Report

2018 Spring-run Chinook Salmon Spawning Assessment within the San Joaquin River, California

Annual Technical Report

2018 Spring-run Chinook Salmon Spawning Assessment within the San Joaquin River, California

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Abbreviations and Acronyms

ATU	Accumulated thermal unit
CDEC	California Data Exchange Center
CDFW	California Department of Fish and Wildlife
CFS	Cubic feet per second
CWT	Coded-wire tag
DWR	California Department of Water Resources
FDX	Full-duplex
FL	Fork length
FMP	Fisheries Management Plan
GPS	Global positioning system
HDX	Half-duplex
HFB	Hills Ferry Barrier
NMFS	National Marine Fisheries Service
NRDC	Natural Resources Defense Council
PIT	Passive Integrated Transponder
rkm	River kilometer
SCARF	Salmon Conservation and Research Facility
SJRRA	San Joaquin River Restoration Area
SJRRP	San Joaquin River Restoration Program
SIG	Small Interdisciplinary Group
USBR	United States Bureau of Reclamation
USFWS	United States Fish and Wildlife Service

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Executive Summary

After the construction of Friant Dam in the 1940's and subsequent increase in water diversions for agricultural use, fall-run and spring-run Chinook salmon (*Oncorhynchus tshawytscha*) were extirpated from the San Joaquin River upstream of the confluence with the Merced River to Friant Dam (Restoration Area). Currently, the San Joaquin River Restoration Program (SJRRP) is working towards restoring the river and maintaining naturally-reproducing and self-sustaining populations of Chinook salmon. Although there is consensus among managers that river connectivity (i.e., flow) and fish passage are restoration priorities, there are additional criteria that need to be addressed for the successful reestablishment of Chinook salmon populations within the San Joaquin River. The current quantity and quality of suitable Chinook salmon spawning habitat in Reach 1 of the Restoration Area remains unclear. To address this concern, we report on spawning activity, habitat preferences, and egg-to-fry survival of adult spring-run Chinook salmon broodstock released into Reach 1 in 2018. Between June and August 2018, the SJRRP released 120 male and 59 female adult broodstock into Reach 1 of the Restoration Area to assess spawning activity. Redd and carcass surveys and emergence trap monitoring were conducted from August 27, 2018 through February 7, 2019 to evaluate spawning success of spring-run Chinook salmon. We identified a total of 42 redds from 59 adult females released in 2018, yielding a redd creation rate of 71%. Redd size and physical characteristics were consistent with natural spring-run Chinook Salmon redds reported in other studies, as were redd substrate composition assessments. We observed low temperatures (<17 °C) in Reach 1 during 2018 and accordingly saw redds more spatially distributed across the reach than during previousChinook Salmon survey years. Spawning activity was detected from September 19 through November 20. carcasses were recovered (12 female, 10 male, 1 unknown) during 2018 and 92% of female carcasses were fully spawned. This year represented the first year that emergence trap installation and monitoring were performed on spring-run Chinook Salmon redds in the San Joaquin River. We observed a total of 165 fry emerge from 10 traps installed within Reach 1, with most emergence coming from one trap. Due to low emergence numbers, we could not discern any clear patterns of emergence timing based off our data. Overall, we observed high levels spring-run Chinook salmon spawning activity in Reach 1 during 2018 but low observed emergence. As a result, we recommend that the SJRRP continue spring-run redd and carcass surveys and expand emergence studies to evaluate the restoration requirements needed for successful long-term establishment of spring-run Chinook salmon in the San Joaquin River. These surveys provide valuable information for future habitat improvement projects, reintroduction activities (i.e. SJRRP salmon population targets), and aid in the development of future management practices.

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Introduction

Historically, the main-stem San Joaquin River sustained the southernmost populations of spring-run, fall-run, and late fall-run Chinook Salmon (*Oncorhynchus tshawytscha*) in North America (Fry 1961; Fisher 1994; Yoshiyama et al. 2000). The San Joaquin salmon runs are defined by the timing of adults returning to freshwater to begin their spawning migration. Adult spring-run Chinook Salmon return in the spring and use headwaters for summer holding followed by late summer/early fall spawning. Adult fall-run and late fall-run Chinook Salmon return in the fall and use lower waters near the valley floor for late fall/early winter spawning (Fisher 1994; Myers et al. 1998). However, following the construction of Friant Dam in 1942, Chinook Salmon and other native fish habitat have become degraded, dewatered, and fragmented (Fry 1961; Warner 1991; Yoshiyama et al. 2001) due to increased groundwater pumping and water diversions. Along the San Joaquin River and its tributaries, mining for aggregate in the floodplains left large, deep pits that provide good habitat for bass and other predators of juvenile salmon (Williams 2006). The cumulative effects of these actions resulted in the elimination of Chinook Salmon runs within the San Joaquin River above the confluence of the Merced River by the 1950's (Fry 1961; Fisher 1994; Yoshiyama et al. 2001; Williams 2006). Chinook Salmon still occur in the major tributaries of the lower San Joaquin River such as the Stanislaus and Tuolumne Rivers (Yoshiyama et al. 2000).

In 2006, a Settlement (Natural Resources Defense Council [NRDC] vs. Rodgers et al. 2006) was reached between NRDC, Friant Water Users Authority, and the U.S. Departments of the Interior and Commerce to help build and enact restoration and water management goals on the San Joaquin River below Friant Dam to the confluence of the Merced River (SJRRP 2010). The fishery restoration goals are to restore and maintain natural fish populations in "good condition" in the San Joaquin River Restoration Area (SJRRA) including naturally reproducing salmon and other native fish species. The Settlement's water management goals were enacted to reduce and/or avoid adverse water supply impacts on the Friant Division long-term contractors that may result from the interim and restoration flows in the SJRRA due to the Settlement. As a result, the San Joaquin River Restoration Program (SJRRP) was created to work towards achieving these goals. The SJRRP is a collaborative effort between the U.S. Fish and Wildlife Service (USFWS), the U.S. Bureau of Reclamation (USBR), National Marine Fisheries Service (NMFS), the California Department of Fish and Wildlife (CDFW), and the California

Department of Water Resources (DWR).

Since its establishment, the SJRRP has accomplished many actions to establish the foundation for reintroduction of spring-run and fall-run Chinook Salmon to the SJRRA (SJRRP 2015). Currently, the SJRRP's restoration priorities are to manage river temperature with sufficient flows and restore volitional fish passage in the SJRRA by 2024 (SJRRP 2018). The SJRRP has also established several Chinook Salmon population targets as outlined in the Fisheries Management Plan (FMP) to guide restoration activities and achieve salmon population viability within the SJRRA (SJRRP 2010). The FMP sets the objective of an egg survival rate of at least 50% for spring-run Chinook Salmon to achieve some of the SJRRP's population targets. A critical component to achieving the outlined population objectives are assessments of the population viability in the Restoration Area. Population viability assessments require the collection of data related to the spawning success (i.e. recruitment to juvenile stage) of individuals within a population and understanding causes of the associated variation (Williams et al. 2002).

Toward this goal, the SJRRP has begun monitoring the reproduction of an experimental population of adult spring-run Chinook Salmon broodstock released into Reach 1A of the SJRRA and associated spawning habitat quality to determine the degree of habitat restoration needed. Since 2016, surplus production of adult Central Valley spring-run Chinook Salmon broodstock (broodstock) at the interim Salmon Conservation and Research Facility (SCARF) have facilitated the first opportunity to monitor the spawning activity of spring-run Chinook Salmon in Reach 1 of the SJRRA in over 50 years. In 2016 and 2017, excess broodstock were released into Reach 1A of the SJRRA and redd and carcass surveys were conducted to identify and categorize spawning habitat use and redd creation rates (McKenzie et al. 2017). Here we report on the results of our third year of spring-run Chinook Salmon spawning surveys in Reach 1 of the SJRRA using an experimental broodstock population.

Redd and Carcass Survey Objectives

The overall objective of this study was to describe spatial and temporal dynamics of naturally spawning broodstock within Reach 1 of the SJRRA in 2018. Specifically, we conducted weekly redd and carcass surveys to:

(1) Quantify the spawning activity and redd characteristics of adult spring-run Chinook Salmon
(2) Assess the spatial and temporal distribution of spawning locations and spawning habitat preferences of adult spring-run Chinook Salmon females

(3) Describe the spatial and temporal trends of spring-run Chinook Salmon carcasses and assess the carcass recovery rate

Emergence Trapping Study Objectives

Emergence traps have been successfully used to determine rates of egg-to-fry emergence survival in relation to environmental variables and to evaluate the ability of fry to escape the hyporheic environment and emerge successfully (Koski 1966; Beacham and Murray 1985). The goal of this study was to assess the survival from egg to emerging fry in naturally produced redds in relation to water quality, velocity and substrate. Emergence traps were used in this study to achieve the following objectives:

(4) Determine the number of emerged fry produced from capped redds

(5) Develop egg-to-fry survival rates from capped redds

(6) Establish emergence timing data and compare to known degree-day relationships for Chinook Salmon

(7) Relate fry production within observed redds to environmental variables hypothesized to affect the survival probability from egg to emerging fry

Methods

Study Area.— Our study was conducted on the upper San Joaquin River below Friant Dam in the SJRRA. The approximately 240 river kilometers (rkm) long Restoration Area is separated into 5 reaches beginning at Friant Dam and ending at the confluence of the Merced River (Figure 1). The San Joaquin River basin has a Mediterranean climate with wet-cool winters and dry-hot summers and is subjected to groundwater and riparian pumping to support agricultural land use (Galloway and Riley 1999; Null and Viers 2013; Traum et al. 2014). As a result, Reach 1 is dominated by effluent reaches and is largely managed during non-flooding conditions to meet the compliance flow target of 0.14 m^3/s at the downstream end (i.e., at Gravelly Ford) of the Reach. In Reach 1, continuous flows are conveyed through a moderately sloped incised gravel-bedded channel that is confined by periodic bluffs or terraces. The channel contains off-channel and in-channel mine pits from historic sand and gravel mining operations (SJRRP 2010). Currently, land uses in the lower reaches of the SJRRA are dominated by anthropogenic urban and agricultural developments (Traum et al. 2014). Historically, the San Joaquin River would flow from the high Sierra Nevada Mountains through San Francisco Bay-Delta and empty into the Pacific Ocean. However, due to long-term operations of dams, water bypasses, diversions, and groundwater pumping, the natural river is dry in areas and Chinook Salmon habitat has been significantly altered. Currently, a connected river is available via the Eastside bypass. Suitable spawning habitat for Chinook Salmon on the San Joaquin River is thought to be restricted to the first 5-7 miles of Reach 1 of the SJRRA. However, the sufficiency of existing habitat in Reach 1 for achieving the Program population objectives needs to be assessed during the reintroduction phase.

