2016 Juvenile Chinook Salmon Trap and Haul Program

Final Monitoring and Analysis Report

SAN JOAQUIN RIVER
RESTORATION PROGRAM

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2016 Juvenile Chinook Salmon Trap and Haul Program

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Executive Summary

A primary goal of the San Joaquin River Restoration Program (SJRRP) is to restore and maintain fish populations in “good condition” in the mainstem San Joaquin River below Friant Dam to the confluence with the Merced River, including naturally reproducing and self-sustaining populations of Chinook Salmon. Successful reintroduction of Chinook Salmon to the Restoration Area (RA) will require a means to transition emigrating juvenile fish from spawning grounds to the Pacific Ocean to promote maturation and return of spawning adults to the system. Adequate and timely flows, and a passable watercourse, may not be available to emigrating salmon during low hydrologic water years in the RA. Low hydrologic water years experienced in the San Joaquin River from 2014-16 provided the SJRRP with an opportunity to evaluate a juvenile salmon trap and haul program to trap and move juvenile Chinook Salmon from unsuitable environmental conditions, bypassing impassable barriers, for release at the furthest most downstream reach of the Restoration Area to promote their continued ocean bound migration. Juvenile trapping consisted of fishing two v-shaped weirs with fish capture boxes and a single rotary screw trap in 2014, and four and three v-shaped weirs with fish capture boxes in 2015 and 2016, respectively. All fish capture locations were in Reach 1A-1B, and all fish were released in Reach 5 of the RA. Trap and Haul efforts resulted in the capture of 1,837, 617, and 2,007 wild juvenile salmon in 2014, 2015, and 2016, respectively. In general, total salmon capture decreased with downstream sample location, likely due to a combination of increased number of upstream redds and predation pressure at downstream sites. In addition, pulsed flow operations that were employed during 2016 sampling appeared to contribute to higher capture of juvenile Chinook Salmon, and is a management tool that warrants further investigation. Pre-transport survival of captured fish increased from 2014 (70.6%) to 2015 (97.6%) and 2016 (95.1%) following installation of a flow diffusing box and second capture box to improve post capture flow refugia. In-transport survival of salmon was >99% across all years, and 2016 24-h post-transport survival estimates suggest there are no significant latent effects on survival associated with the trap and haul process. Low salmon capture totals suggest the Juvenile Trap and Haul Program, as currently designed, would not be sufficient to support a stable population of salmon during low hydrologic water years. However, given the number of observed redds counted (n = 128) in the system and measured swim-up survival levels (551/redd) reported by Castle et al. 2017, and measured weir efficiencies (30-41%), trap and haul capture totals should have been much higher. Causes for low capture success may be attributed to a high abundance of smaller fry emigrating through Reach 1 post emergence, because weir wing-wall mesh sizes were likely inefficient at capturing small fish, or there was a high rate of loss (i.e., predation) prior to salmon having the opportunity to encounter the weirs. If low capture numbers were a result of the weirs inefficiency to capture a high proportion of emigrating fry, then the Juvenile Trap and Haul Program and methods currently used are likely not sufficient to support populations of Chinook Salmon in the Restoration Area. However, low capture numbers due to poor survival through Reach 1 should not preclude the SJRRP from considering the utility of the Juvenile Trap and Haul Program in future years once causes of poor survival are understood and addressed.

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1.0 Introduction

A challenge of restoring extirpated species from a system encumbered with anthropogenic influence is understanding, and then balancing, species-specific biotic and abiotic needs, to promote reintroduction in the face of increasingly demanding human wants (Cooke et al. 2012). The San Joaquin River (SJR) in California's Central Valley (CV) is intensely managed, primarily to support the United States most prolific production of agriculture (Hanson et al. 2009, Lo and Famiglietti 2013). Inclusive in this management effort was the development of dams to support water storage, including Friant Dam on the SJR which, following development in the mid-twentieth century, contributed to the extirpation of Chinook Salmon (*Oncorhynchus tshawytscha*) from the SJR upstream of the Merced River confluence. In response to the current state of the upper SJR fishery, a coalition of environmental groups, led by the Natural Resources Defense Council (NRDC), filed a lawsuit challenging the renewal of long-term water service contracts between the United States and the Central Valley Project Friant Division Long-Term Contractors. The resulting settlement (NRDC, et.al. v. Rodgers, et al. 2006) requires reintroduction of Chinook Salmon into the upper SJR (i.e., Restoration Area; upstream of the Merced River confluence), and includes a long-term goal to reestablish naturally reproducing and self-sustaining populations of these fish. The San Joaquin River Restoration Program (SJRRP, www.restoresjr.net) was established to meet restoration goals defined in the settlement.

There have been significant environmental changes since Chinook Salmon were last present in the Restoration Area (Yoshiyama et al. 2001), and there is uncertainty associated with reintroduction of the species, how they will respond to environmental conditions, and how the system should be managed to promote reintroduction while maintaining water delivery requirements. Given this uncertainty, and the complexity of the SJRRP, the SJRRP Fisheries Management Plan (FMP: SJRRP 2010) was developed to provide an adaptive management approach for the reintroduction of Chinook salmon and other fishes. The ability to adaptively manage fish populations under challenging water constraints will allow SJRRP to use a variety of strategies and techniques to take action when unfavorable environmental conditions persist. The FMP identifies rearing and juvenile emigration as critical life stage-specific processes to be supported for successful reintroduction of the species.

Factors effecting emigration success include suitable water temperatures, adequate and timely flow for downstream movement, and a passable watercourse, all of which may not be available in the Restoration Area, particularly during low hydrologic water-years (Critical High – Critical Low years). The SJR experienced Critical-High (2014), Critical-Low (2015) and Normal-Dry (2016) water years at the onset of important SJRRP data collection efforts. These water-year types provided the program a unique opportunity to evaluate the efficacy of a juvenile salmon trap and haul program to trap and move juvenile Chinook Salmon from unsuitable environmental conditions, bypassing impassable barriers, for release at the furthest most downstream reach of the Restoration Area to promote their continued ocean bound migration. In addition, this effort served as the first post-introduction monitoring effort of movements of salmon during low water-years with (2016) and without (2014-15) pulse flows. Though some comparisons across juvenile trap and haul years are provided in the current report, this report focuses primarily on 2016 efforts, as previous efforts are summarized in Portz et al. 2015.

2.0 Materials and Methods

2.1 Study Area and Fish Collection

Juvenile trap and haul activities took place in the SJRRP Restoration Area, which ranges upstream approximately 150 river miles (RM) from the Merced River confluence (Stanislaus County) to Friant Dam (Fresno County; Figure 1). The Restoration Area is sub-divided into five reaches. Salmon capture occurred at various locations in the most upstream reach (Reach 1A and 1B), and salmon were truck transported for release in the most downstream reach (Reach 5, Figure 2). V-shaped weirs and fish capture boxes (Figure 3) were used to capture emigrating juvenile Chinook Salmon in Reach 1 of the Restoration Area from February 7–May 25, 2016. Three weirs were installed: (1) Scout Island near RM 249.8 (Reach 1A; operated Feb. 7–May 25), (2) Highway 99 near RM 243.1 (end of Reach 1A; operated Feb. 7–May 24), and (3) Skaggs Bridge near RM 235 (Reach 1B; operated Feb. 7–May 23). Weirs were also used in Reach 1 of the Restoration Area in 2014 (n = 3; Feb. 26–May 8) and 2015 (n = 2; Feb. 14–May 10). In addition, a rotary screw trap was used in 2014 at Ledger Island near RM 262.3 (operated Feb. 26–May 5).

Weirs were constructed of a series of panels, encompassing each weir wing wall, connected to a diffuser panel and then to two collection boxes (Figure 4). Each panel was built with PVC-coated 13-mm (0.5-inch) square-opening wire attached to a 1.2×2.4 m (4×8 ft.) marine plywood frame. Panels were connected to each other to create each wall. Walls were supported with intermittently-spaced T-posts, as well as 1.8 m (6 ft.) tall tripods, and were oriented in a V-shaped pattern, with the opening facing upstream and extending away from a diffuser panel. Weir walls were oriented at a sufficient angle in an attempt to provide sweeping flows towards the diffuser panel and then continuing into the collection box, helping to reduce fish impingement against the screen. The diffuser panels were constructed of 5.1×10.2 cm wood frame encasing perforated aluminum plate (6-mm diameter). Dimensions of the diffuser panel were 1.2×0.3×3.1 m (H×W×L, 4×1×10 ft.). The collection box was constructed of marine plywood. In 2014 a single collection box with exterior dimensions of 0.9×0.9×1.2 m (H×W×L, 3×3×4 ft.) was utilized with each weir. In 2015 and 2016 two capture boxes were fished in series, and connected by a 20.3 cm PVC pipe in an effort to increase screen surface area, improve total flow-through, and provide additional in-box velocity refugia. A hinged top lid allowed access for cleaning and fish removal. A 30-cm (12-in.) opening on the upstream side of the box allowed entry for downstream moving fish. Vertically-oriented metal tubing was spaced 5 cm (2 in.) apart, to minimize large fish entering the collection box with captured salmon. The collection box was secured to the terminal end of the diffuser panel with T-posts. A flexible rubber flange eliminated any uneven spacing between the collection box and wing wall that may have permitted fish escapment. V-shaped perforated aluminum plates (6-mm diameter) at the entrance was used to deter fish from easily leaving the capture box.

