Assessment of Spring-run Chinook Salmon Spawning during 2020 within the San Joaquin River, California

Technical Report

SAN JOAQUIN RIVER
RESTORATION PROGRAM

Assessment of Spring-run Chinook Salmon Spawning during 2020 within the San Joaquin River, California

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Contents

Abbreviations and Acronyms

AICc	Akaike Information Criterion with Correction for Finite Sample Sizes
AQI	Air Quality Index
ATU	Accumulated Thermal Unit
C	Celsius
CDEC	California Data Exchange Center
CDFW	California Department of Fish and Wildlife
cfs	Cubic Feet per Second
cm	Centimeter
cm^2	Square Centimeter
CWT	Coded Wire Tag
DO	Dissolved Oxygen
ETF	Egg-to-Fry
FDX	Full-Duplex
FL	Fork Length
FMP	Fisheries Management Plan of the San Joaquin River Restoration Program
FRFH	Feather River Fish Hatchery
ft	Feet
feet/sec	Feet/Second
FWQ	Friant Water Quality California Data Exchange Center Gage
GLM	Generalized Linear Model
GPS	Global Positioning System
H41	Highway 41 Bridge California Data Exchange Center Gage
HDX	Half-Duplex
kHz	Kilohertz
L	Liter
m	Meter
m/s	Meters per Second
ml	Milliliter
mg/L	Milligrams per Liter
mm	Millimeters
MAP	Monitoring and Analysis Plan
n	Sample Size
NMFS	National Marine Fisheries Service
NTU	Nephelometric Turbidity Unit
PIT	Passive Integrated Transponder
POHL	Post Orbital Hypural Length
rkm	River Kilometer
Reclamation	U.S. Bureau of Reclamation
SCARF	Salmon Conservation and Research Facility
Settlement	Stipulation of Settlement in Natural Resources Defense Council [NRDC], et al. v. Kirk Rodgers, et al. 2006.
SD	Standard Deviation

SJF	San Joaquin River below Friant California Data Exchange Center Gage
SJRRA	San Joaquin River Restoration Area
SJRRP	San Joaquin River Restoration Program
SRCS	Spring-run Chinook Salmon
USFWS	U.S. Fish and Wildlife Service

List of Tables

List of Figures

Executive Summary

Native fall-run and spring-run Chinook Salmon populations were extirpated from the San Joaquin River below Friant Dam to the confluence with the Merced River after Friant Dam construction was completed in the 1940s. A primary goal of the San Joaquin River Restoration Program (SJRRP) is to restore to this section of the river (hereafter the San Joaquin River Restoration Area; SJRRA) self-sustaining and naturally-reproducing populations of Chinook Salmon, with a particular focus on the reintroduction of spring-run Chinook Salmon (SRCS).

To aid reintroduction, hatchery-reared SRCS juveniles and broodstock adults, sourced from the Feather River Fish Hatchery, have been released into the SJRRA since 2014 and 2016, respectively. Currently, adult SRCS that migrate into the SJRRA in the spring, and consist of hatchery origin returns, are trapped and hauled to sites in Reach 1 of the SJRRA above existing passage barriers.

A critical need for the SJRRP is to determine if the reestablishing SRCS population can successfully complete important freshwater life stages within the SJRRA. To address this need, SJRRP biologists have monitored SRCS spawning activity, and evaluated the quality and quantity of available habitat for SRCS spawning and early life stage development (eggs and fry). Here, we report on spawning activity and egg-to-fry (ETF) survival of SRCS assessed through redd, carcass, and fry emergence trap monitoring surveys during the 2020 field season (September 2020 through February 2021).

Our surveys indicate that during 2020, 73 redds were constructed by adult SRCS as a result of the release of 136 released broodstock SRCS females and at least 14 female trap and haul SRCS (15 additional trap and haul individuals were of unknown sex). August temperatures in the spawning reach exceeded the critical spawning threshold and may have limited spawning to the upper area of the reach, where the majority of the redds were found.

Physical characteristics and pre-redd substrate composition assessments were generally consistent with natural SRCS redds reported in other studies, suggesting SRCS construct redds similar in size and select similar habitat in the SJRRA. Superimposition of SRCS redds over other SRCS redds was 6.9 percent, which is less than the SJRRP population objective threshold of 10 percent.

Mean size of measured redds was smaller in 2020 than that observed in 2019 when high flow conditions enabled larger hatchery-return salmon to volitionally migrate to SJRRA spawning grounds. Since volitionally hatchery-returning salmon were physically larger than released broodstock adults, hatchery-returning salmon may have created larger sized and more productive redds. Prespawn mortality based on 38 observed broodstock carcasses and 10 observed trap and haul hatchery origin return carcasses collected during 2020 met SJRRP's population objective threshold of less than 15 percent.

Based on five monitored emergence traps, we observed a mean of 377 SRCS fry per redd, yielding an ETF survival of 15.58 percent. While dissolved oxygen below approximately 10 mg/L measured near individual redds may negatively affect fry emergence, more data across a range of near-redd dissolved oxygen values and from dissolved oxygen measured within the redd incubation habitat are needed.

Based on these results, we recommend that the SJRRP continue SRCS redd, adult carcass, and fry emergence surveys. Additional efforts to distinguish redds created by broodstock and trap and haul hatchery returns will help identify potential differences in ETF survival between groups of spawners. These additional studies will provide invaluable information to determine habitat restoration requirements for the successful reestablishment of SRCS within the San Joaquin River.

1.0 Background

Historically, the main-stem San Joaquin River and upper watershed tributaries annually produced up to approximately 500,000 spring-run, fall-run, and late fall-run Chinook Salmon (*Oncorhynchus tshawytscha*) and supported the southernmost spring-run populations in North America (Fry 1961; Fisher 1994; Yoshiyama et al. 2000). Salmon runs are distinguished by the time of year adults return to fresh water, the elevation and type of reaches used for spawning activity, the duration of juvenile residence period, and the time of juvenile emigration. Adult spring-run Chinook Salmon (SRCS) traditionally returned in the spring and used cold pools in higher elevations for summer holding followed by late summer/early fall spawning in upper tributary streams (Yoshiyama et al. 1998). Adult fall-run and late fall-run Chinook Salmon return in the fall and use lower elevation habitats near the valley floor for late fall/early winter spawning (Fisher 1994; Meyers 2019). After construction of Friant Dam, habitat for Chinook Salmon and other native fish has become degraded, dewatered, and fragmented due to increased groundwater pumping and water diversions (Fry 1961; Warner 1991; Yoshiyama et al. 2001). Along the San Joaquin River in the vicinity of Fresno, mining for aggregate within the channel and floodplains also left large, deep pits that provide suitable habitat for black basses (*Micropterus* spp.) and other predators of juvenile salmon (Williams 2006). The cumulative effects of these actions resulted in the rapid decline of Chinook Salmon runs within the San Joaquin River above the confluence of the Merced River and the extirpation of SRCS by 1950 and remaining runs shortly thereafter (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 Merced, Stanislaus, and Tuolumne Rivers, albeit at very reduced numbers compared to historical records (Yoshiyama et al. 2000).

In 2006, a Settlement (Natural Resources Defense Council [NRDC], et al. versus Kirk Rodgers, 2006) was reached between NRDC, Friant Water Users Authority, and the U.S. Departments of the Interior and Commerce to help develop and enact restoration and water management goals on the San Joaquin River below Friant Dam to the confluence of the Merced River (SJRRP 2010). Fishery restoration goals established by the Settlement focus on restoring and maintaining natural fish populations in “good condition” in the San Joaquin River Restoration Area (SJRRA) including naturally reproducing salmon and other native fish species. Interim Flow releases to support SJRRP began in 2009 and concluded in 2014, in conjunction with the start of

Restoration Flows. However, it wasn't until 2016 that the San Joaquin River between Friant Dam and the Merced River confluence was fully connected. Additionally, the Settlement established a water management goal to reduce and/or avoid the impact of adverse water supply on the Friant Division long-term contractors that may result from these Interim and Restoration Flows in the SJRRA. The San Joaquin River Restoration Program (SJRRP) was created to implement the Settlement, and has developed comprehensive plans and actions to achieve those goals. The SJRRP is a multiagency collaborative program between the U.S. Fish and Wildlife Service (USFWS), the U.S. Bureau of Reclamation (Reclamation), National Marine Fisheries Service (NMFS), the California Department of Fish and Wildlife (CDFW), and the California Department of Water Resources (DWR).

Currently, the SJRRP manages Restoration Flows to maintain suitable river temperatures in the SJRRA to promote the recolonization of SRCS. Due to fish passage barriers (e.g., Sack Dam, Mendota Dam, etc.) that preclude upstream adult fish passage, the SJRRP has implemented Adult Trap and Haul (hereafter referred to as “trap and haul”) to trap, haul, and transport returning adult SRCS around instream barriers. Adult spring-run trap and haul efforts are conducted in conjunction with a monitoring effort. To-date, trap and haul efforts have released SRCS into Reach 1 of the SJRRA, and these efforts are anticipated to continue as necessary to alleviate passage concerns, especially in low water years. These management actions were implemented after the SJRRP developed an experimental population of Chinook Salmon using broodstock from the Feather River Fish Hatchery to help recolonize SJRRA (FRFH; SJRRP 2018). Ongoing habitat restoration efforts will support the recolonization of SRCS to the SJRRA; recolonization efforts additionally include annual releases of juvenile SRCS into the Restoration Area and annual releases of sexually mature adult broodstock SRCS from the Interim Salmon Conservation and Research Facility (SCARF) into Reach 1 spawning habitat, the most upstream area of the SJRRA (Figure 1).

The SJRRP Fisheries Management Plan (FMP) has established several criteria to guide fish and habitat restoration activities to achieve salmon population viability within the SJRRA (SJRRP 2010). A major component of data collection has focused on SRCS spawning success (i.e., production of offspring from spawning adults) of individuals within the population and understanding the causes of associated variability. One objective of the FMP suggests that an in-river egg-to-fry (ETF) survival rate of ≥ 50 percent for SRCS is needed to achieve the SJRRP's population target. The FMP also identifies the need to monitor for superimposition among redds because it may reduce ETF survival and limit the ability for the SJRRP to reach salmon production goals. Superimposition occurs when a female salmon selects nearly the same location to build a redd as that occupied by a preexisting redd and then scours and/or deposits substrate on the preexisting redd. Previous studies have shown that superimposition increases as the density of spawning female salmon increases and has been attributed to limited spawning habitat (McNeil 1964; Weeber et al. 2010). The FMP also includes a population objective to achieve an annual minimum of 500 naturally produced adult SRCS that spawn successfully. The annual redd, carcass, and emergence monitoring efforts described in this report will allow the SJRRP to evaluate spawning habitat suitability with biological metrics and assess population viability within the SJRRA.

2.0 Redd Monitoring Survey

2.1 Introduction

Routinely, redd surveys have been used to assess Pacific salmonid (*Oncorhynchus* spp.) escapement, abundance, and spawn timing, and collect physical measurements of salmon nests (redds) (Gallagher et. al 2007). Redd surveys for SRCS in the SJRRA began in 2016 and have continued annually. The purpose of redd surveys within the SJRRA is to provide the SJRRP with information about reproductive behavior, spawn timing, and habitat use and availability for SRCS. Redd surveys were conducted in Reach 1 of the SJRRA in 2020 to address the following objectives during Chinook Salmon reintroduction:

1) Estimate SRCS natural origin returning (or alternatively, trap and haul hatchery origin returns, and/or released broodstock) spawner abundance within Reach 1 of the SJRRA.
2) Calculate redd size to determine the needed spawning habitat area, among other objectives.
3) Monitor the spatial and temporal distribution of SRCS spawning activity and redd production in Reach 1 of the SJRRA.
4) Document the habitat characteristics of spawning site selection.
5) Document the rate and type (deposition and/or scour) of SRCS redd superimposition.
6) Determine the origin of female SRCS (trap and haul hatchery origin returns, wild returns, or released broodstock) that construct each redd via acoustic detections and/or visual observations of Floy tag colors when possible.
7) Estimate the quality of spawning habitat in Reach 1 by documenting textural facies, fine sediment, and velocity directly upstream of natural redds.
8) Evaluate the temporal and spatial suitability of stream temperatures to support the spawning life stage of SRCS.

2.2 Study Area

The SJRRA is approximately 240 river kilometers (rkm) long and separated into five reaches beginning at Friant Dam and ending at the confluence of the Merced River (Figure 1). The SJRRA is located within the San Joaquin Valley and is characterized by a Mediterranean climate with wet-cool winters and dry-hot summers (Null and Viers 2013). Historically, the San Joaquin

River flowed from the high elevations of the Southern Sierra Nevada Mountain Range, meandered southwest until it reached the Central Valley, continued northwest to the Sacramento-San Joaquin Delta, and emptied into the Pacific Ocean (Galloway and Riley 1999). The San Joaquin Basin is dependent upon annual snowpack and the subsequent meltwater that replenishes Millerton Lake above Friant Dam.

However, extensive agricultural land use within the San Joaquin Valley has subjected the San Joaquin River Basin to water diversions, as well as large-scale groundwater and riparian pumping operations to support agriculture (Galloway and Riley 1999; Null and Viers 2013; Traum et al. 2014). Since the Settlement, the SJRRA has been reliant upon dedicated Restoration Flows from the water stored within Millerton Lake. Restoration flows are determined by the Water Year type, the Restoration Administrator's flow recommendation, and compliance requirements for holding contracts to maintain minimum flows at the downstream end (i.e., at Gravelly Ford) of Reach 1 (SJRRP 2017, Figure 1). Currently, a connected river is available via the Eastside Bypass, restricting volitional passage of SRCS to wetter years when spring floods flow through the Chowchilla Bifurcation Structure.

In Reach 1, flows are conveyed through a moderately sloped incised gravel-bedded channel that is confined by periodic bluffs or terraces. The reach contains off-channel and in-channel mine pits from historic sand and gravel mining operations (SJRRP 2010). Currently, land use within Reach 1 through Reach 5 of the SJRRA is dominated by anthropogenic urban and agricultural developments (Traum et al. 2014).

Based on historical spawning surveys and modeled in-river temperatures, suitable spawning habitat for Chinook Salmon is thought to be restricted to the first 8–11 kilometers of Reach 1 of the SJRRA (Gordon and Greimann 2015). Suitable and selected hydraulic conditions for spawning have thus far been found primarily in gravel and cobble-dominated substrates at depths of 1.5-2 feet (ft) and velocities of 1.5-2 feet/second (ft/sec). These results were based on modeled hydraulic conditions and mapped textural (substrate) facies, combined with observations of fall-run Chinook Salmon redds in Reach 1 and nearby tributaries (Gordon and Greimann 2015). Further assessment of hydraulic conditions and substrate selected for spawning is needed for SRCS in Reach 1, as is an estimate of the quantity and quality of suitable SRCS habitat available within Reach 1 to achieve SJRRP's spawning habitat objectives during reintroduction. To address these needs, SRCS redd, carcass, and emergence surveys were conducted by the SJRRP on the San

Joaquin River in Reach 1 of the SJRRA from below Friant Dam (rkm 431) to the Milburn Ecological Unit (rkm 398; Figure 2).