Study Specimens

In 2018, broodstock survival rates were greater than anticipated and exceeded the interim SCARF holding capacity, initiating the release of 179 (120 males and 59 females) excess fish. The first release in 2018 occurred in June at Owl Hollow and consisted of 59 males and 30 females. The second release in 2018 occurred in August at Ball Ranch Bridge and consisted of 61 males and 29 females (Table 1). Prior to the release, 27 males and all 59 females were acoustically tagged intra-gastrically with a 69 kHz Vemco V9 transmitter using a balling gun. Additionally, all fish were tagged sub-dermally on the adjacent margins of each side of the dorsal fin with color coded T-bar tags, which served as a visual indicator of sex, release date, and individual identification. T-bar tags for the June released males were green and female T-bar tags were purple. August released males were tagged with blue T-bar tags and females with orange. Full-duplex (FDX) passive integrated transponder (PIT) tags were implanted through the ventral musculature into peritoneal cavity of all broodstock for individual identification of carcasses. Female broodstock were implanted with an additional half-duplex (HDX) PIT tags through the ventral musculature of the pelvic girdle into the retroperitoneal body cavity. HDX tags were implanted with anticipation that they would be released by females during spawning and would allow us to link each female to her individual redd.

Redd and Carcass Surveys

Redd and carcass surveys were implemented for the 2018 field season from August 27 through November 20. Surveys were performed in daylight hours under ideal conditions (i.e. no heavy rain) between Friant Dam (rkm 430) and Sycamore Island (rkm 407.64) for weeks 1-3, and were then extended to the Millburn Ecological Unit (rkm 397.5) for the rest of the season. In order to effectively and efficiently survey the area, Reach 1 was stratified into three reaches: Friant Dam to Lost Lake, Lost Lake to the Fresno County Sportsmen's Club, and Sportsmen’s Club to the Millburn Ecological Unit (Figure 2). Our surveys were conducted weekly Tuesday through Thursday to allow for a consistent number of days between each survey period.

Surveys were implemented using a drift boat paired with two kayaks and a crew of four to six personnel from USFWS and CDFW. During each survey, the drift boat was navigated in the thalweg of the main river channel and the kayaks were paddled down side channels, river margins, and shallow areas not easily accessible by the drift boat. Kayakers paddled down the river ahead of the drift boat in order to inspect riffles before the drift boat approached. When kayakers reached a riffle, they pulled their kayaks off to the shore and walked down the riffle on foot in order to visually assess the presence of spawning activity, redds, or carcasses. This navigation method allowed complete coverage of all but the widest and deepest sections of river (i.e. in-channel mine pits). All areas were surveyed as thoroughly as possible where safety permitted.

A Vemco VR-100 acoustic receiver was used in conjunction with a hydrophone to detect the presence of any acoustically tagged Chinook Salmon in the survey area. The hydrophone was deployed off the side of the boat while in motion and removed from the water when going through shallow areas to prevent damage. When an acoustic tag was detected, the VR-100 would display the tag identification number, GPS location, detection signal strength, and detection time, all of which were recorded. These location data were used to monitor fish movements throughout the survey season and alert kayakers that a fish may be in the area and potentially on or constructing a redd. If a fish was detected and displayed spawning or redd building behavior, the fish would be observed at a distance to avoid disturbing it. After visual observation, a waypoint with approximate coordinates was recorded and the location revisited weekly until the fish was no longer present. At that time, the redd was identified and measured.

Redd Delineation

Redds were identified by the absence of periphyton on substrate, a defined depression (pit) within the substrate, and a mound (tailspill) of substrate present near the terminal end of the pit. We assigned redds a unique redd identification number, recorded the position, flagged the area, took velocity measurements, measured pit and tailspill dimensions (length, width, and depth) to the nearest 0.01 m, and assessed the substrate upstream of the redd upon first detection. Location data were recorded during surveys using an EOS Arrow 100 sub-meter GNSS unit paired with the ArcCollector mobile app to mark and relocate redds. Pit locations were marked using numbered cattle tags which were anchored to the riverbed adjacent to each redd. These were used to help maintain visual acuity while monitoring redds throughout the survey season. Velocity and depth measurements were made using an OTT MF Pro flowmeter with a top-set rod. A depth measurement was taken pre-redd in undisturbed substrate as close as possible to the incision of the pit. Depth measurements were taken in the lowest point of the pit and highest point of the tailspill (crest) (Figure 3). Test redds were defined as areas in the river cleared of periphyton which lacked a clearly defined pit and tailspill. Tests redds were defined separately from redds, given a unique identification number, and monitored in subsequent weeks to determine if they developed into a redd with clearly defined morphology. We also recorded the channel type (main channel or side channel), channel position (right, left, or center), habitat type (riffle, run, glide, pool, or backwater) where the redd was located.

To assess substrate upstream of redds, we visually gauged the percent of fine sediment (sand, <2.0mm) in the streambed area, a 0.5m x 1.0m patch immediately upstream of the redd pit depression. We determined the relative percentage of different particle sizes present in the streambed directly upstream of the redd. The field methods of Buffington and Montgomery (1999) were adapted to determine the textural facie classification within the pre-redd patch. Textural facies were classified according to the observed proportional occurrence of the three primary grain-size classes of texture (i.e. sand [≤ 2.0 mm], gravel [2 mm to 64 mm], and cobble [64 mm to 256 mm]) in ascending order from least to most abundant. For example, a patch that contained 10% sand, 30% gravel, and 60% cobble would be recorded as SGC. Grain size classes comprising ≤ 5% of the sample area were considered negligible and were omitted from the classification letter codes. Additionally, grain sizes were also omitted if their combined coverage was ≤ 10% of the sample area (i.e., the dominant grain-size class possessed ≥ 90% coverage).

The number of redds affected by superimposition was recorded during data collection. Superimposition was defined as the presence of overlap between two or more redds. Superimposition of redds can be influenced by the limited availability of spawning habitat and a greater abundance of spawning females (McNeil 1964; Weeber et al. 2010). The Fisheries Management Plan (SJRRP 2010) identified superimposition as a potential factor affecting production. If we observed superimposition occurring, we identified the preexisting redd that exhibited signs of superimposition and the superimposition type (deposition of the tailspill, scour of the pit, or deposition and scour of the previously existing redd area). Once a preexisting redd was determined to be superimposed, redd age was no longer recorded.

Carcass Survey

We assessed all broodstock carcasses for the absence of an adipose fin, presence of T-bar tags, acoustic tags, and FDX/HDX PIT tags. We described the surrounding habitat in which the carcass was located such as channel morphology, channel position, and habitat type and took a GPS point where the carcass was found. All carcasses collected were evaluated for decomposition status (fresh; firm decayed; soft decayed; skeleton), identified to sex, examined for spawn status, and fork length was measured to the nearest mm. Carcasses were given a unique ID number and photographed lying on their right side with an identification tag (Figure 4).

Decomposition status of carcasses was based on eye clarity, the presence of blood in the gills, and body firmness. Carcasses where considered “fresh” if they possessed one clear eye, pink coloration within the gills, or had firm bodies; otherwise carcasses were considered “firm decayed” (retention of skin), “soft decayed” (already showing signs decomposition) or “skeleton” (no skin). The sexes of individuals were determined by dissecting the abdominal cavity and looking for the presence of either testes or ovaries. Carcasses in the advanced stages of decomposition were given an “unknown” designation for sex. We classified the spawning condition of female carcasses based on presence or absence of eggs (spawned- few or no eggs present; partially spawned- some eggs present; or unspawned- many eggs present). We removed the heads of all carcasses and preserved them for later coded-wire tag extraction at the Lodi Fish and Wildlife Office.

Emergence Monitoring

Our emergence trap installation and monitoring study took place over a period of approximately 90 days from October 30, 2018 until February 7, 2019. Emergence traps were placed on redds to allow for an even distribution of traps installed through time (i.e., weeks) and space (i.e. riffle complexes in Reach 1). Redds selected for emergence traps had to be accessible on foot and at moderate depths and velocities to enable proper trap installation. Nine initial redds were chosen to be capped. The tenth trap was added after a late redd was found during redd and carcass surveys. Our trap installation, monitoring, and removal schedule was based on the calculation of accumulated thermal units (ATUs), or cumulative temperature over time, where 1 ATU = 1 °C for 1 day (Beacham and Murray 1990; Berejikian et al. 2011). We calculated ATUs by adding average daily water temperatures from the closest California Data Exchange Center (CDEC) station gauge(s) in Reach 1, which included Friant Dam (SJF; rkm 430), Highway 41 Bridge (H41; rkm 410.4), and/or Friant Water Quality (FWQ; rkm 430). We capped redds with traps around 600 ATUs and assumed that emergence would begin at 700 ATUs, based on previous fall-run Chinook Salmon surveys conducted by SJRRP in Reach 1 (Castle et al. 2016a; Castle et al. 2016b). This allowed hydrologic conditions inside the redd to acclimate to trap installation and collect any emerging fry resulting from installation disturbance.