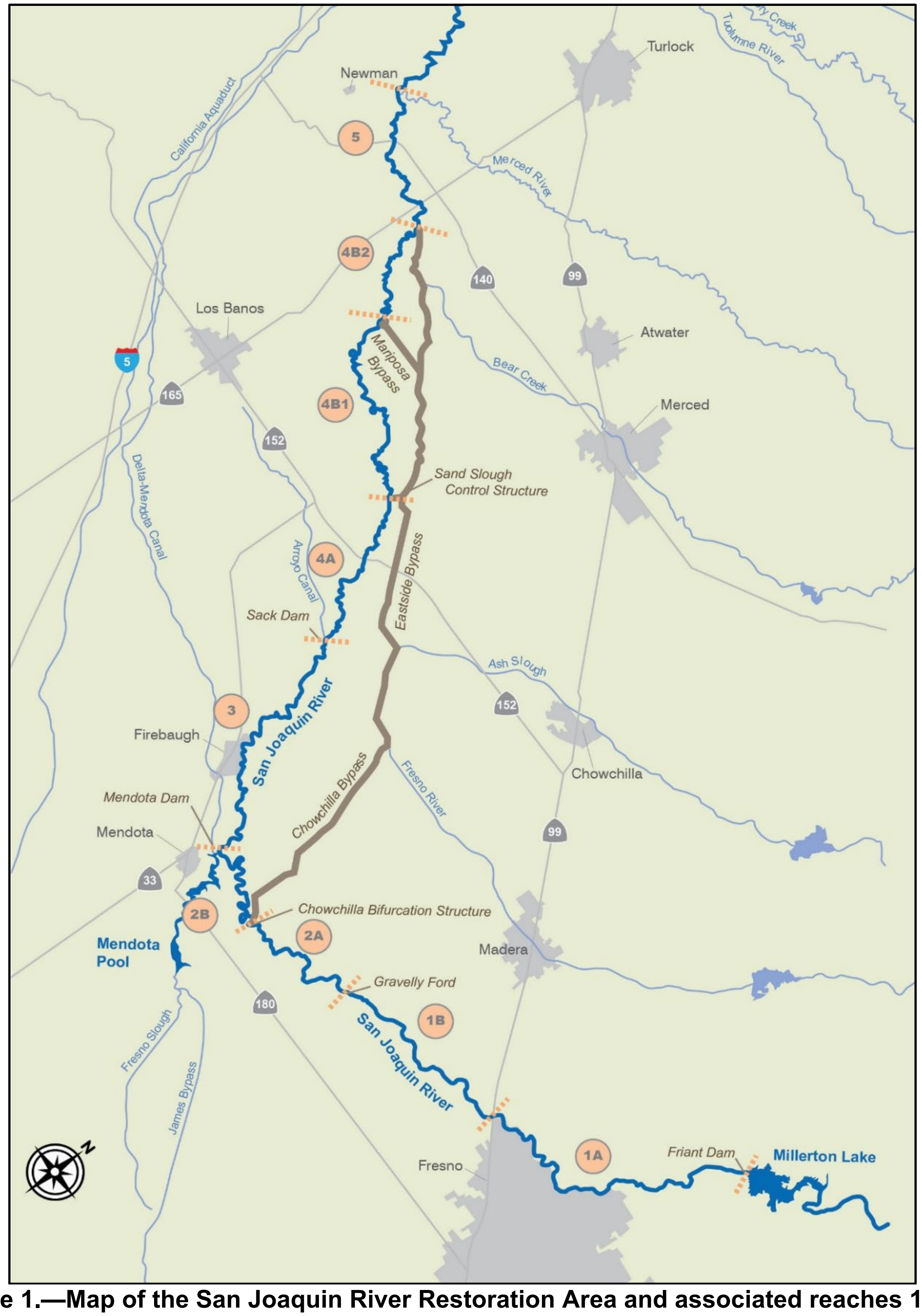


Figure 1.—Map of the San Joaquin River Restoration Area and associated reaches 1A–5. The Restoration Area encompasses the San Joaquin River below Friant Dam to the confluence with the Merced River. Yellow numbered circles identify each Restoration Reach, and the dashed line identifies the boundary between reaches. During the Juvenile Trap and Haul Program, Chinook Salmon were captured in Reach 1, and released in Reach 5.

Figure 2.—Juvenile Trap and Haul fish collection locations in Reach 1A-1B on the San Joaquin River, CA 2014-16.

Figure 3.— Upstream looking image of weirs, diffuser box and capture boxes used to capture emigrating juvenile Chinook Salmon during the San Joaquin River Restoration Program's Juvenile Trap and Haul Program (San Joaquin River, CA).

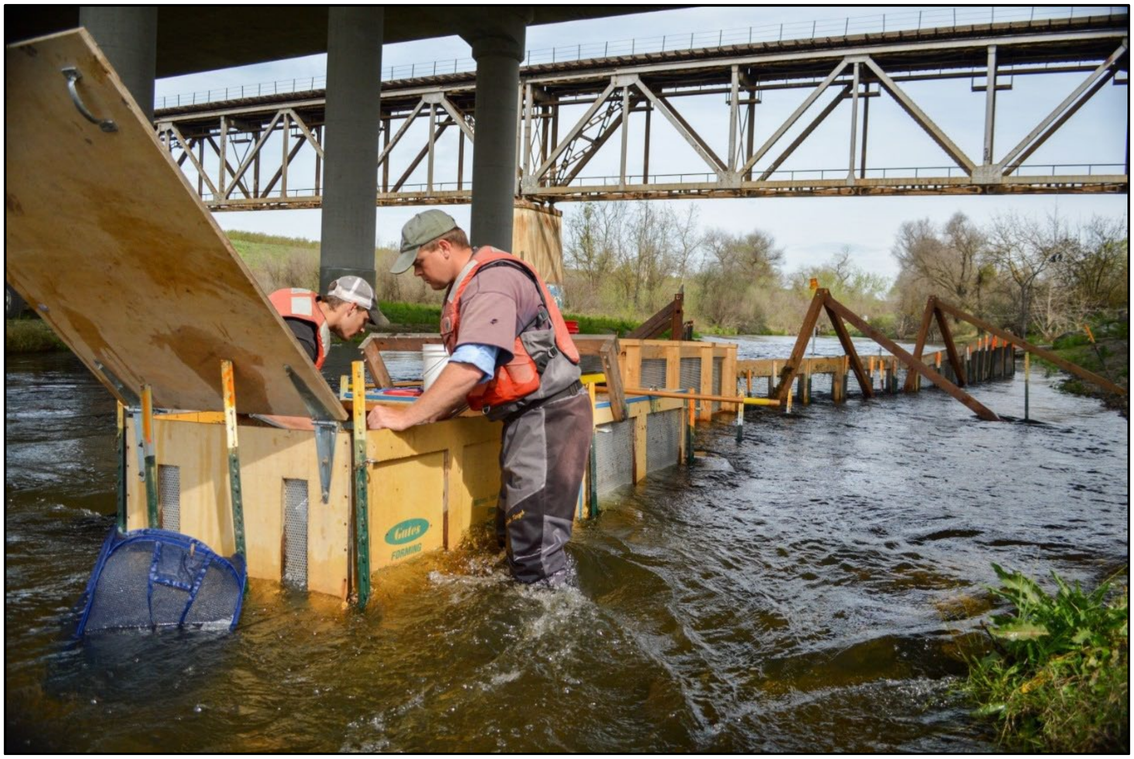


Figure 4.—Bureau of Reclamation Biologists checking the capture box for juvenile Chinook Salmon on the San Joaquin River, CA during the Juvenile Trap and Haul Program.

2.2 Fish Processing and Transport

Sample sites were visited, at a minimum, once daily. Weir panels and the collection box were cleaned of debris, and fish were removed from collection boxes using soft-mesh dip nets. Non-target species were identified, measured (total length, TL), and then released downstream of the trap to prevent recapture. In general, non-targets were identified to species, but during this effort *Lampretra* spp. were defined as lamprey. However, DNA barcoding analysis of tissue samples collected from 22 lamprey indicate Pacific Lamprey (*Lampetra tridentate*) and Kern Brook Lamprey (*Lampetra hubbsi*) represented 19% and 81% of lamprey captured (Keele et al. 2016). Salmon were transferred to a 19-L (5-gallon) bucket and moved to the transport tank for processing. Before transferring fish into the transport tank, salmon were examined for any unique identifiers (i.e., clips, tags, sutures) that would allow differentiation of experimental, pen-raised, and wild salmon, as there were various SJRRP data collection efforts being completed across all years of juvenile trap and haul. In 2014 and 2015 all collected salmon were transported following capture. However, in 2016 all PIT tagged salmon, initially released at each site to estimate weir and capture box efficiency, were released downstream of the weir to estimate survival to the next downstream location. Salmon mortalities were retained for additional studies by Fresno State University. Transported salmon were measured (mm, fork and total length), weighed (in water bath to the nearest tenth gram), each fish was assigned a smolt index, and origin (wild, pen raised, experimental), site, and disposition (dead or alive) was noted prior to water-to-water transference into the transport tank.

Juvenile salmon were transported a minimum of 118 km and maximum of 133 km in a 567 liter (76×122×61 cm) transport tank containing water pumped directly from Reach 1, and released in Reach 5 of the Restoration Area (RM 119; Figure 5). Oxygen was maintained using compressed gas and a micro-diffuser. Oxygen levels were monitored pre- and post-transport and maintained above 8 mg/L. Once reaching the release site, oxygen (mg/L), temperature (°C), and conductivity were measured using a YSI multimeter (YSI, Inc., Yellow Springs, OH), and turbidity (NTU) was measured using a Hach 2100P turbidity meter (Hach Company, Loveland, CO). These parameters were measured at the release site as well as the transport tank. If the temperature difference between the two readings was > 2°C, tank water was tempered to within 2°C of the receiving water by slowly transferring release site water directly into the transportation tank. Once this temperature was reached, fish were released.

2.3 Juvenile Chinook Salmon Condition at Capture

There are changes in water quality (e.g., temperature, turbidity) and habitat (e.g., substrate composition) as the SJR transitions downstream through Reach 1 from Friant Dam to Skaggs Bridge. To evaluate overall fish condition, as well as how changes in water quality and habitat from up- to downstream in Reach 1 may impact condition, log-transformed length-weight regressions of captured salmon from each weir location were compared as an index of fish condition (Anderson and Neumann 1996). Only fish corresponding to the range of sizes captured across sites were compared, as fish < 72 mm or > 125 mm were not generally captured across all sites.

Figure 5.—Juvenile Chinook Salmon being transferred from fish transport tank to 19-L bucket for release in Reach 5 (Insert) of the San Joaquin River Restoration Program's Restoration Area (San Joaquin River, CA).