2.3 Study Specimens

In 2020, the SJRRP studied the spawning activity of trap and haul SRCS and released ancillary adult broodstock SRCS in Reach 1. For visible distinction, trap and haul adults were tagged sub-dermally with different colored and uniquely numbered Hallprint plastic tipped dart fish tags (Hallprint Fish Tags Inc., Australia) on the dorsal fin insertion. Trap and haul SRCS were marked with green and blue dart tags. Tag colors helped with distinguishing trap and haul SRCS from released adult broodstock SRCS and identify when fish were released into Reach 1 of the SJRRA. However, due to restrictions during the COVID pandemic, released adult broodstock SRCS were unable to be tagged.

In addition to the external tags, Vemco (Innovasea Inc., Bedford, Nova Scotia, Canada) V9 69 kHz acoustic tags and Oregon RFID 23 millimeter (mm) half-duplex (HDX) passive integrated transponder (PIT) tags were implanted intra-gastrically with a balling gun. All trap and haul adults were implanted with acoustic and PIT tags. Again, COVID restrictions prevented the SJRRP from acoustic or HDX PIT tagging released adult broodstock SRCS. Acoustic tags were injected with the intent to track behavior and habitat selection throughout spawning season. In concert with acoustic tags, HDX tags were injected with the intent to link individual fish to their successive redd as part of a separate effort by CDFW (Shriver 2015; Shriver 2017). However, all released broodstock were previously tagged as juveniles with full-duplex (FDX) PIT tags to identify individuals while being reared at the Interim SCARF until they were released into the Restoration Area. The FDX tags made it possible to identify released broodstock when they were recovered as carcasses after spawning.

Trap and haul SRCS in 2020 consisted of 14 female, 17 male, and 15 unknown sex that were captured in Reach 5 of SJRRA and transported upstream for successful release into Reach 1. The first two trap and haul adults were released at Camp Pashayan, immediately upstream of California State Route 99 (rkm 389). The remaining 44 were released at Scout Island (rkm 422). Broodstock releases occurred three times in 2020 at Friant Bridge (rkm 267): the first release consisted of 55 females and 57 males, the second in August consisted of 56 females and 62 males, and the third in September consisted of 25 females and 29 males (see Table 3 in Carcass Survey;

Figure 2).

2.4 Survey Effort

Redd surveys were conducted August 31 through November 30, 2020. Surveys were restricted to daylight hours and ideal weather conditions (e.g., without heavy rain). The survey area was divided into three sections to ensure complete spatial coverage from Friant Dam (rkm 431) to Lost Lake (rkm 426), Lost Lake to the Fresno County Sportsmen's Club (rkm 413), and the Fresno County Sportsmen's Club to the Milburn Ecological Unit (rkm 398; Figures 2 and 3). Surveys generally occurred one time per week during the study period. However, the Creek Fire burning in the upper San Joaquin River Watershed at the time, resulted in unhealthy air quality with an Air Quality Index (AQI) ≥ 150. When an AQI ≥ 150 persisted, surveys by drift boat and kayaks were cancelled. Surveys were subsequently completed on foot in areas where spawning has been observed in prior years that were also accessible by land, after AQI reduced below 150.

Surveys conducted from drift boat and kayaks followed protocols from previous sampling years as follows. The drift boat enabled surveys of the thalweg and deep pools; likewise, kayaks were used to help staff survey channel margins and other areas inaccessible to the drift boat. Kayakers paddled ahead and surveyed riffles before guiding the drift boat downstream to minimize disturbance of new and/or ongoing spawning activity. Kayakers traversed upstream of each riffle for an initial inspection of spawning activity before proceeding to the shoreline to walk down the riffle with their kayak for a more thorough visual inspection of spawning activity, areas freshly cleared of periphyton, redds, and carcasses. Areas cleared of periphyton were further investigated to determine if clearing was caused by potential spawning activity or water hydraulics. These areas were documented and observed during successive weeks to see if a pit and defined tailspill developed. Redds were processed according to the methods described in the methods section below.

2.5 Survey Methods

Redds were identified based on freshly exposed substrate cleared of periphyton, a substrate depression into the streambed (pit), and a mound of coarse substrate (tailspill). Redds were given a redd identification number and labeled sequentially to help denote the order of discovery and to estimate emergence timing. Substrate areas that were cleared of periphyton but lacking a tailspill were classified as a test redd and given a test redd identification number. Test redds were monitored during subsequent survey weeks for potential development into a completed redd. If a test redd developed further and had both a pit and a tailspill, it was then given the next sequential redd identification number. After redds were assigned an identification number, GPS location was recorded, a cattle ear tag fastened to a weight was placed adjacent to the pit towards river center and flagging with the redd identification number was attached to riparian vegetation on the nearest shoreline perpendicular to flow. These markers were used to help locate surveyed redds each week to monitor how they changed throughout the survey period, identify superimposition, and locate suitable redds for emergence trap installation. Locations were recorded with an EOS Arrow-100 GNS sub-meter GPS paired with an iPhone 7 and plotted in real time in ArcGIS Online. Velocity and depth measurements were taken with an OTT MF Pro Flow meter and top set rod. Pre-redd depth and velocity measurements were taken undisturbed substrate upstream of the redd pit. Mean water column velocity was measured 60 percent below the surface of the water if water depth was < 1 meter (m). If water depth was > 1m, flow measurements were recorded at both 20 percent and 80 percent below the water surface and averaged. Pit depth measurements were taken at the deepest part of the pit (pit depth) and the tailspill minimum depth was taken at the shallowest point of the tailspill (tailspill crest). Measurements of pit and tailspill length and width and measurements of the distance between tailspill and crest were taken to the nearest 0.01 m (Figure 3).

Habitat characteristics for each redd was also recorded and included channel type, channel position, and habitat type. Channel type was categorized as either main channel or side channel, where the main channel was defined as the cross-section of the wetted river channel that contained the majority of the flow (i.e., greater than 50 percent of the flow) and side channel contained the minority (i.e., less than 50 percent of flow). Channel position while facing downstream was used to document where each redd was within the river (river right, river left, or river center). Habitat type was categorized based upon depth, velocity, and water surface turbulence and consisted of five categories (glide, riffle, run, pool, and backwater). Glides were shallow slow flowing (< 0.5 m depth, < 0.3 meters/second [m/s]) stretches with little or no surface turbulence, riffles were shallow fast (< 0.5 m depth, ≥ 0.3 m/s) reaches, with turbulent water and some partially exposed substrate, runs were deep and fast (≥ 0.5 m depth, ≥ 0.3 m/s) flowing reaches with little surface agitation and no major flow obstructions, pools were deep (≥ 1 m depth), low-velocity areas of water (< 0.3 m/s) with a smooth surface, and backwaters were distinct out-pockets along river margins that were relatively shallow (< 0.5 m depth) and had slow moving, or stagnant water (< 0.3 m/s).

Redds were assigned an age to monitor degradation and superimposition. The remaining redds were aged weekly on a 1–5 scale. An Age 1 redd had clean rocks with no defined pit or tailspill. This was considered a test area or a redd under construction. Age 2 redds were clearly visible with clean substrate and a well-defined pit and tailspill. Age 3 redds had aged substrate, flattened tailspill, fine sediment deposition in the pit, and/or algal growth. Age 4 were old and difficult to discern, and Age 5 redds had no visible traces of a redd, only the marker denoted the location of a previously identified redd. Superimposed redds that had new substrate material in the redd area were documented as being impacted by deposition, whereas preexisting redd areas that had features excavated by a new spawning event were considered to have been scoured. If a preexisting redd experienced both, scour and deposition was recorded. After an observation of superimposition, redds were no longer aged for degradation because superimposition inhibited the accuracy of correct aging, and in some cases tailspill location.

To document the streambed substrate in spawning areas selected by salmon, substrate composition and relative substrate size were visually assessed in a 1-m^2 area directly upstream of incision of the pit of each redd (pre-redd area). Textural facies in pre-redd areas were classified according to methods by Buffington and Montgomery (1999). The percent of fine sediment (sand, ≤ 2.0 mm) in the pre-redd area was recorded. However, if the composition of sand was < 5 percent, then percent of fine sediment was simply recorded as < 5 percent. Classification was made according to the proportional composition of the grain sizes (i.e., sand [< 2.0 mm], gravel [2.0 – 63 mm], and/or cobble [> 63 mm]) in ascending order from least abundant to most abundant. For example, if an area had 15 percent sand, 30 percent cobble, and 55 percent gravel it would be recorded as SCG, where S is sand, C is cobble, and G is gravel. Grain size was confirmed with a gravelometer by measuring the b-axis, where the a-axis is the longest length measurement of each grain and the b-axis is the second longest length (i.e., intermediate axis). If a grain size comprised ≤ 5 percent, it was omitted from the textural facies classification (i.e., CG). If the most dominant grain size was ≥ 90 percent, only this dominant grain size was included (i.e., G).

2.6 Results

In 2020, 75 redds were identified and tracked. From these 75 redds, 73 were documented as SRCS and 2 were determined to be from other species and were not included within the results reported. A total of 43 of these SRCS redds were measured throughout Reach 1 of the SJRRA from the 150 confirmed female (136 broodstock and at least 14 trap and haul hatchery origin return) SRCS that were released. The remaining 30 redds were not measured because they were either superimposed upon or multiple females spawned in the same area for successive weeks (see Figure 4 inset), preventing the measurement of redds prior to degradation. In 2020, 56 redds were between Friant Dam (rkm 431) and Lost Lake (rkm 426), 15 redds were between Lost Lake and the Fresno County Sportsmen's Club (rkm 414), and 2 redds were between the Fresno County Sportsmen's Club and the Milburn Ecological Unit (rkm 398) (Figure 4). SRCS redd distributions in 2020 were similar to previous years with the majority of redds created between Friant Dam and Lost Lake, followed by Lost Lake to the Fresno County Sportsmen's Club, and the Fresno County Sportsmen's Club to the Milburn Ecological Unit (Demarest et al. 2021). Spawning occurred from September 9 through November 30, 2020 (Figure 5). Similar to 2019, the temperature at the Highway 41 (H41) California Data Exchange Center Station (CDEC, http://cdec.water.ca.gov) increased above the upper critical spawning temperature (17 degrees Celsius [°C]) until August 20 and then rose again above the upper critical spawning temperature from August 25 through August 30, 2020 (Figure 6). Water temperatures remained below the critical spawning temperature at Friant Water Quality (FWQ) and San Joaquin River Below Friant (SJF) throughout the observed spawning season. River flow was generally around 400 cfs during the spawning season, as recorded by CDEC gages at SJF and H41 but decreased below 350 cfs by February 1 (Figure 7).

Superimposition was evident at 5 of the 73 SRCS redds in 2020. Deposition was observed at three superimposed redds with substrate from a newly constructed redd deposited onto the pit or tailspill. The remaining two redds had the pit or tailspill scoured by a newly constructed redd. Superimposition was only observed on 6.9 percent of redds in 2020, less than the SJRRP population objective threshold of 10 percent (2018). Mean redd area for the 43 measured redds constructed in 2020 was 4.8 m^2 with standard deviation of 2.0 m (Table 1). Compared to redds from 2019, redd area for 2020 redds was significantly smaller based on a Wilcoxon rank sum W test ($W = 3908$, $p < 0.001$; Figure 8). These 43 redds occupied an area of 205.8 m^2, which suggests that SRCS used approximately 350.4 m^2 for spawning in 2020.

In 2020, most spawning (50.1 percent) occurred where gravel was the dominant textural facie, similar to 2019 (Figure 9). However, 34.1 percent of redds were constructed where cobble was the most dominant textural facie, unlike 2019, where 18.8 percent of redds were constructed in areas where cobble was the most dominant. Spawning in habitats with a higher surface sand content was less prevalent in 2020 (15.9 percent) than in 2019 (31.1 percent) (Figure 9). Redd habitat selection during 2020 was predominately within runs (47.9 percent), glides (41.1 percent), and riffles (9.6 percent) with only a small proportion detected in pools (1.4 percent) (Table 2). The number of redds observed in glides and runs during 2020 was much greater than that detected in 2019 (Table 2). A lower percentage of redds were observed in riffles in 2020 (9.6 percent) than in 2019 (38.8 percent).

2.7 Discussion

For the 2020 field season, the redd survey documented 73 SRCS redds, with most redds observed between Friant Dam and Lost Lake. These 73 redds were created from 330 released adult SRCS. The SJRRP Fisheries Framework (2018) sets a population objective of 2,500 hatchery origin SRCS spawners and 500 natural origin SRCS spawners in the SJRRA during the Recolonization Phase. Once major passage impediments are remedied through constructed fish passage projects to enable volitional passage of migrating adult SRCS, this objective may become more achievable. Temperatures that exceeded the upper critical spawning threshold in August around Highway 41 may have limited spawning to areas upstream of this site; in 2020, most redds were found between Friant Dam and Lost Lake.

Physical characteristics and pre-redd substrate composition assessments were generally consistent with natural SRCS redds observed in Clear Creek and Butte Creek, California (Giovannetti and Brown 2008; McReynolds et. al. 2005), although 2020 spawners built proportionally fewer redds in sand-dominant substrates and more redds in cobble-dominant substrates than their 2019 counterparts. The selection of less sandy spawning sites and lower redd superimposition rate for 2020 versus 2019 redds may indicate less competition for higher quality habitat in 2020. There were fewer spawners in the Restoration Area in 2020 than in 2019. As a proxy, there were approximately one-quarter of the carcasses recovered in 2020 compared to 2019 (see 4.0 Carcass Survey). Another possibility that we cannot preclude given the scope of this study is that there was less available sandy habitat in 2020 than in 2019.

Mean size of measured redds was smaller in 2020 than that observed in 2019 when wet conditions enabled larger, hatchery-return salmon to volitionally migrate to SJRRA spawning grounds (see Demarest et al. 2021). Studies support that larger female fish tend to produce larger redds (Burner 1951, Ottaway et. al, 1981, Neilson and Banford 1983). Hughes and Murdoch (2017) also suggest even a short time of juvenile rearing in a hatchery may be associated with a reduction in redd size and excavation depth. Thus, it is unclear whether differences in mean redd sizes between the two years is due to differences in female fish length, spawner origin (primarily volitional hatchery origin returns in 2019 versus primarily released broodstock in 2020), or both (see 4.0 Carcass Survey). Unfortunately, we had difficulty determining the spawner identity (i.e., trap and haul hatchery origin return or released broodstock) for each redd in 2020. Several redds were clustered together near Friant Dam, prohibiting individual identification and also preventing the measurement of every redd in Reach 1, although close to 60 percent of redds were able to be measured. In addition, COVID measures prevented adequate tagging of released broodstock spawners, but in the future, increased tagging efforts could help tie spawner groups to individual redds. The Interim SCARF may consider reevaluating husbandry practices, including feeding, to determine if hatchery practices can help encourage the expulsion of identifying PIT tags into redds during egg laying.

To accomplish SJRRP goals, continued investigation of spawning activity is crucial to identify which physical and environmental variables affect spawning site selection. Managing Reach 1 water temperatures through Restoration Flows and cold-water pool releases, coupled with gravel augmentation, may be the first steps needed to help create more suitable spawning habitat in support of SRCS natural spawner abundance and juvenile production goals.