Emergence traps consisted of two metal frames that were fastened together with hose clamps.

Frame dimensions were approximately 2.42m long by 1.83m wide at the widest point, with an approximate area of 2.83m^2. A net with small grommets sewn into the mesh was placed over the frame, aligned into pegs on the frame, and secured to the frame using washers and cotter pins. The nets consisted of a 0.32 cm nylon mesh and a canvas skirt. The traps were installed over the top of a redd and tailspill, oriented to fully cover the egg pocket, and anchored into the substrate with 12 rebar posts, each 0.95 cm thick and 76.2 cm long. The rebar posts were pounded through grommets in the canvas skirt and cinched onto the net using washers and hose clamps. The exposed skirt material was then buried in the surrounding gravel and large rocks were sourced from the surrounding riverbed to further anchor the skirt and deter fry escapement and entry of other species. Prior to installation, a plastic collection jar was attached to the funnel end of the trap to ensure that fry disturbed from the substrate during installation were captured. Once the trap was firmly installed, the collection jar was attached to the funnel end of the trap to capture fry that emerged and were carried downstream by the current. This cod end was made from a 3.79 L polyethylene bottle which was specially fabricated to vent water using 0.32 cm mesh on its sides (Figure 5).

Once traps were installed, they were monitored an average of three times a week throughout the study period. Traps were checked based on approximate peak emergence time from ATU calculations. We assumed that peak emergence time for spring-run would be analogous to fall-run and based on previous studies, we used 750-1000 ATU as the benchmark for peak emergence timing (Castle et al. 2016a; Castle et al. 2016b). When a redd was calculated to be in peak emergence, it was monitored more frequently based on the magnitude of emerging fry. Temperature, turbidity, dissolved oxygen, water depth, and velocity in front of each trap were collected during monitoring. Each trap was cleared of debris and scrubbed with a bristle brush to clear off algae and gently push down any fry into the collection jar. Once trap cleaning was complete, the cod end jar was opened and examined for any emergent fry and other species. If any fish were present, they were transferred into a bucket with water and brought to shore to be measured. Salmon and non-salmonid species were placed into separate buckets in order to allow salmon recovery time while other species were being worked up. Any non-salmonid species were identified, measured to fork length, and released downstream. Salmon fry were counted, measured to fork length, assigned a developmental stage, and caudal fin clips were taken from selected fry (up to 3 samples collected from each redd per week until a total of 15 samples were taken per redd) for genetic analysis. The assigned developmental stage corresponded to one of the following: Stage 1 (egg); Stage 2 (just hatched and translucent); Stage 3 (fish has normal coloration and large yolk sac); Stage 4 (fish beginning to absorb yolk); Stage 5 (fish has fully absorbed yolk and is "Seamed up"); Stage 6 (no visible seam). Following measurement, fry were placed back into the recovery bucket and released downstream.

Our initial benchmark to remove the traps (based on previous fall-run studies) ranged from January 10 to April 2 or when each redd reached approximately 1500 ATUs. Due to high seasonal precipitation, the USBR conducted a Flow Bench evaluation in February which resulted in an increase of flows from Friant Dam from approximately 300 cubic feet per second (CFS) to 800 CFS. The increase in flows resulted in unsafe wading conditions and the potential for trap dislodgement; thus the trap removal schedule was amended and all traps were removed prior to February 7, 2019. To begin the removal process, a block net was installed downstream of the redd in order to catch any stray eggs or fry. Immediately prior to each removal, a final trap check was performed and water quality measurements were taken. The rebar pounded into the skirt was pulled out of the gravel and set aside. Several crew members would remove the large rocks anchoring the skirt, lift the trap frame off of the redd, and carefully carry the trap over to the riverbank. During the removal, two additional crew members in dry suits wore snorkels and monitored the redd underwater during removal for any fry or eggs that emerged while the trap was disassembled.

Once the traps were removed, redd incubation habitat sampling was performed to record instantaneous hydraulic conductivity and vertical hydraulic gradient measurements using a temporary piezometer (Barnard and McBain, 1994), a surface/subsurface differentiated core sample of the substrate (McNeil and Ahnell 1964), and hyporheic water quality (e.g. temperature and dissolved oxygen). Sediment samples were collected using a large funnel driven down into the gravel bed at a point 50% of the distance from the pit to the top of the tailspill. To collect hyporehic water samples, a piezometer was driven down into the redd to gather subsurface dissolved oxygen concentrations, temperature, and velocity measurements. Using the piezometer, the water replenishment rate was measured to indicate hyporehic flow. After incubation habitat sampling was complete, each monitored redd was excavated to locate unviable eggs and/or entombed alevin or fry. Excavations were performed by two crew members manually digging through the pit to locate eggs or fry. Once the egg pocket was uncovered, eggs or fry were collected with small dip nets and counted. The location and depth of the egg pocket was recorded and the redd was backfilled with material from the surrounding riverbed.

Analyses

Mean daily water temperature and mean daily flow data were obtained from the SJF and H41

CDEC gauge stations. Values from the H41 gauge during October 20 to November 18 were not reliable, thus these values were excluded from any analyses. Female spawning activity was measured by calculating the percentage of successful redds created, hereafter referred to as redd creation rate. Redd creation rate was calculated by dividing the number of redds created by the number of adult females released during 2018 and multiplying this ratio by 100. We assumed that females only created one redd during the spawning season (Murdoch et al. 2009). The area of each redd was calculated separately for the pit and tailspill by multiplying the length by the width. The total area of the redd was then determined by adding the calculated areas of the pit and the tailspill together. Mean redd area for the season was calculated by averaging the total area of each individual redd. Redd physical characteristics such as depth and pre-redd velocity were averaged across all redds for each study year.

Spatial and temporal trends in redd distribution across Reach 1 were qualitatively described by visual comparison of the number of redd detections to temperature and flow during the spawning and emergence surveys (August 27, 2018, to February 7, 2019). The timing and distribution of spring-run redds from 2016 and 2017 were visually compared to those surveyed in 2018. Post-survey, we used ArcGIS Online and ArcGIS Pro to analyze redd location and create maps to visualize distribution across Reach 1. To analyze mobile monitoring data from the VR100, we used the maximum daily signal per tagged fish to describe detections per week and detection frequency across sexes and release groups (males and females, separated by June or August release times). By converting paired GPS coordinates to distances with the R package Imap, we also calculated the cumulative distance traveled per tagged fish from the first detection point to each subsequent detection point during the survey season. Spawning rate was calculated by taking the number of female carcasses that were fully spawned and dividing by the total number of female carcasses.

Results

Our 2018 spawning surveys were implemented from August 27, 2018 through February 7, 2019, spanning the end of a dry 2018 water year (DWR 2018) and the start of a relatively cold and wet 2019 water year for the San Joaquin River basin (SJRRP 2019). Precipitation from October through February in nearby Madera totaled 21.41cm, or 120% of average (CDEC). During the survey season, mean daily discharge at SJF ranged from 355-440 CFS with normal peaks observed after storm events (Figure 6) and mean daily water temperatures ranged between 9.4-14.3 °C (Figure 7), below the upper lethal limit for spawning (17°C, SJRRP 2018). Mean daily discharge and water temperatures at H41 were 333-507

CFS (Figure 6) and 9.1-16.0 °C, respectively (Figure 7).

We observed a total of 42 redds and 25 test redds created from 59 adult females released in 2018. In general, all redds were detected by October 24 with the exception of NR42SR18 detected on November 20 (Figure). All redds except for NR42SR18 were found to be within the historical spawning period for spring-run Chinook salmon in the San Joaquin River (Yoshiyama et al. 2001, Williams 2006). We observed trout spawning activity in Reach 1 and theorize redd NR21SR18 to be a trout redd. The California Department of Fish and Wildlife manages a trout hatchery along the San Joaquin River just south of Friant Dam and while their stocking strategies don't include the San Joaquin River, there is a potential for fish to escape the hatchery through San Joaquin River fed water supply pipes. We had planned to validate our theory through genetic testing of captured emerging fry however, due to the early removal of the emergence trap installed on this redd, we were unable to collect any fry. We also detected movement of acoustically tagged fish throughout Reach 1 during the spawning survey, however our mobile monitoring surveys found no clear differences in the cumulative distances moved between the different release groups (May or August), or between sexes (Figure 9).

Redd creation rate during 2018 (71%) was greater than 2016 (30%) and 2017 (24%, Table 2). In 2018, mean redd area was 3.25m^2 and ranged from 0.94 m^2 to 9.65 m^2. Redds were formed at mean depth of 0.52m and pre-redd velocity of 0.66m/s. Mean pit area was 1.43m^2 and mean maximum pit depth was 0.61m (Table 3). Mean tailspill area was 1.82m^2, with a mean depth of 0.4m and mean minimum depth of 0.7m. These characteristics were similar to spring-run redds found during 2016 and 2017 spawning surveys The 2018 mean redd area was smaller than the 2017 mean redd area (5.0m^2), but the range of minimum and maximum redd areas was consistent within years. Mean pit area was smaller than in 2017, but both years reported a larger pit area than 2016, when mean pit area was only 0.67m^2. Overall, the physical characteristics of 2018 redds were more similar to 2017 redds than either year's redds were to 2016 redds (Table 3). The 2018 redd areas also fell within the size ranges observed for Clear Creek (Newton et al. 2004) and Butte Creek redds (McReynolds et al. 2005), two spring-run populations inhabiting Sacramento River tributaries. However, the largest redd in Clear Creek (66.8 m^2) greatly exceeded the largest 2018 redd in the SJRRA (9.65 m^2).