2.4 Post-Transport Survival Estimate

Capture and transport of juvenile salmon from Reach 1 to Reach 5 of the Restoration Area results in exposure to significantly different water quality conditions, as the SJR in Reach 5 is comprised largely of agricultural return, is typically warmer, more turbid and higher in conductivity (Hutcherson et al. 2017). Because handling, transport, and water quality conditions can have an effect on fish survival (Barton et al 1980; Maule et al 1988; Schreck et al 1989), a small-scale post-transport release site survival experiment was completed in 2016. To incorporate temporal variance in fish size and water quality, once weekly across the 2016 sample season, approximately 20 Chinook Salmon were removed from the transport container and transferred to an enclosed net pen (61×81×135 cm) constructed of 6 mm mesh and situated approximately 4 m off shore at the release site. Fish in the net pens were evaluated after 24 h to quantify survival, and all surviving fish were then released to continue emigration.

2.5 Capture Box Predation Evaluation

Juvenile Chinook Salmon predation is assumed to be factor that could limit the successful introduction of the species to the Restoration Area, and significant predation loss following entry into the capture boxes could impair the effectiveness of the trap and haul effort (Workman 2013). Though capture boxes were designed to minimize capture of larger fish capable of consuming juvenile salmon (see *Study Area and Fish Collection* above), piscivores did enter the boxes on occasion, and prior monitoring efforts indicate predation occurs when piscivores have access to salmon in the boxes (Root et al. 2016). To further evaluate salmon loss in the capture boxes, and to provide basic information on piscivore effects on juvenile salmon in the SJR, diet contents of all non-native piscivores assumed large enough to consume juvenile salmon were sampled. To extract diet contents, predators were transferred to a bucket (15 L) and exposed to a lethal dose of Tricaine Methansfulonate (MS222, $\geq$ 250 mg/L). Piscivores were measured for total length (mm), their stomachs were extracted using scissors, and contents were identified. Since transfer of preserved fish to a laboratory setting was not practical, small invertebrates were often simply identified as such (aside from crayfish), and fish were identified to the lowest taxonomic level possible with the absence of a microscope, and measured for total length (mm).

2.6 Weir and Capture Box Efficiency

Weirs and capture boxes were designed to maximize capture efficiency of emigrating juvenile salmon. However, SJR flows and excessive debris loads necessitated the selection of panel mesh sizes (13 mm) that would permit some continuous flow even when congested with debris. In addition, a narrow open section for nearshore boat passage was required at all sites. Mesh size larger than max fish height and open sections for boat passage could impact weir and capture box efficiency. Total capture efficiency provides information on the utility of this sample gear for the capture of juvenile salmon, but is also an important metric necessary to better estimate abundance of emigrating juvenile salmon in Reach 1 of the Restoration Area.

Weir efficiency was measured using release-recapture of PIT tagged fish. PIT tag antennas were erected upstream (~ 75 m) of each weir site to estimate the total of non-participants, or fish that swam upstream and outside of the influence of the weir, as well as downstream (~ 10 m) to estimate the percentage of fish that move through or around the weir and downstream past the capture box. To capture effects of diel period on fish movement, releases of PIT tagged Chinook salmon (size range = 65-120; n = 180-200 per replicate release) were completed upstream of the weir, but downstream of the upstream antenna, every two hours from 0500 to 2100. Capture boxes were checked for PIT tagged salmon immediately before each successive release of fish, and then daily during normal trap and haul procedures. Captured PIT tagged fish were scanned, measured (total length in mm) and recorded, then released downstream of the weir and capture box, but upstream of the downstream antenna. Releasing PIT tagged fish downstream of the weir provided an estimate of the downstream antenna efficiency, which was incorporated into the following equation to estimate weir capture efficiency:

$$e_b = n_b / n_p = n_b / n_d = n_b / n_a + n_b = n_b / (n_c / e_a) + n_b$$

Where

$\boldsymbol{e_b}$: *efficiency of weir (collection box),* $\boldsymbol{n_b}$: *# fish in collection box,* $\boldsymbol{n_p}$: *# fish potentially caught in collection box,* $\boldsymbol{n_r}$: *# fish released,* $\boldsymbol{n_u}$: *# fish that swim upstream,* $\boldsymbol{n_s}$: *# fish that stay,* $\boldsymbol{n_d}$: *# fish that swim downstream,* $\boldsymbol{n_a}$: *# fish at downstream antenna,* $\boldsymbol{n_c}$: *# fish detected downstream antenna,* $\boldsymbol{e_a}$: *efficiency of antenna*

To further clarify points or loss and provide data to improve future designs to maximize fish capture, a simplistic estimate of capture box efficiency was obtained. A single point estimate of capture box efficiency at each location was derived by inserting PIT tagged salmon in each capture box (31-50 fish in total) then recovering remaining PIT tagged fish in the capture box following a 24 h period.

2.7 Weir and Capture Box Flow Mapping

As mentioned previously, weirs, diffuser panel, and duel capture boxes were designed and installed in a fashion to promote sweeping and increasing velocities as fish approached the diffuser panel, to improve fish capture, but then reduced velocities as water moved through the diffuser panel and into the capture box to improve velocity refugia and minimize in-box screen impingement. To validate weir design and installation technique once weekly velocity profiles were obtained at each weir location throughout the duration of sampling. Velocities (ft/s) were measured using a velocity meter (Marsh-McBirney model 2000, Frederick, MD) attached to a wading rod (Fondriest Environmental, Fairborn, OH). Velocities, measured as the 30 s average at each location, were recorded along the upstream face of each weir wall and at mid-channel (between weir walls) 10, 20, and 30 m upstream of the diffuser panel and also at the entrance, mid-way through, and at the terminal end of the diffuser panel as water transitioned into the first capture box. Water velocity was measured at 60% water depth at each location, unless water depth was greater than 0.9 m then two measurements (20% and 80% of water depth) were taken. Because velocities were measured weekly during sampling and over a wide range of flows, velocities are reported as mean changes in velocity (Δ ft/s) between each progressive up and downstream location to detail changes in velocity as water progresses to and through the diffuser panel.

2.8 Data analysis

Total wild juvenile Chinook Salmon captured by day, as a function of salmon length at capture, and across years, as well as percentage of species captured in 2016 by weir location was plotted for comparison. Total daily Chinook Salmon capture was compared to daily flow from the nearest in-river sensors (Figure 1; Highway 41 for Scout Island, Donnie Bridge for Highway 99, and the sensor at Skaggs Bridge for that respective site). Data were downloaded from the California Data Exchange Center website (http://cdec.water.ca.gov/) and daily mean ± standard deviation were calculated from the available data. Differences in water temperature, as well as rate of water temperature increase throughout the 2016 sample period, were compared across sites using a One-Way ANCOVA. A one-way ANCOVA indicated no significant difference between the slopes of the regression lines (log-transformed length-weight regression) between sites, which permitted a statistical comparison of fish condition using the Holm-Sidak pairwise method. Site-specific velocity profiles, weir efficiency, 24 h post-transport survival, and predation loss were summarized and presented in figure or table format. All statistical analyses were conducted using SigmaStat 3.5 software (Systat Software Inc., Richmond, California); the significance level (α) for all analyses was 0.05.

3.0 Results and Discussion

Across 108 sample days, a total of 2,007 wild juvenile fall-run Chinook Salmon were captured during 2016 juvenile salmon trap and haul efforts, exceeding sample days and total wild salmon capture numbers in 2014 (71 sample days, 1,837 wild and 556 pen-raised) and 2015 (85 sample days, 617 wild and 1 pen-raised salmon; Figure 6). Catch per unit effort (CPUE, fish/day) of wild fish caught in 2016 (18.6 fish/d) was lower than observed in 2014 (25.9 fish/d), and higher than 2015 (7.3 fish/d). Of the salmon captured in 2016, 1,852 (92.3%) were transported, 1,841 (91.7%) were released successfully, 4 (0.2%) died during transport, 7 (0.4%) died during 24 h post-transport survival estimates, and 102 (5.1%) were in-box or on-wing wall morts. In addition, 32 salmon (1.6%) were sent to Fresno State University for stomach content analysis.

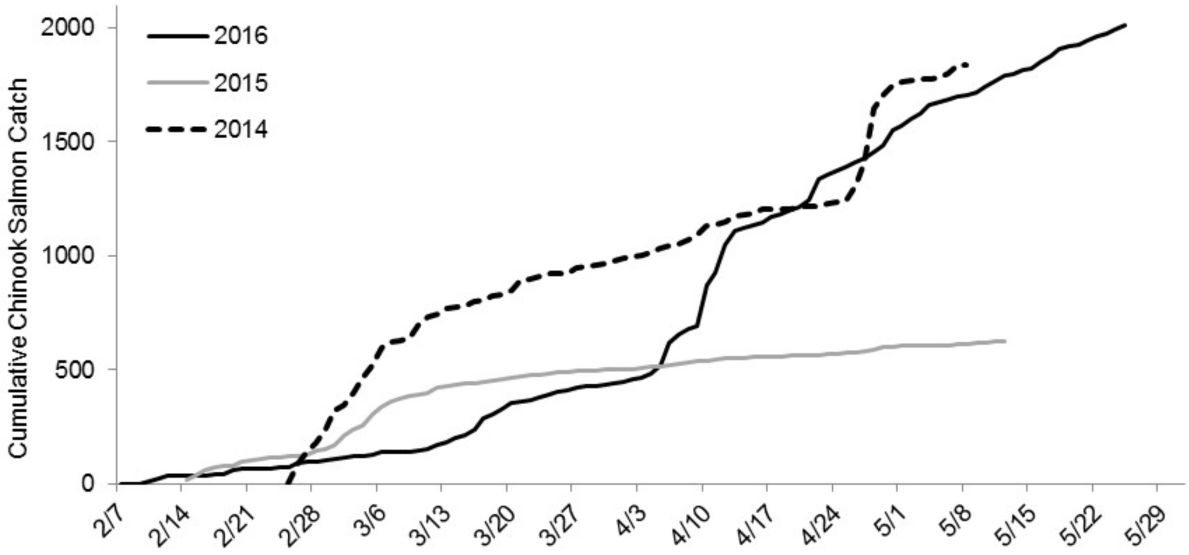


Figure 6.—Cumulative capture of wild juvenile Chinook Salmon on the San Joaquin River during the San Joaquin River Restoration Program's Juvenile Trap and Haul Program, 2014-2016.