2.8 Tables

Table 1. Spring-run Chinook Salmon redd characteristics observed within Reach 1 of the San Joaquin River Restoration Area for sampling years 2019 and 2020.

	2019			2020		
	n=122			*n*=43		
Variable	Mean	SD	Range	Mean	SD	Range
Redd Area (m^2)	9.1	5.5	1.0-27.5	4.8	2.0	0.9-19.7
Tailspill length(m)	2.6	1.1	0.8-6.5	1.6	0.7	0.6-3.8
Tailspill Width(m)	1.9	0.7	0.6-4.0	1.3	0.5	0.5-2.9
Tailspill Area (m^2)	5.4	3.6	0.6-19.5	2.4	2.0	0.5-11.0
Pit Length(m)	1.7	0.6	0.6-4.0	1.3	0.5	0.6-2.8
Pit Width (m)	2.1	0.9	0.5-5.9	1.6	0.7	0.6-3.3
Pit Area (m^2)	3.7	2.4	0.4-13.4	2.4	1.9	0.4-8.7
Pit Excavation Depth (m)	0.1	0.1	0.0-1.3	0.1	0.1	0.0-0.3
Depth Upstream Pre-Redd (m)	0.5	0.2	0.1-1.2	0.6	0.2	0.2-1.0
Pre-Redd Velocity (m/s^2)	0.6	0.3	0.00-1.5	0.6	0.2	0.2-1.1

Table 2. Summary of spring-run Chinook Salmon redd spawn site habitat classification (riffles, runs, glides, and pools) for the San Joaquin River Restoration Area in 2019 and 2020.

	2019	2020
Redd Total	209	73
Riffles	38.8%	9.6%
Runs	36.4%	47.9%
Glides	23.0%	41.1%
Pools	1.9%	1.4%
Undocumented	-	-

2.9 Figures

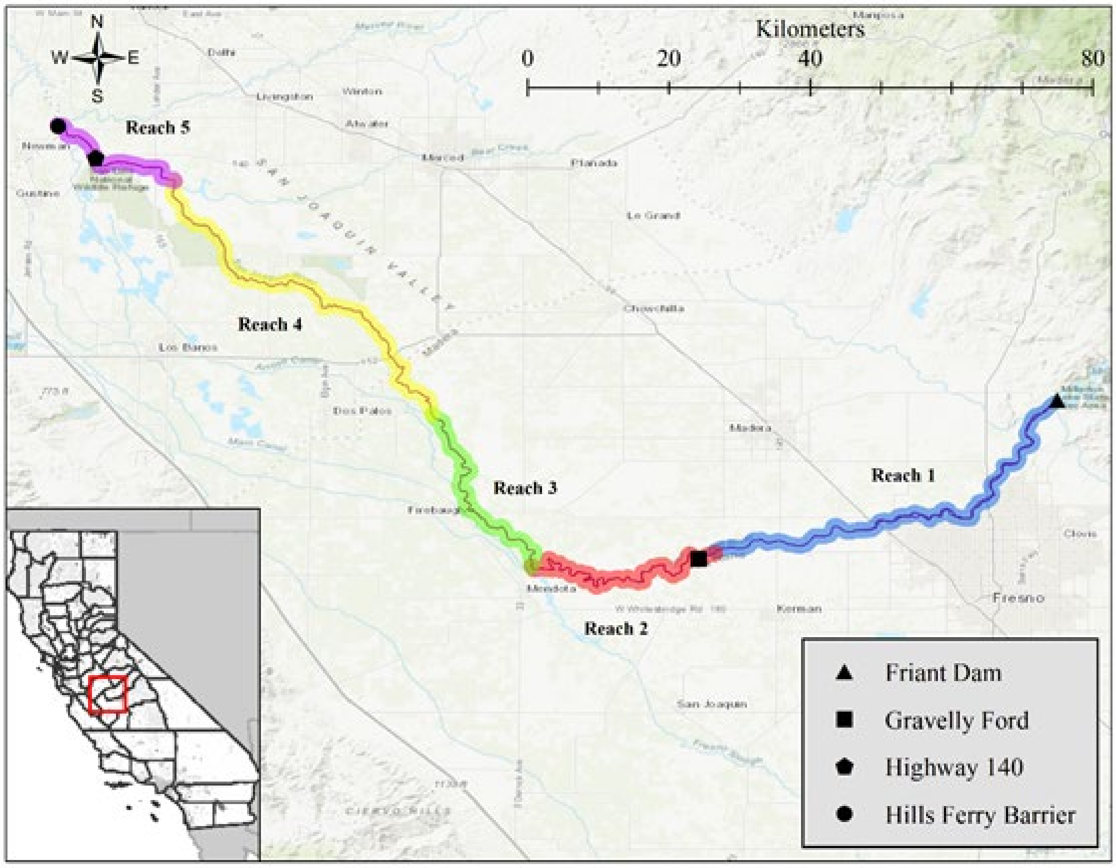

Figure 1. The San Joaquin River Restoration Area (SJRRA) within the San Joaquin River, California. The SJRRA is separated into five reaches, which are delineated using labels and unique colored lines. The five reaches of the Restoration Area span from Friant Dam (rkm 431) to the confluence of the San Joaquin River with the Merced River (rkm 190).

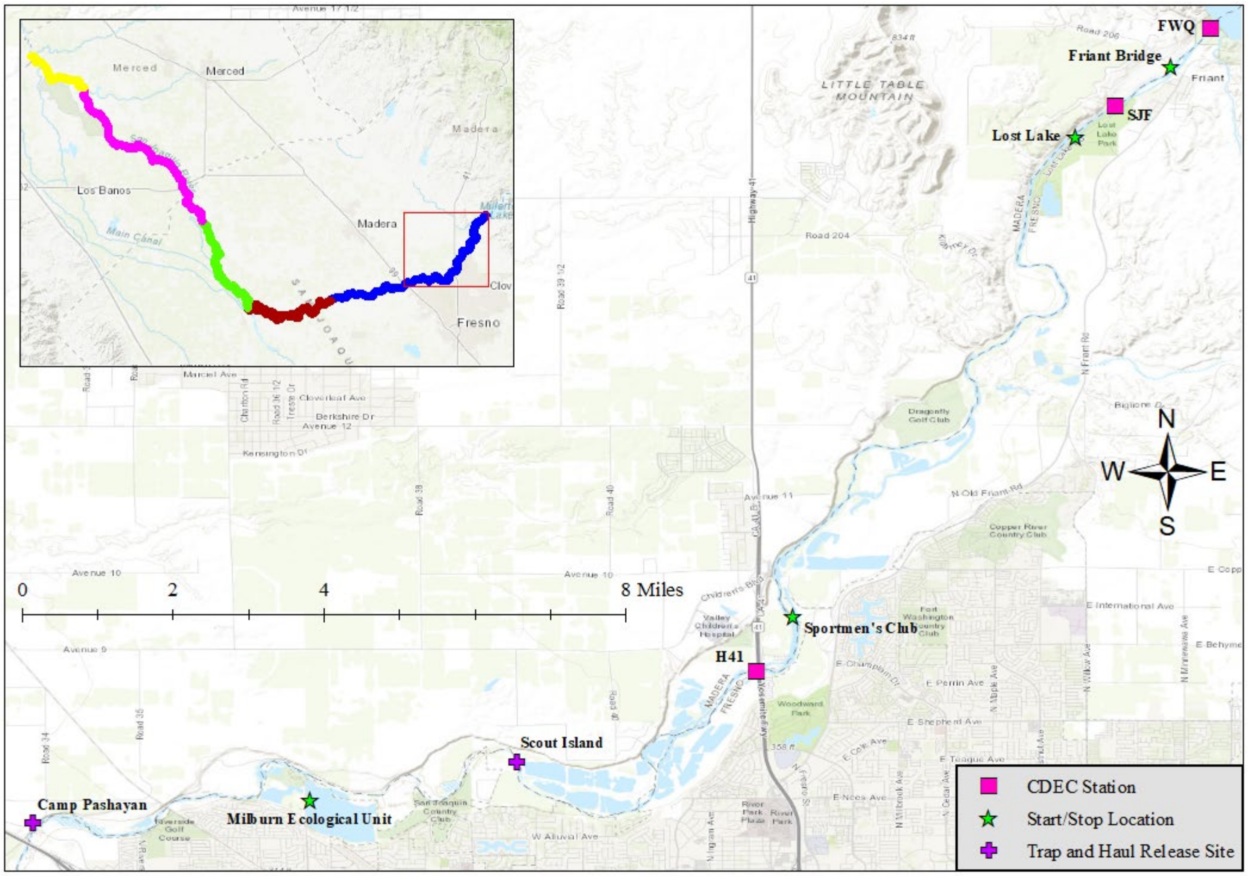

Figure 2. The locations of trap and haul (March 16 through May 23, 2020) and broodstock (June 4 through September 2, 2020) spring-run Chinook Salmon adults release sites in Reach 1 of the San Joaquin River Restoration Area. Trap and haul release sites are labeled with purple crosses, the beginning and end of the survey reaches for redd and carcass monitoring are labeled with green stars, and California Data Exchange Center (CDEC, http://cdec.water.ca.gov) temperature gages are labeled with pink squares. Ancillary adult broodstock releases occurred at Friant Bridge in Reach 1.

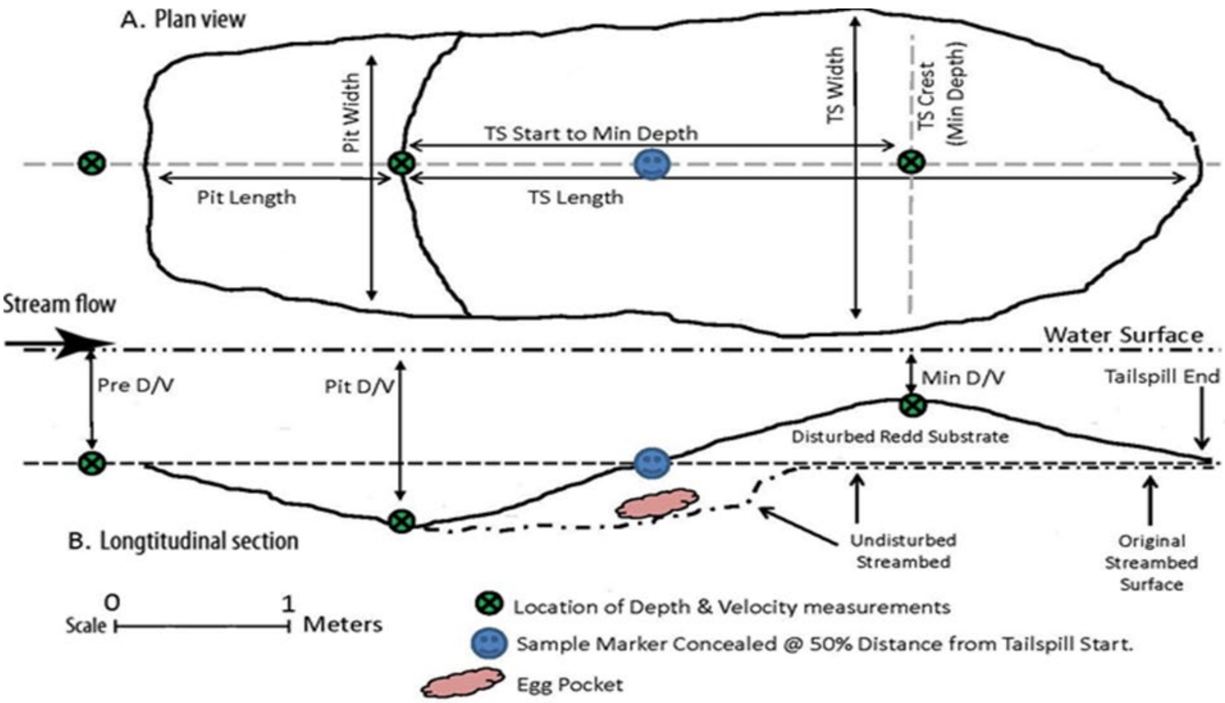

Figure 3. Plan view (A), longitudinal view (B), and corresponding measurements and features of a typical Chinook Salmon redd. Inspired by Burner 1951.

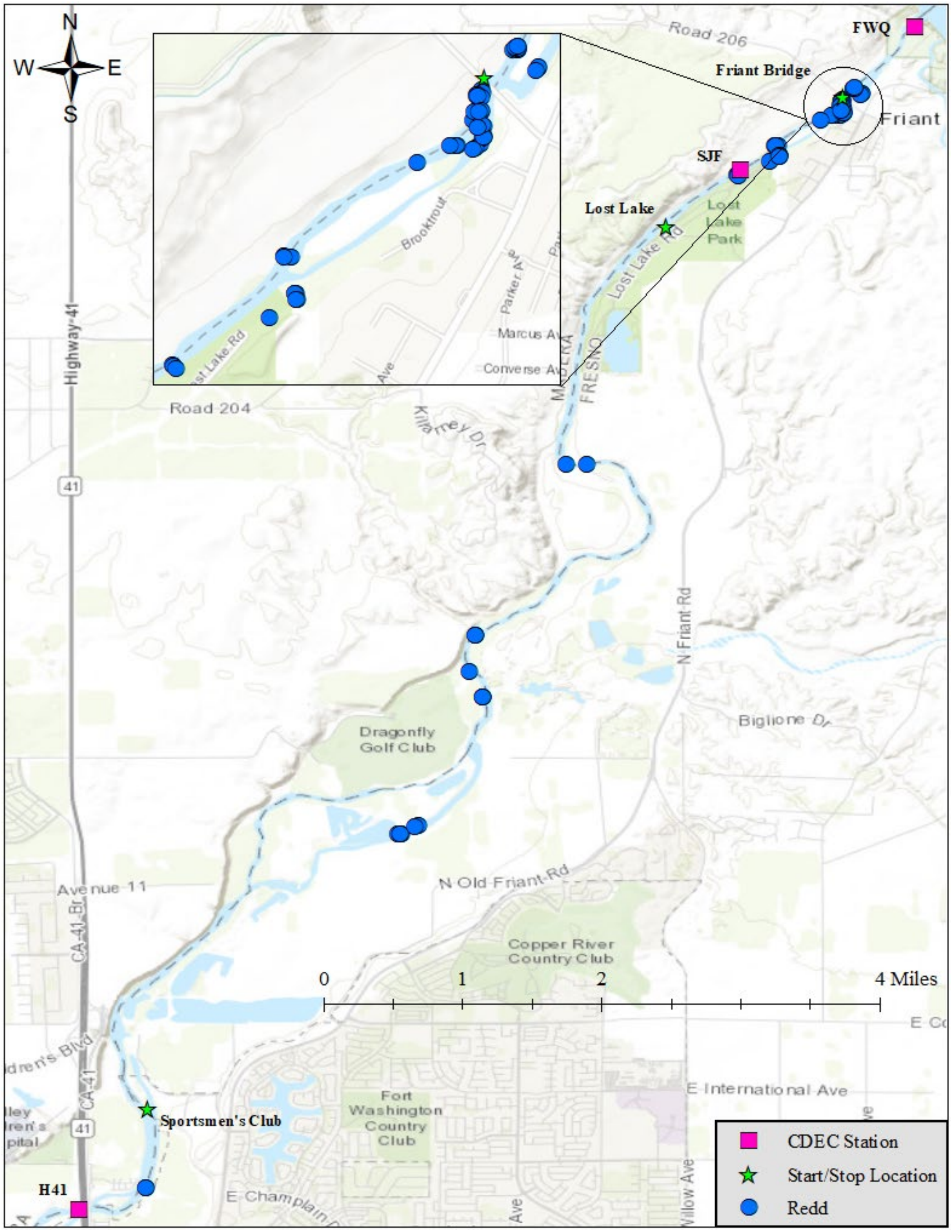

Figure 4. The locations of spring-run Chinook Salmon redds (September 15 through November 30, 2020) in Reach 1 of the San Joaquin River Restoration Area. The beginning and end of the survey reaches for redd and carcass monitoring are labeled with green stars, and California Data Exchange Center (CDEC, http://cdec.water.ca.gov) temperature gages are labeled with pink squares. Monitoring was conducted in three survey reaches: Friant Dam (rkm 431) to Lost Lake (rkm 426), Lost Lake (rkm 426) to Fresno County Sportsmen's Club (rkm 414), and Fresno County Sportsmen's Club (rkm 414) to Milburn Ecological Unit (rkm 398; not pictured).

