Fall-run Chinook Salmon Trap and Haul 2012–16

Final Monitoring and Analysis Report

SAN JOAQUIN RIVER
RESTORATION PROGRAM

August 2017 – Final Report

San Joaquin River Restoration Program

Fall-run Chinook Salmon Trap and Haul 2012–16

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August 2017

EXECUTIVE SUMMARY

A primary goal of the San Joaquin River Restoration Program is the reintroduction of a naturally-reproducing, self-sustaining population of Chinook Salmon (*Oncorhynchus tshawytscha*) to the upper San Joaquin River, California. Current river conditions and in-river obstacles (e.g., canals, dewatered river sections, dams) do not support anadromy, and salmon must be provided assistance to circumvent barriers to reach suitable spawning habitat. To study behavior and spawning site preference prior to reintroduction, fall-run Chinook Salmon passing Hills Ferry Barrier, an instream picket-fence intended to prevent upstream movement of fish situated near the confluence of the San Joaquin River and Merced River, were captured and translocated from the downstream end of the Restoration Area (Reach 5) to a location near Fresno, California (Reach 1). Salmon were captured with fyke nets in the mainstem San Joaquin River, Mud and Salt Sloughs, near the confluence of the San Joaquin River and Eastside Bypass, and using dip nets at the terminal end of irrigation canals. Once captured, length, gender, condition, presence/absence of adipose fin, and reproductive status were recorded. Photographs and a tissue sample (fin clip) for genetic analysis were also collected for each individual. A uniquely-numbered and colored Petersen disc tag was affixed to each salmon to indicate gender and month of capture to promote identification during post-release surveys. From 2012–15, primarily female salmon were intragastrically implanted with acoustic transmitters, and in 2016 with PIT tags. This allowed for post-release monitoring. Following capture, the majority of individuals were transported from Reach 5 to Reach 1 for release. Transport conditions varied slightly across years, but generally involved truck-mounted (1,324 liters) or trailer-mounted (2,574 liters) fish transport tanks and equipment to maintain adequate water quality conditions during truck transport. The remaining salmon (< 19 male-female pairs, 3.5 percent across all years) were retained for artificial streamside spawning, which resulted in production of ~260,000 eggs across all years and test fish for juvenile habitat-use, survival, emigration, and thermal tolerance studies. The Bureau of Reclamation and CDFW captured and transported 119, 367, 510, 933, and 676 adult fall-run Chinook Salmon annually from 2012 to 2016, respectively. Based on proportion of adipose clipped fish and coded wire tag data from recovered carcasses, the majority of these fish were three-year-old returning adults, of hatchery origin, and from the Mokelumne River Hatchery. Across all years of sampling, the mean male-to-female ratio was 2.6:1. The distribution of collected salmon varied across sample sites, by method, and year of sampling. However, across all years, the majority of salmon were captured the last week of November and first week of December. Survival of transported fish ranged from 93.0–99.7 percent during the reported period. Following release into Reach 1A, mean adult salmon distance moved and travel rate across all years was 20.5 km and 10.3 km/d, respectively.

The preferred citation for this report is:

Root, S., Z. Sutphin, J. Hutcherson, C. Hueth, D. Portz, P. Ferguson, and M. Bigelow. 2017. *San Joaquin River Fall-run Chinook Salmon Trap and Haul, 2012–16*. San Joaquin River Restoration Program, Final Monitoring and Analysis Report. Bureau of Reclamation, Denver Technical Service Center, Colorado.

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Introduction

Historically, the San Joaquin River (SJR) supported an abundant and stable population of spring- and fall-run Chinook Salmon (*Oncorhynchus tshawytscha*; Yoshiyama et al. 1998). However, Central Valley spring-run Chinook Salmon were extirpated from the system by the mid-twentieth century following the completion of Friant Dam (Warner 1991), and have since been state and federally listed as a threatened species (NMFS 2016; CDFW 2016). Fall-run Chinook Salmon are still present in the lower SJR. The Hills Ferry Barrier (HFB), a picket weir, is constructed annually by the California Department of Fish and Wildlife (CDFW) to divert salmon into the Merced River. Instream barriers (e.g.., dry riverbed, Sack and Mendota dams) prevent salmon from accessing suitable spawning habitat in the upper SJR. Furthermore, salmon that circumnavigate the HFB and access the SJR above the confluence of the Merced River are exposed to false navigational cues, such as irrigation and refuge return flows (e.g., Salt and Mud Slough), that may promote straying into largely uninhabitable environments.

In response to conditions in the upper SJR, 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) required reintroduction of Chinook Salmon into the upper SJR, and included 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.