Increase in 2016 catch, and annual differences in CPUE, cannot fully be attributed to production, as there was a lower number of released adult females and observed redds in 2014 (87 adult females, 81 redds), but a higher number in 2015 (208 females, 202 redds), compared to 2016 (176 females, 128 redds; Castle et al. 2016; Castle et al. 2017). Higher capture of juvenile salmon in 2014 is attributed to high capture success (47.9% of total salmon captured) of a single rotary screw trap (RM 262) placed immediately downstream (~50 m) of known redd locations (Portz et al 2015). Increased catch and CPUE in 2016 compared to 2015 is likely due, in part, to the pulsed flow regime employed in 2016. In the second week of April 2016, pulse flows were initiated in an effort to promote downstream movement of fish. Pearson Product Moment Correlation indicates a significant positive relationship between flow and capture at Scout Island and Skaggs Bridge ($r = 0.42$, $p < 0.001$; $r = 0.24$, $p = 0.02$, respectively), but no significant relationship at Highway 99 ($p = 0.05$). This relationship is particularly evident when evaluating effects of pulse flows on total capture of juvenile Chinook Salmon (Figure 7). In addition, it is worth noting that frequent occurrences of partial or total weir failure at elevated flows could have precluded the possibility of revealing a stronger relationship between capture rates and flow, and also likely effected total capture of juvenile salmon. Nonetheless, the experimental pulse releases completed in 2016 were the first attempts to manipulate in-river flow conditions to encourage juvenile salmon emigration in the Restoration Area, and data collected during these efforts suggest pulse flows are a useful management technique to promote downstream movement of juvenile fall-run Chinook Salmon. Also of interest is the correlating decrease in temperature coincident with the pulse flows. Such flows during the capture season served to decrease temperature differences over a short duration between Scout Island and downstream sites (Figure 8). While such differences are typically only a few degrees centigrade, such adjustments to the flow regime could be important for increasing downstream survival—temperatures above 20°C can negatively impact migrating juvenile salmon (Van Vleck *et al.* 1988; Myrick and Cech 1998).

Similar to what was observed in previous years, total capture of salmon in 2016 tended to decrease with distance downstream (Portz et al. 2015). During 2016, the majority of wild salmon were captured at the most upstream Scout Island weir (n=1,219, 61%), while the Highway 99 weir (n=513, 25%) and Skaggs Bridge weir (n=275, 14%) were less productive (Figure 9). This is likely due, in part, to the higher abundance of redds observed upstream of Scout Island (n = 88) and Highway 99 (n = 44), compared to those between Highway 99 and Skaggs Bridge (n = 5). However, this could also be reflective of higher predation losses of salmon in 1B. The percentage of total fish captured comprised of juvenile Chinook Salmon decreased with downstream location (Figure 9). Members of the family Centrarchidae (Centrarchids) were the dominant species captured at all sites in 2016 (Figure 9). However, there was an interesting transition of a composition dominated by Redear Sunfish (*Lepomis microlophus*) and Bluegill (*Lepomis macrochirus*) at the most upstream location (Scout Island) to composition dominated by black bass (combined Largemouth (*Micropterus salmoides*) and Spotted Bass (*Micropterus punctulatus*)) at the two most downstream locations (Highway 99 and Skaggs Bridge). This apparent transition in Centarchid species assemblage from 1A to 1B is supported by 2013-14 Inventory and Monitoring data (raft electrofishing) which indicates a 2-5 fold increase in CPUE of black bass (*Micropterus spp.*) from Reach 1A to 1B (Hutcherson et al. 2017). Bluegill are opportunistic predators, feeding largely on aquatic insects, snails, and smaller fish. However, their smaller mouths likely limit their ability to consume salmon smolts. Redear sunfish feed primarily on snails, clams, and insect larvae (Moyle 2002). Of the adult Bluegill (n = 6) and Redear Sunfish (n = 5) sampled for diets during this monitoring effort (see Predation section below), none had consumed fish. In contrast, once *Micropterus spp*. exceed 100-150 mm in length, their diet consists primarily of fish (Lewis et al. 1961; Scalet 1977). This is also supported by diet data collected during sampling. Therefore, it is plausible to assume a higher rate of predation loss as emigrating juvenile salmon transition downstream through Reach 1B.

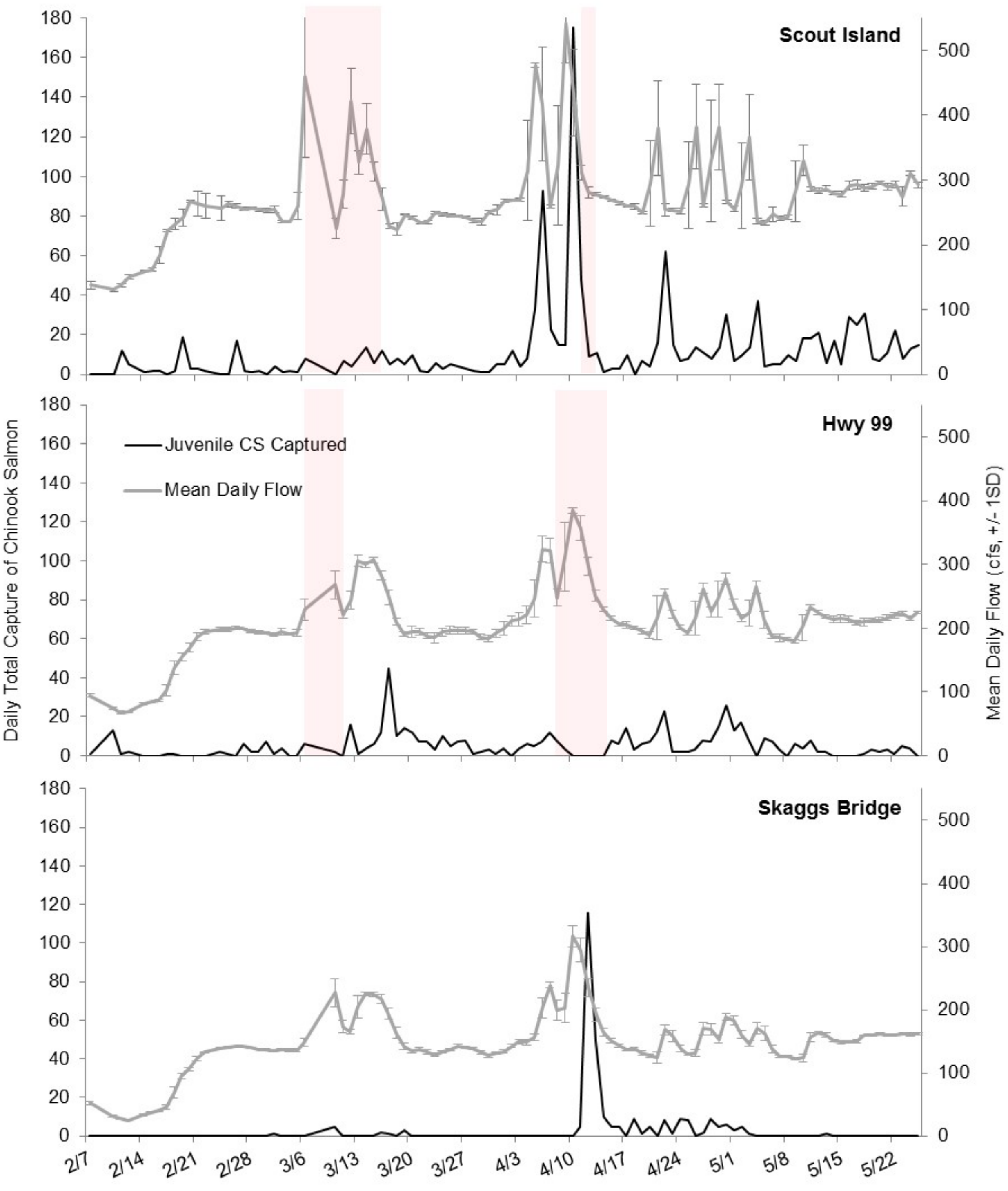


Figure 7.—Effect of pulse flow (grey line; flows depicted as mean daily value ± SD) on capture success (black line; total daily capture) of juvenile Chinook Salmon during San Joaquin River Restoration Program's Juvenile Trap and Haul Program. Light pink shading represents time periods when weir failure occurred due to high flows.

