Gravelly Ford were previously contributing to decreased juvenile passage.

Figure 1.—Rotary screw trap locations in the San Joaquin River Restoration Area during the 2021–22 sampling season. Map depicts the upstream reaches of the Restoration Area; dashed lines indicate delineations between reaches and sub-reaches. Map provided by Andrew Minks, Bureau of Reclamation, Sacramento, California.

The start of the monitoring period coincided with initial observations of juvenile salmon at the RST locations during previous efforts (Hutcherson et al. 2021; 2023; 2024). Periods of trap operation are listed in Table 1. The first three upstream RSTs were placed in the fishing position concurrently on November 8, 2021. The Gravelly Ford RST was not placed into the fishing position until January 7, 2022. This followed the initial catch of wild salmon at Hwy 99, with the assumption that salmon would not be observed at Gravelly Ford until encountered at the nearest upstream trap (Hwy 99). Elevated levels of periphyton occurred in upstream areas of Reach 1 during the second half of the sampling season. The periphyton quickly clogged the mesh in the RSTs, stopping cone rotation and preventing operation. After a period of unsuccessfully managing these elevated levels, the decision was made to cease operation of the Owl Hollow RST on March 17; likewise, the Scout Island RST was removed from the fishing position March 28. Sampling at the Hwy 99 and Gravelly Ford RSTs concluded June 3.

Table 1.— Sampling dates for rotary screw trap (RST) locations during 2021–22 sampling season.

RST Site:	Start:	Stop:
Owl Hollow	11/8/2021	3/17/2022
Scout Island	11/8/2021	3/28/2022
Hwy 99	11/8/2021	6/3/2022
Gravelly Ford	1/7/2022	6/3/2022

2.2 Trap Placement and Operation

At all but the Gravelly Ford location, RSTs were secured with a 13-mm (1/2-in.) wire rope attached high enough from the water surface to allow passage 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. Each 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 river users to its presence. Figure 2 illustrates the installed Owl Hollow RST in operation. Site conditions at the Gravelly Ford 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.—Owl Hollow rotary screw trap attached to high line wire rope via snatch block (not visible) and 10 mm-diameter wire ropes (made apparent to recreationalists using pink flagging). Lateral rope, connected to shoreline, on downstream side of trap prevents excessive swaying. Photo credit: Bureau of Reclamation.

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), temperature, dissolved oxygen (YSI Pro; YSI Incorporated, Yellow Spring, OH), and turbidity (Infrared light turbidimeter; Cole-Parmer, Vernon Hills, IL).

Additionally, dissolved oxygen and temperature loggers were also affixed to each trap that recorded values at 30-minute intervals throughout the season (HOBO dissolved oxygen logger; Onset Computer Corp.; Bourne, MA). Debris loads were categorically annotated (low, medium, high) based on the proportion of the live well filled with debris (no debris to one-third full, one- to two-thirds full, and more than two-thirds full, respectively) 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. Salmon were anesthetized in a solution of 40–60 mg/L MS-222 (tricaine methanesulfonate) before processing. Wild fish were differentiated from efficiency fish (see *Efficiency Tests* section below) by the presence of an adipose fin and lack of identifying marks. Wild salmon were measured for fork (FL; mm) and total length (TL; mm), and a tissue sample was collected from the caudal fin for genetic analysis. Recaptured efficiency salmon were measured in a similar manner, though no tissue samples were collected. Salmon greater than 45mm FL were weighed (nearest 0.1 g). 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 on this differentiation, and the RST 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. When trap-specific capture totals exceeded 60 individuals, the first 60 spring-run Chinook Salmon were processed as described, and the remainder enumerated.

Bycatch were identified to species, when possible. In some cases, fish too small to identify without the aid of magnification (e.g., young-of-year centrarchid and cyprinid spp.) were identified only to family or genus. Bycatch were enumerated and measured to total length (TL; nearest mm). In cases where numbers of any one species exceeded 20 at an RST, a subsample of 20 fish was measured for length, and the remaining fish were enumerated. Bycatch are not discussed within the body of this report, but data are available in Appendix A. Likewise, information from fish submitted for additional analyses (e.g., Fish Health Center histopathology analyses) is available in Appendix B. After processing and recovery, all fish were transported in the recovery bucket and released approximately 30 m downstream of the RST to minimize the likelihood of recapture at the same location.

2.4 Efficiency Tests

Accurate estimation of RST efficiency (i.e., the proportion of salmon moving downstream that are captured in the RST) is needed to determine total passage of juvenile salmon past each installed trap. Since RST efficiency can be affected by variables like environmental conditions and fish sizes (Pilger et al. 2019), each of the four RSTs was evaluated at regular intervals to determine trap efficiency through the sampling season. For each RST location, efficiency releases were completed every 1–3 weeks, from December–May (on average, every 1.8 weeks across RST locations; see Appendix D for more details), using groups of marked hatchery salmon. These spring-run Chinook Salmon were provided via production at CDFW's SCARF.

As of this publication, all juvenile salmon released into the Restoration Area are required to receive a coded wire tag (CWT) prior to release. Two sizes of CWT are available, half-size (0.5 mm) and full size (1.1 mm). Salmon less than 55 mm FL received a CWT and those greater than 55 mm FL received a full-size CWT. Since fry are primarily captured during the early portion of the sampling season at the upstream sample sites, four efficiency evaluations were completed at each of the two upstream RSTs (Owl Hollow and Scout Island) using groups of half-size CWT salmon. Additionally, four group releases also occurred at Friant Dam. The intent of these releases was to help determine survival from near the spawning grounds, where redds are typically clustered, to the downstream RSTs. These evaluations were completed December–January. The fish used in efficiency releases the remainder of the sampling season were full-size CWT salmon.

In addition to the CWT, salmon used to evaluate trap efficiency were further distinguished by providing a colored fin marking based on location and date of release. Prior to marking, fish were anesthetized in a 40–60 mg/L solution of MS-222. Following anesthesia, fins were marked with a needleless, CO_2-powered injector (NEWWEST Technologies, LLC., Santa Rosa, CA). Tag color was provided by using tattoo ink diluted 12-to-1 with distilled water (Figure 3). By varying the color and fin combinations for every RST and release date, staff could ascribe recaptured fish to specific releases. A subsample of 10 percent of the fish in each release group was measured (FL/TL [mm]; weight [g]) to describe morphometrics of each group. Fish were typically given a 48-h recovery period prior to release.

Following recommendations made in the Fish and Wildlife Service's Comprehensive Assessment and Monitoring Program, rotary screw trap protocol (CAMP protocol; [USFWS] 2008), fish were released 400–800 m upstream of each RST location. Fish were released after sunset since wild salmon outmigration typically occurs at night (Chapman et al. 2013). Following the first release of efficiency fish, personnel checked any captured salmon for the presence of a colored fin mark during any subsequent RST checks. Staff recorded the location/color of salmon having such markings. Processing and release procedures were like those for wild salmon and are outlined in the *Fish Processing* section above; however, no tissue samples were collected from efficiency release fish.

Figure 3.—Example of hatchery-reared, marked spring-run Chinook Salmon *(Oncorhynchus tshawytscha*) used for rotary screw trap efficiency tests. Photo credit: Bureau of Reclamation.

2.5 Analyses

2.5.1 Genetic Analyses

The Southwest Fisheries Science Center Santa Cruz Laboratory received 1,538 tissue samples from juvenile Chinook Salmon captured in RSTs from the San Joaquin River during the 2021–22 trapping season. Using standard laboratory protocols, DNA was extracted, and all individuals genotyped with a set of 214 microhaplotype genetic markers (Baetscher et al. 2018), which consists mostly of highly variable markers for pedigree analysis, as well as a small set (n = 10) for identification of genotypes in the chromosome 28 region strongly associated with seasonal migration timing in Chinook Salmon (i.e., fall- vs. spring- vs. winter-run; Thompson et al. 2020). These microhaplotype markers also include the majority of the 96 single-nucleotide polymorphism (SNP) markers that have been employed throughout the project to date (Clemento et al. 2014). Importantly, since 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, they allow both parentage-based analyses, as well as stock identification and traditional population genetic analyses.

Analysis of these samples proceeded incrementally. Duplicate genotypes from fish sampled multiple times, analogous to recaptures in a mark-recapture framework, were first identified. Size data were analyzed to estimate 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 SCARF captive broodstock adults and broodstock from the Feather River Hatchery (the source of SCARF broodstock and their siblings). For juveniles sampled from 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.

2.5.2 Rotary Screw Trap Efficiency and Production

Trap efficiency is based on the ratio of recaptured, marked fish, to the total number of released, marked fish. These ratios can be applied to the number of wild fish captured to estimate the total number of naturally produced fish (i.e., those juveniles produced from in-river redds, regardless of maternal origin) moving past each RST. Genetic analysis of tissue samples collected from salmon permitted the opportunity to reveal potential recaptures at all RST locations. Any recaptures at the same location (i.e., that particular fish was recaptured at the same RST as its previous capture) were only counted during the initial instance of capture. Under the constraints of RST efficiency evaluations, the following assumptions were made (Volhardt et al. 2007; [USFWS] 2008):

- hatchery fish are representative of wild fish, both in size and behavior
- all fish have equal probability of capture
- marked fish remain readily identifiable within each efficiency interval
- all released fish move downstream and have an equal opportunity to encounter downstream RSTs
- trap efficiency is constant within each efficiency interval
- the population is closed

Seasonal production was estimated using the daily catch and the corresponding RST efficiency rate at each trap location for spring-run Chinook Salmon—since these estimates rely on the total number of naturally produced salmon captured at each RST, production can also be thought of as the total number of spring-run Chinook Salmon passing each RST location. Any other captured salmonids (e.g., fall-run Chinook Salmon, other *Oncorhynchus spp.* based on genetics or length-at-date regressions) were excluded from these analyses. Production at each RST was estimated both as a total of all spring-run Chinook Salmon and, more specifically, as a function of maternal origin. Based on results of the genetic analysis, juveniles were ascribed to a maternal origin of one of three classes: SCARF broodstock, adult salmon captured during Trap and Haul efforts in Reaches 4 and 5, or unknown adults. The following description for evaluating production was used for both approaches, with the previous distinctions considered.

The following stratified mark-recovery approach from (Carlson et al. 1998), and further outlined in (Volhardt 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 and $v(\hat{n}_i)$ is the variance for the production estimates 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, suppose the first efficiency release at Hwy 99 was January 31 and the second on February 14. Trap efficiency calculated at this first interval is used to estimate production of wild fish from trap installation until the next efficiency release on February 14.

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

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

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

Traps were occasionally placed in the non-fishing position (e.g., over holidays, during periods of high flows when trap access was considered unsafe). Furthermore, trap operation was sometimes inhibited because of debris preventing RST rotation. To account for fish that would have otherwise been captured during these periods, missed salmon were calculated by the slope of the line across the non-fishing period using catch before and after this interval:

$$c_i = (d_i)\left[{(c_n - c_0)}\big/{(D_{NF} + 1)}\right] + c_0,$$

where $c_i$is the catch on day, d_i, of the non-fishing period, c_0 is the catch the day before the non-fishing period, c_n is the catch the day after the non-fishing period, and D_{NF} is the total days in the non-fishing period.

Post hoc analyses of survival to the next downstream RST (*see* Survival of Efficiency Release Groups) indicated initial Hwy 99 trap efficiency estimates did not accurately reflect trap efficiency. This was likely a function of the release site for Hwy 99 efficiency tests influencing salmon behavior post-release—the area immediately downstream from the release location being densely packed with hyacinth (*Eichhornia crassipes*; Figure 4). Therefore, like a previous season where the efficiency fish release location did not adequately reflect RST efficiency (Hutcherson et al. 2020), those fish released at the next upstream location (Scout Island) were used to better estimate Hwy 99 trap efficiency during the affected periods.

Figure 4.—Hyacinth mat (*Eichhornia crassipes*), downstream of the Hwy 99 efficiency fish release location, and upstream of the rotary screw trap. Photo taken during spring 2021. Photo credit: Bureau of Reclamation.

2.5.3 Survival

Survival is calculated for wild salmon, as well as for efficiency release groups. The survival of wild salmon directly relates to quantifying this objective in the Fisheries Framework ([SJRRP] 2018), from upstream locations near the spawning grounds to areas downstream where the remaining RSTs are located; however, because wild salmon tend to hold during rearing periods where little movement is detected, this makes it difficult to distinguish whether survival is a function of time, or some other component respective to those stretches between RSTs (Hutcherson et al. 2021; 2023; 2024).

Hatchery salmon marked for RST efficiency releases, though, tend to move rapidly downstream following release. These groups are tagged from the same hatchery stock, meaning they are similar in size when released, and groups are released concurrently across RST locations. Since these fish tend to move downstream rapidly, and fish are easily distinguishable from both wild salmon and other efficiency release groups upon recapture, evaluating survival between RST locations permits an evaluation of in-river conditions (e.g., bathymetry, in-river features, varying predator distributions) that might affect survival within these stretches of river, holding variables, such as timing and fish size, constant.

2.5.3.1 *Survival of Wild Salmon*

Wild salmon survival evaluates differences in wild salmon estimates at each RST location (Thedinga et al. 1994; Pyper and Justice 2006). The primary assumption of this approach, though, is that juvenile production occurs upstream of the RST locations. Therefore, estimates at downstream RSTs would be indicative of downstream survival, accounting for losses through those specific river stretches. While not all redds were located upstream of Owl Hollow, the majority (~97 percent; 31 of 32 redds) were identified upstream of this location during redd surveys prior to the start of monitoring (Demarest et al. 2024). This is the most direct approach to estimate absolute survival across the sampling season, from upstream to downstream. By estimating how many salmon are produced from the spawning grounds in Reach 1 and successfully emigrate beyond downstream RSTs, these efforts will provide data towards answering Objective 2 above as well as the fry-to-smolt survival objective established in the Fisheries Framework ([SJRRP] 2018).