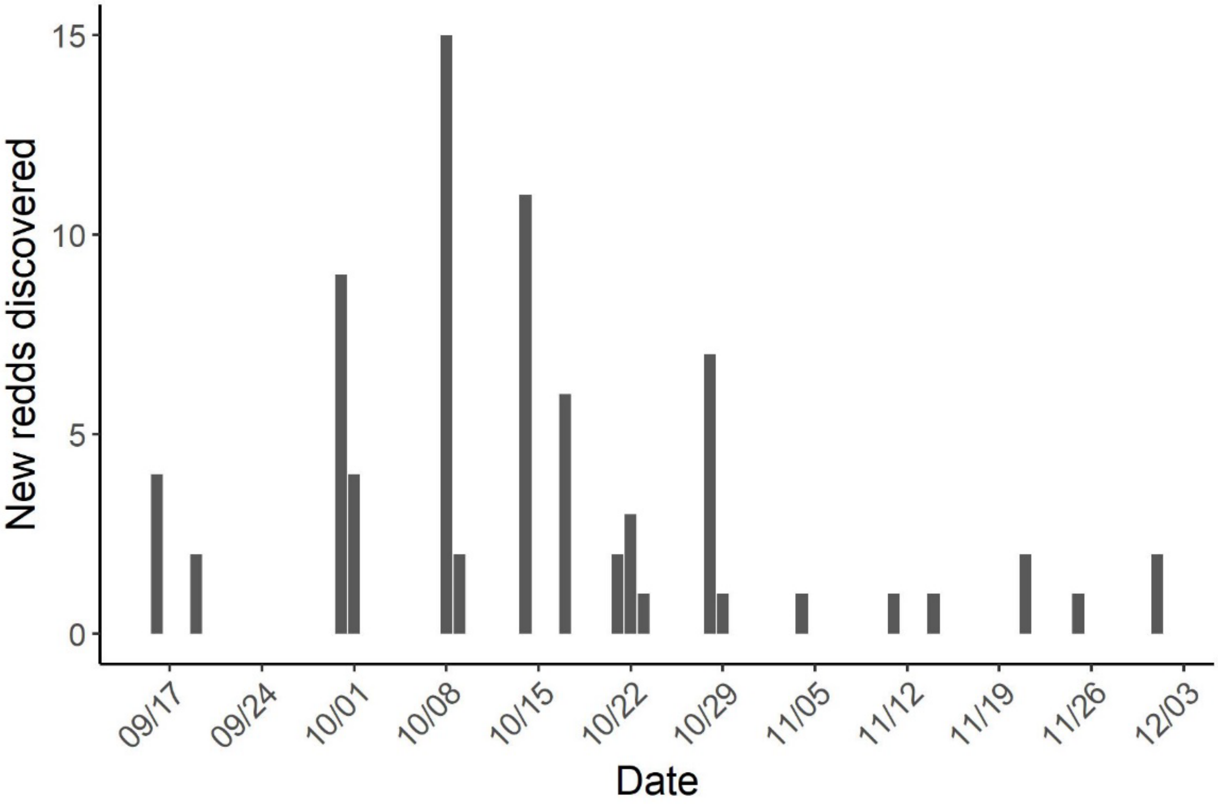

Figure 5. Summary of the total number of spring-run Chinook Salmon redds detected each survey day in Reach 1 of the San Joaquin River Restoration Area during 2020.

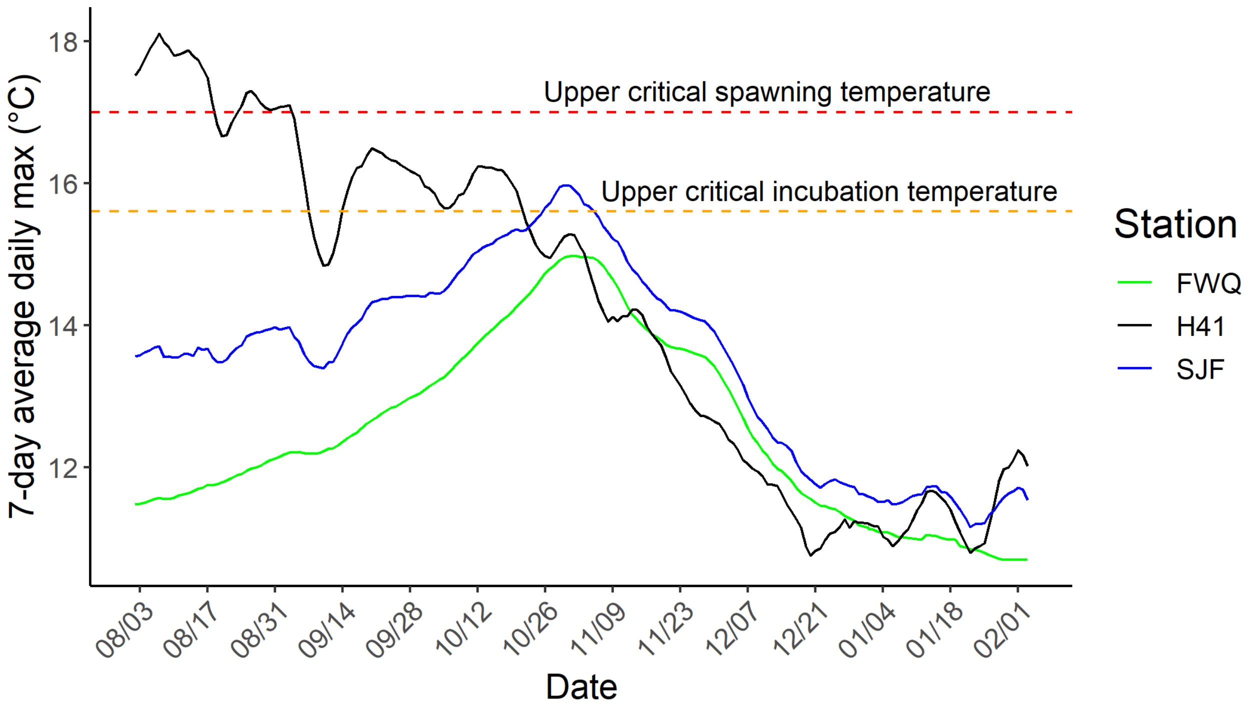

Figure 6. Seven-day average of daily maximum temperatures (°C) recorded in the San Joaquin River downstream of Friant Dam (rkm 428 SJF and rkm 430 FWQ) and below Highway 41 (rkm 410; H41) from August 2020 to February 2021. Temperature data were obtained from the California Data Exchange Center (CDEC, http://cdec.water.ca.gov). The upper critical spawning temperature threshold for Chinook Salmon spawning is indicated by the red dashed line at 17 °C, and the upper critical incubation temperature threshold is denoted by the orange dashed line at 15.6 °C (SJRRP 2010). See text for more information.

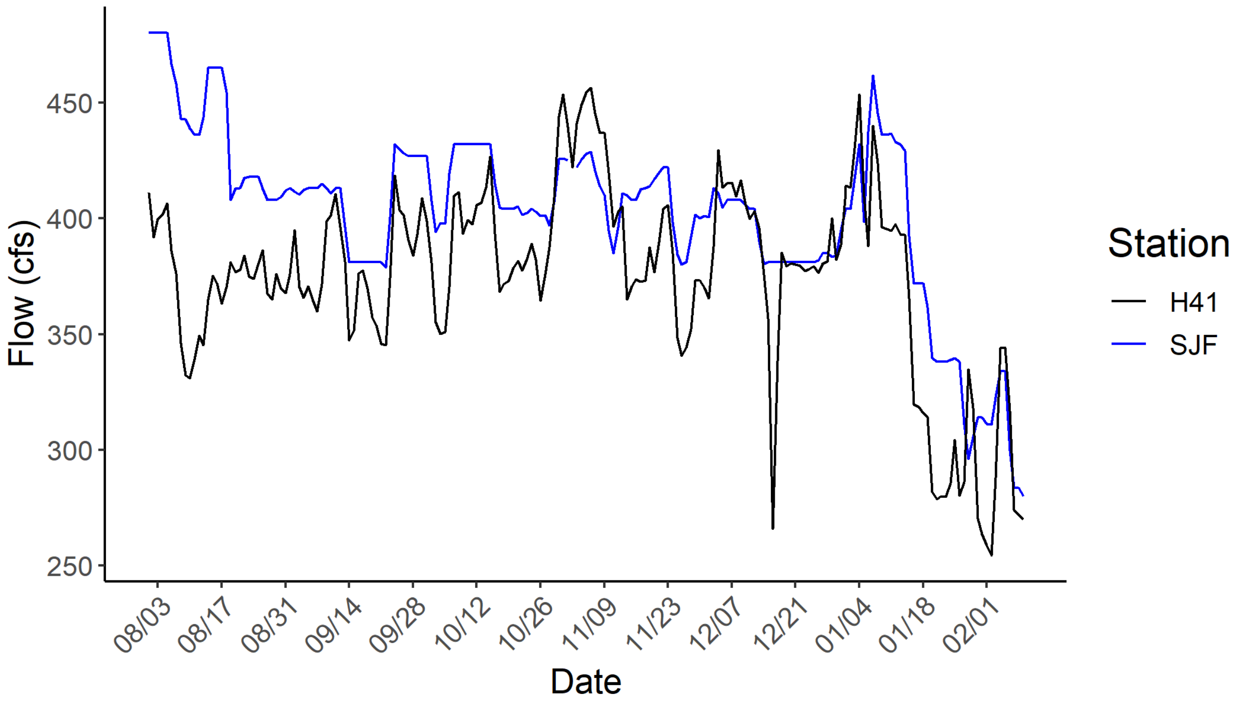

Figure 7. Mean daily river flow (cfs) recorded in the San Joaquin River near Friant Dam (rkm 430; SJF) and Highway 41 (rkm 410, H41) August 2020 through February 2021. Flow data were obtained from the California Data Exchange Center (CDEC, http://cdec.water.ca.gov).

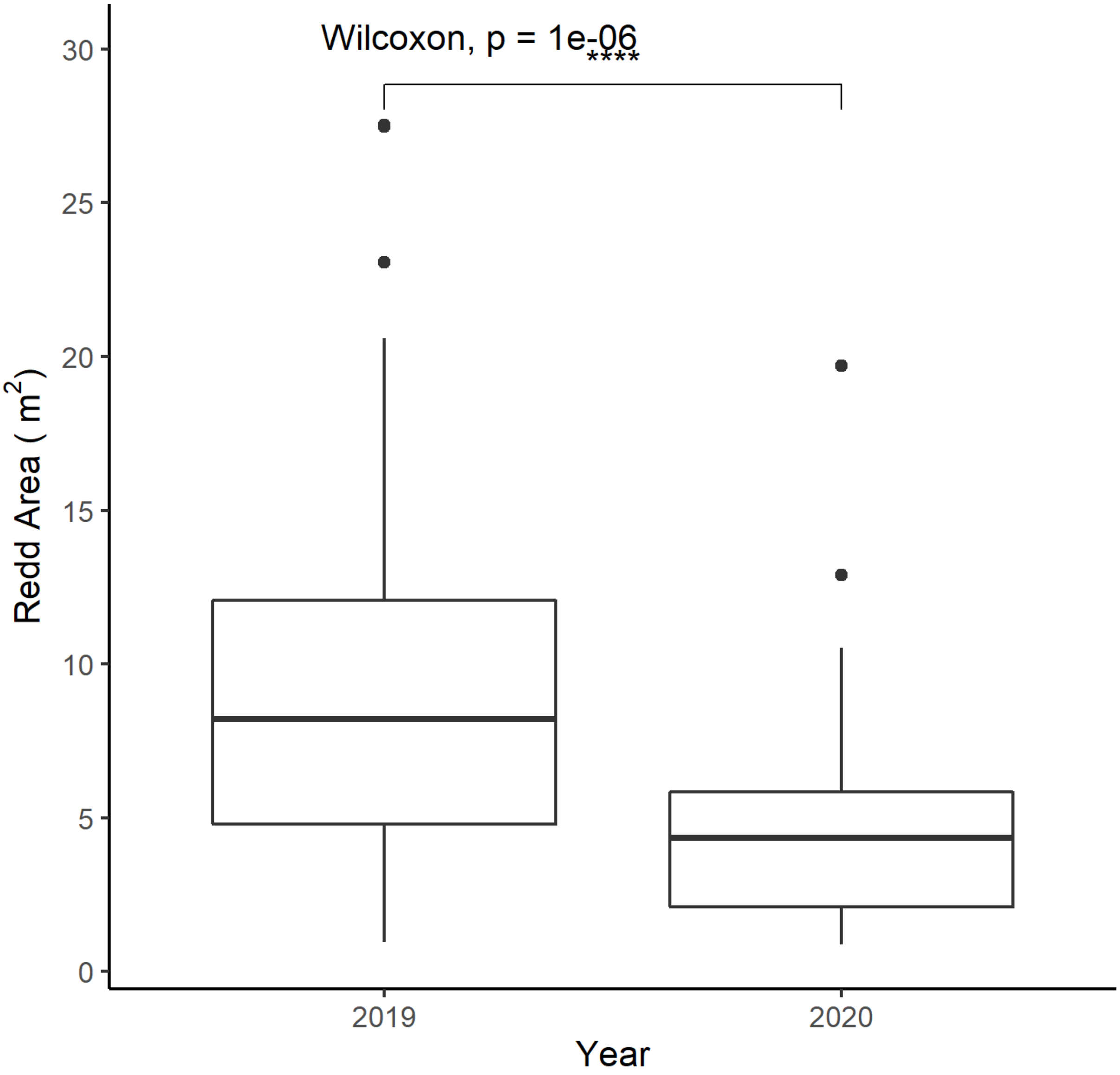

Figure 8. Boxplot of redd areas (m^2) for 2019 to 2020, with the horizontal black line showing the median individual redd area. The hinges include inter-quartile range, the lower whisker extends from the smallest value to the first quartile, the upper whisker extends from the third quartile to 1.5 times the inter-quartile range, and the dots above are outliers. There was a significant difference between years 2019 and 2020, as indicated by **** ($p < 0.0001$).