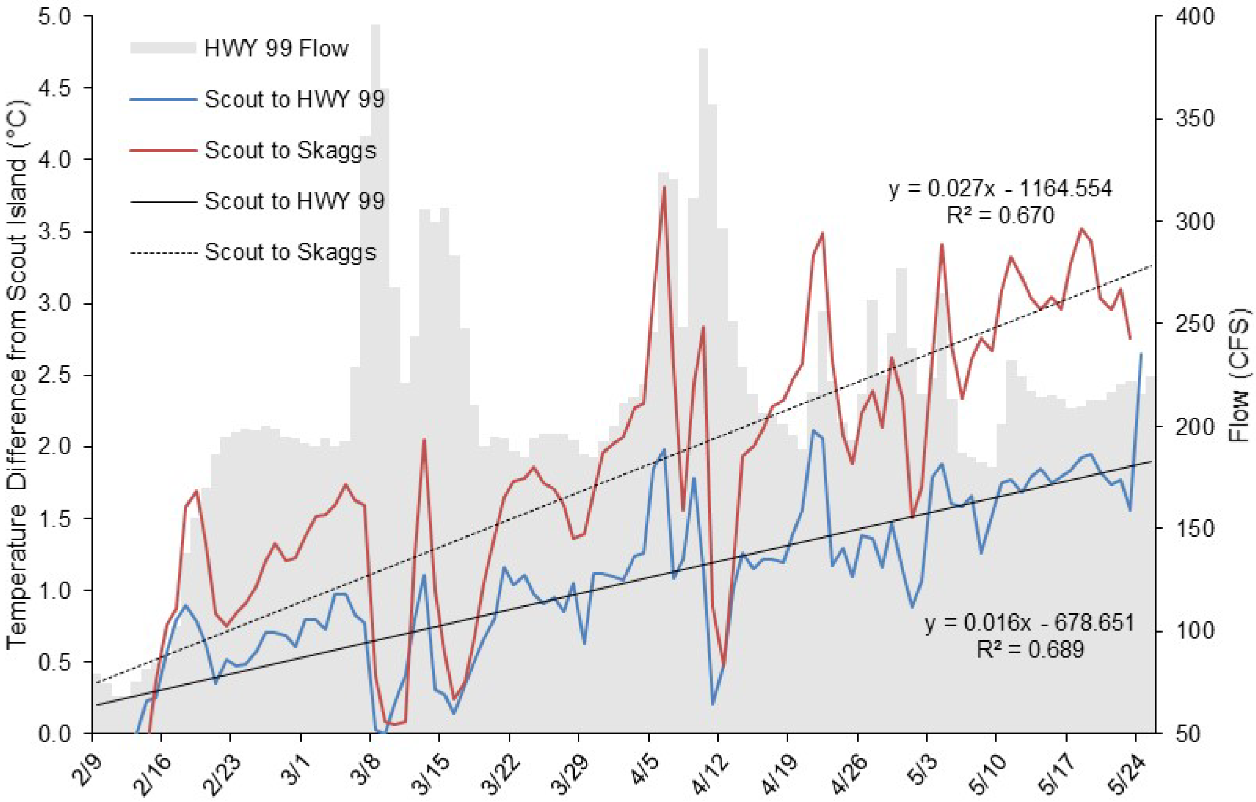
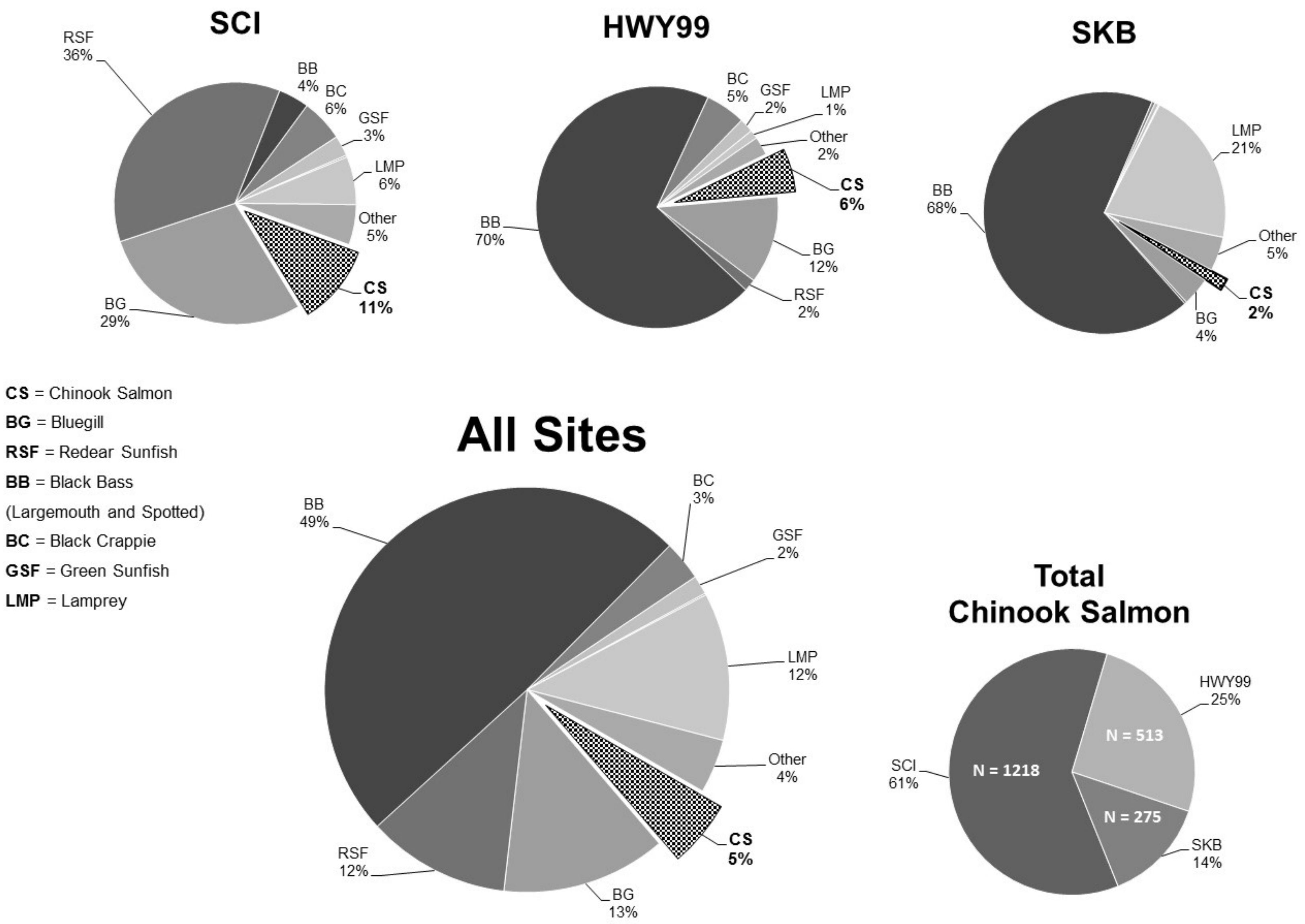


Figure 8.—Temperature differences (°C) from Scout Island to Highway 99 (blue line) and Skaggs Bridge (red line) and corresponding flows (cfs) near Highway 99 (measured from nearest sensor at Donnie Bridge, approx. 2.2 river miles downstream of Highway 99 wier). Trendlines indicate divergence in temperature increases from Scout Island over time.

Chinook salmon total length at capture ranged from 33-127 mm, and, as expected, mean length at capture, across all sites, increased as the sample season progressed. Mean length (± standard deviation) of salmon captured at Scout Island, Highway 99, and Skaggs Bridge were 90.0 (± 20.6 mm), 86.9 (± 22.8 mm), and 96.4 (± 11.3 mm), respectively. Mean length at capture is likely influenced by size effects on weir efficiency, as total capture of Chinook Salmon increased the second week of April once mean fish length at capture exceeded 90 mm (Figure 10). However, piscivores are gape limited and generally consume prey whole, and, as a result, are constrained by the relationship between piscivore mouth size and prey body depth (Hambright 1991). In addition, swimming ability and predator avoidance tends to improve with size (Hale 1999). Therefore, it is plausible to assume predation loss of smaller salmon in Reach 1 may have also been a contributing factor. This is supported by the fact that no salmon less than 72 mm were captured at the furthest downstream weir location (Skaggs Bridge).



CS = Chinook Salmon
BG = Bluegill
RSF = Redear Sunfish
BB = Black Bass
(Largemouth and Spotted)
BC = Black Crappie
GSF = Green Sunfish
LMP = Lamprey

Figure 9.—Percent capture of fish and total juvenile Chinook Salmon captured during the San Joaquin River Restoration Program's 2016 Juvenile Trap and Haul Program at Scout Island (SCI), Highway 99 (HWY99), and Skaggs Bridge (SKB).

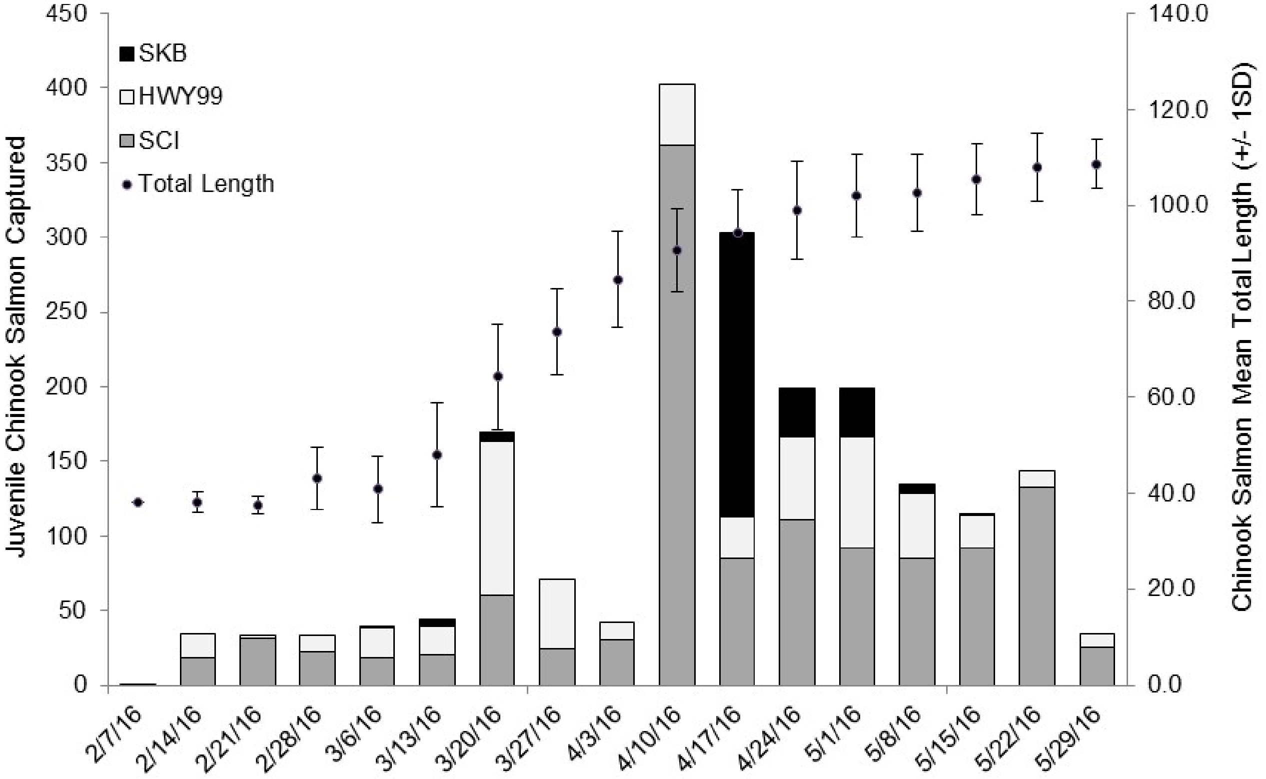


Figure 10.—Site-specific total weekly capture and mean (± 1SD) fork length (mm) of juvenile Chinook Salmon during San Joaquin River Restoration Program Juvenile Trap and Haul Program.