Though significant changes have occurred in the upper SJR (e.g., habitat, flow regime, thermal regime) since construction of Friant Dam, there is a lack of data quantifying how environmental conditions will affect life-stages and critical life functions (e.g., spawning, redd development and production, fry emergence, juvenile emigration, and survival) of Chinook Salmon post reintroduction. The Fall-Run Chinook Salmon Trap and Haul Program takes advantage of a unique opportunity to capture adult salmon that have circumnavigated the HFB and transport them to suitable spawning grounds in upstream reaches. Additionally, this supports multi-agency (e.g., Bureau of Reclamation [BOR], CDFW, U.S. Fish and Wildlife Service [USFWS]) data collection and monitoring designed to identify parameters that will promote future efforts to establish viable populations of spring- and fall-run Chinook Salmon in the SJR. In addition, the trap and haul program provides data to determine the feasibility of such translocation efforts to support future populations if necessary (i.e., during water years when upstream passage is not possible), the effectiveness of the HFB, as well as other important metrics of concern (e.g., temporal immigration patterns, fish condition, hatchery origin, sex ratio, age-class distribution).

1.0 Methods

1.1 Study Location and Period

The Fall-Run Chinook Salmon Trap and Haul Program has been completed annually 2012–16, and typically took place October–December, with some minor efforts completed in early January. However, sampling was initiated in September 2013 as flow conditions and temperatures were deemed suitable for capturing adult salmon. Program activities took place in the SJRRP Restoration Area, encompassing ~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. Fyke-netting of fish occurred at various locations in the most downstream reach (Reach 5) and adjacent sloughs (Figure 2). Four locations were sampled each year of the program: Hills Ferry Barrier (RM 118.5), Mud Slough (RM 121.2), Salt Slough (RM 128.8) and Upper Van Clief (RM 135.8). The Lower Van Clief location (RM 135.8) was sampled 2015–16 and Butch's Levee (RM 119.0) was sampled 2013–16. Though the locations of the nets in Mud and Salt Slough were some distance upstream in those respective waterways, the RM locations listed indicate the confluence with the mainstem SJR. In addition to fyke-netting, salmon were captured by dip-netting in the terminal ends of several irrigation canals near Los Banos (these ultimately connect to Salt Slough; Figure 2). Following capture and processing, salmon were truck-transported to Reach 1A, and released upstream of Highway 99 Bridge at Camp Pashayan (RM 243.3; 2012–15) or Scout Island (RM 250.7; 2016). Fish were released at Scout Island in 2016 because of the concern that construction activities, occurring at the Highway 99 Bridge, could have impacted fish health and behavior.