2.5.3.2 *Survival of Efficiency Release Groups*

The second method used to estimate survival is based on a stratified mark-recapture (Bjorkstedt 2005), and relies on recaptured efficiency fish, which are hatchery-reared fish identified with a color-fin mark combination. Because residence time of naturally produced salmon encompasses the entire season, and since specific redds from which each fish emerges are not readily identifiable, estimating environmental changes contributing to survival is not currently possible with this cohort. Conversely, each efficiency group is introduced to the river at a specific location and time, and recaptured fish are readily identifiable because of the applied colored fin marks. Since efficiency fish often move more rapidly than naturally produced fish (Hutcherson et al. 2021) and they are easily identifiable, evaluating effects of environmental conditions on survival is more feasible using these fish. Survival using efficiency fish release groups was estimated using the same process outlined in Hutcherson et al. (2021):

> Survival…was estimated using the recapture of marked fish between RSTs (Hutcherson et al. 2020). The…total number of marked fish from each efficiency test, released at upstream RSTs, and surviving to the Hwy 99 RST, is estimated as the sum product, $\sum\left({}^{1}/_{e_i}\right) m_{ij}$, using the following matrices:

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

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 (from either upstream RST releases), captured in the i^{th} interval. Survival for each marked release is then estimated using:

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

where M_j is the total number of marked fish, *M*, released in group *j*. See Appendix B for an example.

Survival estimates were calculated for each release group between the stretches of Owl Hollow to Hwy 99 and from Hwy 99 to Gravelly Ford. Typically, survival is compared between each trap location (Hutcherson et al. 2023; 2024); however, given the issues with the Hwy 99 efficiency release location, these sections were chosen instead. These stretches are similar in length (Owl Hollow–Hwy 99: 15.5 RM; Hwy 99–Gravelly Ford: 15.7 RM) and provide an opportunity to evaluate differences between the areas encompassing the spawning grounds compared to the remaining section downstream in Reach 1 of the RA. Table 2 identifies the stretches between RST locations and the total river miles in between. To evaluate potential differences in survival between the Owl Hollow–Hwy 99 and Hwy 99–Gravelly Ford reach, a paired t-test was used. Only releases within 24 hours of one another were used for comparison.

Table 2.—Rotary screw trap stretches, and river miles between trap locations, used to evaluate survival of juvenile Chinook Salmon (*Oncorhynchus tshawytscha*) released during rotary screw trap efficiency evaluations during 2021–22 monitoring efforts.

Rotary screw trap stretches:	River miles between locations:
Friant Dam–Owl Hollow	9.0
Owl Hollow–Scout Island	8.4
Scout Island–Highway 99	7.1
Highway 99–Gravelly Ford	15.7

Water temperature, turbidity, flow, and average fish length within each release group were initially considered for analysis to determine factors influencing survival rates. Water temperature was collected using temperature loggers deployed at each RST during the sampling season (HOBO data logger; Onset Computer Corp., Bourne, MA). Daily averages were calculated from 30-minute continuous logging intervals. Turbidity data were collected once daily at each RST location. Flow data were downloaded from the California Data Exchange Center website (CDEC.water.ca.gov) from gaging stations downstream of Friant Dam near Lost Lake Recreation Area (RM 265), near Highway 41 (RM 255), and upstream of the Gravelly Ford RST (RM 228). Average daily flow was calculated using 15-min recorded intervals from those three gaging stations. Fork and total length (mm), and weight (g) were recorded for 10 percent of each efficiency group, for each RST, during the tagging process—FL data were used to determine whether the size of the fish and survival were correlated.

Pearson Product Moment Correlation was used to evaluate collinearity among the independent variables: average flow, temperature, and turbidity following release and average fork length of each efficiency release group. When independent variables were correlated ($p = 0.05$ and $r^2 \geq 0.70$), the variable with the poorest relationship to survival was removed and the analyses continued (Giorgi et al. 1997). After removing collinear variables, regression analyses were used to evaluate survival in the respective sections between RST locatoins (Owl Hollow–Hwy 99 and Hwy 99–Gravelly Ford). An alpha value, α=.05, was used to determine statistical significance across analyses.

2.5.4 Daily growth rate

Recaptures of naturally produced salmon, identified through genetic analyses following tissue sample processing *post hoc*, were used to evaluate growth rates in the Restoration Area. The difference in recorded weights between capture events was divided by the total days between recapture to determine absolute growth, or the daily growth rate (Hopkins 1992). Only salmon captured more than two weeks apart were included in these analyses to permit suitable time for measurable growth between capture events, permitting fish to recover from handling stress, and allowing sufficient time between measuring where the precision of the measuring equipment would have negligible effects on measured weights. When the initial event of capture included salmon less than 45 mm TL, the initial weight was estimated based on length weight regressions from the current season. Results are compared to juvenile objectives in Fisheries Framework ([SJRRP] 2018).

Recaptures in previous sampling seasons were relatively limited (Hutcherson et al. 2023; 2024). To provide a meaningful metric which to compare against the criterion in the Fisheries Framework (SJRRP 2018) when there are few recaptures, a secondary method to estimate spring growth rate was also evaluated. A growth regression was developed for the entire spring-run cohort. This regression was created using length-at-date data combined with the length-weight relationship of captured fish. While a summer growth criterion is indicated in the Fisheries Framework (SJRRP 2018), evaluations were restricted to spring growth since juvenile spring-run Chinook Salmon sampling efforts ceased before the beginning of the summer period (June 21, 2022).

Predictions bands for length-at-date are generated annually (Hutcherson et al. 2023; 2024). To correlate this to seasonal growth, length-weight data were log-transformed to describe the linear relationship between the two (Anderson and Neuman 1996), and the developed regression subsituted into the prediction equation for length-at-date. The slope of the line was evaluated during the spring period to give an approximation of growth during the specified interval.

3.0 Results

3.1 Salmon Capture at Rotary Screw Traps

A total of 1,579 salmon were captured across the four RSTs during the 2021–22 field season (Table 3). Of the total catch, 1,538 fish were sampled for genetic analyses (Garza and Clemento 2023). Of those, 89 were removed from the analyses due to missing data at 100 or more of the genetic markers. Of the remaining 1,449 fish, 80 appeared to be fall-run at the RoSA markers, 3 were undetermined and the remainder were confirmed as spring-run. Of the tissue samples where maternal origin was determined, a total of 712 were from trap and haul adults released after capture in Reaches 4–5 and 227 were from broodstock fish released from the SCARF. The maternal identification of the remaining samples was categorized as "unknown." The difference between the total fish captured and processed samples were the result of either fish not sampled for analysis (e.g., instances of high capture when plus counts were recorded, fish not sampled before being returned to the river), or where processing issues precluded determination. Fish that were either not sampled or categorized as "unknown" following genetic analyses were grouped based on length-at-date—

Figure 5 identifies captured fish by total length (mm) and date of capture. A prediction band (99 percent confidence that spring-run Chinook Salmon lie within this band) was developed from the genetically identified spring-run fish to help distinguish between spring-run Chinook Salmon and non-spring-run salmonids captured. Many of the salmonids captured during the 2021–22 sampling season that were not identified as spring-run Chinook Salmon also had very high rates of missing data at the remaining genetic markers, suggesting they were not actually Chinook Salmon. Additional genetic evaluation to determine species was not performed, but non-Chinook (trout or kokanee), likely escapees from the San Joaquin Hatchery have been previously identified. Only fish classified as spring-run Chinook Salmon during the 2021–22 sampling season were included in production and survival estimates.

Table 3.—Total juvenile Chinook Salmon (*Oncorhynchus tshawytscha*) captured during 2021–22 rotary screw trap operation in the San Joaquin River Restoration Area. Italicized numbers indicate total fish, by subgrouping (based on maternal genotypes), captured within respective groups (in bold). The "unknown" category includes those fish that were not sampled for genetic analyses or with insufficient data for genotyping and, ultimately, categorized based on length-at-date. "Other" salmon are those fish that were not spring-run Chinook Salmon, either determined through genetic analyses or excluded based on length-at-date.

	Owl Hollow	Scout Island	Hwy 99	Gravelly Ford	Totals:
Spring-run	1,232	71	163	2	**1,468**
Trap & Haul	*636*	*25*	*50*	*1*	*712*
Broodstock	*218*	*4*	*5*	*0*	*227*
Unknown	*378*	*42*	*108*	*1*	*529*
Other	26	15	65	5	**111**

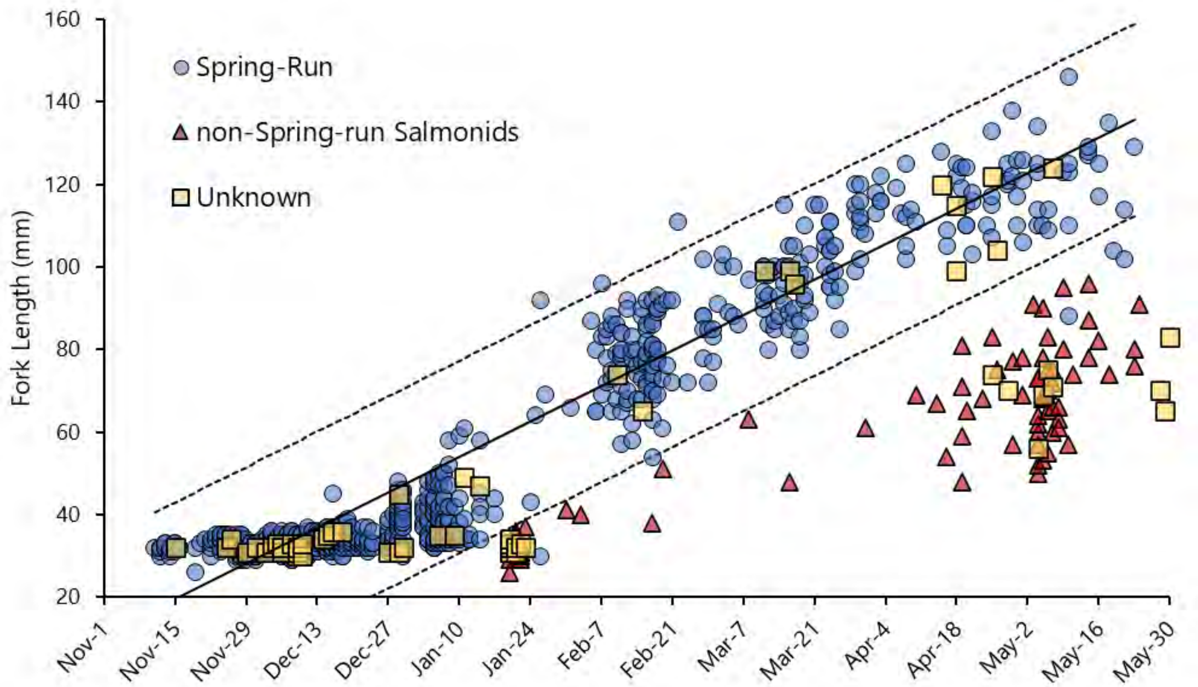

Figure 5.—Genetic results of sampled fish and subsequent prediction bands (dashed lines; 99 percent) based on size and date of capture for spring-run Chinook Salmon (*Oncorhynchus tshawytscha*) captured during the 2021–22 sampling season. Unknown fish (identified by yellow diamonds) either had missing tissue samples or insufficient genetic data to confidently categorize.

Most of the spring-run Chinook Salmon were captured as fry from November–January at the Owl Hollow RST (Figure 5). There was a period of reduced catch mid-January and relatively few parr-sized salmon (40–60 mm FL) were captured (Figure 6). After this, most fish captured the remainder of the season were predominately smolts (> 60 mm FL), captured across the four RST locations.