3.1 Survival

Survival of juvenile Chinook Salmon in capture boxes at Scout Island, Highway 99, and Skaggs Bridge was 97.2, 89, and 96.7%, respectively (4.9% mortality across all sites). Pre-transport survival in 2016 (95.1%) and 2015 (97.6%) were high in comparison to 2014 (70.6%). It is assumed using the diffuser box and additional capture boxes at each site in the last two years of juvenile trap and haul allowed for increased velocity refugia, reduced capture box screen impingement, and, thus, increased survival. In-transport survival of salmon was >99% across all years. In general, transport water temperature was lower and dissolved oxygen levels were higher compared to release site conditions in 2016 (Figure 11). Mean (± standard deviation) post release survival of Chinook Salmon in 2016 (n = 6) was 90.7 ± 16.3%. Post-release survival estimates were not measured in previous years. Survival during four of six replicates was 100%, inclusive of replicates completed in April when fish were exposed to warmest temperatures (Table 1). Therefore, two replicates, completed March 25 (84.2 % survival) and March 31, 2016 (60.0 % survival), had a significant influence on overall results. During these two replicates completed in March, SJR flows were higher than during other replicates. Based on observations of the fish during these replicates, it is probable increased mortality was due, in part, to the inability of fish to seek suitable velocity refugia at elevated flows because net pens were set off-shore in flow and away from any nearshore structure. Though this is a poorly replicated small-scale effort, in the absence of the two replicates completed at high flows, this data suggests shortterm (≤ 24 h) survival of juvenile salmon, post-transport and release, is high and there are no significant latent effects associated with capture and transport operations.

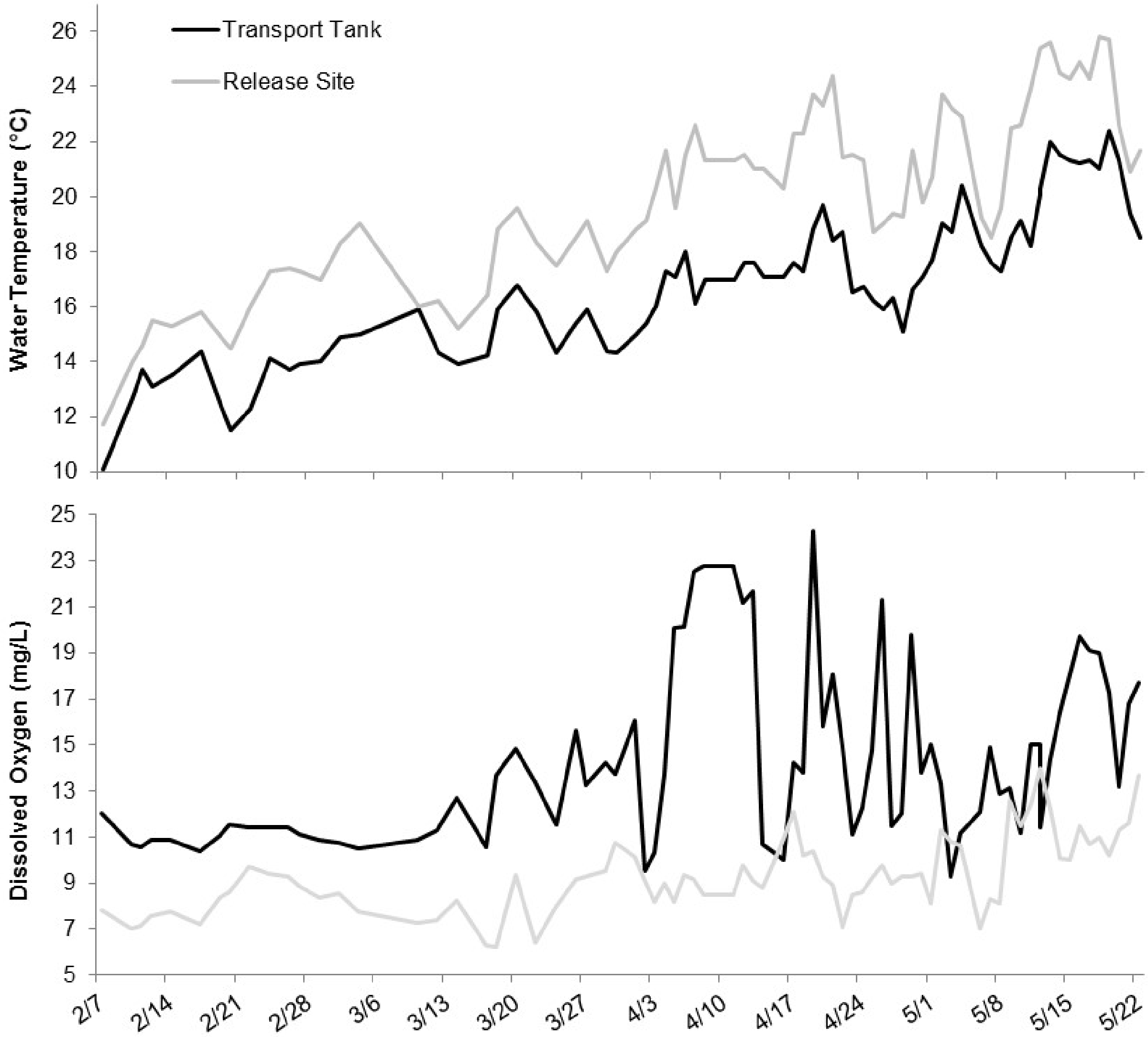


Figure 11.—Water temperature and dissolved oxygen conditions measured in the transport tank, prior to fish release, and at the fish release site in Reach 5 of the San Joaquin River Restoration Program's Restoration Area.

Table 1.—Test dates and water quality conditions during juvenile Chinook Salmon 24-h post-transport survival assessment.

Date	Flow (cfs)	Turbidity (NTU)	Temperature (°C)	Dissolved Oxygen (mg/L)	% Survival
2/19/2016	307.7	23.0	14.6	8.2	100
2/26/2016	284.0	21.1	16.7	8.0	100
3/25/2016	683.9	22.9	18.5	8.8	84

3/31/2016	466.0	30.6	18.0	9.5	60
4/7/2016	310.6	33.1	21.1	7.8	100
4/28/2016	216.5	25.9	19.8	8.9	100
Mean ± SD	*378 ± 171*	*26 ± 5*	*18 ± 2*	*9 ± 1*	*91 ± 16*

3.2 Predation

In addition to capture box and transport induced mortality, capture box predation contributed to loss of juvenile Chinook Salmon during trap and haul. Diet contents from a total of 90 fish comprising 7 species were examined—28 from Scout Island, 45 from Highway 99, and 17 from Skaggs Bridge. Of those, 33 fish, composed of 5 species, had consumed fish. Thirty-four fish had empty stomachs; 23 contained only invertebrates. Ninety-three fish were recovered from those 33 predators, of which 35 were Chinook Salmon (Figure 12). In 2015, 40 predators, comprised of 4 species, had consumed 104 fish, of which 10 were Chinook Salmon. Because fish, both predators and prey, were confined to capture boxes, estimates may not be reflective of actual levels or species-specific predation loss that occurs in Reach 1 of the Restoration Area. However, predation of Chinook Salmon, as a percentage of the total fish consumed and across all piscivores sampled ranged from 25 – 58% (Figure 12), which greatly exceeds the percentage of all fish captured of which salmon contribute (5% across all sample locations, see Figure 9). This suggests, at least when confined to capture boxes, salmon may be easier prey or preferentially targeted by piscivores. Observations made during daily capture box checks indicated juvenile salmon tended to remain exposed in the middle of the box and upper portion of the water column, and were, perhaps, an easier target for predation.

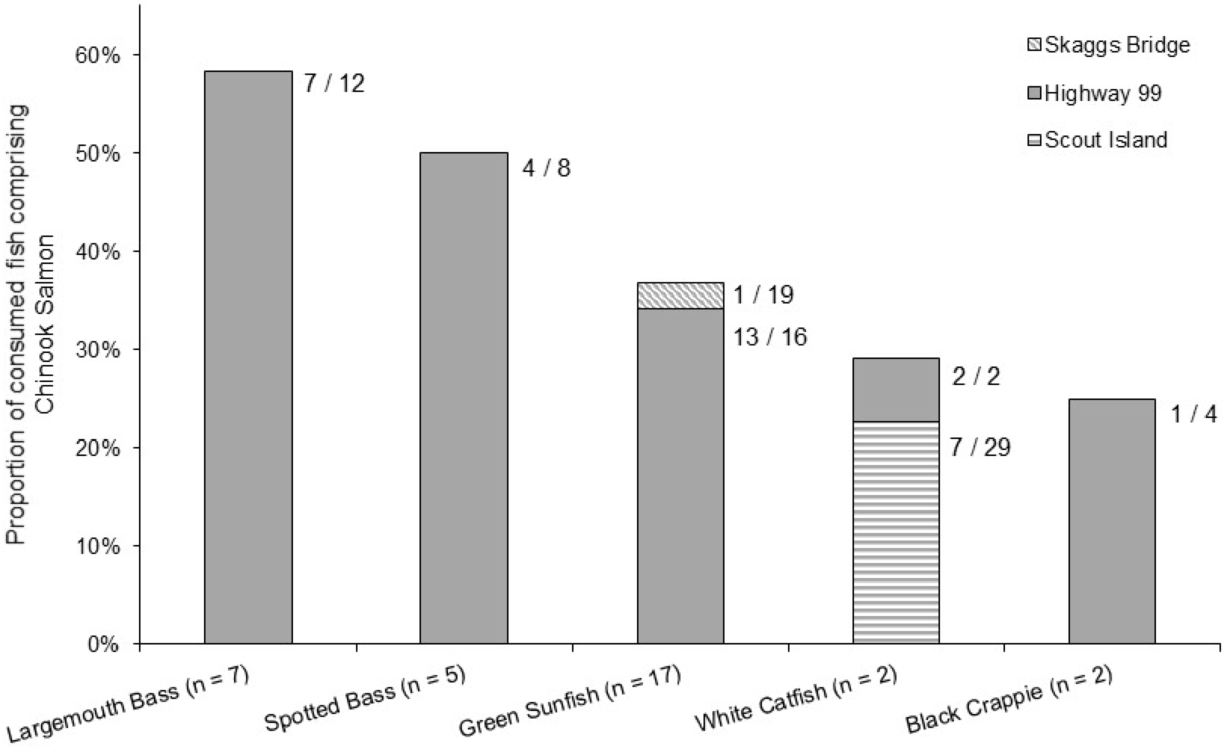


Figure 12.— Proportion of Chinook Salmon comprising total consumed fish, by species and sample location. Sample size on x-axis indicates total predators sampled, which contained fish. Corresponding column values indicate the total ratio of salmon/fish consumed at the respective sampling locations.