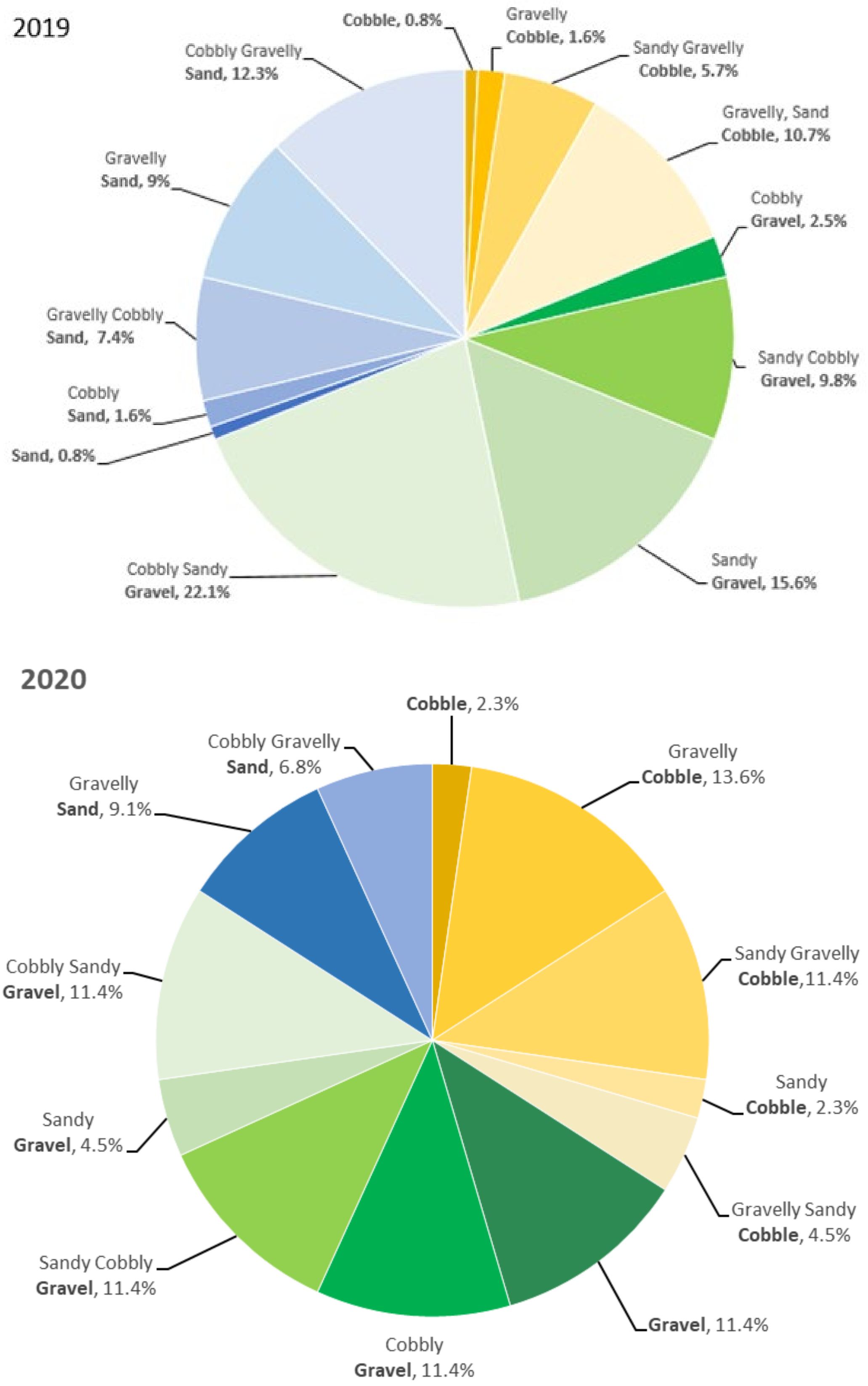

Figure 9. Percent of redds within each facies category for 2019 (*n* = 209) and 2020 (*n* = 43).

3.0 Carcass Survey

3.1 Introduction

Since Chinook Salmon are semelparous, salmon carcass recoveries allow fisheries biologists to document the sex, spawn status, age, and origin of individual salmon, while also enabling the collection of biological samples for additional studies (Johnson et al. 2007). Similar to redd surveys, carcass surveys for SRCS in the SJRRA began in 2016. The SRCS carcasses recovered during carcass surveys are used to inform the following objectives during reintroduction:

1) Estimate the sex ratio of spawning SRCS.
2) Assess the biological attributes including spawning status and condition (e.g., carcass decay and disease).
3) Determine the spawning age distribution from coded wire tags (CWT).
4) Describe the spatial trends of carcasses recovered within the SJRRA.

Additionally, SRCS carcasses recovered during these surveys provide the SJRRA with the opportunity to collect genetic samples and eye lenses and otoliths. Genetic samples are used for parentage analysis and eye lenses and otoliths support analyses of isotope microchemistry to identify juvenile rearing habitat outside the SJRRA, as well as conditions experienced within the ocean.

3.2 Methods

After carcass recovery, the origin of carcasses encountered during surveys were categorized based on the presence of external dart tags, PIT tags, and acoustic tags. Carcasses discovered are identified as trap and haul or broodstock adult releases based on their internal or external tags. All trap and haul adults were implanted with both acoustic and PIT tags. Carcasses discovered with external dart tags were identified as a trap and haul adult SRCS. If external dart tags were absent but PIT tag readers detected a FDX tag, carcasses were identified as a broodstock released adult SRCS. All released broodstock adults were implanted with FDX tags. If carcasses recovered had no tags present, these individuals were classified as a naturally returning SRCS, until they were later confirmed as broodstock by the CWT. Coordinates for each carcass, and the channel type, channel position, and habitat type at carcass recovery location were recorded.

Carcasses were classified by level of decomposition (fresh, decayed firm, decayed soft, or skeleton). Decomposition was designated by eye clarity, blood remaining in the gills, and the state of tissue decay. Carcasses with clear eyes and blood remaining in the gills were classified as “fresh”, while fish with cloudy eyes and no blood in the gills were classified as “decayed firm” or “decayed soft”. Muscular tissue of carcasses categorized as “decayed firm” had stiff tissue whereas carcasses categorized as “decayed soft” had a less firm muscular tissue but were mostly intact. Fish carcasses that were more decayed, had a substantial quantity of missing muscular tissue, and were falling apart were classified as a skeleton.

Sex for each carcass was established by dissection, based on the presence of testes or ovaries/eggs in the peritoneal cavity. Spawn status for female carcasses was determined by the approximate quantity of eggs remaining (≤ 1,200 for spawned, 1,201 to 2,800 for partially spawned, or ≥ 2,801 for unspawned). Spawn status categories were established based on 30, 30–70, and ≥ 70 percent of average fecundity (4,000) recorded from the Interim SCARF and the FRFH egg takes. If a carcass was too decayed, sex was recorded as unknown. Sex, spawn status, fork length (FL), and post orbital hypural length (POHL) measured to the nearest millimeter, were documented. The presence or absence of an adipose fin was recorded, with lack of an adipose fin indicating hatchery origin. Images of all carcasses were taken with the fish lying on its right side by a measuring tape and identification tag (Figure 10).

Heart tissue samples of all trap and haul and suspected volitional returning SRCS carcasses were collected for parentage analysis in 2020. Heart tissue samples approximately 1 square centimeter (cm^2) were collected by dissection of the pericardial cavity. Samples were stored in 2 milliliter (ml) screw cap vials filled with 70 percent ethanol, and provided to the NOAA Southwest Fisheries Science Center for analysis (results pending). Heads and tags of all carcasses were collected and preserved. After the survey season, CWTs, otoliths, and eyes were extracted and preserved from heads. CWTs were read with a Magniviewer Coded Wire Tag Microscope to provide the CWT release code. Release codes were then queried within SJRRP records to identify origin, brood year, release date, and release location as well as the total number of fish per release group. Otoliths and eyes were extracted for isotope analysis to identify juvenile salmon rearing habitat outside the SJRRA. Results from isotope analyses are not yet available.

3.3 Results

During 2020, 48 SRCS carcasses were recovered and consisted of 38 broodstock and 10 trap and haul hatchery origin returns (Table 3). There were 39 carcasses recovered within the SJRRA from Friant Dam to Lost Lake, eight from Lost Lake to the Fresno County Sportsmen's Club, and only one recovered from the Fresno County Sportsmen's Club to the Milburn Ecological Unit (Figure 11). From the SRCS released in the SJRRA, 13 percent of broodstock and 22 percent of trap and haul hatchery return carcasses were recovered.

Broodstock carcasses (*n*= 38) included a sex ratio of 1:2.17 (M:F), and nearly all females (96 percent) had fully spawned. Trap and haul hatchery origin return carcasses recovered (*n* = 10) included a sex ratio of 1.2:1 (M:F), with all females fully spawned (Table 3). Therefore, the pre-spawn mortality was only 4 percent for broodstock with no trap and haul hatchery origin return pre-spawn mortalities recovered. Mean FL for trap and haul hatchery returns ranged from 117 to 190 mm larger than broodstock carcasses (Table 3). This corresponded to differences in mean POHL of carcasses that ranged from 79 to 118 mm larger for trap and haul hatchery origin returns versus released broodstock SRCS carcasses. No external evidence of disease was noticed.

From the 48 SRCS carcasses recovered, 96 percent were adipose clipped and 73 percent were identified to have a CWT. Two of the 48 CWTs were lost during extraction and 11 were not present or recovered for subsequent identification. The remaining 35 carcasses consisted of two groups, trap and haul hatchery origin returns (*n* = 8) which were captured in Reach 5 and released into Reach 1 or broodstock (*n* = 27) that were released directly from the Interim SCARF into Reach 1. Trap and haul hatchery origin returns were from brood years 2016 and 2017, whereas broodstock were from brood years 2015 through 2017 (Table 4). Age classes of carcasses recovered were 45.8 percent age-3, 22.9 percent age-4, 4.2 percent age-5, and 27.1 percent were unknown because CWTs were lost or absent during extraction.

3.4 Discussion

As with the distribution of redds in 2020, most carcasses were found between Friant Dam and Lost Lake. Less than one-quarter of SRCS released as either trap and haul hatchery origin returns or broodstock releases into Reach 1 of the SJRRA were recaptured as carcasses. Murdoch et al. (2010) estimated an overall carcass recovery rate of 26 percent for female SRCS and 15 percent for male SRCS in Washington State during a carcass mark-recapture survey. Like Murdoch et al. (2010), we found that the sex ratio of SRCS carcasses recovered in the SJRRA was approximately 1:2 (M:F; for both broodstock and trap and haul hatchery return groups). The higher recovery of females than males as carcasses, despite an overall sex ratio of close to 1:1 (M:F) of mature fish released, does not necessarily indicate that proportionally fewer males participated in successful spawning. Instead, studies on SRCS by Murdoch et al. (2009) support that sexually dimorphic behavior may result in the recovery of more female than male SRCS carcasses. They suggested that behavior of female SRCS generally includes the construction of a redd and nest guarding until senescence, while males may spawn with multiple females but begin to drift downstream when their energy is depleted. In contrast, a salmon escapement study on the Lower American River recovered a greater proportion of males (59 percent) than females (41 percent) during carcass surveys in 2016 through 17 (Phillips and Mamola 2017). It is possible that the several deep pools located below spawning riffles in the San Joaquin River may have made it more difficult to recover downstream drifting male SRCS carcasses.

To date SRCS broodstock donor sources have all been collected from FRFH (typically as eggs) and reared for maturity at the Interim SCARF or Satellite Incubation and Rearing Facility (SIRF) immediately below Friant Dam for juvenile and yearling production releases or released as broodstock in excess of hatchery use. As a result, in 2020 all carcasses containing a CWT originated from the FRFH or SCARF (Table 4). The Fisheries Framework (SJRRP 2018) calls for a diversity of adult age classes to contribute to the San Joaquin River SRCS population. This guidance document suggests that the age of return measured at the hatchery should be 3 or more-year classes, with a minimum 10 percent of each of the following age classes: 2, 3, 4-year-olds. The carcass survey found no 2-year-old spawners, but more than 10 percent of age 3- and 4-year-olds and even a small percentage of 5-year-olds. However, it should be noted that the SJRRP's population objective for spawning age class diversity may focus on those fish contributing to the hatchery broodstock, rather than on those spawning in the river.

Individual trap and haul carcasses were of greater length overall than broodstock carcasses for SRCS recovered in the SJRRA. The increased size of trap and haul carcasses compared to broodstock carcasses was also observed in 2019 (Demarest et al. 2021). Studies have found that higher-quality diets available during marine residency of juvenile Chinook Salmon have been correlated to improved juvenile body condition, growth, survival, and subsequent increased abundance of returning adults one year later (Beamish and Mahnken 2001; Wells et al. 2012). If improved juvenile growth and body condition also translate to greater adult condition and individual size, then larger ocean-going SRCS individuals could produce larger and more fecund redds. The evidence here continues to point to the importance of the ocean-rearing phase for growth of SRCS.

3.5 Tables

Table 3. Summary of count, sex, and spawn status for successfully released broodstock and trap and haul hatchery origin return adult spring-run Chinook Salmon, and subsequent carcasses recovered in Reach 1 of the San Joaquin River Restoration Area in 2020. One trap and haul hatchery origin return carcass was categorized with an unknown gender due to degradation.

	Released Broodstock		***Trap and Haul Hatchery Origin Returns***		
	Female	Male	Female	Male	Unknown
Fish Released	136	148	14	17	15
Carcasses Recovered	26	12	6	3	1
% Recovery	19%	8%	43%	18%	7%
Mean Fork Length mm (SD)	545 (76)	572 (95)	674 (109)	762 (67)	662 (0)
Mean Post Orbital Hypural Length mm (SD)	466 (62)	468 (73)	578 (99)	586 (50)	545 (0)
% Unspawned	4%	-	0%	-	-
% Spawned	96%	-	100%	-	-

Table 4. Summary of Coded Wire Tag (CWT) codes, hatchery origin, brood year, and sex of trap and haul hatchery return and broodstock spring-run Chinook Salmon carcasses recovered in 2020 in Reach 1 of the San Joaquin River Restoration Area. All carcasses recovered originated from the Feather River Fish Hatchery (FRFH) or Interim Salmon Conservation and Research Facility (SCARF) and then were released by San Joaquin River Restoration Program.

			Trap and Haul Hatchery Origin Returns			***Released Broodstock***		
CWT Code	Hatchery Origin	Brood Year	Male	Female	Unknown	Male	Female	Unknown
60514	FRFH	2015	-	-	-	1	1	-
61406	FRFH	2016	-	1	1	-		-
61421	SCARF	2016	-	-	-	2	6	-
61423	SCARF	2016	1	-	-	-	-	-
61437	SCARF	2017	-	2	-	-	-	-
61439	SCARF	2017	1	2	-	-	-	-
61442	SCARF	2017	-	-	-	2	14	-
61445	SCARF	2017	1	-	-	-	-	-
No CWT		-	1	1	-	6	2	1
CWT Lost		-	-	-	-	1	1	-

3.6 Figures

Figure 10. A recovered released broodstock spring-run Chinook Salmon carcass. The measuring tape and identification tag indicate recorded data.