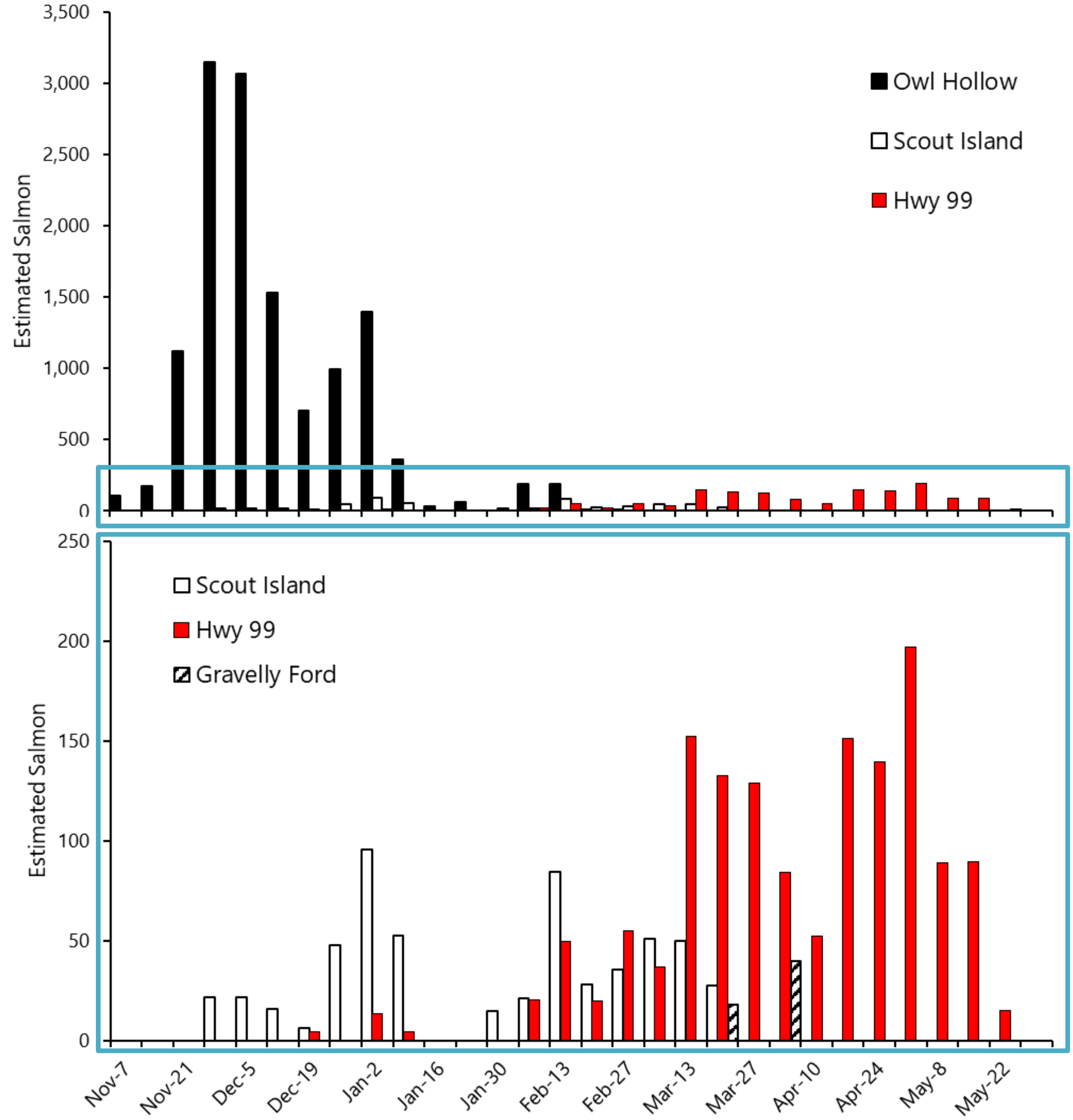

Figure 6.—Weekly estimates of spring-run Chinook Salmon (*Oncorhynchus tshawytscha*) at each rotary screw trap (RST) location in Reaches 1–2 of the San Joaquin River Restoration Area during the 2021–22 sampling season. Estimates are based on capture numbers, extrapolated to account for trap efficiency. The top figure includes the three upstream RSTs and the bottom figure, which is the magnified portion of the box from the upper figure, depicts total salmon at each of the three downstream RSTs.

Flows were elevated during the latter part of the monitoring season (Figure 7), especially when compared to the previous years' monitoring efforts when flows were relatively stable throughout the season (Hutcherson et al. 2023; 2024). These elevated flows reduced RST efficiency (Appendix D); however, salmon capture at the operational RSTs during this period indicated traps were still operational (Figure 6).

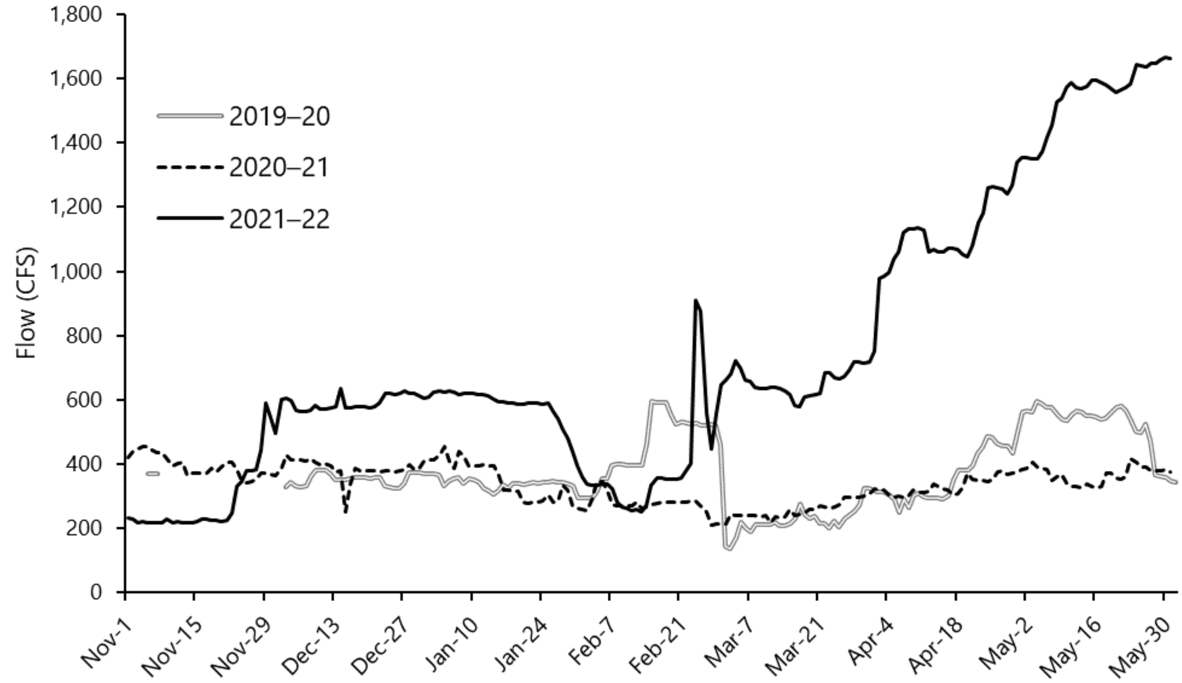

Figure 7.—Average daily flows (CFS) in the San Joaquin River at the Highway 41 gaging station (cdec.water.ca.gov) during the 2019–20, 2020–21, and 2021–22 juvenile spring-run Chinook Salmon (*Oncorhynchus tshawytscha*) monitoring seasons.

3.2 Rotary Screw Trap Efficiency and Production

Mean RST trap efficiencies ranged from 4.6–14.4 percent (Table 4). *Post hoc* survival analyses (*see* Survival of Efficiency Release Groups) of efficiency release groups from Scout Island to Hwy 99 exceeded 100 percent for the latter part of the monitoring season—this indicated that fewer fish from the release groups were captured at the target RST downstream than should be expected—the release location for those efficiency groups released upstream of the Hwy 99 RST were likely affected in some manner where their recapture was not adequately reflecting actual trap efficiency. Therefore, during those periods where survival estimates from release locations at RST upstream of Hwy 99 exceeded 100 percent, Scout Island-released efficiency fish were used as a surrogate to estimate Hwy 99 trap efficiency (Hutcherson et al. 2020; 2021). Efficiency estimates for each interval at the four RST locations are presented in Appendix D—note that releases at Owl Hollow and Scout Island continued after the traps were removed from fishing to help understand downstream movement and survival from those release sites to downstream RSTs.

Table 4.—Adjusted average rotary screw trap (RST) efficiency estimates and corresponding standard deviation, for groups of marked juvenile Chinook Salmon released during the 2021–22 monitoring season.

RST Location:	Efficiency (percent):	±Std. Dev. (percent):
Owl Hollow	10.1%	2.4%
Scout Island	14.4%	3.4%
Hwy 99	14.3%	4.8%
Gravelly Ford	4.6%	2.9%

Weekly production estimates for spring-run Chinook Salmon were greatest at Owl Hollow November–January, declining the remainder of the season. At Owl Hollow, the production estimate for spring-run Chinook Salmon was 13,133 ± 2,162 (± 95 percent CI; Figure 8). Survival of fry released near Friant Dam to Owl Hollow averaged 50.8 percent (SD = 8.5 percent) across the four release groups December–January. Based on this, an estimated 25,852 salmon were produced from the spawning grounds upstream of Owl Hollow.

Estimates of total spring-run Chinook Salmon moving past Scout Island were 574 (± 135). And the total estimated salmon moving past the Hwy 99 and Gravelly Ford RSTs were 1,437 (± 238) and 58 (± 84), respectively. The Owl Hollow and Scout Island RSTs were removed from operation before the conclusion of the monitoring season due to elevated periphyton and subsequent trap clogging issues. Since the juvenile salmon emigrating past Scout Island were estimated to be fewer in number than at Hwy 99, it was presumed the trap removal at Scout Island prevented accurate estimates for the season. Therefore, subsequent analyses specific to Scout Island are not included hereafter.

Of the progeny where the maternal identification was known, estimates of trap and haul salmon at Owl Hollow exceeded those of broodstock progeny two-to-one (Figure 9); however, the trap and haul progeny are only represented by 19 adult females and broodstock progeny at Owl Hollow are ascribed to a known 24 females (Figure 10). When evaluating redd production, by incorporating the estimated survival of fry to Owl Hollow, trap and haul adults produced about three-and-a-half times as many offspring as broodstock adults (Figure 11).

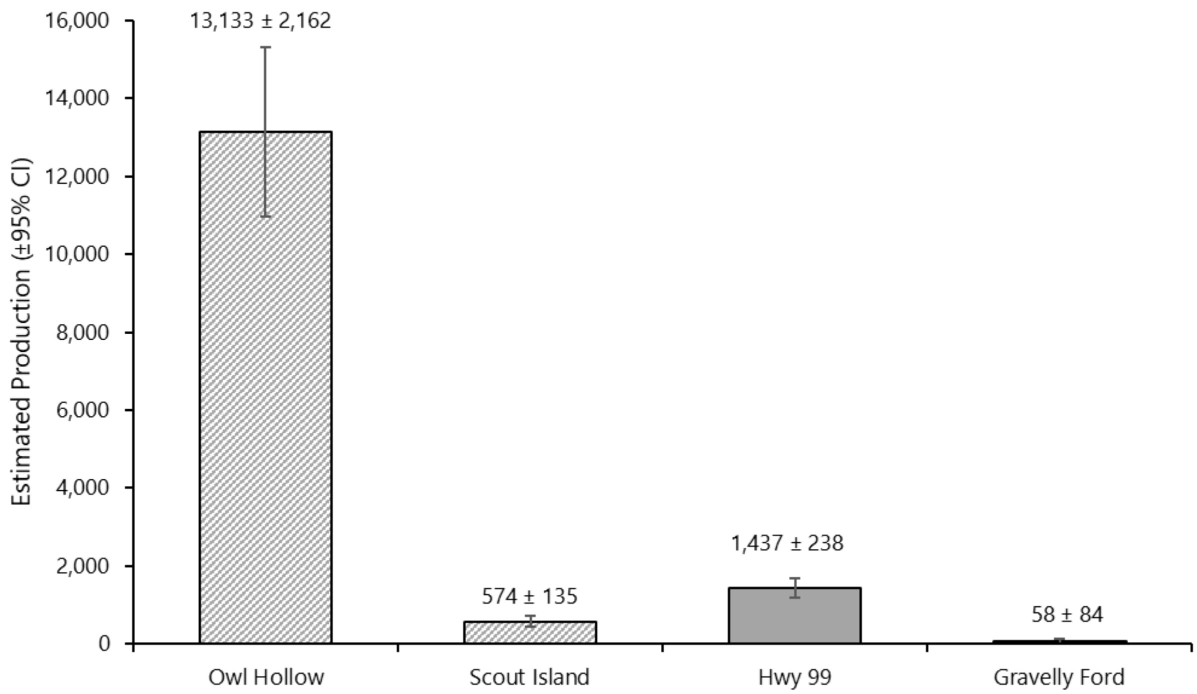

Figure 8.—Total (± 95 percent confidence interval) estimated juvenile Chinook Salmon (*Oncorhynchus tshawytscha*) passing each rotary screw trap location in Reaches 1 and 2 of the San Joaquin River Restoration Area during the 2021–22 sampling season. Owl Hollow and Scout Island are identified with the dashed pattern to highlight the fact these rotary screw traps do not encompass the entire sampling period—they were removed March 2022 due to trap clogging.

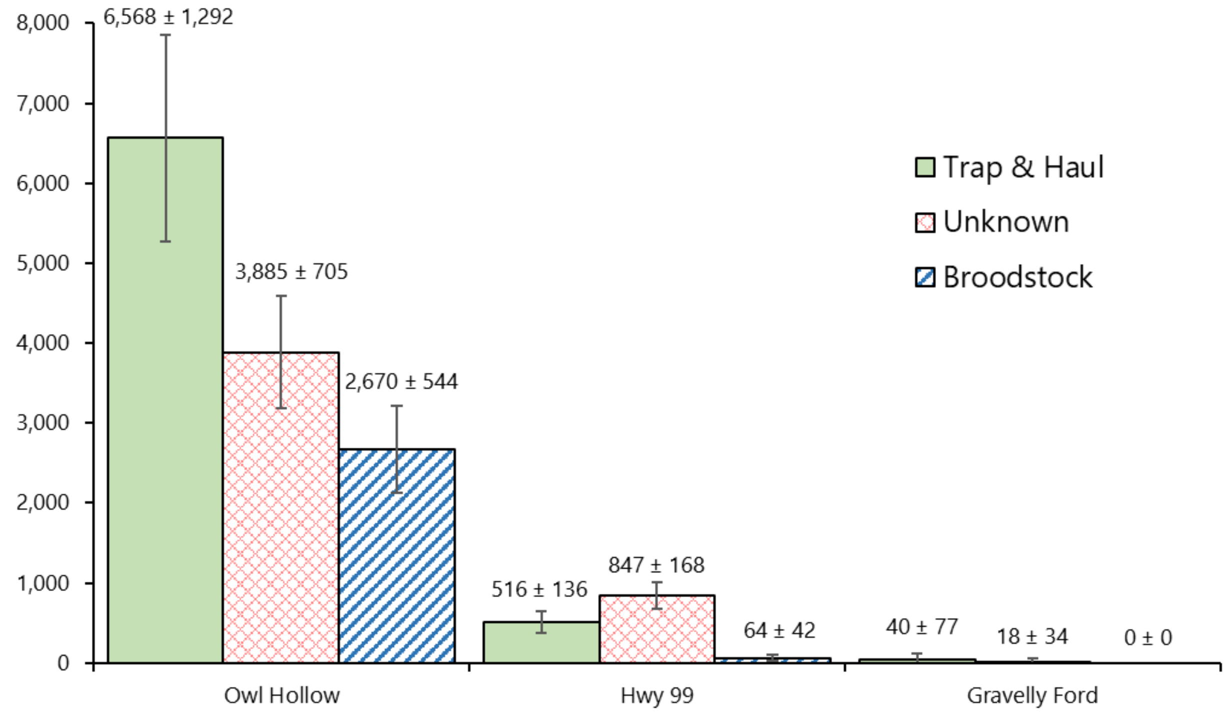

Figure 9.—Total spring-run Chinook Salmon (*Oncorhynchus tshawytscha*), by maternal origin, estimated at rotary screw trap locations in Reaches 1–2 of the San Joaquin River Restoration. Error bars represent the 95 percent confidence interval of the estimate.