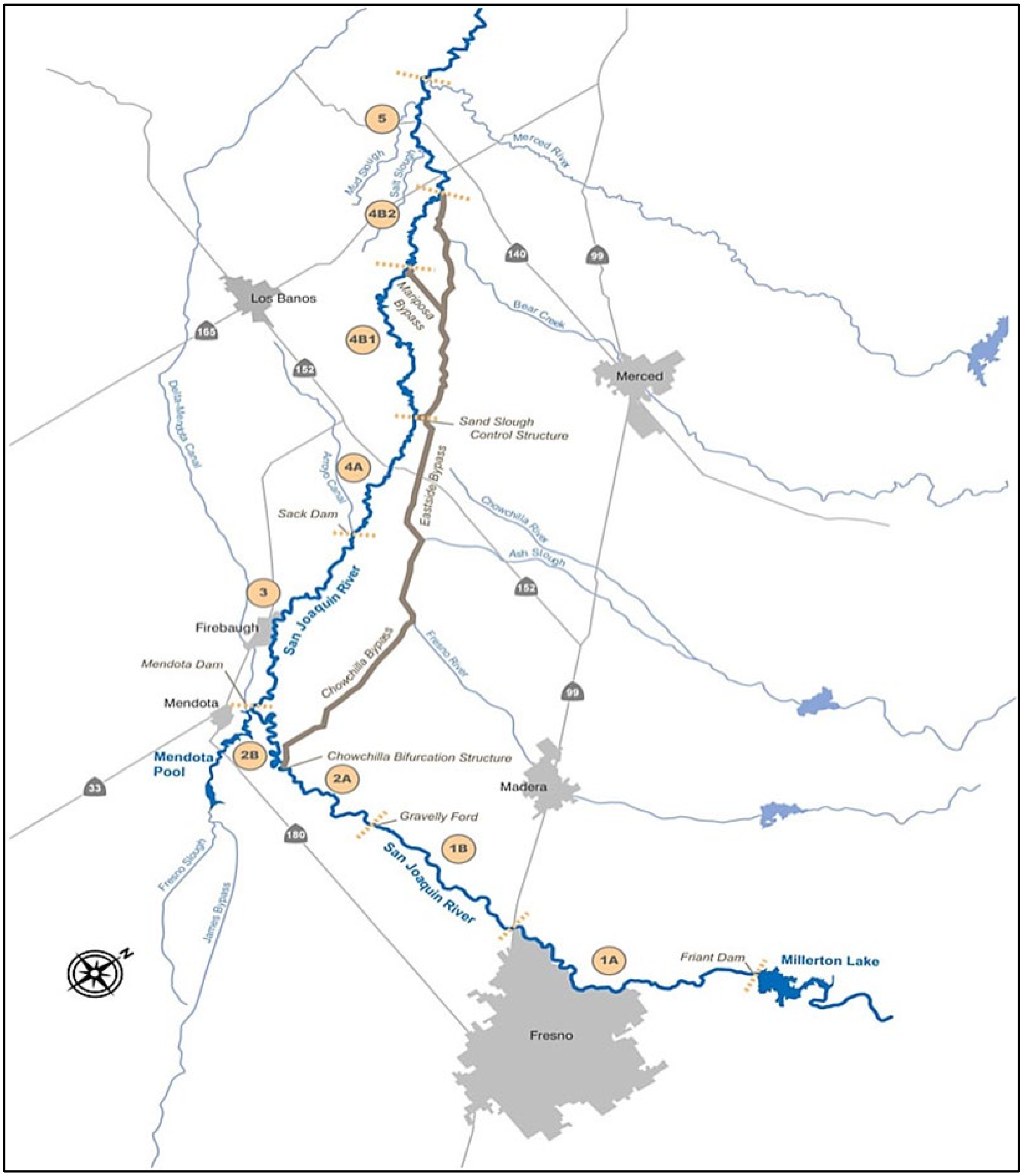

Figure 1.—Map of the San Joaquin River Restoration Area and associated reaches 1A–5. The Restoration Area encompasses the San Joaquin River below Friant Dam to the confluence with the Merced River. Yellow numbered circles identify each Restoration Reach, and the dashed line identifies the boundary between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

Figure 2.—Fyke net locations (Hills Ferry, Butch's Levee, Mud Slough, Salt Slough, Lower and Upper Van Clief) and primary dip net locations (remaining markers—lower right on map), where adult fall-run Chinook Salmon were captured as part of the Fall-Run

Chinook Salmon Trap and Haul Program. The state of California, with the San Joaquin River Restoration Area highlighted in blue, is depicted at the bottom left.

1.2 Sample Gear and Methodology

Fyke Netting

Fyke nets, constructed of a 1.2 or 1.8 m square entry, followed by a series of three circular compartments, with 2.4 cm square no. 252 knotless nylon mesh, were used to capture fish in Reach 5 of the Restoration Area. Separating the three circular compartments was a mesh-constructed partition, which tapered to a 25-cm opening—this reduces the possibility of fish escaping the net after capture. Wing-walls (1.2 or 1.8 m high) extended in a v-shaped pattern downstream, and were used to guide upstream-moving fish into the net (Figure 3). Fyke nets were secured to t-posts driven into the substrate. Sample sites with suitable depths and widths, and minimal in-river obstructions were selected to permit maximum gear efficiency. In general, all fyke nets fished continuously throughout each sample period. On occasion, elevated water levels and flows resulted in safety hazards which required temporary removal of nets. Nets were checked at least once daily for fish, net scour, and damage, and were cleaned to prevent debris buildup, and were reset and repaired as necessary.

Figure 3.—Fyke net used to capture adult Chinook Salmon at the mainstem Hills Ferry Barrier location in Reach 5 of the San Joaquin River Restoration Area.

Dip Netting

California Department of Fish and Wildlife personnel captured adult salmon in the terminal ends of irrigation canals. Two to four individuals used long handled dip nets and worked in unison, making continuous sweeps as they progressed towards the terminal end of the waterway where adult fish were generally observed congregating. These efforts were more spatially and temporally intermittent than fyke netting efforts, and were generally completed when salmon were observed in these locations.