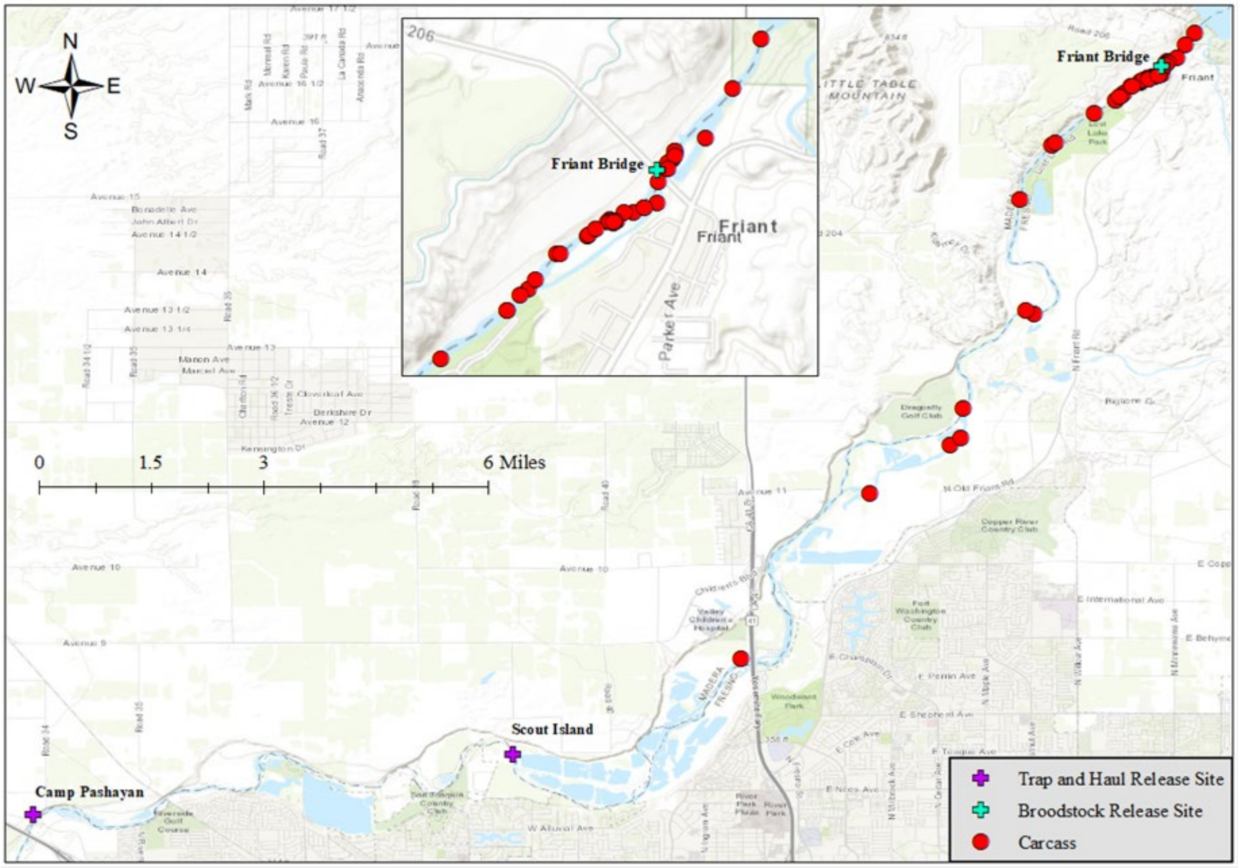

Figure 11. The locations of recovered adult spring-run Chinook Salmon carcasses (September 19 through November 2, 2020) and release sites for the adult spring-run Chinook Salmon broodstock (June, August, and September 2020) and trap and haul hatchery origin returns (April and May 2020) within the San Joaquin River Restoration Area.

4.0 Emergence Trapping Survey

4.1 Introduction

In the past, emergence traps have been used as a method to assess ETF survival and associated environmental characteristics that may affect emergence from the hyporheic environment for Chinook Salmon fry in the San Joaquin and Tuolumne Rivers (TID/MID 1991; Meyers 2019). The SJRRP initiated emergence trapping of SRCS redds in 2018 and this effort is ongoing. The goal of this survey is to enumerate the number of SRCS eggs that successfully developed and emerged as fry from redds in the SJRRA. Associated physical and chemical water quality characteristics including substrate composition, velocity, temperature, dissolved oxygen (DO), and turbidity are collected to gain a better understanding of characteristics that may influence ETF survival. The emergence trap survey is used to accomplish the following objectives:

1) Determine the developmental stage and size of emergent fry of SRCS in Reach 1 of the SJRRA.
2) Develop representative empirical counts of emerging alevin from natural redds in the SJRRA.
3) Document emergence timing for SRCS.
4) Relate fry production within observed redds to environmental variables hypothesized to affect the survival from egg to emerging fry, and assess the inter-annual variability of emergence success.
5) Determine ETF survival (emergence) rate from SRCS trapped redds. Use estimates of female fecundity from SCARF broodstock and Feather River natural returns to calculate percent survival.

4.2 Methods

The 2020 emergence trap installation and monitoring study was conducted October 27, 2020 through February 4, 2021. Emergence traps were placed on selected redds to allow for a distribution across riffle complexes in Reach 1 and over redd creation dates. Due to limitations in the emergence trap design, the redds selected had to be accessible on foot, of appropriate size, and at moderate depths and water velocities. Due to issues related to COVID, only 5 redds were chosen based on these constraints (Figure 12). The 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). For each emergence trapped redd, we calculated ATUs by adding average daily water temperatures over the incubation and emergence period (i.e., from date of redd discovery to trap removal) from the closest California Data Exchange Center (CDEC) station gage(s), which included FWQ (rkm 430), SJF (rkm 428), and/or H41 (rkm 410). Redds at or upstream of rkm 429 were assigned FWQ, redds downstream of rkm 429 and upstream of rkm 423 were assigned SJF, those downstream of rkm 423 and upstream of rkm 414 were assigned SJF/H41 for temperatures, and those downstream of rkm 414 in this year were assigned H41 (see Figure 12). Each redd was covered with an emergence trap once it reached 600 ATUs, approximately five days prior to the onset of emergence. Prior fall-run Chinook Salmon surveys in Reach 1 suggested that emergence would start around 650 ATUs with peak emergence occurring between 750-1,000 ATUs and emergence ending by 1,700 ATUs (Castle et al. 2016a; Castle et al. 2016b; TID/MID 1991). Thus, emergence traps were intended to be removed after reaching 1,700 ATUs. Early installation and removal after 1,700 ATUs ensured that all fry were captured during emergence.

The emergence trap design was modeled after the Lower Tuolumne Don Pedro Project Fisheries Study report (TID/MID 1991) that consisted of two metal frames fastened together with hose clamps. The frames were tear drop-shaped, measuring approximately 2.42-m long by 1.83-m wide at the widest point, then decreasing in width towards the tail end with an approximate area of 2.83 m^2. A net consisting of 0.32-centimeter (cm) nylon mesh surrounded by a blue canvas skirt was placed over the frame. Small grommet holes were sewn into the mesh and secured with cotter pins and washers to metal pegs on the frames to prevent the net from disconnecting from the frame to minimize escapement. The traps were placed over the top of a redd and oriented to fully cover the egg pocket and as much of the tailspill as possible. The skirt was anchored into the substrate with 12 rebar posts, each 1-cm thick and 76-cm long. The rebar posts were pounded through grommets in the canvas skirt and cinched down using washers and hose clamps to prevent the skirt from rising. The exposed skirt material was then buried up to 30 cm in the substrate to prevent fry from escaping. 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 checked, and then reattached to the funnel end of the trap to capture any fry that emerged. The jar consisted of a 3.8 Liter (L) polyethylene bottle with a 15-cm diameter funnel glued to the jar. Two holes were cut into the side of the jar and 0.32 cm nylon mesh was glued on top, allowing water to flow through to reduce salmon mortality in the jar (Figure 13).

Once traps were installed, they were checked 24 hours later, to look for fry that could have emerged prematurely due to the disturbance from trap installations. Thereafter, traps were checked three times weekly until projected peak emergence. Traps were checked more frequently during peak emergence (i.e., > 100 fish when checked) to increase survival by reducing the time spent inside the collection jar. When emergence declined (i.e., ≤ 10 fish when checked), checks were reduced to twice weekly. Water temperature, turbidity, DO, water depth, and velocity at upstream and downstream ends of each trap were collected during each trap visit. Water temperature and DO were collected on the substrate surface with a YSI multi-probe Pro 2030. Turbidity was measured just below the water surface with a Hach 2100Q Portable Turbidimeter. Water velocity was measured at 60 percent of the water column depth with an OTT Hydromet MF-pro Water Flow Meter. During trap checks, each trap was cleared of debris and scrubbed with a bristle brush to remove organic matter. After cleaning, the collection jar was checked for any fry and/or other species. If fish were present, they were transferred into a bucket filled with water and brought to shore for processing. Salmon and non-salmonid species were sorted and placed into separate buckets to be processed. Salmon fry were counted, measured to FL, and assigned a developmental stage. 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 "buttoned up"); stage 6 (no seam). Caudal fin clips were taken from selected fry (up to 3 samples collected from each redd/week until a total of 15 samples/redd were taken) for genetic analysis to help determine parentage. After processing, Chinook salmon fry were released downstream of the trap. Any non-salmonid species were identified, measured to FL, and released downstream of the trap.

The initial timeline to remove the traps was January 29 through March 4, when each redd reached approximately 1,700 ATUs, the upper threshold when emergence ceased for previous fall-run emergence monitoring within the SJRRA (Castle et al. 2016a; Castle et al. 2016b). However, for all monitored traps, observed fry emergence ended before the 1,700 ATU threshold was reached. Therefore, all traps were removed by February 1 and excavated by February 4. This coincided with the removal of the 5 trapped redds when ATUs were between the values of 1,383 and 1,587. When the trap was removed, a vertical array of Solinst Level Logger 5s was inserted into the egg pocket of the freshly uncovered redd. Level logger arrays were installed to collect data for 48 to 72 hours to capture minimum and maximum temperature fluctuations in the egg pocket as part of CDFW's Monitoring and Analysis Plan (MAP) Study 30 (Shriver 2014) that aims to quantify gravel permeability and intragravel flow in the spawning reach and relate to spawning success The level logger arrays were removed after 48 to 72 hours and redds were excavated. The same procedure was conducted for all five traps. Trap removal involved placing a block net downstream of the trap to catch any fry or stray eggs that were released during the process. While the block net was set, a final trap check was performed, and water quality measurements were taken. All the rocks covering the skirt were then removed, followed by removing the rebar. The emergence trap netting and frame were then lifted off the redd and carried to shore while two other crew members in dry suits monitored for eggs or fry dislodged during trap removal. After trap removal, staff from CDFW sampled the redd incubation habitat. Once completed, each redd was excavated to locate any remaining eggs and/or entombed alevins or fry. At the beginning of each excavation, a pole was placed at the start of the tailspill to signify the center of the redd. Excavation consisted of two crew members digging through the pit and tailspill to find the egg pocket(s) and any entombed fry. Eggs or fry dislodged from the egg pocket(s) were collected with dip nets and placed into containers to be counted. After no new eggs were encountered, width and depth of the egg pocket were recorded, as was the total area excavated. The redd was then backfilled with material from the surrounding riverbed.

4.3 Analysis

Emergence results were related to environmental variables hypothesized to influence the survival of egg to emerging fry within Reach 1 (SJRRP 2010). In particular, the relationships between the variables of water velocity, sand composition, DO at the surface of the redd, flow, and temperature with observed emergence in each monitored redd were investigated. Water velocity upstream of each redd and DO were measured during periodic field checks at each redd during the emergence trap study. The redd sand composition data were collected during the redd sampling described earlier. Mean daily flows calculated from continuous CDEC gage data provided a more general measurement of water volume moving through the spawning grounds, and these calculations supplemented the more localized, but discrete information on water velocity obtained at each redd during field checks. In addition to mean daily flows, calculations based on continuous data from neighboring CDEC gage(s) were also used to estimate mean daily water temperatures and 7-day averages of the daily maximum water temperatures per redd. As gage station FWQ does not have a flow sensor, only two gages, SJF and H41, were used to calculate mean daily flows. Missing temperature and flow data for 2020 were linearly interpolated using the ‘zoo’ package in R. See Demarest et al. (2021) for additional information on methodology for addressing missing temperature and flow values during the 2018 and 2019 field seasons.

We explored data from three years (2018, 2019, and 2020) of SRCS emergence trapping to determine the response of emergent fry count to the environmental variables described previously, within the context of 26 candidate generalized linear models (GLMs). Continuous predictor variables were standardized to have a mean of zero and standard deviation of one prior to inclusion in models. Throughout the analysis, the data were overdispersed with respect to a Poisson distribution, based on calculating a ratio of the residual deviance to the degrees of freedom greater than one (Aho 2013). To account for overdispersion, negative binomial distributions with log link functions were fit. The best approximating candidate GLM was determined using an information theoretic approach (Burnham and Anderson 2002), as indicated by the candidate model with the lowest Akaike Information Criterion with small sample bias adjustment (AICc; Hurvich and Tsai 1989). DO was highly negatively correlated with mean flow (Pearson correlation coefficient $r^2 = -0.77$), thus these two variables were not included together within candidate models (see Dorman et al. 2013). We excluded five redds with missing data (NR40 and NR42 in 2018, and NR12, NR128, and NR189 in 2019) from these analyses. As there were no fry or eggs observed in NR40 and NR42, these were assumed to be test redds.

Emergence timing for SRCS during 2020 was analyzed for each emergence trapped redd by regressing the cumulative proportion (0.5, 0.95, and 0.99) of emerged fry against the calculated ATUs over the incubation period. A binomial likelihood with logit link was used to make the estimate, based on fry counts observed during each field check of the emergence traps and associated calculations of ATUs from neighboring CDEC gage(s). A similar analysis was conducted to relate the cumulative proportion of emerged fry to the days since the redd was discovered. The redd discovery date provided a proxy of the egg incubation start date.

The ETF survival was also estimated for 2020 emergence trapped redds. ETF survival is often the proportion of eyed-eggs within a redd that survive to emerge as fry from the gravel (Jensen et. al 2009). Here, the ETF survival estimate for 2020 was calculated as a percentage, by dividing the average number of fry that emerged from all traps each year by the average fecundity (i.e., number of eggs produced per female) and multiplying the results by 100. Fecundity for adult female SRCS that naturally return to the San Joaquin River is unknown. Thus, we used an estimate of fecundity in the calculation of ETF survival based on the average fecundity from Interim SCARF broodstock (2,420 eggs) and average fecundity from returning SRCS to the FRFH (4,703 eggs) (P. Adelizi and A. Kastner, CDFW, personal communication, 2021). This approach to calculating ETF survival assumes that all eggs deposited within redds are viable, fertilized, and successfully developed to the eyed-egg stage.