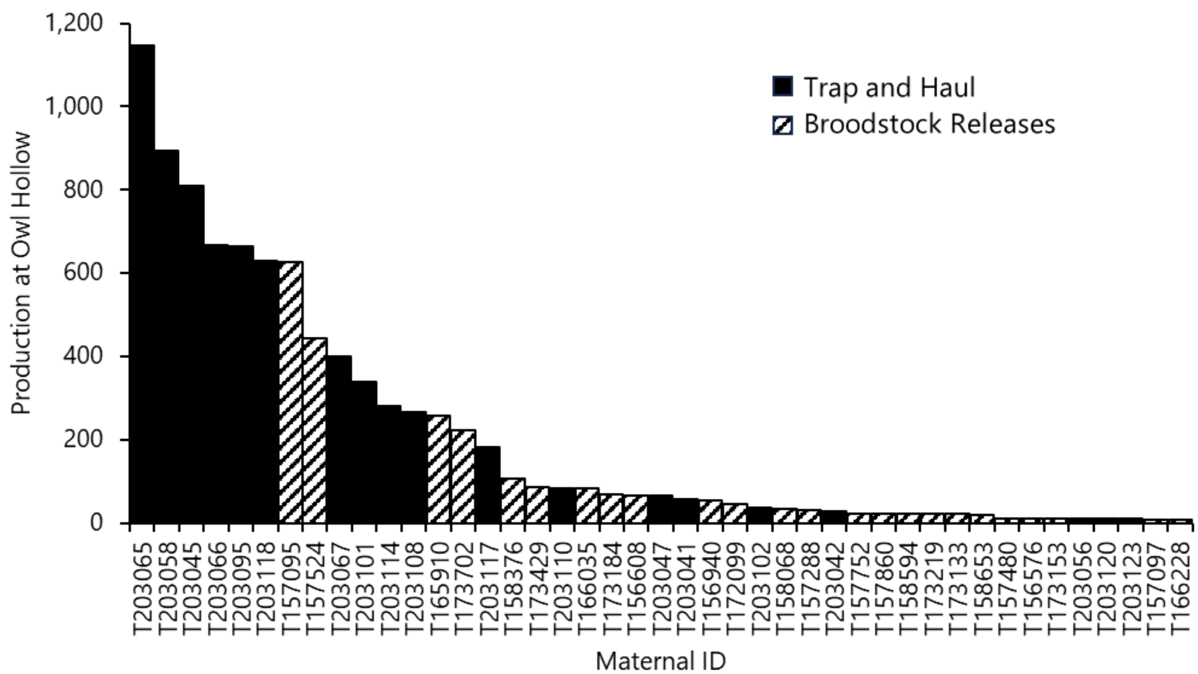

Figure 10.—Estimated family group size of Chinook Salmon (*Oncorhynchus tshawytscha*), as a function of maternal ID and origin (i.e., broodstock adults or trap and haul-captured salmon), passing the Owl Hollow rotary screw trap during the 2021–22 sampling season.

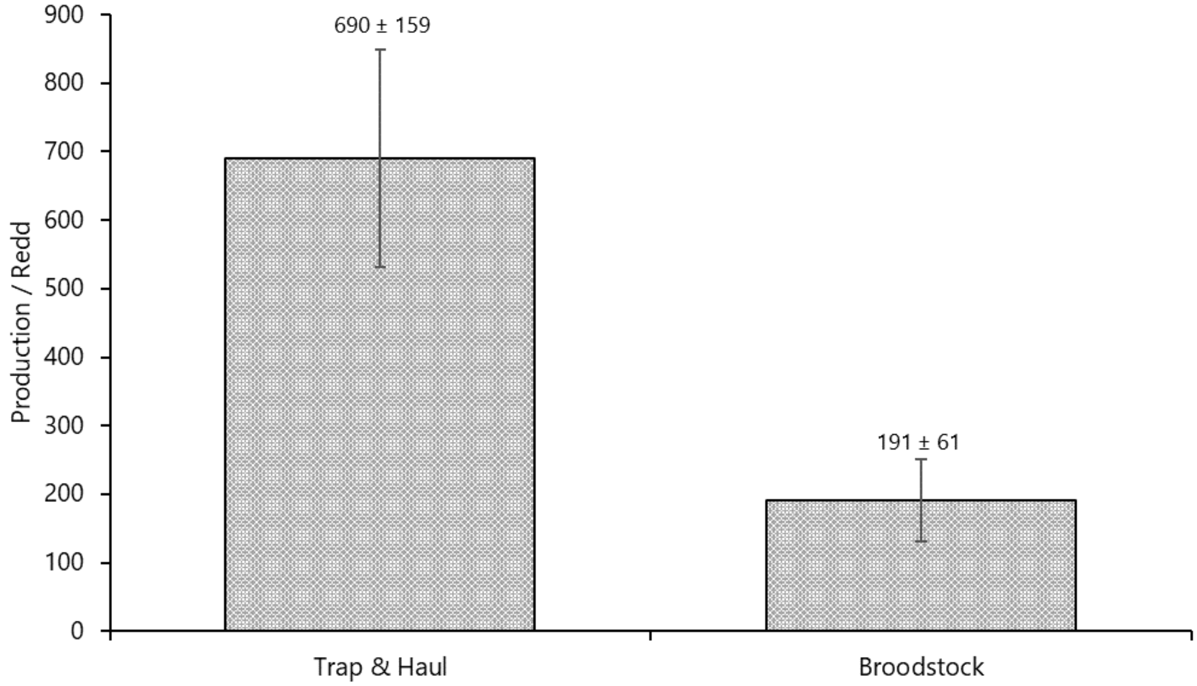

Figure 11.—Spring-run Chinook Salmon (*Oncorhynchus tshawytscha*) production per redd, incorporating survival estimates from spawning grounds near Friant Dam and wild salmon at the Owl Hollow rotary screw trap. Error bars represent the 95 percent confidence interval for the standard error of the mean.

3.3 Survival of Naturally Produced Salmon

Since nearly all surveyed redds were upstream of the Owl Hollow RST (31 of 32 surveyed redds, or about 97 percent; Demarest et al. 2023), survival to downstream RSTs was estimated by evaluating the difference in total salmon moving past each RST location (Figure 7). Since juvenile salmon at Scout Island were estimated to be fewer in number than Hwy 99, it was presumed the early trap removal at that location likely precluded accurate estimates of salmon moving beyond that location. Resultantly, survival estimates are indicated as a function of the sections between the Owl Hollow and Hwy 99 RSTs and the Hwy 99 and Gravelly Ford RSTs (Table 5). Survival of all spring-run Chinook Salmon from Owl Hollow to Hwy 99 was 10.9 percent, similar to the 2020–21 season (10.1 percent; Hutcherson et al. 2024). The most downstream trap during the previous sampling season was San Mateo, approximately 31 river miles from Hwy 99, while the Gravelly Ford location during the 2021–22 season was about half that distance. Though survival from Hwy 99 to the most downstream RST was estimated higher during the 2021–22 season, the total salmon physically captured in RSTs at these downstream locations across years was in the single digits. Furthermore, trap efficiency during the period when salmon were captured in the 2021–22 sampling season was low (Appendix D) and not considered reliable (n= 58±84; *see* Figure 8). Again, as with the previous sampling season, the proportion of trap and haul progeny successfully emigrating to downstream locations was markedly higher than broodstock progeny, when those fish could be accurately ascribed to maternal genotypes.

Table 5.—Survival estimates, using naturally produced Chinook Salmon (*Oncorhynchus tshawytscha*) between indicated rotary screw trap locations in Reaches 1–2 of the Restoration Area of the San Joaquin River. "OH" is Owl Hollow, "H99" is Highway 99, and "GF" is Gravelly Ford.

	Overall	Trap & Haul	Broodstock
OH–H99	10.9%	7.9%	2.4%
H99–GF	4.0%	7.8%	0.0%

3.4 Survival of Efficiency Release Groups

The use of Scout Island efficiency fish to adjust Hwy 99 trap efficiencies (*see* Rotary Screw Trap Efficiency and Production) precluded estimating survival of efficiency release groups from Scout Island to Hwy 99. Instead, survival was evaluated as a function of the river section between Owl Hollow and Hwy 99 as well as Hwy 99 to Gravelly Ford. Evaluating survival for paired releases of efficiency fish revealed mean survival from Owl Hollow to Hwy 99 was 47.5 percent (SD = 30.6 percent) and from Hwy 99 to Gravelly Ford was 20.8 percent (SD = 12.8 percent); however, the difference in survival between paired releases was not statistically significant ($t(5) = 2.11$, $p = 0.09$).

Among the evaluated variables regarding survival from Owl Hollow to Hwy 99, flow and fish length were strongly correlated (Table 6); because flow had a weaker correlation to survival ($r(9) = 0.20$, $p = 0.56$), it was eliminated from consideration. Best subset regression indicated length and temperature, but not turbidity, were the variables to include in survival analyses ($r^2 = 0.99$, $C_p = 2.14$, $p_{\text{length}} < 0.01$, $p_{\text{temperature}} < 0.01$). Multiple linear regression was used to evaluate the variables in predicting survival; however, the ability of the model to predict survival was not significant ($r^2_{\text{adj.}} = 0.37$, $F(2,8) = 2.39$, $p = 0.15$). Neither length ($\beta = 0.01$, $p = 0.14$) nor temperature ($\beta = -0.02$, $p = 0.79$) were significant predictors of survival.

Table 6.—Results of Pearson Product Moment Correlation for variables considered in survival analyses from the Owl Hollow to Hwy 99 rotary screw traps.

	FL (mm)	Turbidity (NTU):	Temp. (°C)
Flow (CFS)	$r = 0.79$ $p < 0.01$ $n = 11$	$r = 0.29$ $p = 0.54$ $n = 7$	$r = -0.14$ $p = 0.69$ $n = 11$
FL (mm)		$r = -0.41$ $p = 0.37$ $n = 7$	$r = -0.56$ $p = 0.08$ $n = 11$
Turbidity (NTU):			$r = -0.10$ $p = 0.84$ $n = 7$

All variables considered for survival analyses with respect to the Hwy 99–Gravelly Ford section were considered significantly correlated to one another (Table 7). Turbidity had the strongest correlation with survival, though regression analysis indicated it was not a significant predictor of survival ($r^2 = -0.08$, $F(1,6) = 0.54$, $p = 0.49$).

Table 7.—Results of Pearson Product Moment Correlation for variables considered in survival analyses from the Hwy 99 to Gravelly Ford rotary screw traps.

	FL (mm)	Turbidity (NTU)	Temp. (°C)
Flow (CFS)	$r = 0.94$ $p < 0.01$ $n = 8$	$r = -0.76$ $p = 0.03$ $n = 8$	$r = 0.91$ $p < 0.01$ $n = 8$
FL (mm)		$r = -0.88$ $p < 0.01$ $n = 8$	$r = 0.95$ $p < 0.01$ $n = 8$
Turbidity (NTU):			$r = -0.81$ $p = 0.01$ $n = 8$

3.5 Emigration Timing

Initial salmon detection at the Owl Hollow RST started mid-November (November 11), reaching its peak early December, and tapering down early to mid-January (Figure 6). Some single digit numbers of salmon were still being captured mid-February, but daily catch rates were more consistently zero when trap operation ceased March 2022. Initial salmon capture at the Scout Island RST was December 2 and intermittent captures occurred until trap cessation in March. A single salmon was captured at Hwy 99 mid-December, but subsequent captures were not encountered until January 7, 2022. Thereafter, catch rates increased and remained relatively steady the remainder of the sampling season, gradually tapering off until the final salmon capture at that location on May 23 (Figure 12). Most individuals (98.2 percent) emigrating beyond Highway 99, which construes the downstream extent of the spawning grounds as these salmon move into downstream reaches of the RA, were smolts (1.1 percent fry and 0.7 percent parr). Only two spring-run Chinook Salmon were captured in the Gravelly Ford RST—one late March and one early April. The limited captures at this location make it difficult to discern any patterns related to timing.