1.3 Fish Processing and Transport

The following information was recorded for each salmon captured: capture location, fork and total length (FL/TL; mm), overall condition, reproductive status, and adipose fin presence/absence (Figure 4). From 2012 to 2015, condition was noted as poor, fair, or good based on best judgement. In 2016, the following criteria was established as a function of the total area of visible external damage: poor (>25 percent), fair (5–25 percent), and good (<5 percent). External damage included any combination of noticeable lacerations, sores, and tissue deterioration. Reproductive status was noted as pre-spawn (no eggs or milt expressed), ripe (eggs or milt expressed), or spawned (noticeable absence of firm and distended abdomen). If mortality had occurred, fate was recorded (e.g., net entanglement, unknown cause). A small tissue sample was collected from the dorsal fin for genetic analyses. All fish that were transported for release in Reach 1 were provided an externally visible tag. In 2012 T-bar tags (Floy Tag and Mfg., Inc., Seattle, Washington) were injected into the dorsal musculature of salmon using an injection gun (Mark II, Floy Tag and Mfg. Inc., Seattle, WA). In subsequent years, Petersen disc tags (3.2 cm diameter; Floy Tag & Mfg. Inc.) were affixed to either side of the dorsal musculature, immediately below the dorsal fin, using a 10-cm nickel pin (Figure 5). Each disc tag had a unique identification number, and was color-coded to differentiate gender and month of capture—this aided in post-release redd and carcass surveys. In addition to external tags, from 2012 to 2015, some salmon were intragastrically implanted with an acoustic transmitter (VEMCO V13, 48 mm long 6.35g, 69 kHz transmitter; VEMCO, Bedford, NS, Canada) using a glycerin-coated balling gun to permit tracking and identification of redd locations in Reach 1 (Figure 6). During these post-release monitoring efforts, it was observed that acoustic transmitters were generally expelled concurrent with the release of eggs. This observation allowed investigation of a more cost-effective alternative to identifying redd locations, and in 2016 some salmon were intragastrically implanted with a PIT tag (23 mm, half duplex; Oregon RFID, Inc., Portland, OR). Since a primary objective of post-release monitoring was to identify redd locations, females were generally targeted for acoustic and PIT tagging. During the initial year of the program (2012), some males also received an acoustic transmitter.

During processing, fish were maintained in a tub containing SJR water to limit atmospheric exposure and handling stress. Prior to transfer to the fish-transport tank, a side-profile picture of each salmon was taken as a quality control measure (Figure 7). Each acoustic transmitter emitted a unique signal, and permitted tracking of salmon after release. Several pairs of fish were retained each year to support CDFW streamside spawning activities. In addition to salmon, bycatch from fyke nets were measured (FL/TL; mm) and recorded. These fish were returned to the river, upstream of the fyke nets to minimize likelihood of re-capture.

Figure 4.—A mobile processing station was set up at each site to measure fish, assess condition, acquire tissue samples, affix external tags, and implant acoustic transmitters

and PIT tags. Fish were held in a tub filled with river water during processing to minimize stress.

Figure 5.—Petersen disc tags were attached to Chinook Salmon via a nickel-plated pin inserted through the dorsal musculature. Each tag had a unique number, and was color-coded to aid in identifying gender and month of capture after release.

Figure 6.—A balling gun was used to intragastrically implant acoustic tags into Chinook Salmon, allowing tracking of fish after release in Reach 1 of the San Joaquin River Restoration Area.

Figure 7.—After processing and prior to transfer to the fish transport tank, a photograph of each fish was taken. Note the label identifying the Petersen disc tag number and gender, and the small tissue missing from the dorsal fin (genetic tissue sample).

After processing, salmon were transferred to a tank and truck-transported to Reach 1A. Transport water was collected near the netting sites (typically the Hills Ferry Barrier location) to minimize differences between river and tank water quality. From 2012 to 2014, BOR used a 1,324-L fish transport tank, and in 2015–16, a 2,574-L trailer-mounted fish transport tank was used (Figure 8). California Department of Fish and Wildlife used 1,893 or 3,028-L tanks, depending on anticipated salmon capture (Figure 9). Oxygen was supplied to all tanks via compressed gas cylinders and micro bubble diffusers (Pentair Aquatic Eco-Systems, Apopka, FL) and Fresh-Flo aerators (Fresh-Flo Corp., Sheboygan, WI). In 2016 dissolved oxygen (DO, mg/L) and temperature (°C) were measured daily at each netting location, in the transport tank before and after transport, and at the fish release site. In all other years, DO was checked prior to transporting fish to ensure equipment was functioning properly and an adequate supply of oxygen was available (>8 mg/L). Given the design of the haul tank used 2012–14, fish were individually netted using dip nets and transferred to the river for release. In 2015, fish were released via a 0.3-m diameter tube, allowing for water-to-water transfer and reduced handling at release (Figure 8).

Figure 8.—Trailer-mounted haul tank (2,574-L; at left) and release method (at right) used by Bureau of Reclamation during the 2015 and 2016 Fall-Run Chinook Salmon Adult Trap and Haul Program.