4.4 Results

In 2020, a total of 1,883 fry (377 ± 544; mean ± 1 SD) were observed in the five trapped redds; 389 were mortalities (Table 5). For the 2020 season, new jars were constructed with stronger materials to prevent any jars from breaking while on the trap. NR12SR20 (rkm 429) had the lowest amount of emergence with only 31 emerged fry throughout the season. NR29SR20 had the greatest amount of emergence with 1,291 emerged fry. The mean FL for all emerged fry in 2020 was 31.9 ± 1.4 mm (mean ± 1 SD; Table 5). Of the 1,883 fry that emerged, 96.5 percent were classified as stage 5 in their development, 2 percent were stage 4, and 1.5 percent were comprised of stages 2 and 3. There were no stage 6 fry seen in 2020. Due to Level Logger Array availability, trap removal and excavation occurred at two separate dates. For all five traps, excavations occurred 48 to 72 hours after the trap was pulled from the redd. Upon excavation, unhatched eggs were found in all five emergence traps (Table 5). The number of unhatched eggs ranged from 4 (NR13SR20) to 434 (NR12SR20). The mean number of eggs recovered per redd was 259.

In 2020, the mean start of emergence was 750 ATUs (range of 635 to 874 ATUs; Table 5) and 99 percent of fry emergence was estimated to have completed by 1,371 ATUs (range of 986 to 1,371 ATUs; see Figure 14(A)). Across the five sampled redds, 99 percent of fry emergence was estimated to have completed by 71 to 104 days after the redd was first discovered (Figure 14(B)). The duration of emergence in 2020 ranged from 7 to 55 days with a mean of 36 days per redd (Table 5). However, due to the early removal of the emergence traps, all five of the trapped redds did not reach 1,700 ATUs before being removed. None of the trapped redds were producing fry at the time of trap removal.

Patterning in the residuals of emergence count from trapped redds versus environmental predictors and fitted values indicated poor GLM fits that were not remedied with transformations, perhaps due to unaccounted for predictors and/or limited sample size. Mean estimates of environmental variables measured from each redd are presented in Table 6. Predictions generated from model fits were often accompanied by large confidence intervals, indicating a high degree of uncertainty in the predictive capacity of the tested models. With these caveats in mind, we present the best approximating candidate model for predicting fry emergence with the lowest degree of uncertainty in model-predicted responses, since it may provide insights for future studies. This model contained only a quadratic function of DO as a predictor for fry emergence ($AIC_c = 270.10$, $\Delta AIC_c = 0.34$, $df = 4$, weight = 0.22). This candidate model predicts that the number of emerged fry remains very low below approximately DO = 10 milligrams per liter (mg/L) and only when redd surface DO exceeds 10.5 mg/L, does fry production exceed 500 (based on the lower 95 percent confidence limit; Figure 15). However, uncertainty in the estimate of predicted fry also greatly increases at increased levels of DO and several of the observed data points (colored dots) are outside the model-based predictions (Figure 15).

In 2020, the average fecundity of broodstock SRCS (2,420 eggs) spawned at the Interim SCARF and the average fecundity of returning SRCS (4,703) to the FRFH was used to calculate ETF survival. The mean ETF survival estimate was 8 percent and 15.58 percent for 2020 for the monitored emergence trapped redds. The percentage of mortalities per redd, when weighted by the number of emergent fry, was 21 percent (Table 7).

4.5 Discussion

Based on five redds monitored with emergence traps, emergence during 2020 was below the goal for ETF survival of ≥ 50 percent outlined in the FMP (SJRRP 2010). Monitoring of emergent fry at SRCS redds within the Restoration Area during 2018 and 2019 also yielded ETF survival estimates below SJRRP's goal (0.90 percent and 21.62 percent, respectively based on Interim SCARF fecundity; Demarest et al. 2021). However, it was noted that four of the collection jars on the emergence traps in 2019 fell off during peak emergence, resulting in an underestimate of emergence for that year. In 2020, despite improvement to the adhesive connecting the collection jars to the emergence traps, the ETF survival estimate did not surpass 2019's ETF survival estimate. The weighted average number of mortalities per redd in 2020 (21 percent) also exceeded that from 2019 (8 percent) and more closely resembled the mortality estimate from 2018 (20 percent; Demarest et al. 2021). In both 2018 and 2020, released broodstock made up a larger proportion of spawners than in 2019 when high flow conditions allowed for volitional hatchery return fish to migrate from the ocean to Reach 1 of the SJRRA. Thus, the presence of fewer ocean-rearing spawners and/or poorer incubation conditions may have contributed to reduced emergence success in 2020 compared to the previous year. Stark et al.'s research (2018) determined that egg viability (survival until the eyed-egg stage) was significantly greater for wild-origin versus captive-reared SRCS in East Fork Salmon River, Idaho. Linking individual redds to spawner group identity (e.g., distinguishing redds produced by volitionally passed and trap and haul hatchery origin returns versus broodstock released spawners) is needed to better understand the role of spawner characteristics in determining ETF survival and the utility of releasing broodstock spawners as a reintroduction strategy.

Although monitored redds in 2020 had fewer emerged fry and a greater weighted mortality rate than redds from 2019, those fry that did emerge were from a later stage of development (≥ stage 5) in 2020 (96 percent) than in 2019 (69 percent; Demarest et al. 2021). Spawners in 2020 tended to choose less sandy substrates than in 2019; spawners from 2019 may have been limited in available spawning habitat of sufficient quality. In areas with higher concentrations of fine sediment, it has been noted that many fry emerge without fully absorbing their yolk sac (stage 4 and below; Cardenas et al. 2016; Tappel and Bjornn 1983).

In 2020, SRCS fry emerged at similar ATUs to what has been documented for fall-run Chinook Salmon in the SJRRA from prior emergence studies (Castle et al. 2016a; Castle et al. 2016b). Previous work has shown that emergence typically begins around 650 ATUs, so emergence traps are placed at approximately 600 ATUs, or about five days prior to the beginning of fry emergence (Castle et al. 2016a; Castle et al. 2016b). Similar emergence timing of fall-run and SRCS across three years of data suggests most emergence still occurs between 650 and 1,700 ATUs for SRCS. The five monitored redds in 2020 exhibited emergence until approximately 1,370 ATUs (or 104 days after redd discovery), and in 2018 the final of six emergence-trapped redds produced fry until 1,229 ATUs. However, in 2019, seven out of twelve emergence-trapped redds were still producing fry beyond 1,370 ATUs. Overall, similarities in emergence timing between fall-run and SRCS show that the use of ATUs is still a successful method for predicting emergence timing, and continued emergence monitoring may reveal causes for differences in fry development rates. We recommend in future study years to continue installing the emergence traps at approximately 600 ATUs as this has shown to be a justifiable time to start installing the emergence traps to capture the beginning of fry emergence.

Results from GLM and model selection did not yield precise quantitative estimates of emergence based on modeled relationships with hypothesized environmental variables. However, visual observation of predictions from the top-performing model suggests that fry emergence likely has some positive relationship with DO at the redd surface. Furthermore, DO may need to exceed approximately 10 mg/L at the redd surface to not greatly limit emergence (Figure 15). Note that there were only four trapped redds where emergence exceeded 10.75 mg/L (see the dashed red line in Figure 15), when the model predicted a mean drop in emergence with additional DO increases. Given the low sample size and large 95 percent confidence intervals above 10.75 mg/L contributing to these model predictions, we do not place any confidence in this apparent decline in emergence at very high DO levels. Having additional data on emergence counts from trapped redds at higher DO levels may help reduce uncertainty in estimates of fry emergence count based on DO as a predictor, especially at higher DO values. Although the measured values of DO near the redds exceeded the SJRRP objective for DO greater than 7 mg/L (SJRRP 2021) in 2020 (Table 6) and the two other analyzed years (Demarest et al. 2021), it is possible that conditions of the substrate and hyporheic exchange require much higher surface DO levels to oxygenate the eggs under the gravel. Another caveat is that most of the redds below this ~ 10 mg/L threshold were from the 2018 field season and were produced by spawners of broodstock origin, in contrast with many of the redds at higher DO levels (which were associated with more trap and haul or volitionally-returning hatchery spawners in 2019 or 2020; see Figure 15). Thus, DO levels could be masking a relationship between spawner origin and emergence success that we are currently (without genetic results for all years) unable to resolve. See Demarest et al. (2021) for further discussion of field observations and potential differences between broodstock and volitionally-returning hatchery spawners.

Similarly, there may be other unmodeled factors, particularly at higher DO levels, that contribute more to the variation in emergence success and have yet to be identified. In 2020, USFWS and CDFW also began installing DO and temperature loggers within constructed artificial redds to study the conditions of the subsurface redd environment that directly affects egg and fry development and to determine the potential effects of emergence traps on intragravel flow and DO. Results from CDFW's MAP Study 30 (Shriver 2014), which was implemented during the fall-run Chinook Salmon spawning season and was reinstated in 2021, will also contribute to a better understanding of spawning habitat quality and potential implications for fry emergence.

4.6 Tables

Table 5. The 2018 through 2020 fry emergence start and end accumulated thermal units (ATU), emergence duration, count, incidental mortalities, size, and excavated egg count in Reach 1 of the San Joaquin River Restoration Area. Data is derived from point data measured during emergence trap checks. The location (rkm) of the trapped redd is provided.

[a] Indicates the redd was excavated later than when the trap was removed.

Year	*Redd #*	*Location (rkm)*	*Start (ATU)*	*End (ATU)*	*Days of Emergence*	*Fry Count*	*Mortality*	*Fry Size (mm)*		*Eggs Found*
								Mean (SD)	**Range**	
2020	NR05SR20[a]	430	677	1379	55	37	6	31 (1.5)	25-33	303
2020	NR12SR20[a]	429	874	1319	38	31	2	31 (0.8)	30-34	434
2020	NR13SR20[a]	429	874	965	7	54	19	33 (0.8)	30-34	4
2020	NR29SR20[a]	429	635	1026	31	1291	269	31 (2.1)	24-35	167
2020	NR54SR20[a]	412	691	1245	50	470	93	33(1.7)	24-36	386

Table 6. Mean environmental characteristics for each emergence trapped redd and overall means and standard deviations in the San Joaquin River Restoration Area, during 2020. Data is derived from point data measured during emergence trap checks.

Redd #	*Dissolved Oxygen (mg/L)*	*Turbidity (NTU)*	*Temperature (°C)*	*Depth (m)*		*Velocity (m/s)*	
				Above Trap	*Below Trap*	*Above Trap*	*Below Trap*
NR05SR20	9.544	1.783	12.448	0.585	0.411	0.418	0.474
NR12SR20	10.234	1.720	12.321	0.329	0.317	0.333	0.466
NR13SR20	10.292	1.663	12.350	0.396	0.359	0.733	0.998
NR29SR20	10.455	1.673	11.816	0.516	0.332	0.492	1.039
NR54SR20	11.162	1.279	11.395	0.419	0.367	0.689	0.974
Mean	*10.337*	*1.623*	*12.066*	*0.449*	*0.357*	*0.533*	*0.790*
(SD)	*0.578*	*0.198*	*0.448*	*0.101*	*0.036*	*0.173*	*0.293*

Table 7. Annual mean adult spring-run Chinook Salmon fecundity and egg-to-fry (ETF) survival estimates. Percent ETF survival was calculated using the estimated fecundity of broodstock at the Interim Salmon Conservation and Research Facility (SCARF) and returns to the Feather River Fish Hatchery (FRFH).

Year	***Fecundity SCARF Broodstock***	***Fecundity FRFH Returns***	***Number of Emergence Traps***	***Mean Fry Emergence***	***SD Fry Emergence***	***Egg-to-Fry Survival SCARF Broodstock (%)***	***Egg-to-Fry Survival FRFH Returns (%)***
2020	2,420	4,703	5	377	544	15.58	8.02

4.7 Figures

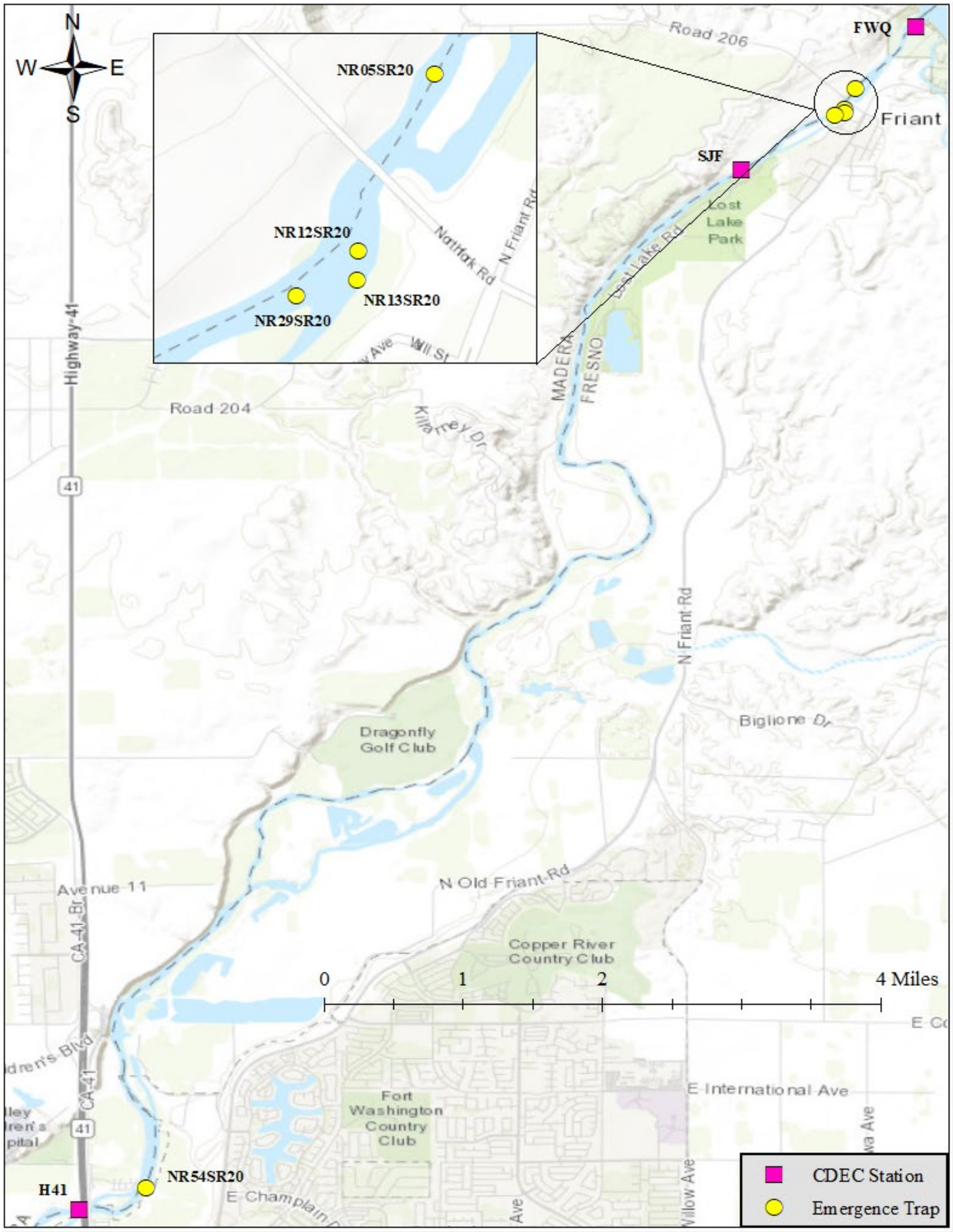

Figure 12. Locations of emergence traps for spring-run Chinook Salmon in the San Joaquin River Restoration Area, 2020. The inset map indicates the emergence-trapped redds within areas of high redd density, and the pink boxes show California Data Exchange Center (CDEC) stations within the area.