3.3 Condition / Temperature

A one-way ANCOVA indicated no significant difference between slopes of regression lines between sites, which permitted a statistical comparison of fish condition. Using the Holm-Sidak pairwise comparison method, a significant difference between fish condition was observed between Scout Island and Highway 99 ($p < 0.001$) and Scout Island and Skaggs Bridge ($p = 0.007$). However, fish condition between Highway 99 and Skaggs Bridge was not significantly different ($p = 0.965$). Un-transformed data is presented in Figure 13. While the apparent differences between these regressions appears minimal, such differences over the small scale of the study, both as a function of time and linear distance, may suggest such differences could be important over the entire migration route of juvenile Chinook Salmon *en route* to the Pacific Ocean. However, it is important to note that this apparent difference in condition may be effected by the natural changes in morphology that occur during smoltification, as weight to length ratios and condition factor typically decrease during this process (Hoar 1976; Winans and Nishioka 1987). Site-specific percentage of salmon identified as smolts at Scout Island, Highway 99, and Skaggs Bridge, were 80%, 65%, and 92%, respectively. To some degree this may explain differences in condition between Scout Island and Skaggs Bridge. However, this doesn't explain significant differences in condition between salmon captured at Scout Island and Highway 99. Though there are a multitude of factors that can effect fish growth and condition (Clarke et al. 1981; Morgan and Iwama 1991; Sommer et al. 2001), water temperature is commonly accepted as having a significant impact (Kjelson et al. 1981). Analysis of temperature profiles recorded at each weir site in 2016 indicate a significant interaction between temperature and date (one-way ANCOVA; $p < 0.001$). Likewise, upstream to downstream, average temperature was significantly higher across sites, and across the sampling season, temperatures increased at a significantly faster rate from upstream to downstream locations (0.061, 0.076, and 0.089°C/day at Scout Island, Highway 99, and Skaggs Bridge, respectively; Figure 14). Temperatures that provide optimal conditions for rearing and growth may vary depending on food availability and quality. However, Marine and Cech (2004) reported juvenile Chinook Salmon reared at 17-20°C and 21-24°C experienced decreased growth (and impaired smoltification) compared to those maintained at 13-16°C, and USEPA (2001) lists 10-15.6°C as the optimal temperature zone for rearing Chinook Salmon. Temperatures at the most upstream site (Scout Island) didn't consistently exceed 16°C until April 12, whereas temperatures at Skaggs Bridge consistently exceeded 16°C nearly a month earlier (March 18).

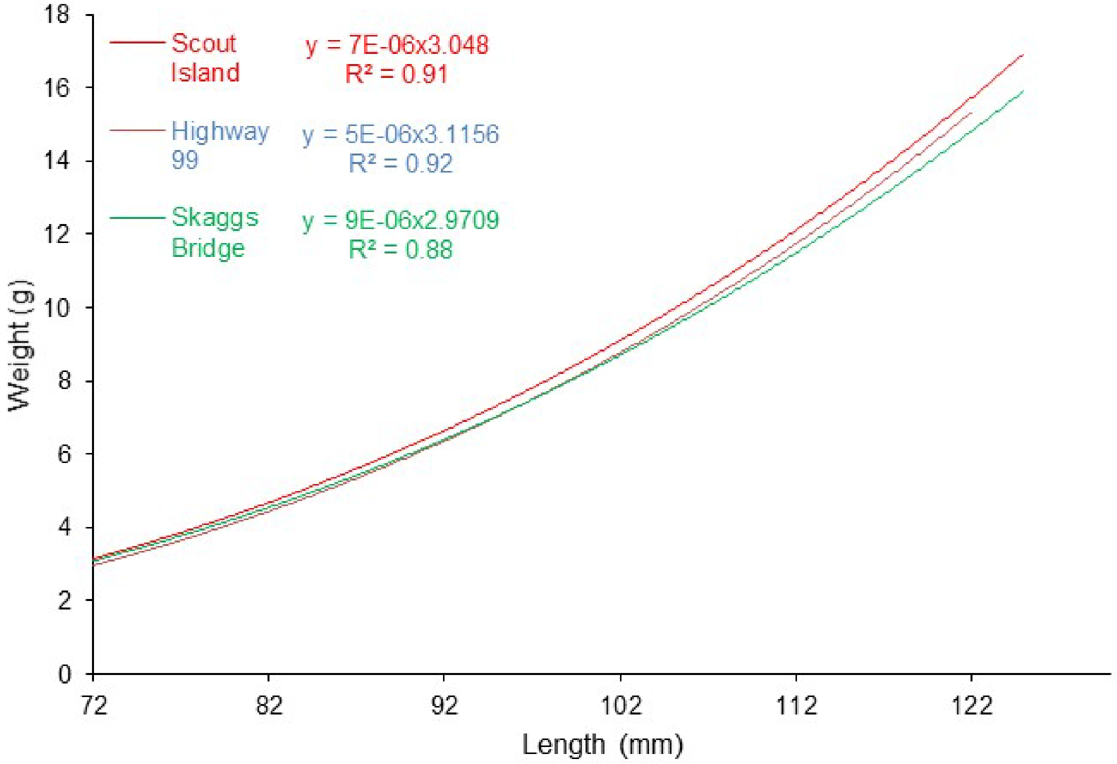


Figure 13.— Length-weight regression trendlines for juvenile Chinook Salmon captured at respective locations during 2016 trap and haul efforts.

3.4 Weir and capture box efficiency

In general, weirs and diffuser channel combined to generate increasing velocities as water flowed towards the diffuser channel, then decreased through the diffuser panel to promote increased capture box velocity refugia (Figure 15). Across all replicate releases to quantify weir capture efficiency, a portion of tagged salmon were captured or detected at the downstream antenna array after subsequent release(s) of other replicates (> 2 h). Because of likely interactions between replicate releases, and, therefore, pseudoreplication concerns, weir efficiency was calculated and reported assuming true replication (n = 9), allowing for an estimate of variance, but also as the sum total of all releases (n=1; Table 2). Sum total weir efficiency at Highway 99, Scout Island, and Skaggs Bridge, were 29.9, 34.6, and 41.2%, respectively. Equations used to calculate these values relied on estimates of PIT tag antenna efficiencies, which ranged from 37.4 – 68.3%. Weir efficiencies measured in 2016 were within the range of those estimated in 2015 (Table 2). No weir efficiency estimates were obtained in 2014. Unfortunately, capture box swim-out was higher than expected at all sites (59.4 – 83.9%), which likely had a major influence on total weir efficiency. If modifications can be made to negate capture box swim-out, weir efficiency could be improved to nearly 50%, which would ultimately improve total capture of fish. Weir efficiencies were not applied to total capture to estimate survival because efficiencies were only estimated at one short time period and during one flow regime, and were not completed during pulse flow events when the majority of salmon were captured and weir failure commonly occurred. Weirs and capture box efficiency likely greatly exceeds rotary screw trap efficiency (0 – 15%), another device commonly used to capture emigrating juvenile salmon (USFWS 2010). Though weir development, installation, and maintenance is labor intensive, when quantifying survival or populations weirs may be more appropriate, particularly when abundance of spawning adults and juvenile emigration numbers are likely to be low, because inefficiency of screw traps may not provide level of precision necessary for robust estimates.