The majority of redd locations were detected in the main channel of the river (35/42 redds), with few (7/42 redds) located in side channels. Spatially, the majority of redds were detected in the river margins (31/42 redds), versus the river center (11/42 redds). Mesohabitats of redd included both riffles (20/42 redds) and runs (22/42 redds) evenly. Visual substrate assessments showed that redds were created in habitats dominated by gravel (20/37 measured redds), cobble (13/37 redds), sand (3/37 redds), and boulder (1/37 redds, Table 4).

Spring-run redds in 2018 appeared to have greater spatial distribution than in previous years. This year, 38 out of 42 redds were located upstream of Highway 41 (Figure 10). The 4 redds detected downstream of Highway 41 in 2018 represent the first spring-run redds described in this area of Reach 1 in over 60 years. The majority of redds in 2016 and 2017 were clustered in the very upper reaches of Reach 1 near Friant Dam, while 2018 redds were more distributed throughout the Reach, appearing as far downstream as Scout Island.

We observed two instances of superimposition in 2018, between redds NR03SR18/NR13SR18 and NR14SR18/NR30SR18. Both cases involved deposition of material onto the other redd. We attempted to measure the degree of superimposition but in both cases, fish present near the newer redd impeded our ability to get close and measure while features were clear. In subsequent weeks after the fish were gone, the newer redd had aged, making it difficult to measure.

Carcass Surveys

Twelve female, 10 male, and 1 unknown spring-run Chinook Salmon carcasses were detected during the 2018 field season (Table 5). Our overall carcass recovery rate was 12.80%, 20.35% for female carcasses and 8.33% for male carcasses. The recovery rates by sex were similar to 2017 results, suggesting that female carcasses may be more likely to be recovered than male carcasses. 91.7% of female carcasses were fully spawned upon examination. This high percentage is consistent with our high levels of spawning activity visually observed and redd creation rate in 2018. In 2017 the number of fully spawned carcasses recovered was lower, 77%. There were no spring-run carcasses recovered in 2016.

Twenty-one out of 23 carcasses were found in the main channel, and all were recovered with their adipose fin clipped. Carcasses were found in pools (10/23), riffles (2/23), glides (7/23), and backwater areas including land (4/23). Two recovered carcasses were drawn to our attention by river conservancy volunteers around Sycamore Island. Two additional carcasses were located inside pools on the main channel of the river which were too deep to retrieve and therefore not included in carcass detection counts. Extracted coded-wire tags (CWTs) confirmed all carcasses detected were released excess broodstock from the SCARF. HDX PIT tags were collected from 9 carcasses, still embedded in the ventral musculature of the pelvic girdle. We were unsuccessful in linking females to specific redds through HDX PIT tags, as a large number of female carcasses did not expel the tags during spawning.

Emergence Monitoring

Ten redds distributed throughout Reach 1 from Friant to Wildwood were monitored for emerging fry in 2018 (Table 6, Figure 10). We observed 33 total expired fry and 165 total living fry emerge from six of the ten capped redds (Table 7). Redd NR33SR18 had the largest number of fry emerge (129 alive and 19 expired) accounting for 78% of the total live fry and 58% of the total expired emergence counts. Redd NR28SR18 had the second largest number of emerged fry (18 alive and 8 expired) and redd NR25SR18 had the least number of alive emerging fry (one) and no expired fry. The remaining three monitored redds had similar but low counts of alive (5-6) and deceased (1-3) fry emerge. Four traps (NR02SR18, NR17SR18, NR40SR18, NR42SR18) did not have any fry emerge throughout the study (Table 7). The mean FL for all emerged fry was 32.9 mm and all were classified as Stage 5, having fully absorbed yolk sacs and "seamed up". Tissue samples for parentage based tagging (results pending as of this report) were taken from 29 fry throughout the monitoring period (Table 7). Upon excavation, we recovered undeveloped eggs from four (NR10SR18, NR25SR18, NR27SR18, NR28SR18) of six redds which had fry emerge, confirming that spawning had occurred at those redds. No eggs were detected at redds NR02SR18 and NR17SR18, suggesting these may have been "test redds" where a female created the redd but never deposited eggs. We declined to excavate NR40SR18 and NR42SR18, as the traps were removed prematurely due to increased water flows.

Based on fall-run emergence experiments in the SJRRA, we predicted that emergence would begin near 700 ATU. Values observed at the start (638 – 1053 ATUs) and end (973 – 1229 ATUs) of emergence varied widely across the six redds that had fry emerge (Table 7). First emergence after trap installment varied widely (4 – 36 days, Table 7). Due to low emergence and inconsistent timing of emergence based on ATUs, we could not discern any clear patterns of emergence timing based on our data. Incubation habitat data is still under analysis, therefore no inferences about emergence, or lack thereof, in respect to habitat variables can be made at the time of this report.

Mean daily water temperatures taken at capped redds ranged from 10.7-12.0 °C, dissolved oxygen ranged from 9.4-10.3 mg/L, and turbidity ranged from 2.5-3.5 NTU. Our recorded mean temperatures at emergence traps throughout the study period were within the optimal incubation temperature range (<13°C) for spring-run Chinook Salmon (SJRRP 2010, Beer and Anderson 2001). We did not record any major fluctuations in temperature or flow regimes during the duration of the study period.

Incubation Habitat Monitoring

Results from the incubation habitat monitoring are still pending analysis at the time of this report.

Discussion

In 2018 we documented the largest number of spring-run Chinook Salmon redds created by our experimentally released adult broodstock since releases began in 2016. This may be a result of our increased male to female ratio (2:1) and the presence of optimal water temperatures in Reach 1 in 2018. Redd locations were more spatially diverse than previous years, likely due to the optimal water temperatures throughout the spawning reach. However we did not meet the SJRRP spring-run fecundity target of 4,200 eggs per female and egg-to-fry survival of at least 50 percent (SJRRP 2010). We were unable to relate fry production or survival probability to environmental variables associated with the capped redds because of the extremely low emergence. Additionally, low emergence and the overall low number of juveniles captured in the Rotary Screw Traps set by the SJRRP in Reach 1to document juvenile survival leads us to speculate there are confounding factors associated with the incubation habitat that may be at play.

Although our incubation habitat data was unavailable at the time of this report, it is worth mentioning that a recent Technical Memorandum published by the SJRRP (Meyers 2019) determined that the quality of the existing incubation habitat in Reach 1 of the SJRRA is significantly limiting fry production and suggests enhancement efforts will be necessary for the Program to achieve its egg-to-fry survival targets. During our redd excavations, we observed eggs embedded in a well-compacted fine substrate which can be a contributing factor to low survival of eggs. The abundance of fine sediments in the San Joaquin River is due to a multitude of reasons including mining, Friant Dam construction, erosion, and streambed widening (Williams and Wolman 1984; Williams 2006). These issues are concerning due to the negative relationship between fine sediment accumulation and egg-to-fry survival (Chapman 1988 and Meyers 2019). Meyers (2019) demonstrated that fine sediment accumulation within the redd and the ambient bed surrounding the redd decreases hyporheic flow rate, which is important for oxygen delivery and metabolic waste removal as eggs develop. He determined that hydraulic conductivity is a function of local sediment transport and that sediment transport can vary across spawning locations due to river discharge. The variability in sediment deposition between sites may explain why we had higher emergence in redd NR33SR18 compared to the extremely low emergence recorded at the other emergence traps.

Overall, during 2018 we observed high levels of spring-run Chinook Salmon spawning activity but low emergence. When volitional passage is restored to the San Joaquin River, adults will be able to access spawning grounds unaided. It is critical that we understand the quality of the spawning habitat and how spring-run spawning site selection determines spawning success in Reach 1. As a result, we suggest that the SJRRP continue spring-run redd and carcass surveys and emergence trapping. These surveys provide valuable information for future habitat improvement projects, reintroduction activities (i.e. SJRRP salmon population targets), and aid in the development of future management practices in a variety of ecological conditions. In the case of egg development and fry survival, we are particularly interested in collecting more robust data on timing patterns and environmental conditions inside redds for emerging fry.

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Tables

Table 1. Summary of ancillary spring-run Chinook Salmon brookstock adult releases into Reach 1 of the San Joaquin River Restoration Area (SJRRA) from 2016-2018. *Data from McKenzie et al., 2017

	2016*		**2017***		**2018**	
	Female	*Male*	*Female*	*Male*	*Female*	*Male*
Adults released	10	15	55	60	59	120
Average fork length (mm)	539	492	581	534	553	545
Proportion of Males	-	0.6%	-	0.52%	-	0.67%

Table 2. Redd creation rates and the number of adult female spring-run Chinook Salmon broodstock released per year into Reach 1 of the SJRRA.

	# Females Released	**Redds Detected**	**Redd Creation Rate**
2016	10	3	0.30
2017	55	13	0.24
2018	59	42	0.71

Table 3. Spring-run Chinook Salmon redd attributes and habitat characteristics of observed redds within Reach 1 of the SJRRA across sampling years 2016 to 2018.