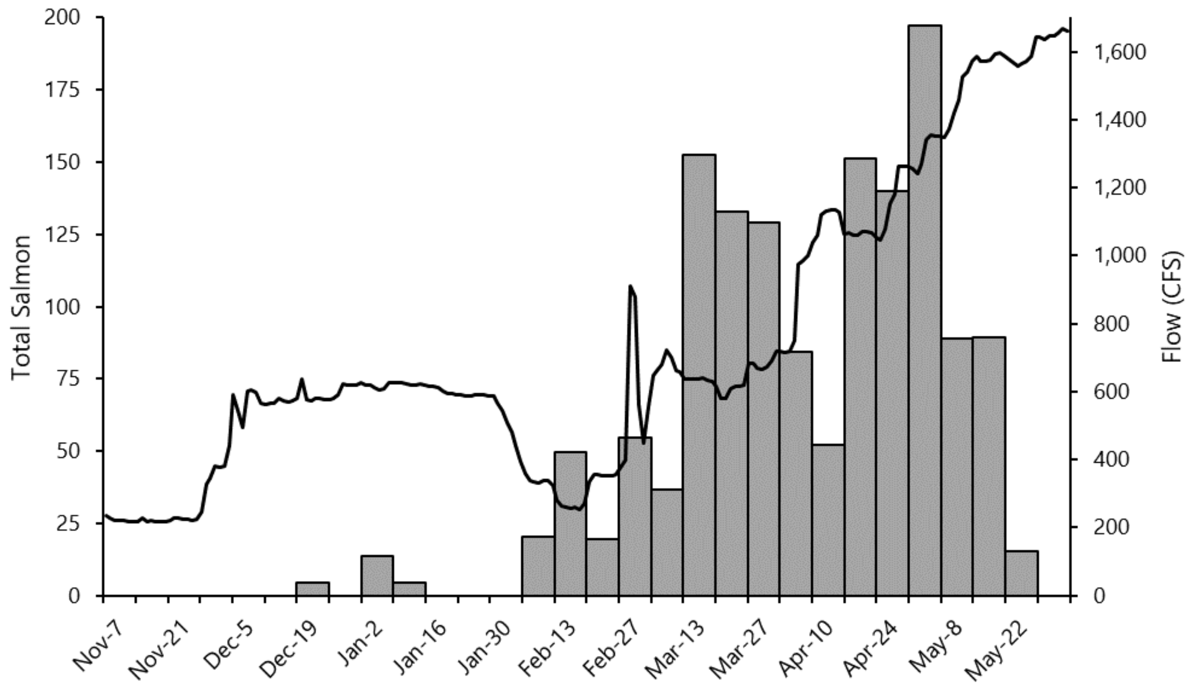

Figure 12.—Downstream movement of spring-run Chinook Salmon (Oncorhynchus tshawytscha) at the Highway 99 rotary screw trap during the 2021–22 sampling season. Histogram bars indicate total salmon estimated each week (left vertical axis), and the solid line indicates the flow (CFS, measured at Highway 41; right vertical axis) during the concurrent period.

3.6 Growth Rate

A total of 10 recaptured salmon, affirmed via genetic analyses, were included for estimating daily growth. These fish were subsequently captured between 37 and 132 days after the initial capture event. Of these 10 salmon, the initial capture event for 6 salmon was before the fish were greater than 45 mm TL; therefore, the initial weight was estimated based on length-weight regressions from spring-run salmon captured this season. The average daily growth rate was 0.15 ± 0.11 g/d (mean ± 1.96*standard error). Of these 10 fish comprising the recaptures, though, none were exclusively captured during the spring months, precluding an estimation comprising solely spring growth.

Using a combination of length-at-date data (Figure 4), and the linear relationship of log-transformed length-weight data (Figure 13), the relationship between weight through the sampling season was developed (Figure 14). Since the relationship of growth through the sampling season is curvilinear, daily growth through this period was approximated by flattening the portion of the curvilinear regression from the start of spring (March 19, 2022) onwards (Figure 15). The slope of this line indicates the approximate daily growth (0.29 g/d).

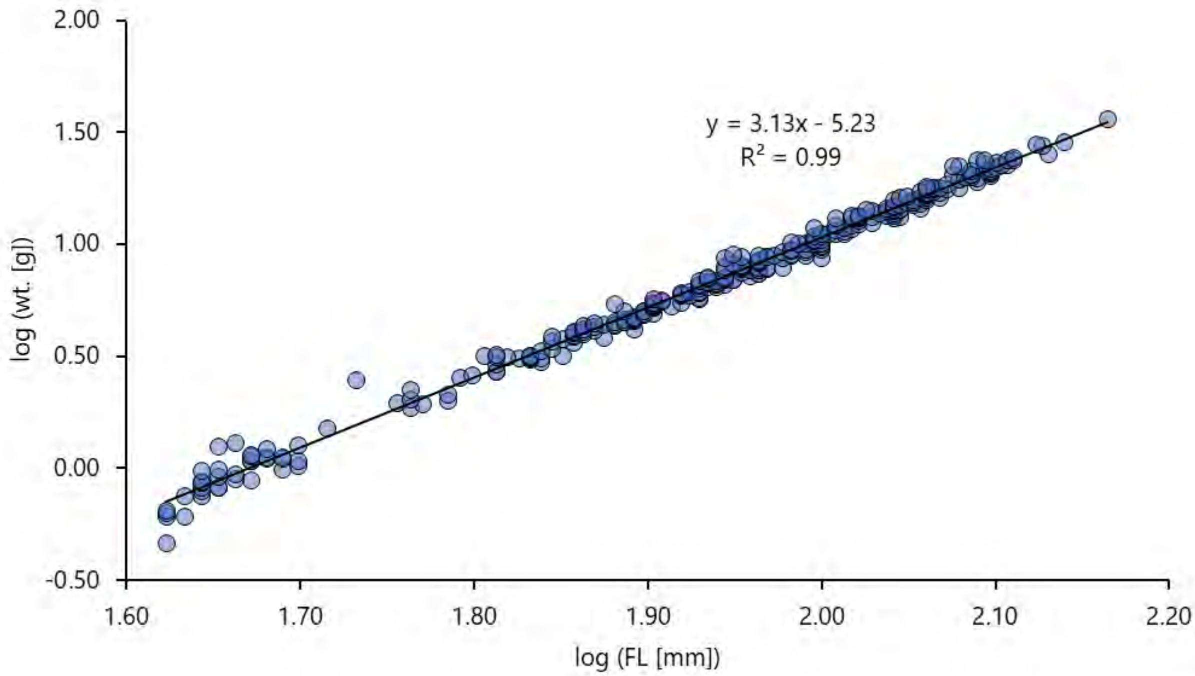

Figure 13.—Log-transformed length-weight regression for spring-run Chinook Salmon (*Oncorhynchus tshawytscha*) captured during the 2021–22 sampling season.

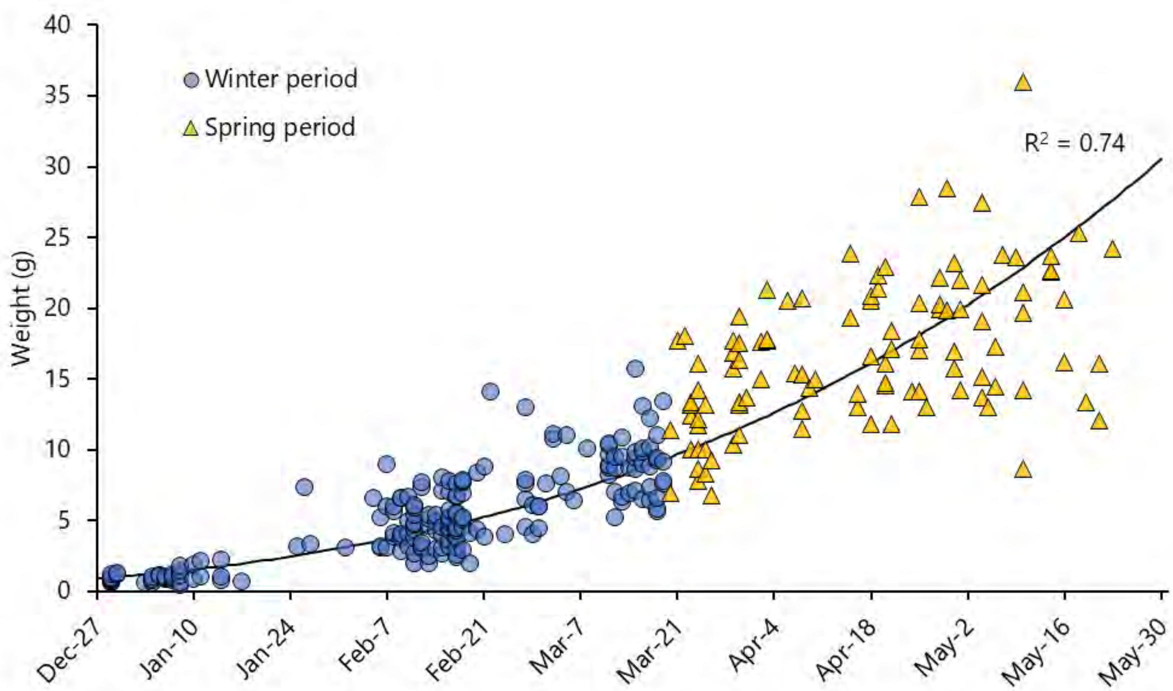

Figure 14.—Curvilinear regression (solid line) indicating the relationship between growth and capture date of spring-run Chinook Salmon (*Oncorhynchus tshawytscha*) during the 2021–22 sampling season. The blue circles indicate the fall-winter interval, and the yellow triangles indicate the spring period.

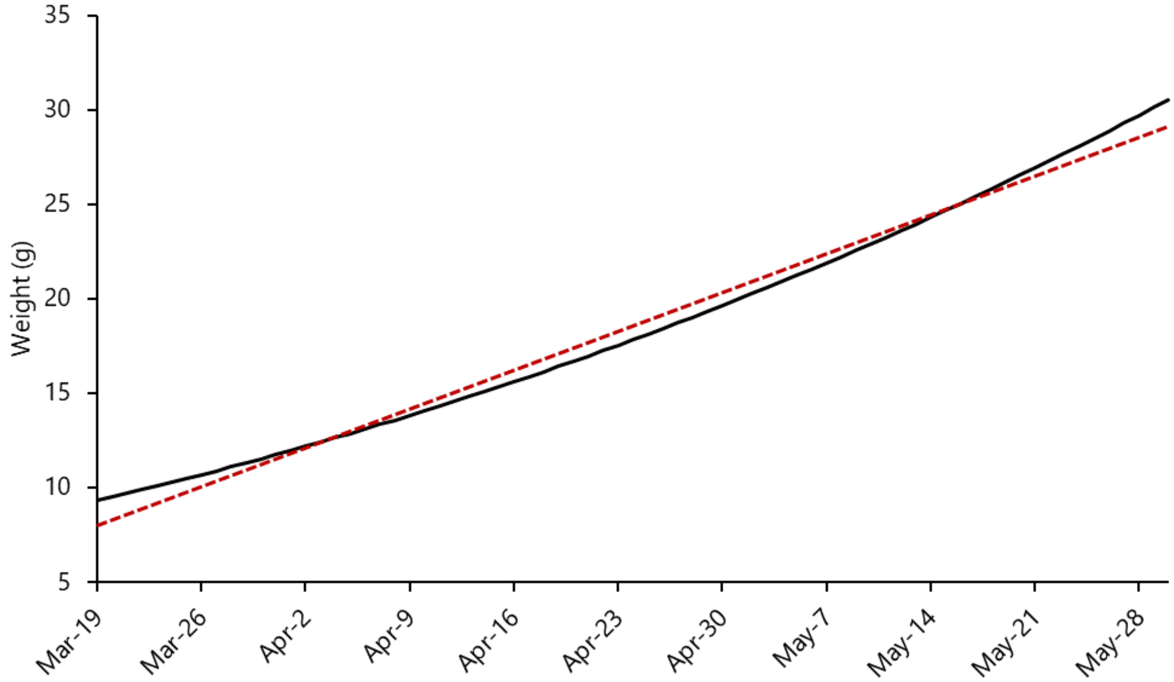

Figure 15.—Weight-at-date curve (solid line) and approximate linear growth (dashed line) during the spring 2022 Chinook Salmon (*Oncorhynchus tshawytscha*) capture period (March 19–May 30). The slope of the dashed line indicates the approximate daily growth of the spring-run cohort (0.29 g/d) in this interval.

4.0 Discussion

Production at Owl Hollow during the 2021–22 sampling season comprised an estimated 13,133 spring-run Chinook Salmon. During redd surveys preceding the RST monitoring efforts, crews identified 31 redds upstream of the Owl Hollow location (Demarest et al. 2023). In 2020–21, the total number of surveyed redds upstream of Owl Hollow was 71 (Demarest et al. 2022); however, only 7,713 salmon were estimated to comprise production that season (Hutcherson et al. 2024). And in the 2019–20 monitoring season, when flood conditions permitted naturally returning fish to reach spawning grounds, along with broodstock and trap and haul adult salmon, an estimated 290–360 adults contributed to the production of 83,603 fish (Garza and Clemento 2022; Hutcherson et al. 2023). Estimated survival from Owl Hollow to Hwy 99 was similar when comparing both the most recent seasons (10.1 percent during 2020–21 and 10.9 percent during 2021–22), but only about 3 percent in 2019–20. These data indicate that total production per contributing adult female were greater in 2019–20 and 2021–22 (approximately 250–425 juveniles at Owl Hollow per female genotype) compared to 2020–21 (approximately 100 juveniles per contributing redd); however, downstream survival was much lower during the 2019–20 season when compared to the latter two.