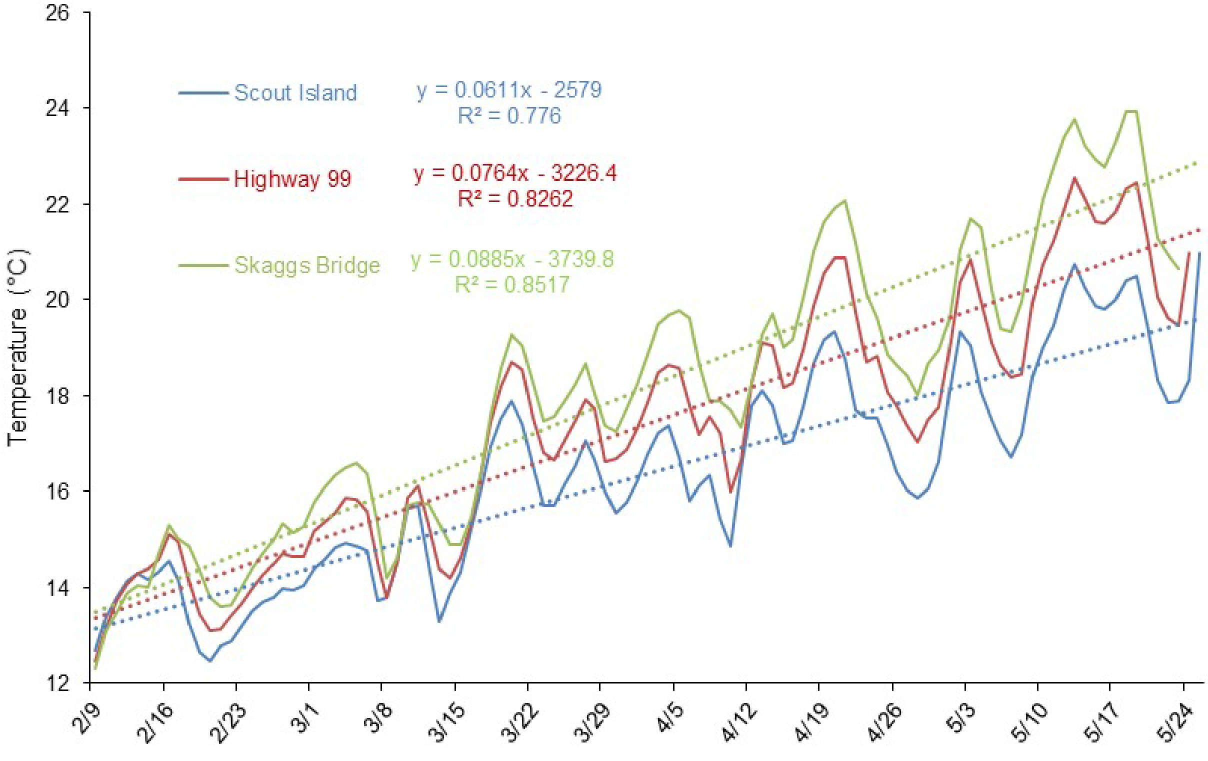


Figure 14.—Temperatures (°C) recorded at each weir location during 2016 juvenile Chinook Salmon trap and haul efforts. Trendlines (corresponding dotted lines) indicate increasing, and diverging temperatures across sample sites, upstream to downstream.

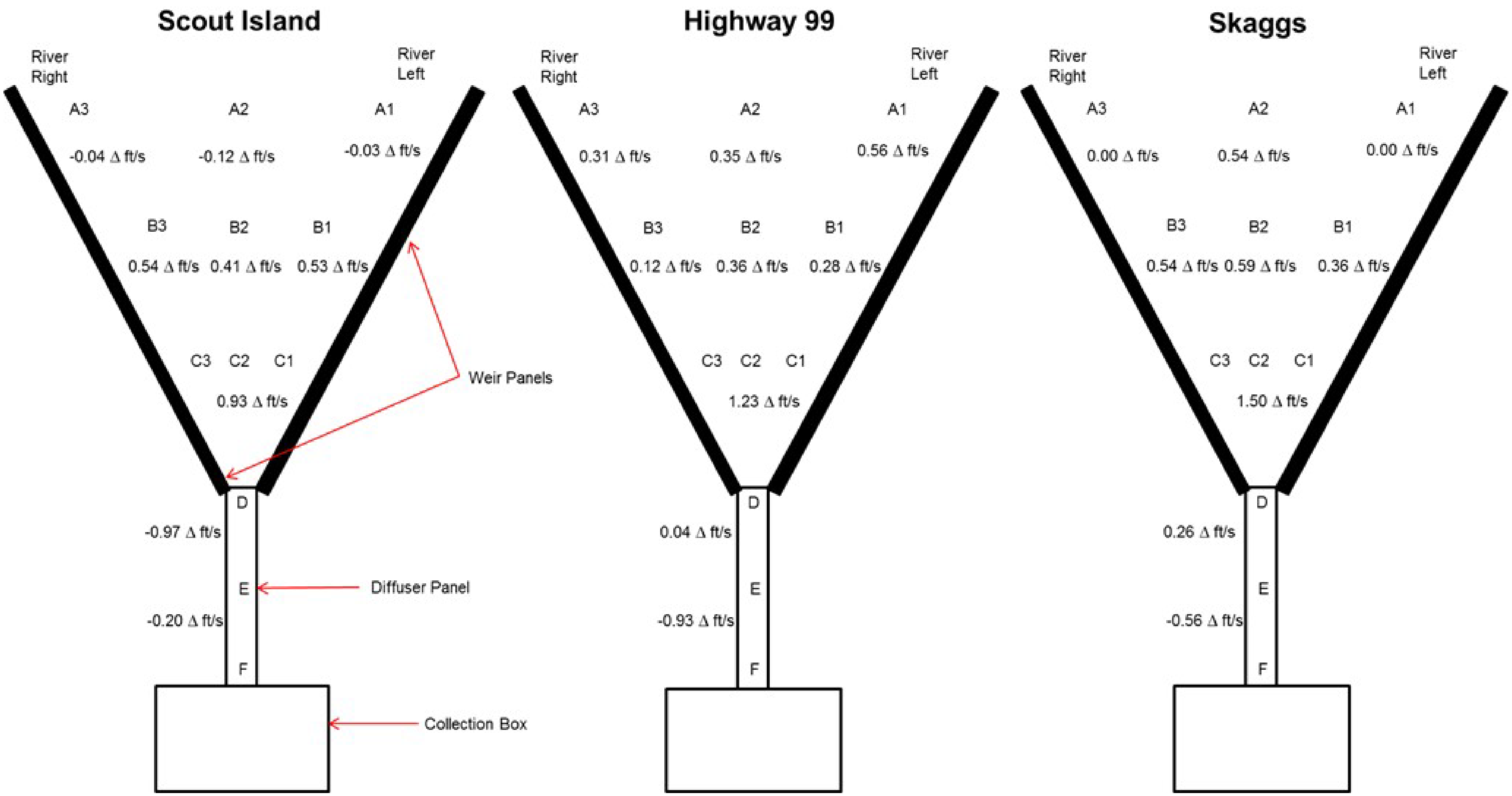


Figure 15.—Water velocity profiles, reported as changes in velocity (Δ ft/s) from nearest upstream location, depicting how flows generally increased towards opening of diffuser, but then dissipated as water (and fish) approached the collection box. This system was designed to promote fish movement to the diffuser panel, but also to create velocity refugia in the collection box.

Table 2.— Weir efficiencies for juvenile Chinook salmon at three locations in Reach 1A of the San Joaquin River Restoration Area in 2016 (top table) and 2015 (bottom table). Nine replicate releases of typically 180 - 200 PIT tagged Chinook salmon, at two hour intervals between 0500 and 2100, were utilize to quantify weir efficiency. Weir efficiency A assumes true replication of releases, and no interaction between replicates (no pseudoreplication). Weir efficiency B assumes interaction and pseudoreplication, and is the total weir efficiency of all releases combined. Weir efficiency C incorporates % of fish, over a 24 h holding period, that swam out of the capture box.

Weir Location	Dates	Replicates (n)	Weir Efficiency A (%)	Weir Efficiency B (%)	Weir Efficiency C (%)	Antenna Efficiency (%)	Capture Box Swim-Out (%)
Scout Island	4/14 - 4/17/16	9	32.3 ± 10.1	34.6	50.5	68.3	64
Highway 99	4/18 - 4/21/16	9	29.1 ± 4.3	29.9	49	37.4	59.4
Skaggs Bridge	4/16 - 4/20/16	9	38.2 ± 15.4	41.2	45.5	38.2	83.9
Scout Island	4/27 - 4/29/15	NA	NA	40.7	NA	32.1	–
Highway 99	4/13 - 4/17/15	NA	NA	42.4	59.6	75.3	71.1

4.0 Conclusions

The primary objective of the Juvenile Trap and Haul program was to evaluate the efficacy of described methods to support Chinook Salmon populations in the San Joaquin River during low hydraulic water years when volitional downstream passage may not be available. Capture, transport, and release of 1,184 juvenile salmon would lead to the assumption that the program would not be sufficient to support significant returns of adult spawners and, ultimately, a stable population. However, when considering the number of redds observed in 2016 (n = 128) and an assumed egg-to-fry survival of 551/redd, as reported for fall-run Chinook Salmon in Reach 1 by Castle et al. 2017 (2015 data), approximately 70,500 fry could have been available for capture. Based on weir efficiencies (30-41%), and in the absence of any other factors, capture totals should have greatly exceeded those observed in 2016. This leads to the conclusion that either a high proportion of smaller fry, that were less likely to be captured using weirs, were emigrating through the study area, or there was a high rate of loss (i.e., predation, natural mortality) prior to fish having the opportunity to encounter the weirs. If low capture numbers were a result of the weirs inefficiency to capture a high proportion of emigrating fry, then the Juvenile Trap and Haul Program and methods currently used are likely not sufficient to support populations of Chinook Salmon in the Restoration Area. However, low capture numbers due to poor survival through Reach 1 should not preclude the SJRRP from considering the utility of the Juvenile Trap and Haul Program in future years once causes of poor survival are understood and addressed.

Juvenile Trap and Haul Program efforts provided some of the foremost data sets detailing emigration and survival of juvenile fall-run Chinook Salmon in the upper San Joaquin River since extirpation of the species from this reach and since the development of the San Joaquin River Restoration Program. Results from 2016 suggest decreased survival and condition of salmon from upper (Reach 1A) to lower reaches (Reach 1B and 2) of the Restoration Area. Dominant species captured at these locations, and data summarized in Hutcherson et al. (2017) and Hueth et al. (In Draft), provide evidence that elevated predation likely contributes to reduced survivability and emigration totals. However, poor egg-to-fry survival may also be a contributing factor (Castle et al. 2016, 2017). Factors effecting site-specific condition of juvenile salmon likely require further investigation. However, water temperatures exceeding the thermal preference of juvenile salmon in lower reaches of the study area could have contributed to this effect. Juvenile Trap and Haul results also indicate that a pulsed flow regime is a management level tool that can be used to promote downstream movement of juvenile salmon in the Restoration Area. However, given the possibility of reduced survivability and condition with emigration and holding in downstream sections of Reach 1B and 2, perhaps the optimal SJRRP strategy should be to create side- and off-channel habitats in Reach 1A to promote rearing, and initiate pulse flows when salmon have reached a larger size at which they are more suited at evading predators.

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