	2016			**2017**			**2018**		
Variable	**Mean**	**SD**	**Range**	**Mean**	**SD**	**Range**	**Mean**	**SD**	**Range**
Redd area (m^2)	3.05	1.20	1.73-4.08	5.0	2.51	1.77-9.79	3.25	1.88	0.94-9.65
Tailspill area (m^2)	2.38	0.96	1.35-3.25	2.78	1.32	1.14-4.96	1.82	0.94	0.46-3.87
Pit area (m^2)	0.67	0.26	0.38-0.83	2.21	1.42	0.63-5.18	1.43	1.12	0.33-5.78
Max pit depth (m)	0.35	0.05	0.32-0.40	0.60	0.16	0.36-0.92	0.61	0.25	0.24-1.22
Depth upstream pre-redd (m)	0.39	0.06	0.34-0.46	0.51	0.16	0.26-0.82	0.52	0.25	0.18-1.14
Pre-redd velocity (m/s)	0.66	0.21	0.51-0.90	0.58	0.20	0.29-0.89	0.66	0.25	0.22-1.54

Table 4. 2018 Redd locations, habitat characterization, and substrate textural facies in Reach 1 of the SJRRA. Substrate textural classifications are based on the relative abundance of grain sizes [S- sand (≤ 2.0 mm), G- gravel (2 mm to 64 mm), and Cobble (64 mm to 256 mm)] composing > 5% of substrate samples listed from least to most abundant. We noted if redds were found in the main channel (MC) or a side channel (SC) of the river. Channel position was noted as being river center (RC), river right (RR), or river left (RL). Redds were found in two habitat types: riffles (RF) and runs (RN).

Redd Number	Latitude	Longitude	Channel Type	Channel Position	Habitat Type	Substrate Type	% Fine Sediment
NR01SR18	36.93747	-119.74899	MC	RC	RF	S,C,G	10%
NR02SR18	36.92949	-119.75102	MC	RC	RF	S,C,G	10%
NR03SR18	36.92957	-119.75114	MC	RR	RF	G,S,C	30%
NR04SR18	36.87489	-119.79774	SC	RR	RF	S,G,C	10%
NR05SR18	36.97414	-119.73642	MC	RL	RN	S,G,C	15%
NR06SR18	36.97420	-119.73643	MC	RL	RN	C,S,B	12%
NR07SR18	36.94410	-119.73894	MC	RR	RF	-	-
NR08SR18	36.94412	-119.73895	MC	RR	RF	-	-
NR09SR18	36.93225	-119.75263	MC	RR	RN	G,C	5%
NR10SR18	36.93745	-119.74802	MC	RL	RF	C,S,G	25%
NR11SR18	36.93229	-119.75260	MC	RR	RN	S,C,G	20%
NR12SR18	36.93763	-119.74892	MC	RR	RF	S,G,C	6%
NR13SR18	36.92958	-119.75113	MC	RR	RF	S,G,C	13%
NR14SR18	36.91602	-119.75816	MC	RC	RF	S,G,C	7%
NR15SR18	36.99087	-119.71404	MC	RR	RF	C,G,S	75%
NR16SR18	36.99069	-119.71377	MC	RL	RN	S,C,G	20%
NR17SR18	36.99065	-119.71361	SC	RC	RN	C,S,G	30%
NR18SR18	36.99016	-119.71459	SC	RC	RF	C,G,S	30%

NR19SR18	36.91026	-119.76914	MC	RR	RN	S,C,G	10%
NR20SR18	36.91030	-119.76917	MC	RC	RN	C,S,G	20%
NR21SR18	36.87840	-119.78620	MC	RL	RF	G,C	5%
NR22SR18	36.87588	-119.79454	MC	RL	RF	S,C,G	15%
NR23SR18	36.87593	-119.79446	MC	RR	RN	-	-
NR24SR18	36.99018	-119.71380	SC	RR	RF	C,S,G	35%
NR25SR18	36.95377	-119.74225	MC	RC	RN	S,G,C	5%
NR26SR18	36.92961	-119.75098	MC	RC	RN	C,S,G	35%
NR27SR18	36.92963	-119.75112	MC	RR	RN	S,C,G	35%
NR28SR18	36.92544	-119.75172	MC	RR	RN	S,C,G	30%
NR29SR18	36.91602	-119.75816	MC	RL	RF	S,C,G	15%
NR30SR18	36.91602	-119.75813	MC	RC	RF	G,S,C	35%
NR31SR18	36.91611	-119.75804	MC	RR	RN	-	-
NR32SR18	36.91611	-119.75812	MC	RR	RN	C,S,G	45%
NR33SR18	36.91612	-119.75820	MC	RR	RN	C,S,G	40%
NR34SR18	36.87853	-119.78649	MC	RR	RF	C,S,G	30%
NR35SR18	36.99012	-119.71483	MC	RL	RN	G,S,C	40%
NR36SR18	36.98596	-119.72029	SC	RC	RN	S,C,G	10%
NR37SR18	36.86116	-119.84181	MC	RR	RN	S,G	20%
NR38SR18	36.98698	-119.72076	MC	RR	RN	C,G	2%
NR39SR18	36.98631	-119.72036	SC	RR	RF	G,C	2%
NR40SR18	36.91031	-119.76911	SC	RC	RN	C,S,G	40%
NR41SR18	36.99014	-119.71466	SC	RL	RN	-	-
NR42SR18	36.87838	-119.78623	MC	RL	RF	S,C,G	10%

Table 5. Summary of count, sex, and spawning status of adult spring-run Chinook Salmon recovered as carcasses and processed in Reach 1 of the SJRRA across field seasons 2016 to 2018. Not listed: 1 carcass of unknown sex found in 2018

	2016		**2017**		**2018**	
	Female	*Male*	*Female*	*Male*	*Female*	*Male*
Fish Released	10	15	55	60	59	120
Carcasses Recovered	0	0	13	4	12	10
Recovery %	0	0	23.63%	6.67%	20.34%	8.33%
Fully Spawned %	0	-	77%	-	91.67%	-

Table 6. Location and number of days that emergence traps were installed over 10 selected redds in Reach 1 of the SJRRA in 2018-2019.

Redd Number	Location	Latitude	Longitude	Date Trap Installed	Date Trap Removed	Days Capped
NR02SR18	Lower Willow	36.92949	-119.75102	10/30/2018	01/31/2019	93
NR10SR18	Upper Willow	36.93795	-119.74803	11/06/2018	02/06/2019	92
NR28SR18	DS of LDC	36.92519	-119.75193	11/13/2018	02/07/2019	86
NR33SR18	Rank Island	36.91611	-119.75820	11/13/2018	02/07/2019	86
NR21SR18	Wildwood	36.87840	-119.78620	11/14/2018	02/08/2019	86
NR17SR18	Friant	36.99065	-119.71361	11/19/2018	02/05/2019	78
NR27SR18	Lower Willow	36.92963	-119.75112	11/19/2018	02/06/2019	79
NR25SR18	Ledger Island	36.95377	-119.74225	11/20/2018	02/05/2019	77
NR10SR18	Owl Hollow	96.91031	-119.76911	12/03/2018	02/08/2019	67
NR42SR18	Wildwood #2	96.87838	-119.78623	01/02/2019	02/07/2019	36

Table 7. 2018 Emergence trap season emergence totals, mortalities, genetic samples collected, eggs recovered, mean emerged fry size, and range of fry size for each emergence trap. Emergence timing data reported as accumulated thermal units (ATUs) calculated on the first and last date that emergence was observed at each redd. Mean environmental parameters measured at each capped redd (dissolved oxygen, turbidity, temperature).

Redd Number	Season Emergence Totals	Season Mort Totals	Genetic Samples Taken	Eggs Recovered	Mean Fry Size (mm)	Emergence Start (ATU)	Emergence End (ATU)	Date First Emergence	Date Last Emergence	DO (mg/L)	Turbidity (NTU)	Temp (C)
NR02SR18	0	0	-	-	-	-	-	-	-	9.45	2.53	12.03
NR10SR18	5	1	4	465	31.6	954	1071	12/3/2018	12/12/2018	9.47	2.62	11.99
NR17SR18	0	0	-	0	-	-	-	-	-	9.49	2.59	11.94
NR21SR18	6	3	5	0	31.8	875	1025	12/5/2018	12/17/2018	9.51	2.68	11.92
NR25SR18	1	0	0	159	N/A	1053	1053	12/26/2018	12/26/2018	9.52	2.59	11.89
NR27SR18	6	2	6	131	32.2	785	1229	12/5/2018	1/11/2019	9.51	2.66	11.89
NR28SR18	18	8	9	156	32.75	638	973	11/17/2018	12/12/2018	9.49	2.67	11.94
NR33SR18	129	19	5	0	36.1	998	1010	12/14/2018	12/15/2018	9.52	2.67	11.92
NR40SR18	0	0	-	-	-	-	-	-	-	9.67	2.69	11.51
NR42SR18	0	0	-	-	-	-	-	-	-	10.28	3.47	10.71