Flows were generally higher in the 2021–22 sampling season when compared to the 2020–21 and 2019–20 sampling periods (Figure 7). While it has been suggested that differences in flows could encourage fish to move downstream in a greater magnitude (Giannico and Healey 1998), the similar rates of survival, comparing 2021–22 to 2020–21, and low survival rates in 2019–20 seem to indicate other variables are likely having a greater influence on downstream survival. Factors contributing to downstream survival were difficult to predict from the evaluated variables; however, shifts in predator interactions (Perry et al. 2010) or changing factors throughout the season may be more likely (Zabel and Achord 2004). As with previous seasons, efficiency fish tended to move downstream quickly and were most often captured at downstream RST locations within the first week of release (typically over 90 percent, on average, within 3 days of release). Survival of efficiency salmon between traps was higher than naturally produced salmon—approximately 48 and 21 percent, from Owl Hollow–Hwy 99 and Hwy 99–Gravelly Ford, respectively, as compared to approximately 11 percent between both respective stretches for naturally produced salmon. This would seem to indicate that survival may be a factor of residence time in the system, and perhaps the rearing period for naturally produced salmon corresponds to lower rates of survival. It will likely be necessary to incorporate additional evaluations in future efforts to better understand environmental variables and interactions affecting downstream survival.

Unremarkable from any of the previous monitoring efforts (Hutcherson et al. 2020; 2021; 2023; 2024), most of the salmon were captured as fry during November–December. A period with correspondingly low rates of capture proceeded, and smolts were captured thereafter mostly at downstream RST locations. Few parr were captured, relative to the total proportion of other life stages encountered, suggest that salmon initially move downstream of spawning grounds shortly after emergence but tend to hold/rear upstream of Scout Island. This was the first sampling season where the downstream most RST was located at Gravelly Ford—the transition from Reach 1 to 2. Moving the RST to this location was a result of low survival to the previous downstream location, San Mateo, and an attempt to better understand if salmon loss was occurring between Hwy 99 and Gravelly Ford, or further downstream to the San Mateo location. While survival estimates suggested more salmon reached this location, it is noteworthy to point out that the estimate is represented by two individuals during a period of relatively low trap efficiency; hence the large confidence interval (58 ± 84 fish; 95 percent CI). Additional sampling years will be necessary to identify if survival from Hwy 99 to Gravelly Ford is more problematic between there and Hwy 99 or further downstream. The Fisheries Framework ([SJRRP] 2018) objective pertaining to fry-to-smolt targets five percent survival to the confluence of the RA and Merced River. Current monitoring only permits estimates to the downstream-most RST. Estimated survival from the Owl Hollow RST to Hwy 99 is 10.9 percent (Table 5). Combined with an estimated survival from Hwy 99 to Gravelly Ford (11.2 percent), the survival estimate from Owl Hollow to Gravelly Ford was only 1.2 percent. Additional study years, and evaluation beyond the current juvenile monitoring sites will be needed to determine survival to the confluence of the Merced River.

Nonetheless, improving juvenile survival through upstream reaches will likely be necessary to reach the objectives of the Fisheries Framework. Large numbers of non-native centrarchids (bass/sunfish) are captured during RST monitoring efforts (Appendix A: Bycatch). Piscivores present in these areas could certainly impact juvenile salmon survival (Reynolds et al. 1993; Kondolf et al. 1996). Additionally, abandoned in-river mine pits exist in sections of the river in these areas where juvenile salmon are present. These create areas where migrational cues may be muted and could potentially provide a sink for predators that may affect salmon survival and migration ([EA Engineering] 1992; Olsson et al. 2001). Many of the action items in the Fisheries Framework ([SJRRP] 2010), such as isolating high priority mine pits, restoring floodplain habitat, or creating off-channel rearing areas could benefit juvenile salmonid survival through Reach 1 and 2 by reducing straying and predation, and improve streamflows through these areas.

Flows were primarily increasing during the 2021–22 sampling season. Additionally, a large flow pulse occurred through the overnight hours of February 24 into the early hours on February 25, peaking over 1,700 CFS. During these periods, the upstream RSTs were placed in the non-fishing position for safety purposes. Periphyton present in upstream areas of Reach 1 were a persistent issue the remaining of the season. The periphyton clogged the mesh screen of the cones, precluding operation—the traps would stop rotating when this happened and few if any fish were captured. This resulted in the removal of the Owl Hollow and Scout Island RST traps from operation late March; however, much of the data collected during the March fishing period at Owl Hollow was unsuitable for use because of the limited number of days that were unaffected by these conditions. Since Owl Hollow peak catch occurred prior to this period, and Hwy 99 estimates peaked late-March, moving into April, it was presumed that the total salmon moving past Scout Island was not accurately represented in the limited dataset.

Concerns of periphyton persisted in the subsequent sampling years following the study period described in this report. To mitigate this concern, a flushing pulse took place during the summer period of 2024, to reduce periphyton buildup through the rest of the sampling season. While debris levels were not monitored quantitatively, periphyton levels appeared manageable during the late fall and winter periods, still permitting trap operation while concurrently capturing juvenile salmon; however, during spring 2025, periphyton loading in the Owl Hollow RST again became unmanageable, even with twice daily trap cleanings. The result was the cessation of RST operation at Owl Hollow prior to the end of the monitoring season. At the Scout Island RST, periphyton levels were noticeable during the later spring periods as well. Without an understanding of the origin of this periphyton, and ability to manage trap clogging, RST use may be limited at these upstream locations during future monitoring efforts. Truncation of the monitoring periods at these upstream RSTs could preclude the ability to identify late-moving salmon from the spawning areas in Reach 1.

Also, during the 2021–22 study period, water hyacinth upstream of the Hwy 99 RST covered a large section of the river, forming a dense mat (Figure 4). Periodically, sections of this mat would separate, floating downstream to the Hwy 99 location and prevent RST operation. Accurate estimates of salmon rely on consistent trap operation. And while there are methods to estimate catch across short periods of non-fishing, persistent periods of non-fishing and interrupted operation affect the precision of the estimates or preclude estimations entirely. It may be prudent during future RST monitoring to evaluate debris exclusion devices that would help limit downstream floating vegetation and other debris from stopping cone rotation. Additionally, it is suspected this dense area of aquatic vegetation, which was just downstream of the Hwy 99 efficiency fish release site, had an influence on the efficiency fish behavior. This was determined because the survival of efficiency release fish at the next upstream location (Scout Island) was overestimated based on initial RST efficiency estimates at Hwy 99. It is possible salmon released at the Hwy 99 release site may have distributed to the margins before continuing downstream, where the hyacinth had a bias on their distribution as compared to fish already emigrating in the thalweg. This illustrates the need to manage water operations, like pulsed flows to reduce periphyton (Flinders and Hart 2009) or spraying and removal of nuisance species like water hyacinth.

Very few wild salmon were recaptured in RSTs, limiting the ability to estimate growth with this method (Hutcherson et al. 2024). Furthermore, in many instances, the initial capture of these fish occurred while they were fry and prior to collecting weights (weights were collected only after salmon reached 45 mm TL). In such instances, weights had to be estimated via length-weight correlations. Inconsistenies in the metrics used to evaluate growth using recaptures and the scarcity of available data from recaptured salmon urge evaluation via other means. In conjunction with recaptures, growth was described this season using length-weight data, correlated with length-at-date (LAD) regressions to generate a weight-at-date curve (*see* Figure 5 and 14). By using this method, growth data may be evaluated using the entire cohort during the sampling period, and ideally better represent growth across the population. While growth as a function of weight is not linear, approximated growth during the spring period was 0.29 g/d, short of the criteria of 0.4 g/d established in the Fisheries Framework ([SJRRP] 2018). Growth will continue to be evaluated in future seasons; however, using recaptures to estimate this metric is unlikely to prove useful until sufficient numbers of fish are present on an annual basis; therefore, growth data will be evaluated in subsequent years using LAD and length-weight regressions during the monitored periods.

The ability to pair genetic data provided by the Southwest Fisheries Science Center (NOAA Fisheries) with fish catch in RSTs continues to provide invaluable information for understanding patterns of emigration, growth, production, and survival. Identifying the maternal genotypes contributing to progeny captured in RSTs permits an understanding of the minimum number of redds contributing to production—i.e., for each maternal genotype identified, we know at least that as many redds produced offspring. Since individual progeny in the Restoration Area can be ascribed to specific females (i.e., maternal genotype), determining the difference in production estimates of individual family groups (Figure 10) at specific RST locations may help understand survival and timing across RST locations. Annual salmon escapement can be quite variable (Van Hyning 1968) which can affect total production in any given system; however, measuring production per redd may provide a means to evaluate long-term restoration efforts towards improving the capacity of the Restoration Area of the San Joaquin River to support sustainable populations of Chinook Salmon.

This was the first season where biologists provided a colored fin mark to half-size CWT fish—previously, half-size CWT fish were only fin-clipped to permit identification at the target RST release location (Hutcherson et al. 2024). Tagging these smaller fish proved feasible and, thus, permitted identification of recaptured fish beyond the original release location. This helped to estimate survival of downstream-moving fry with using efficiency fish. In addition, using the survival estimate methods described herein for efficiency fish, the release of smaller tagged fish near spawning grounds closer to Friant Dam may help better understand survival upstream of the first RST (Owl Hollow).

Continued monitoring of spring-run Chinook Salmon will 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. Additionally, the continued collection of data through these early Restoration phases may help develop standards for future efforts. For example, coordinating length-at-capture data, which is often used to distinguish salmon runs in other California river systems (Johnson et al. 1992), across multiple sampling years and in conjunction with genetics may help distinguish unique cohorts of salmon present in the Restoration Area. This could help in future years when volitional passage is available for both spring- and fall-run salmon, when genetically testing all fish is not logistically or financially feasible.

Future restoration activities, including the construction of bypass structures at Sack Dam and Mendota Dam, 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. Resultantly, 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. This, in turn, provides the opportunity to collect data pertaining to objectives 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.

5.0 References

[CFS] Cramer Fish Sciences. 2014. *Rotary screw trapping operation protocol—a detailed protocol for rotary screw trapping field operations for the Stanislaus River.* Prepared for the U.S. Fish and Wildlife Service, 44 pp.

[EA Engineering] EA Engineering, Science, and Technology. 1992. "Fisheries studies report." *Report of the Turlock Irrigation District and Modesto Irrigation District pursuant to Article 39 of the license for Don Pedro project (Project No. 2299) before the US Federal Energy Regulatory Commission (Vol II).*

[SJRRP] San Joaquin River Restoration Program. 2010. "Fisheries Management Plan: A framework for adaptive management in the San Joaquin River Restoration Program." 164pp.

[SJRRP] San Joaquin River Restoration Program. 2018. "Fisheries framework: spring-run and fall-run Chinook Salmon, Version 5, Volume 1." 87pp.

[USFWS] U.S. Fish and Wildlife Service. 2008. *Draft rotary screw trap protocol for estimating production of juvenile Chinook salmon.* Comprehensive Assessment and Monitoring Program, Sacramento, California: Document prepared by the U.S. Fish and Wildlife Service, 44pp.

Achord, S., R.W. Zabel, and B.P. Sandford. 2007. "Migration timing, growth, and estimated parr-to-smolt survival rates of wild Snake River spring-summer Chinook Salmon from the Salmon River Basin, Idaho, to the Lower Snake River." *Transactions of the American Fisheries Society* 136: 142–154.

Anderson, R.O., and R.M. Neuman. 1996. "Length, weight, and associated structual indices." In *Fisheries Techniques, Second Edition*, edited by B.R. Murphy and D.W. Willis, 447–482. Bethesda, MD: American Fisheries Society.

Baetscher, D.S, A.J. Clemento, T.J. Ng, E.C. Anderson, and J.C. Garza. 2018. "Microhaplotypes provide increased power from short-read DNA sequences for relationship inference." *Molecular Ecology Resources* 18: 296–305.

Baggerman, B. 1960. "Salinity preference, thyroid activity and the seaward migration of four species of Pacific salmon (Oncorhynchus)." *Journal of the Fisheries Research Board of Cananda* 17: 295–332.

Beckman, B.R., D.A. Larsen, B. Lee-Pawlak, and W.W. Dickhoff. 1998. "Relation of fish size and growth rate to migration of spring Chinook Salmon smolts." *North American Journal of Fisheries Management* 18: 537–546.

Bjorkstedt, E.P. 2005. *DARR 2.0: Updated software for estimating abundance from stratified mark-recapture data.* NOAA Technical Memorandum NMFS NOAA-TM-NMFS-SWFSC-368, U.S. Department of Commerce, National Oceanic and Atmospheric Administration, National Marine Fisheries Service.

Bourret, S.L., C.C. Caudill, and M.L. Keefer. 2016. "Diversity of juvenile Chinook salmon life history pathways." *Reviews in Fish Biology and Fisheries* 375–403.

Carlson, S.R., L.G. Coggins, and C.O. Swanton. 1998. "A simple stratified design for mark-recapture estimation of salmon smolt abundance." *Alaska Fishery Research Bulletin* 5: 88–102.

Castle, C., N. Cullen, J. Goodell, Z. Jackson, A. Shriver, M. Workman, and J. Kirsch. 2016. *Fall-run Chinook Salmon spawning assessment during 2013 and 2014 within the San Joaquin River, California.* San Joaquin River Restoration Program Annual Technical Report, Lodi, California: US Fish and Wildlife Service, 27 pp.

Chapman, E.D., A.R. Hearn, C.J. Michel, A.J. Ammann, S.T. Lindley, M.J. Thomas, P.T. Sandstrom, et al. 2013. "Diel movements of out-migrating Chinook salmon (Oncorhynchus tshawytscha) and steelhead trout (Oncorhynchus mykiss) smolts in the Sacramento/San Joaquin watershed." *Environmental Biology of Fishes* 96:273–286.