Figure 13. An emergence trap installed during 2019. The red arrow indicates flow direction.

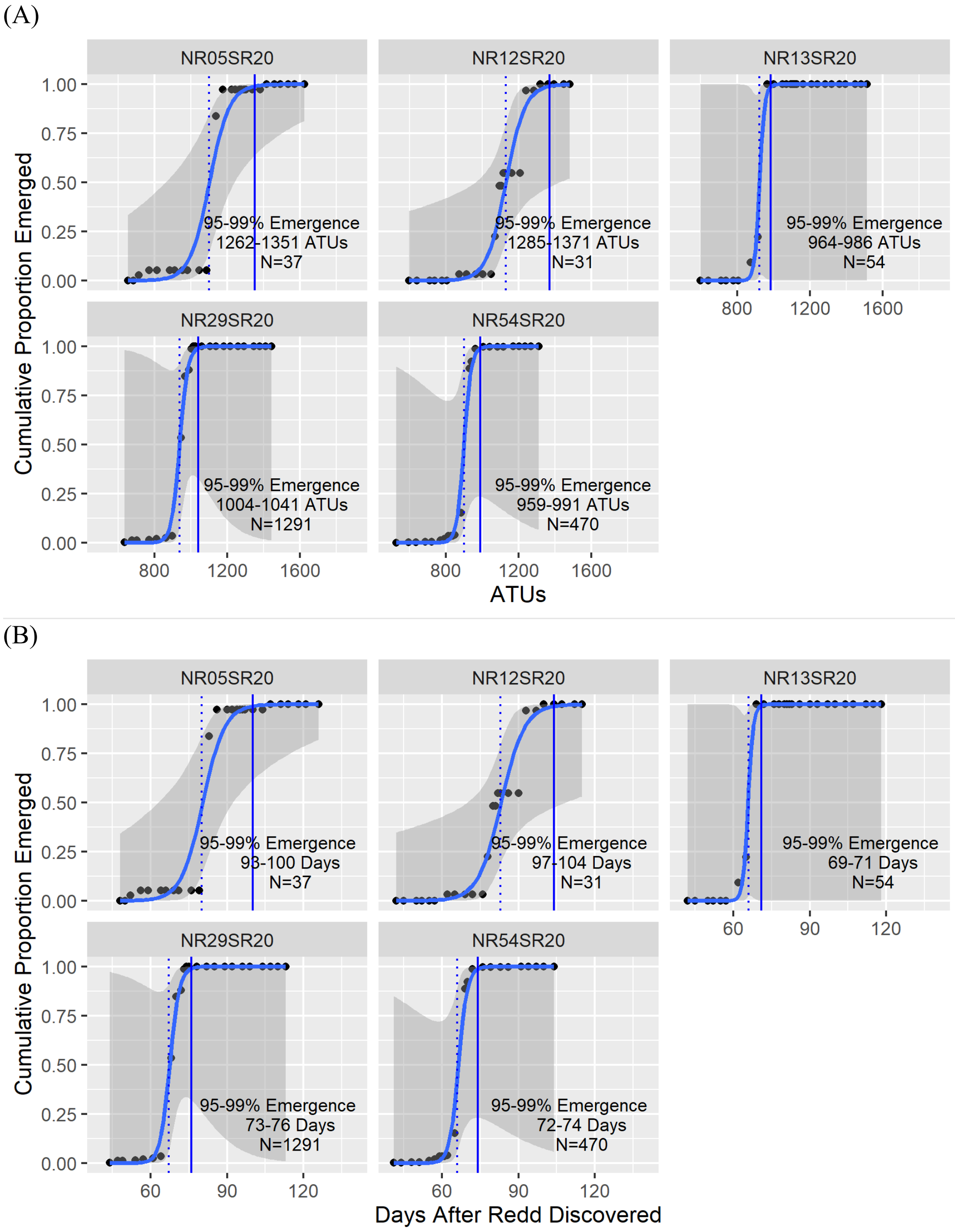

Figure 14. Cumulative proportion of emerged fry per redd sampled with an emergence trap during 2020 based on (A) Accumulated Thermal Units (ATUs; °C), and (B) days since discovery of the redd (a proxy for the beginning of incubation). Vertical dotted blue lines are the estimated ATUs (A) and days after redd discovery (B) at which 50 percent of the redd's fry had emerged, and vertical solid blue lines correspond to 95 percent of emergence. Shaded gray areas are 95 percent confidence intervals, with N equal to the total fry per redd.

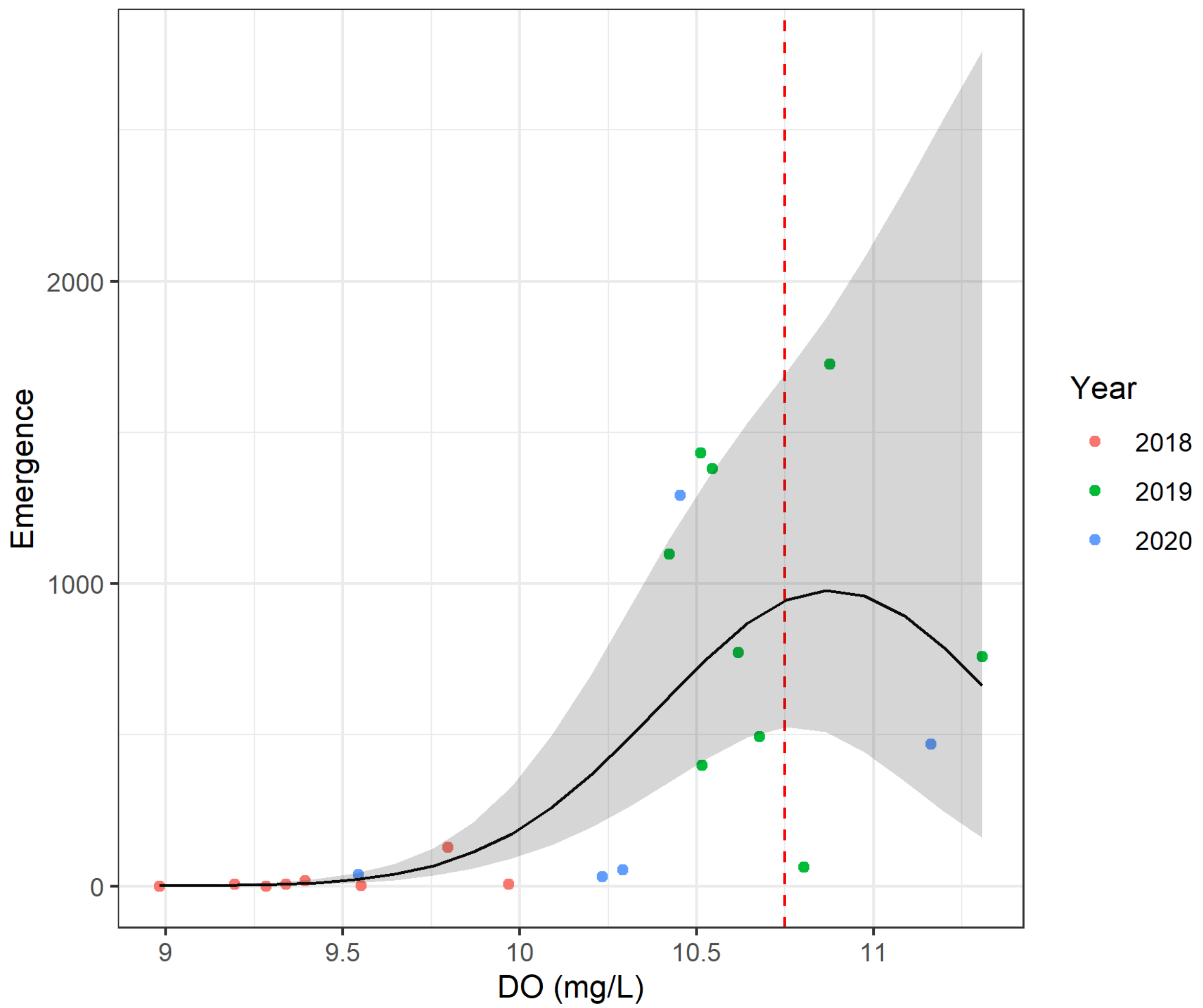

Figure 15. Predicted values (black line) and 95 percent confidence intervals (gray shaded region) of emergence fry count based on dissolved oxygen (DO; mg/L) at the surface of the redd. Colored dots are observed values distinguished by survey year. Predictions of emergence at dissolved oxygen concentrations greater than approximately 10.75 mg/L (demarcated by the dashed red line) are based on limited observations and considered unreliable.

5.0 Conclusions and Recommendations

In 2020, 97 percent of spawning was observed in the 11 rkm directly downstream of Friant Dam. The spatial distribution of spawning and temperatures surpassing the upper critical temperature threshold for spawning (17 °C) near Highway 41 may indicate that suitable spawning habitat was restricted in 2020. In future years, maintaining cold water releases from Friant Dam during the spawning season, when possible given Water Year type and available cold water pool volume, could help expand suitable spawning habitat.

Returning adult SRCS were also exposed to temperatures that exceeded the optimal temperature threshold (15 °C; SJRRP 2018) at both capture and release during trap and haul operations. During capture in Reach 5, water temperatures ranged from 18–23.3 °C, and salmon were released into Reach 1 at water temperatures of 14.8–19.1 °C (Sutphin and Root 2020). Studies on SRCS in Battle Creek, CA by Ward and Kier (1999) suggested that exposure to temperatures between 16–19 °C may lead to infertility and pre-spawn mortality. The SJRRP may want to consider the benefits of releasing captured adults further upstream in Reach 1 of the SJRRA in cooler water temperatures to enhance spawning success, if a main focus of the Recolonization Phase is to increase the number of spring-run spawning naturally (SJRRP 2018). Currently trap and haul adults are released into water at the release location that is no greater than a river temperature of 20 °C, and restrict differences in transport tank and river temperatures to 4 or 5 °C. We recommend having a discussion with the FMWG to further refine the release strategy to reflect a maximum daily temperature of 20 °C given water temperatures may continue to rise later in the day after a release event. Such considerations should be weighed alongside SJRRP study objectives defined for other life stages (e.g., adult holding habitat selection).

Mean individual redd area was 4.3 m^2 smaller in 2020 compared to 2019. Released broodstock adults were a larger proportion of the spawning population in 2020 than in 2019, when most of the spawners were trap and haul and volitional hatchery returns. Demarest et. al. (2021) suggested that trap and haul and volitional hatchery returns may produce larger redds than broodstock released adult SRCS. Similar studies have found that fish size is related to redd size, suggesting that larger Chinook Salmon produce larger redds (Burner 1951; Ottaway et al. 1981; Neilson and Banford 1983). If this relationship holds true within the SJRRA, redd size will likely increase with a larger proportion of adult SRCS returning to the SJRRA from the ocean. Burner

(1951) also suggested that Chinook Salmon need approximately four times their redd size of suitable spawning habitat per spawning pair. The SJRRP (2018) has set a long-term (i.e., beyond 2040) SRCS abundance target of 22,500 spawning females (or equivalently, 22,500 spawning pairs with an assumed 1:1 M:F ratio) . If four times the average redd size (9.1 m^2 based on 2019 data; Shriver and Tham 2020) is needed per spawning pair of SRCS, approximately 819,000 m^2 of suitable spawning habitat will be needed to reach the long-term production target of 22,500 female SRCS spawners. If, in the future with a greater proportion of naturally-returning SRCS, the average redd size increases above 9.1 m^2, even more suitable spawning habitat may be needed. Based on temperature thresholds for incubation and emergence (Gordon and Greimann 2015; SJRRP 2018), the first 8 to 11 rkm below Friant Dam for most Water Year types have water temperatures suitable for Chinook Salmon to successfully spawn and produce viable offspring. Modeling suggests that the first 8 rkm downstream of Friant Dam provides approximately 53,000 m^2 of spawning habitat that is thermally and hydraulically suitable to Chinook Salmon (see Gordon and Greimann 2015), therefore capable of supporting up to 1,456 spawning females or a total of 2,912 spawners, if a 1:1 (M:F) sex ratio is assumed. During the Recolonization Phase, the SJRRP set a population target of 500 natural origin return spawners and an overall spawning escapement target of ≥ 3,000 spawners that includes both natural origin returns and hatchery origin returns (SJRRP 2018). Since it is estimated that SJRRA can support 2,912 spawners currently, the SJRRP would need to add approximately 1,600 m^2 of suitable SRCS spawning habitat to reach the population and escapement targets during the Recolonization Phase.

Emergence trapping results in 2020 resulted in ETF survival estimates that were below the goal outlined in the FMP (SJRRP 2010). There are likely many physical and biological factors that contribute to reduced ETF survival. Preliminary results indicated that DO measured at the substrate surface of trapped redds has a positive relationship with emergence. However, more data is needed to develop a clearer relationship and identify other contributing factors. With additional years of emergence trapping and measurements of incubation habitat as obtained through CDFW’s MAP Study 30 (Shriver 2014) and other studies, the SJRRP could identify the other factors influencing emergence and potentially use these conclusions to inform habitat restoration.

Demarest et. al. 2021 suggested there may be difference in ETF survival between ocean-rearing returns versus broodstock released spawners. During spawning surveys in 2020, documenting spawner identity for each redd was unsuccessful. Due to spring-run holding throughout the summer, color coded dart tags are commonly covered in algae and difficult to discern. To help with documenting spawner identity, larger color-coded disc tags could be used in place of dart tags to make visual identification easier. Additionally, the SJRRP does supplemental drone surveys a few times a year to assist with mapping spawning habitat during the SRCS spawning season in Reach 1 of the SJRRA. In future years, additional drone surveys as a part of regular redd and carcass surveys may be able to help identify spawner origin by capturing images of SRCS tag color associated with individual redds. Although spawner identity was not determined with observations, genetic analyses of tissue samples collected from emergence trap fry, recovered carcasses, and juveniles collected with rotary screw traps are still in progress. Results from genetic analyses will identify the parentage of progeny that were successfully produced by SRCS and elucidate spawning success for each type of spawner. By continuing to improve our understanding of the biological and habitat attributes that contribute to successful spawning, information obtained from the redd, carcass, and emergence surveys can help inform restoration actions and an adaptive management program that aids the reintroduction of SRCS to the San Joaquin River.

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