Figures

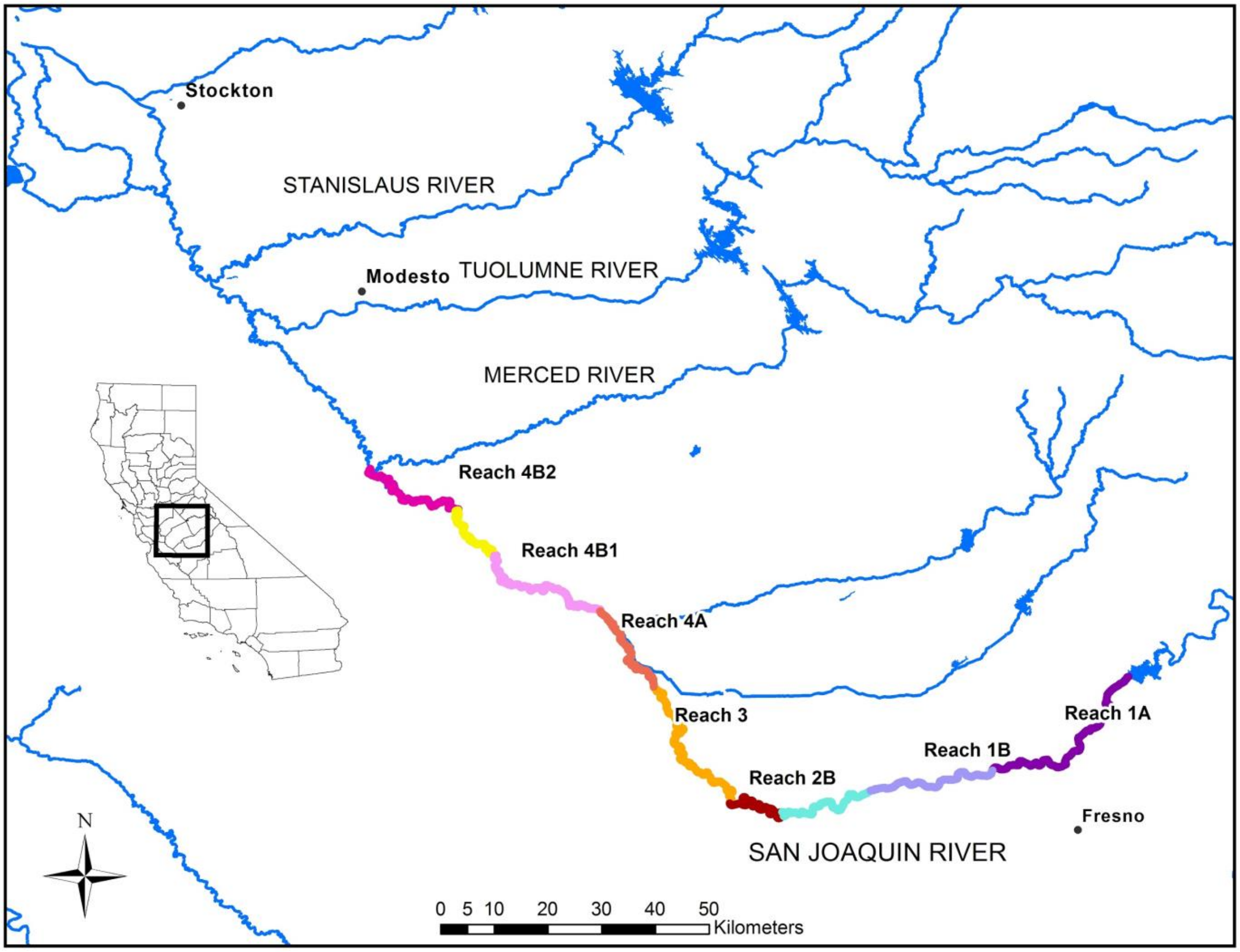

Figure 1. The San Joaquin River Restoration Area (SJRRA) within the San Joaquin River, CA. The SJRRA is stratified into five reaches which are delineated using labels and unique colored lines.

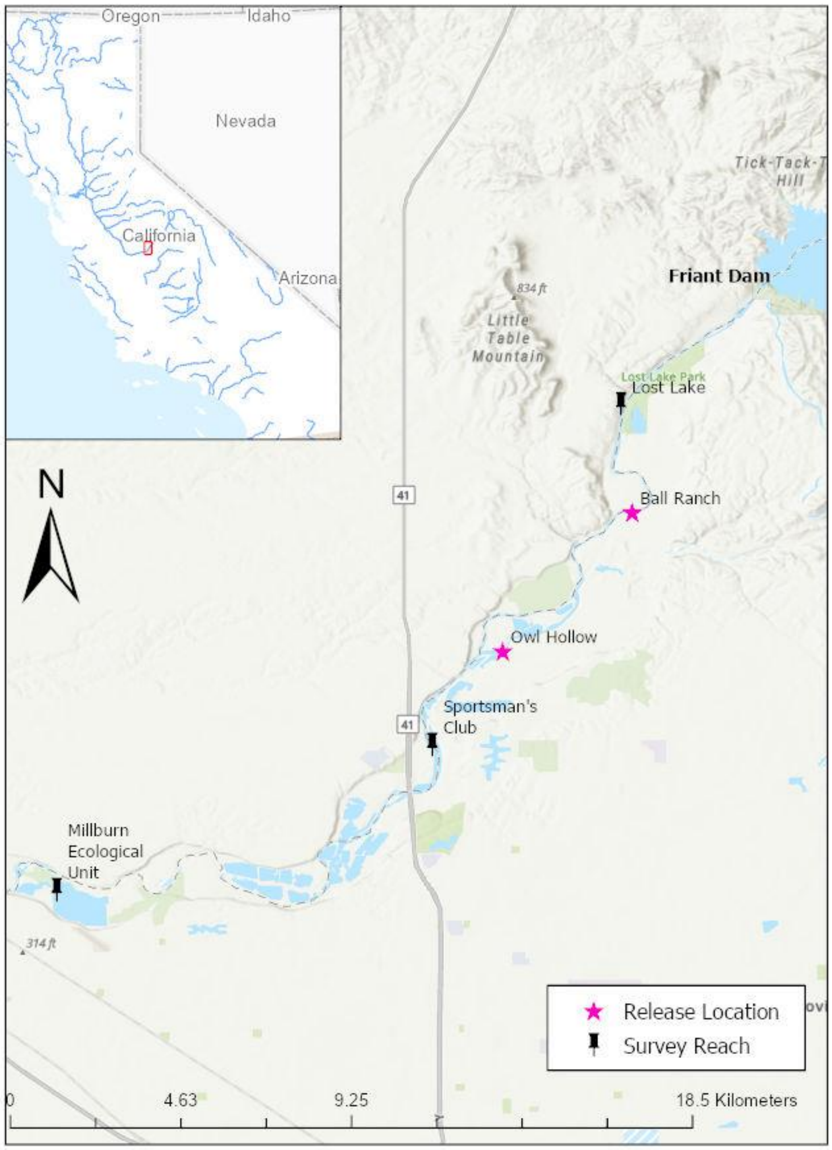

Figure 2. Map of 2018 Redd and Carcass survey reaches within Reach 1 of the SJRRA near Friant Dam. Reaches were broken into three days: Friant Dam to Lost Lake, Lost Lake to Fresno Sportsman's Club, and Sportsman's Club to Millburn. Adult broodstock release locations are noted.

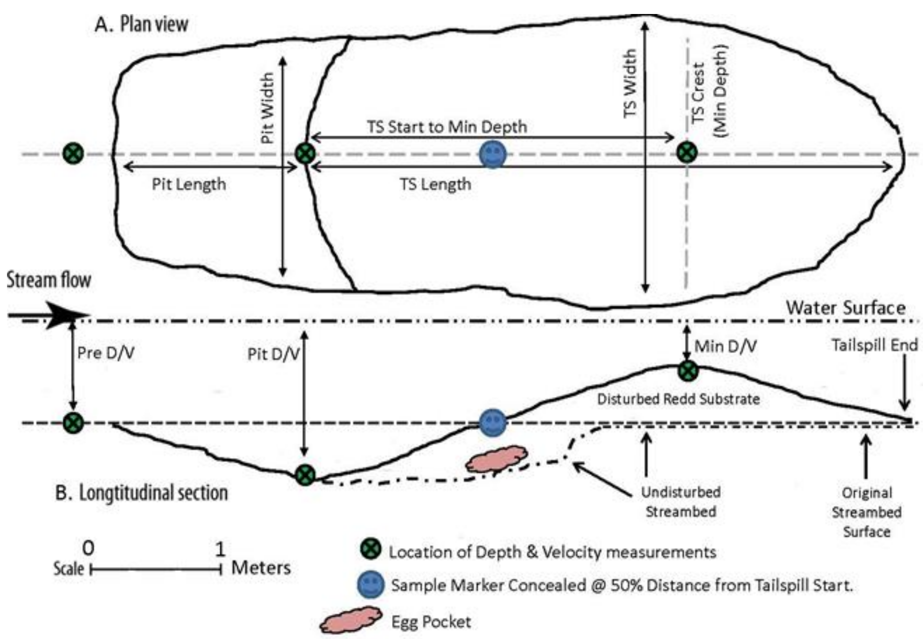

Figure 3. Plan View (A) and Longitudinal View (B) of a typical Chinook Salmon redd. Details of redd features and associated measurements recorded during redd surveys are shown.

Figure 4. A spring-run Chinook Salmon carcass found in 2018. All carcasses were photographed for a record of the presence/absence of an adipose fin, T-bar tag numbers and colors, and length. Carcasses were photographed lying on their right side with label tag containing identification information.

Figure 5. An emergence trap placed on a spring-run Chinook Salmon redd. The pear-shaped net is installed over the pit, egg pocket, and tailspill of the redd by hammering rebar into the surrounding riverbed. The exposed rebar is covered with orange caps for safety (pictured) and the canvas skirt of the trap is backfilled with large rocks from the surrounding area. The tapered cod end is downstream and features a collection jar where emerged fry are collected.