Clemento, A.C., E.D. Crandall, J.C. Garza, and E.C. Anderson. 2014. "Evaluation of a single nucleotide polymorphism baseline for genetic stock identification of Chinook Salmon (Oncorhynchus tshawytscha) in the California Current large marine ecosystem." *Fishery Bulletein* 112: 112–130.

Crane, D.P, D.H. Ogle, and D.E. Shoup. 2019. "Use and misuse of a common growth metic: guidance for appropriately calculating and reporting specific growth rate." *Reviews in Aquaculture* 1–6.

Demarest, A, L. Yamane, A. Raisch, N. Fischer, H. Swinney, E. Strange, and A. Shriver. 2023. *Assessment of spring-run Chinook Salmon spawning during 2021 within the San Joaquin River, California.* U.S. Fish and Wildlife Service, Lodi, California: San Joaquin River Restoration Program Annual Technical Report.

Demarest, A., A. Raisch, L. Yamane, E. Strange, and A. Shriver. 2022. *Assessment of spring-run Chinook Salmon spawning during 2020 within the San Joaquin River, California.* San Joaquin River Restoration Program Annual Technical Report, U.S. Fish and Wildlife Service, Lodi, California.

Demarest, A., A. Raisch, L. Yamane, L. Smith, and A. Shriver. 2021. *Assessment of spring-run Chinook Salmon spawning during 2019 within the San Joaquin River, California.* U.S. Fish and Wildlife Service, 85 pp.

Dickhoff, W.W., B.R. Beckman, D.A. Larsen, C. Duan, and S. Moriyama. 1997. "The role of growth in endocrine regulation of salmon smoltification." *Fish Physiology and Biochemistry* 17: 231–236.

Durkacz, S., L. Smith, L. Yamane, A. Demarest, and A. Raisch. 2019. *Spring-run Chinook Salmon spawning assessment within the San Joaquin River, California.* San Joaquin River Restoration Program Annual Technical Report, U.S. Fish and Wildlife Service, Lodi, California.

Ewing, R.D., C.E. Hart, C.A. Fustish, and G. Concannon. 1984. "Effects of size and time of release on seaward migration of spring Chinook salmon, Oncorhynchus tshawytscha." *Fishery Bulletin* 82: 157–164.

Flinders, C.A., and D.D. Hart. 2009. "Effects of pulses flows on nuisance periphyton growth in rivers: a mesocosm study." *River and Research Applications* 25:1320–1330.

Furney, N.B., S.G. Hinch, A.L. Bass, C.T. Middleton, V. Minke-Martin, and A.G. Lotto. 2016. "Predator swamping reduces predation risk during nocturnal migration of juvenile salmon in a high-mortality landscape." *Journal of Animal Ecology* 85: 948–959.

Garza, J.C., and A. Clemento. 2022. *Annual report—year 2020 activities; San Joaquin River Restoration Program (SJRRP); genetic analysis for spring-run San Joaquin River Chinook Salmon.* NOAA Fisheries and the University of California Santa Cruz Institute of Marine Sciences, 10pp.

Garza, J.C., and A. Clemento. 2023. *Genetic analysis for spring-run San Joaquin River Chinook Salmon.* Annual report—year 2021 activities, NOAA Southwest Fisheries Science Center and the University of California Santa Cruz, Institute of Marine Sciences, 7 pp.

Giannico, G.R., and M.C. Healey. 1998. "Effects of flow and food on winter movements of juvenile Coho Salmon." *Transactions of the American Fisheries Society* 127:645–651.

Giorgi, A.E., T.W. Hillman, J.R. Stevenson, S.G. Hays, and C.M. Peven. 1997. "Factors that influence the downstream migration rates of juvenile salmon and steelhead through the hydroelectric system in the mid-Columbia River Basin." *North American Journal of Fisheries Management* 17:268–282.

Hopkins, K.D. 1992. "Reporting fish growth: a review of the basics." *Journal of the World Aquaculture Society* 173–179.

Hueth, C., D. Portz, Z. Sutphin, and J. Hutcherson. 2017. *San Joaquin River Chinook salmon (Onchorhynchus tshawytscha) smolt PIT tag monitoring program, 2012–14.* U.S. Department of the Interior, Bureau of Reclamation, Denver, Colorado.

Hutcherson, J, Z. Sutphin, J. Giannetta, J.C. Garza, and A. Clemento. 2024. *Juvenile spring-run Chinook Salmon production, survival, and emigration in the San Joaquin River Restoration Area: 2020–21 Monitoring and Analysis Report.* San Joaquin River Restoration Program Annual Technical Report, Denver, Colorado: Bureau of Reclamation, Technical Service Center, 50pp.

Hutcherson, J., Z. Sutphin, J. Giannetta, M. Grill, J.C. Garza, and A. Clemento. 2023. *Juvenile spring-run Chinook Salmon production, survival, and emigration in the San Joaquin River Restoration Area: 2019–20 monitoring and analysis report.* Bureau of Reclamation, Denver Technical Service Center, Denver, Colorado, 46 pp.

Hutcherson, J., Z. Sutphin, P. Ferguson, M. Grill, J.C. Garza, and A. Clemento. 2020. *Juvenile spring-run Chinook Salmon production and emigration in the San Joaquin River Restoration Area, 2017–18 monitoring and analysis.* U.S. Department of the Interior, Bureau of Reclamation, Denver, Colorado.

Hutcherson, J., Z. Sutphin, P. Ferguson, M. Grill, J.C. Garza, and A. Clemento. 2021. *Juvenile spring-run Chinook Salmon production and emigration in the San Joaquin River Restoration Area, 2018–19 monitoring and analysis.* U.S. Department of the Interior, Bureau of Reclamation, Denver, Colorado.

Johnson, R.R., F.W. Fisher, and D.D. Weigand. 1992. *Use of growth data to determine the spatial and temporal distribution of four runs of juvenile Chinook salmon in the Sacramento River, California.* U.S. Fish and Wildlife Service, Report AFF-FRO-92-15, Red Bluff, California.

Jones, O., and J. Want. 2010. "COLONY: a program for parentage and sibship inference from multilocus genotype data." *Molecular Ecology Resources* 10: 551–555.

Komourdjian, M.P., R.L. Saunders, and J.C. Fenwick. 1976. "Evidence for the role of growth hormone as a part of a 'light-pituitary axis' in growth and smoltification of Atlantic Salmon." *Canadian Journal of Zoology* 54: 544–551.

Kondolf, G.M., J.C. Vick, and T.M. Ramirez. 1996. "Salmon spawning habitat and rehabilitation on the Merced River, California: an evaluation of project planning and performance." *Transactions of the American Fisheries Society* 125:899–912.

Larsen, D.A., B.R. Beckman, K.A. Cooper, D. Barrett, M. Johnston, P. Swanson, and W.W. Dickhoff. 2004. "Assessment of high rates of preciocious male maturation in a spring Chinook Salmon supplementation hatchery program." *Transactions of the American Fisheries Society* 133: 98–120.

Melnychuk, M.C., D.W. Welch, and C.J. Walters. 2010. "Spatio-temporal migration patterns of Pacific salmon smolts in rivers and coastal marine waters." *PLoS ONE* 5(9): e12916. https://doi.org/10.1371/journal.pone.0012916.

Olsson, I.C., L.A. Greenberg, and A.G. Eklöv. 2001. "Effect of an artificial pond on migrating brown trout smolts." *North American Journal of Fisheries Management* 21:498–506.

Perry, R.W., J.R. Skalski, P.L. Brandes, P.T. Sandstrom, A.P. Klimley, A. Ammann, and B. MacFarlane. 2010. "Estimating survival and migration route probabilities of juvenile Chinook Salmon in the Sacramento-San Joaquin River Delta." *North American Journal of Fisheries Management* 30:142–156.

Pilger, T.J., M.L. Peterson, D. Lee, A. Fuller, and D. Demko. 2019. "Evaluation of long-term mark-recapture data for estimating abundance of juvenile fall-run Chinook Salmon on the Stanislaus River from 1996 to 2017." *San Francisco Estuary and Watershed Science* 17(1).

Pyper, B., and C. Justice. 2006. *Analyses of rotary screw trap sampling of migrating juvenile Chinook Salmon in the Stanislaus River, 1996–2005.* Cramer Fish Sciences, Gresham, Oregon, 140pp.

Reynolds, F.L., T.J. Mills, R. Benthin, and A. Low. 1993. *Restoring Central Valley streams: a plan for action.* Sacramento, California: California Department of Fish and Game, 217 pp.

Roper, B.B., and D.L. Scarnecchia. 1996. "A comparison of trap efficiencies for wild and hatchery age-0 Chinook Salmon." *North American Journal of Fisheries Management* 16: 214–217.

Roper, BB., and D.L. Scarnecchia. 1999. "Emigration of age-0 chinook salmon (Onchorhynchus tshawytscha) smolts from the upper South Umpqua River basin, Oregon, U.S.A." *Canadian Journal of Fisheries and Aquatic Sciences* 56: 936–946.

Scheuerell, M.D., R.W. Zabel, and B.P. Sandford. 2009. "Relating juvenile migration timing and survival to adulthood in two species of threatened Pacific salmon (Oncorhynchus spp.)." *Journal of Applied Ecology* 46: 983–990.

Solomon, D.J. 1978. "Migration of smolts of Atlantic salmon (Salmo salar L.) and sea trout (Salmo trutta L.) in a chalkstream." *Environmental Biology of Fishes* 2:223–229.

Sutphin, Z., and S. Root. 2021. *2020 Adult spring-run Chinook Salmon monitoring and trap and haul in the San Joaquin River Restoration Area.* San Joaquin River Restoration Program Annual Technical Report, ENV-2021-082, Bureau of Reclamation, Denver Technical Service Center, Colorado.

Sutphin, Z., and S. Root. 2022. *2021 Adult spring-run Chinook Salmon monitoring and trap and haul in the San Joaquin River Restoration Area.* San Joaquin River Restoration Program Annual Technical Report, Denver, Colorado: Bureau of Reclamation, Denver Technical Service Center.

Sutphin, Z., C. Hueth, J. Hutcherson, S. Root, and D. Portz. 2018. *Juvenile Chinook Salmon trap and haul program 2014–2016.* U.S. Department of the Interior, Bureau of Reclamation, Denver, Colorado.

Sutphin, Z.S., S. Durkacz, M. Grill, L. Smith, and P. Ferguson. 2019. *2019 adult spring-run Chinook Salmon monitoring, trap and haul, and rescue actions in the San Joaquin River Restoration Area*. San Joaquin River Restoration Program Annual Technical Report ENV-2019-088, Bureau of Reclamation, Denver Technical Service Center, Colorado.

Sykes, G.E., S.L. Johnson, B.A. Miller, T.E. Nickelson, and D.E. Seiler. 2009. "Temperature and flow effects on migration timing of Chinook Salmon smolts." *Transactions of the American Fisheries Society* 138:1252–1265.

Tattam, I.A., J.R. Ruzycki, P.B. Bayley, H.W. Li, and G.R. Giannico. 2013. "The influence of release strategy and migration history on capture rate of Oncorhynchus mykiss in a rotary screw trap." *North American Journal of Fishery Management* 32: 237–244.

Thedinga, J.F., M.L. Murphy, S.W. Johnson, J.M. Lorenz, and K.V. Koski. 1994. "Determination of salmonid smolt yield with rotary screw traps in the Situk River, Alaska, to predict effects of glacial flooding." *North American Journal of Fisheries Management* 14: 837–851.

Thompson, N.F., E.C. Anderson, A.J. Clemento, M.A. Campbell, D.E. Pearse, J.W. Hearsey, A.P. Kinziger, and J.C. Garza. 2020. "A complex phenotype in salmon controlled by a simple change in migratory timing." *Science* 370: 609–613.

Van Hyning, J.M. 1968. *Factors affecting the abundance of fall Chinook Salmon in the Columbia River*. PhD Thesis, Corvallis: Oregon State University.

Volhardt, G.C., S.L. Johnson, B.A. Miller, T.E. Nickelson, and D.E. Seller. 2007. "Rotary screw traps and inclined plane screen traps." In *Salmonid Field Protocols Handbook: Techniques for Assessing Status and Trends in Salmon and Trout Populations*, 235–266. Bethesda, Maryland: American Fisheries Society.

Volkhardt, G., P. Topping, L. Fleischer, T. Miller, S. Schonning, D. Rawding, and M. Groesbeck. 2005. *2004 juvenile salmonid production evaluation report: Green River, Wenatchee River, and Cedar Creek*. FPA 05-13, Washington Department of Fish and Wildlife, 107pp.

Wedemeyer, G.A., R.L. Saunders, and W.C. Clarke. 1980. "Environmental factors affecting smoltification and early marine survival of anadromous salmonids." *Marine Fisheries Review* 42: 1–14.

Zabel, R.W., and S. Achord. 2004. "Relating size of juveniles to survival within and among populations of Chinook Salmon." *Ecology* 85:795–806.

6.0 Appendix A: Bycatch

During the 2021–22 field season, 23,101 non-target fish, comprising 27 species were captured in the four rotary screw traps (Table A-1). Native fish comprised 42.2 percent of the bycatch during the 2021–22 sampling season, with Pacific Lamprey contributing most of those fish. Nonnative species comprised 57.8 percent of the bycatch. Centrarchids (Sunfish family) made up 90.6 percent of the nonnative bycatch captured during the concurrent period, with Black Crappie constituting most fish captured within Centrarchidae (59.2 percent).

Table A-1.—Total bycatch in all rotary screw traps during the 2021–22 sampling season. Asterisk denotes native species to the San Joaquin River; however, Rainbow Trout are likely hatchery-introduced fish.