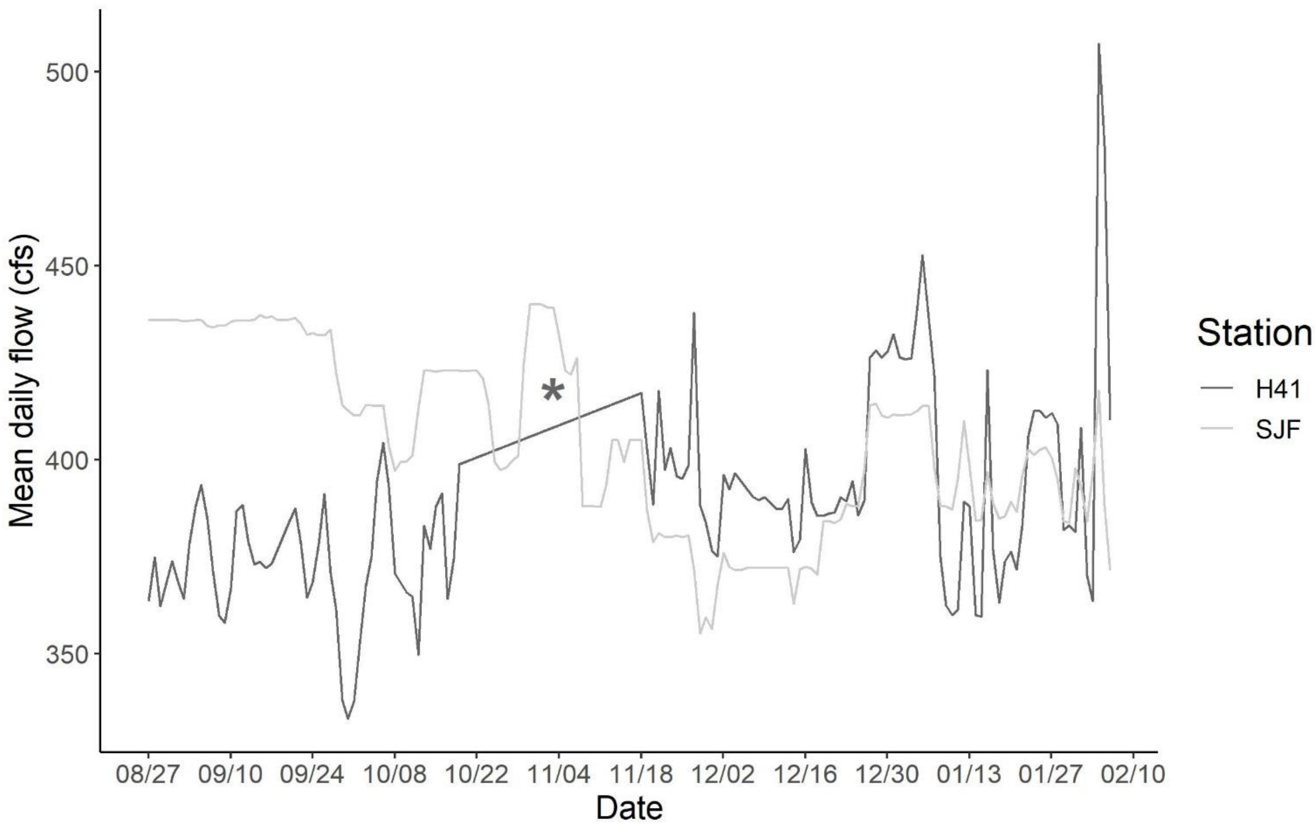

Figure 6. Mean daily river flow (CFS) recorded near Friant Dam (SJF; rkm 430) and Highway 41 (H41; rkm 410.4) within Reach 1 from August 2018 through February 2019. Flow data were obtained from the California Data Exchange Center (CDEC, http://cdec.water.ca.gov). The asterisk (*) indicates missing gauge data for H41.

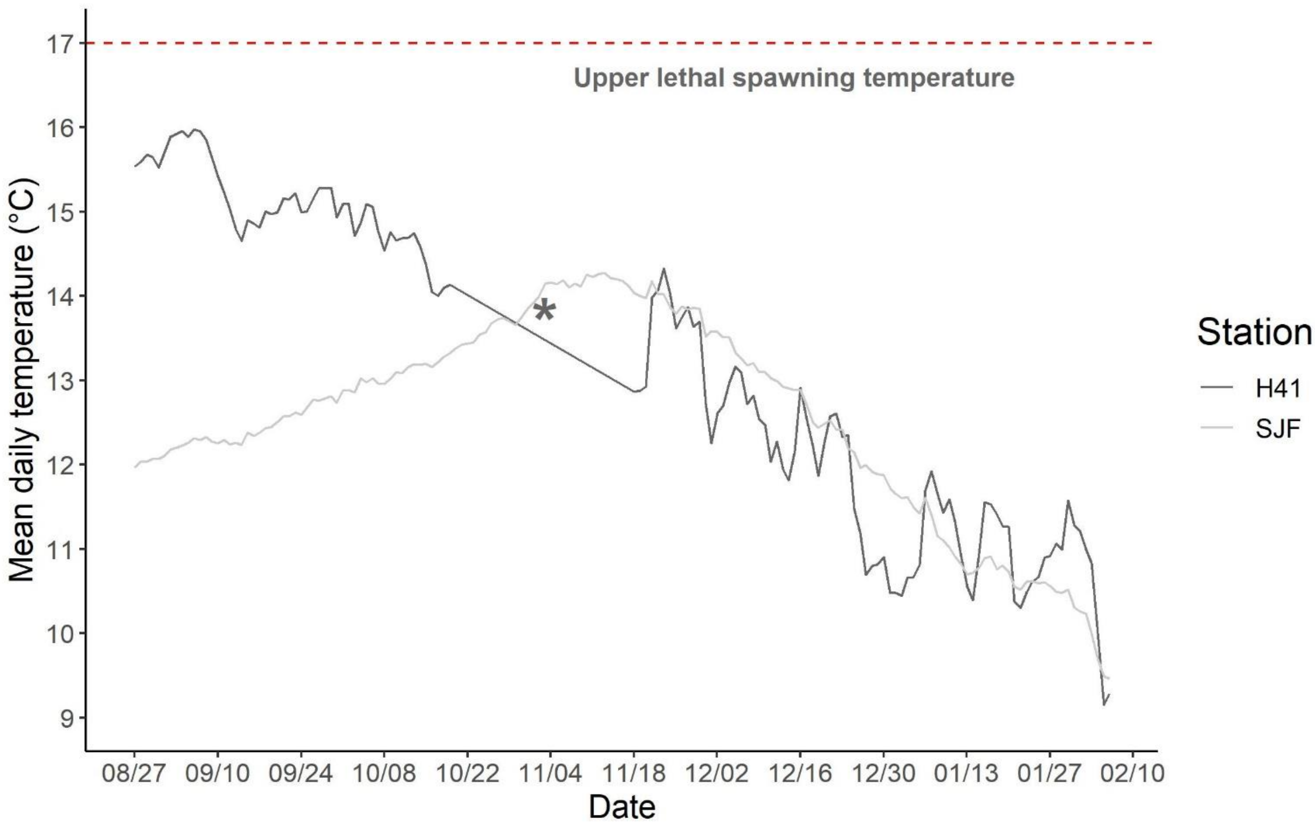

Figure 7. Mean daily water temperature (°C) recorded near Friant Dam (SJF; rkm 430) and Highway 41 (H41; rkm 410.4) within Reach 1 August 2018 through February 2019. Temperature data were obtained from CDEC (http://cdec.water.ca.gov). The upper lethal temperature threshold for Chinook Salmon spawning is indicated by the red dashed line at 17ºC (SJRRP 2010). The asterisk (*) indicates missing gauge data for H41.