Family:	Species:	Common Name:		Season Totals:
Petromyzontidae	*Lampetra hubbsi*	Kern Brook Lamprey	*	7
	Entosphenus tridentatus	Pacific Lamprey	*	5357
	Petromyzontidae spp.	Unidentified spp.	*	923
Clupeidae	*Dorosoma petenense*	Threadfin Shad		737
Cyprinidae	*Cyprinus carpio*	Common Carp		9
	Pimephales promelas	Fathead Minnow		52
	Notemigonus crysoleucas	Golden Shiner		54
	Carassius auratus	Goldfish		20
	Ptchocheilus grandis	Sacramento Pikeminnow	*	128
Catostomidae	*Catostomus occidentalis*	Sacramento Sucker	*	1882
Cobitidae	*Misgurnus angullicaudatus*	Weather Loach		5
Ictaluridae	*Ameiurus melas*	Black Bullhead		1
	Ameiurus natalis	Yellow Bullhead		94
	Ameiurus spp.	Bullhead spp.		54
	Ictalusus puntatus	Channel Catfish		24
	Ameiurus catus	White Catfish		25
Salmonidae	*Oncorhynchus mykiss*	Rainbow Trout		3
Poeciliidae	*Gambusia affinis*	Mosquitofish		180
Cottidae	*Cottus asper*	Prickly Sculpin	*	171
	Cottus spp.	Unidentified spp.	*	4
Gasterosteiade	*Gasterosteus aculeatus*	Threespine Stickleback	*	1284
Centrarchidae	*Micropterus salmoides*	Largemouth Bass		8
	Micropterus punctulatus	Spotted Bass		27
	Micropterus spp.	Black Bass spp.		141
	Pomoxis nigromaculatus	Black Crappie		7152
	Pomoxis annularis	White Crappie		1
	Lempomis macrochirus	Bluegill		1577
	Lepomis cyanellus	Green Sunfish		242
	Lepomis gibbosus	Pumpkinseed		1
	Leopomis microlophus	Redear Sunfish		2390
	Lepomis gulosus	Warmouth		28
	Leopmis spp.	Unidentified spp.		520

7.0 Appendix B: Fish Health Center Histopathology Results

Fish Health Assessment in the San Joaquin River Restoration Reach 2022

Sample Dates: March – May 2022

Principal Investigator(s):

Name	Contact Information
Ken Nichols	Ken_Nichols@fws.gov
Scott Foott	Scott_Foott@fws.gov

Objective:
Survey salmonid (juvenile Chinook) and non-salmonid fish from the San Joaquin River for fish pathogens.

Narrative Summary:

A total of 23 Chinook salmon smolts were collected, sacrificed, fixed in the field, shipped to the lab. All Chinook were processed for histology, and no culture for bacterial or viral pathogens was performed. Infections with *Ichthyobodo sp.* were observed in histology sections of gill. *Ichthyobodo* are ubiquitous flagellated protozoans that infect a broad range of fish species. These gill infections were light and not deemed a significant health problem. No signs if internal parasites common in the Sacramento/San Joaquin Basin (*Ceratonova shasta*, *Tetracapsuloides bryosalmonae* or *Parvicapsula minibicornis*) were observed in intestine and kidney sections.

A total of 163 non-salmonid fish (various centrarchid species listed below) were collected, sacrificed in the field and overnighted to the fish health center laboratory. Fish arrived at the lab cold and in good condition. Necropsy and tissue collection was performed by fish health center personnel the day of receipt. No viral pathogens were detected. Motile Aeromonad or Pseudomonad bacteria were cultured from 9-38% of given sample groups with no associated pathology. These bacteria are common in the aquatic environment and digestive tract of fish; they are not primary pathogens and likely not a significant health problem in these fish. Various nematodes without associated inflammation or other signs of disease were observed on gross examination of the viscera of these fish. Trematode metacercariae infections of the eye (presumptive *Diplostomum*) were observed in 4% (4/95) of fish examined. Low number of parasites were observed and the impact of these eye infections were not known.

Partner Contacts:

Name	Company/Agency
Zachary Sutphin	USBR
Heather Swinney	USFWS

U.S. Fish & Wildlife Service
California-Nevada Fish Health Center
National Wild Fish Health Survey Sampling Report

Results:

Location: San Joaquin River Restoration Area — Case(s): 22-016, 050, 066, 081
Species: Redear Sunfish — Total Fish: 76

Tissue	Assay	No. Samp	Total Fish	No. Pos	Pathogen*
Kidney	Bacteriology Culture	74	74	28	Aeromonas/Pseudomonas complex
Eye	Microscopic Exam	48	48	1	*Diplostomum sp.*
Viscera	Gross Exam	51	51	2	Unidentified Nematode
Kidney/Spleen	Virology Cell Culture	15	72	0	[no virus detected]

Location: San Joaquin River Restoration Area — Case: 22-017, 049, 065, 080
Species: Bluegill — Total Fish: 52

Tissue	Assay	No. Samp	Total Fish	No. Pos	Pathogen*
Kidney	Bacteriology Culture	50	50	12	Aeromonas/Pseudomonas complex
Eye	Microscopic Exam	33	33	2	*Diplostomum sp.*
Viscera	Gross Exam	29	29	2	Unidentified Nematode
Kidney/Spleen	Virology Cell Culture	17	52	0	[no virus detected]

Location: San Joaquin River Restoration Area — Case: 22-018
Species: Black Crappie — Total Fish: 24

Tissue	Assay	No. Samp	Total Fish	No. Pos	Pathogen*
Kidney	Bacteriology Culture	24	24	2	Aeromonas/Pseudomonas complex
Eye	Microscopic Exam	10	10	1	*Diplostomum sp.*
Viscera	Gross Exam	10	10	0	[no parasites observed]
Kidney	Virology Cell Culture	5	24	0	[no virus detected]

Location: San Joaquin River Restoration Area — Case: 22-064, 082
Species: Green Sunfish — Total Fish: 11

Tissue	Assay	No. Samp	Total Fish	No. Pos	Pathogen*
Kidney	Bacteriology Culture	11	11	1	Aeromonas/Pseudomonas complex
Eye	Microscopic Exam	4	4	0	[no parasites observed]
Viscera	Gross Observation	2	2	1	Unidentified Nematode
Kidney	Virus Cell Culture	3	11	0	[no virus detected]

Location: San Joaquin River Restoration Area — Case: 22-072, 079
Species: Chinook Salmon — Total Fish: 23

Tissue	Assay	No. Samp	Total Fish	No. Pos	Pathogen*
Kidney	Histology	22	22	0	[no parasites observed]
Intestine	Histology	23	23	0	[no parasites observed]
Gill	Histology	23	23	2	*Ichthyobodo sp.*

* Presumptive ID only – no confirmation DNA testing performed

8.0 Appendix C: Example of Calculating Survival for an Efficiency Release Group

The following is a hypothetical example of how a group of marked hatchery salmon, used to estimate RST efficiency, were used to estimate survival to downstream RST locations:

- For the sake of simplicity, let's say there were three monthly efficiency periods during a season—March, April, and May where efficiency was evaluated and only two RST locations were used—Scout Island and Hwy 99.
- At the beginning of each month, 600 efficiency fish were released at both RST locations.
  - The fish released just upstream of each RST provide trap efficiency estimates for that specific location and period (e.g., fish released just upstream of Hwy 99 in March are used to estimate trap efficiency at Hwy 99 for the period of March).
  - Some of the efficiency fish released at Scout Island will eventually swim downstream and encounter the Hwy 99 RST, but not all fish released at Scout Island in March will necessarily make it to the Hwy 99 RST in March. While the majority are likely to move downstream and encounter the Hwy 99 RST in March, some may encounter the Hwy 99 in April and some in May.
  - Keeping in mind that no RST is 100 percent efficient in capturing downstream moving fish, the total number of fish captured at the Hwy 99 RST from Scout Island would have to be extrapolated to provide an estimate of the actual number of downstream moving salmon that encounter or move past the Hwy 99 RST.
- Evaluating a single efficiency group released in March, traveling from Scout Island to Hwy 99.
  - A total of 50, 10, and 6 fish from Scout Island were captured at Hwy 99 in March, April, and May, respectively.
- The calculated efficiency for the Hwy 99 RST during March, April, and May, was 20, 10, and 15 percent, respectively.
- The survival of the efficiency group released in March at Scout Island would be the sum of the extrapolated totals of fish encountering the Hwy 99 RST during each efficiency period evaluated (March, April, and May):
  - 50 fish captured in March from March-released Scout Island group at Hwy 99 divided by 20 percent Hwy 99 RST efficiency during March (50/0.2 = 250 fish), plus
  - 10 fish captured in April from March-released Scout Island group captured at Hwy 99 RST divided by 10 percent Hwy 99 RST efficiency in April (10/0.1 = 100 fish), plus
  - 6 fish captured in May from March-released Scout Island group at Hwy 99 RST divided by 15 percent Hwy 99 RST efficiency in May (6/0.15 = 40 fish).
- So, the total fish estimated to have encountered or moved past the Hwy 99 RST from the March release group from Scout Island was 390 fish (250 fish in March +100 in April + 40 in May).

- In this example, the total fish from that release group (n = 390) divided by the initial group size (n = 600) gives an estimated survival of 65 percent for that specific group (390/600 = 0.65).

9.0 Appendix D: Rotary Screw Trap Release Groups and Efficiency Estimates

Table D-1.—Marked efficiency release data for individual release groups during the 2020–21 sampling season at the Owl Hollow and Scout Island rotary screw traps. Data includes release group (i), location, interval which the release was considered, group size (M_i), and total marked fish recaptured (m_i) within efficiency interval. No trap was installed at the Friant location; instead, these fish were to evaluate survival from spawning grounds to the first rotary screw trap.

Release Interval (i):	Location:	Start Interval:	Stop Interval:	Released (M_i):	Recaptured (m_i):	Efficiency (m_i+1)/(M_i+1):
1	Friant	11/1/21	12/14/21	599	–	–
2	Friant	12/15/21	1/5/22	595	–	–
3	Friant	1/6/22	1/20/22	602	–	–
4	Friant	1/21/22	5/28/22	600	–	–
1	Owl Hollow	11/1/21	12/13/21	600	64	10.8%
2	Owl Hollow	12/14/21	1/5/22	600	54	9.2%
3	Owl Hollow	1/6/22	1/20/22	600	50	8.5%
4	Owl Hollow	1/21/22	2/2/22	596	44	7.5%
5	Owl Hollow	2/3/22	2/23/22	600	86	14.5%
6	Owl Hollow	2/24/22	3/8/22	600	0	0.2%
7	Owl Hollow	3/9/22	3/16/22	600	0	0.2%
8	Owl Hollow	3/17/22	4/6/22	600	0	0.2%
9	Owl Hollow	4/7/22	4/13/22	499	0	0.2%
10	Owl Hollow	4/14/22	4/20/22	750	0	0.1%
11	Owl Hollow	4/21/22	4/27/22	750	0	0.1%
12	Owl Hollow	4/28/22	5/28/22	750	0	0.1%
1	Scout Island	11/1/21	12/14/21	173	31	18.4%
2	Scout Island	12/15/21	1/5/22	173	35	20.7%
3	Scout Island	1/6/22	1/20/22	183	20	11.4%
4	Scout Island	1/21/22	2/2/22	164	20	12.7%
5	Scout Island	2/3/22	2/23/22	599	84	14.2%
6	Scout Island	2/24/22	3/8/22	600	0	0.2%
7	Scout Island	3/9/22	3/16/22	600	73	12.3%
8	Scout Island	3/17/22	4/6/22	599	65	11.0%
9	Scout Island	4/7/22	4/13/22	500	0	0.2%
10	Scout Island	4/14/22	4/20/22	650	0	0.2%
11	Scout Island	4/21/22	4/27/22	648	0	0.2%
12	Scout Island	4/28/22	5/28/22	650	0	0.2%

Table D-1 (continued)— Marked efficiency release data for individual release groups during the 2020–21 sampling season at the Hwy 99 and San Mateo rotary screw traps. Data includes release group (i), location, interval which the release was considered, group size (M_i), and total marked fish recaptured (m_i) within efficiency interval.

Release Interval (i):	Release Location:	Start Interval:	Stop Interval:	# Released (M_i):	Recaptured (m_i):	Efficiency $(m_i+1)/(M_i+1)$
1	Hwy 99	11/1/21	2/23/22	600	132	22.1%
2	Hwy 99	2/24/22	3/9/22	503	82	16.4%
3	Hwy 99	3/10/22	3/17/22	600	117	19.6%
4	Hwy 99	3/18/22	4/6/22	599	78	13.2%
5	Hwy 99	4/7/22	4/13/22	500	74	15.0%
6	Hwy 99	4/14/22	4/27/22	648	72	11.2%
7	Hwy 99	4/28/22	5/19/22	749	75	10.1%
8	Hwy 99	5/20/22	5/31/22	772	50	6.6%
1	Gravelly Ford	11/1/21	2/24/22	194	12	6.7%
2	Gravelly Ford	2/25/22	3/9/22	200	9	5.0%
3	Gravelly Ford	3/10/22	3/17/22	240	25	10.8%
4	Gravelly Ford	3/18/22	4/6/22	229	12	5.7%
5	Gravelly Ford	4/7/22	4/13/22	400	9	2.5%
6	Gravelly Ford	4/14/22	4/21/22	400	6	1.7%
7	Gravelly Ford	4/22/22	4/27/22	399	12	3.3%
8	Gravelly Ford	4/28/22	5/31/22	400	5	1.5%