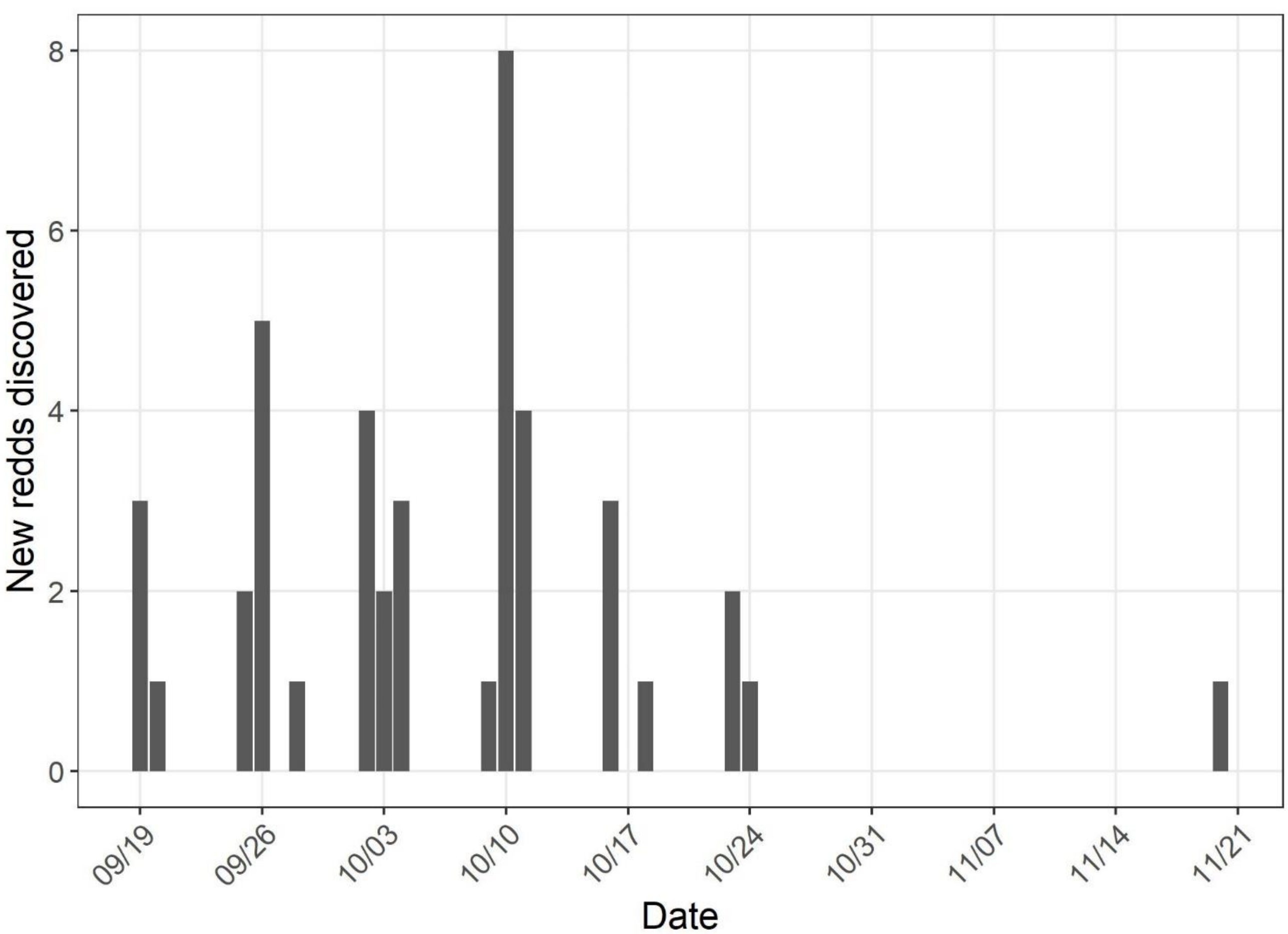

Figure 8. Number of new spring-run Chinook Salmon redds detected across weeks during 2018 within Reach 1 of the SJRRA.

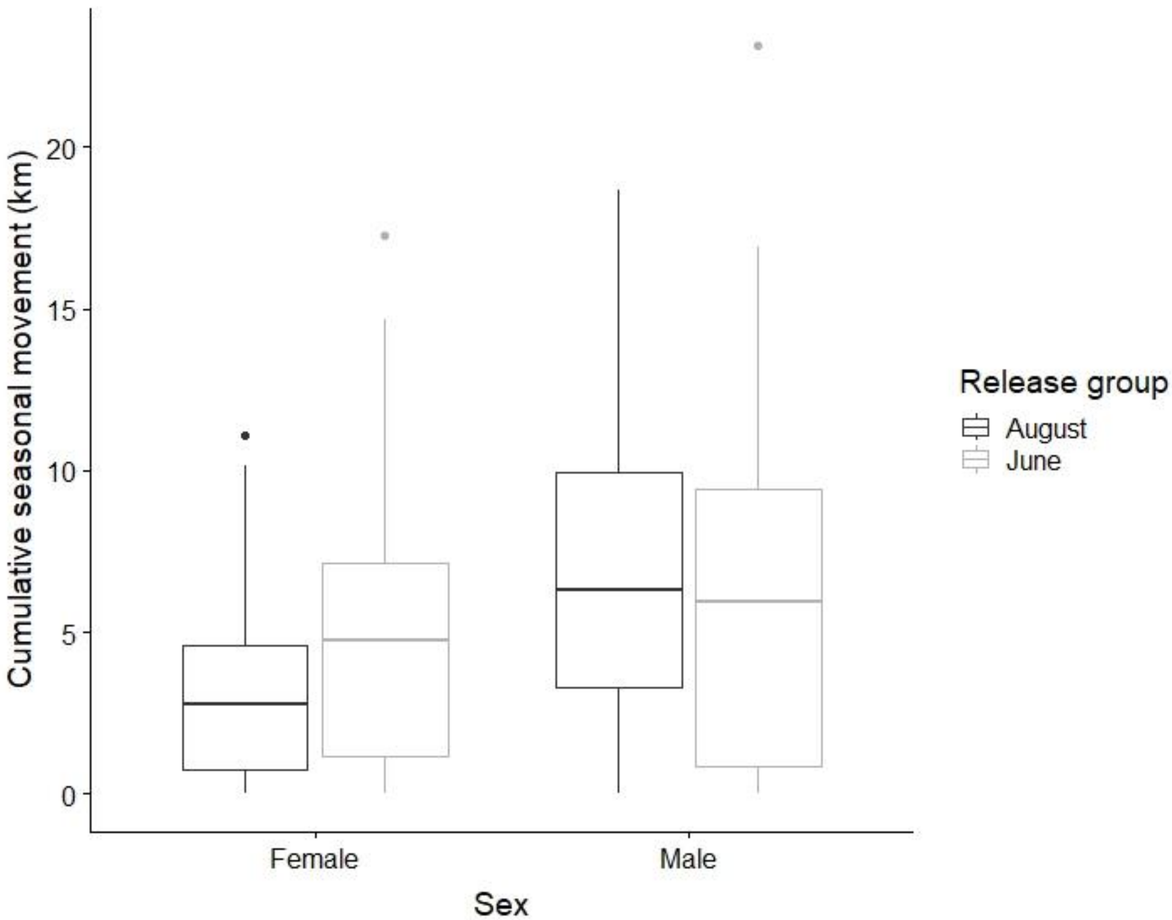

Figure 9. Cumulative seasonal movement (km) of adult released salmon by sex and release group. There were no clear differences in the cumulative distances moved by either release group (May or August) or sex. The boxes represent the 1st and 3rd quartiles (25th and 75th percentiles) of the data range, the horizontal line is the median, and the whiskers are 1.5 times the interquartile range.

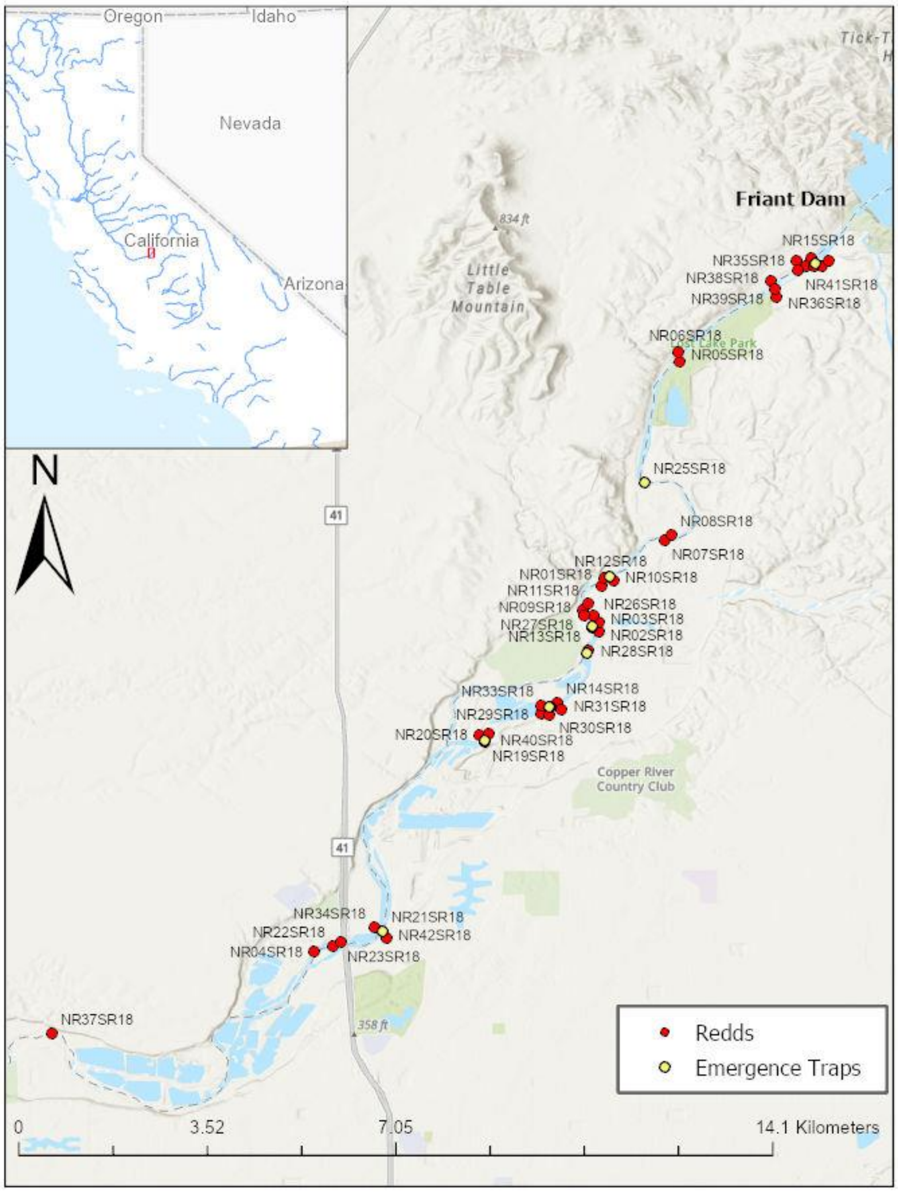

Figure 10. The locations of detected spring-run Chinook Salmon redds (September - November 2018) and the locations of the 10 redds selected for emergence trap (October 30, 2018 - February 8. 2019) in Reach 1 of the SJRRA.