Figure 9.—Fall-run Chinook Salmon being transferred to the California Department of Fish and Wildlife's fish-transport tank.

1.4 Data Analyses

Percent of total salmon captured as a function of netting location and sample week, total salmon capture by mean daily flow (CFS) in the mainstem SJR, as well as size and gender distribution were graphed for qualitative comparison. In addition, fish fate (e.g., released, spawned, mortality) by gender and year were summarized. Annual carcass surveys conducted by CDFW and USFWS following salmon releases allowed for coded wire tag (CWT) recovery from deceased fish in Reach 1. This permitted identification of hatchery origin from recovered salmon. To standardize for uneven sampling efforts across sites and years, fyke net capture data is also presented as catch-per-unit-effort (CPUE; salmon/day). Catch-per-unit-effort was not calculated for dip-netting, since this capture method was used opportunistically/sporadically. Bycatch was summarized as total annual species-specific capture, as well as a function of the percentage of total fish captured across sites.

Effects of mainstem flows upstream and downstream of the Merced River confluence on total capture of salmon were evaluated. Flow data downloaded from USGS National Water Information System (http://waterdata.usgs.gov/ca/nwis/d) stream gauge station 11273400 (SMN) was used to estimate flows at the HFB sample site. Whereas stream gauging station 11274000 (NEW), situated ~0.15 RM downstream of the Merced River confluence, was used to estimate combined Merced River and Reach 5 SJR flows.

Flows from Mud and Salt Slough were assumed to correlate to the difference recorded at gauging stations up- and downstream of these inputs. Stream gauging station 11260815 (SJS) records flows on the mainstem SJR in Reach 5, ~4.17 RM upstream of the Salt Slough confluence, and gauging station 11261500 (FFB) records flows on the mainstem ~3.87 RM upstream of the Mud Slough confluence. Salt Slough flows were estimated as the difference between flows from FFB and SJS, and Mud Slough flows were estimated as the difference in flows from stations FFB and SMN. Flow data were available in 15–60-min intervals, but were converted to mean weekly flow for analysis. Temperature data were also obtained from the SMN sensor. This information is presented in Appendix A, Figure A-2.

1.5 Acoustic Telemetry

Single-channel acoustic monitoring receivers (VR2W, 69 kHz acoustic monitoring receiver; VEMCO, Bedford, NS, Canada) capable of identifying coded transmitters implanted in fall-run Chinook Salmon were strategically distributed from just below SR 99 Bridge (240.7 RM) to just below Friant Dam (267.4 RM). There were 12, 22, 19, and 25 receivers placed in-river in 2012–15, respectively, to monitor fish movements throughout Reach 1 (Figure 10; Appendix A, Table A-1). Acoustic receivers were moored between a buoy and cement block, which held receivers vertically in the water column, and were anchored to the bank using stainless steel cable (Figure 11). Receivers were installed in September and retrieved by March. In addition to the stationary receivers in the SJR, tagged fish were manually tracked using a portable hydrophone, from boat and from shore, to determine fish locations between receivers or specific locations within sections of the river. This activity was done in conjunction with redd and carcass surveys and can be found in reports pertaining to those activities (Castle et al. 2016a, 2016b). As a result of this activity some of the tags that had been previously placed in a fish were recovered during carcass surveys and later reused.

Figure 10.—Locations of acoustic receivers used to monitor movement of adult fall-run Chinook Salmon 2012–15. The state of California, with the San Joaquin River Restoration Area highlighted in blue, is shown at the bottom right.

Figure 11.—Acoustic receiver (VEMCO), attached to an anchor and buoy, prior to being deployed in Reach 1 of the San Joaquin River Restoration Program Restoration Area. Receivers were used to monitor adult fall-run Chinook Salmon movements following capture in Reach 5 and release in Reach 1.

1.6 Streamside Spawning

Streamside spawning occurred at the CDFW Satellite Incubation and Rearing Facility (SIRF) located in Friant, CA. Eggs were stripped from the female into a colander using the incision spawning method (Leitritz and Lewis 1980), and rinsed with 0.9 percent saline solution to separate ovarian fluid before being placed into a mixing tub. Milt was then extracted from males and placed directly into the mixing tub with eggs. Fertilized eggs were rinsed with a 0.9 percent saline solution followed by a 100 ppm iodophor solution, then wrapped in wetted cheesecloth and disinfected with a 30 minute bath treatment containing 100 ppm free iodine. After disinfection, eggs were measured volumetrically to estimate fecundity and placed into vertical incubation trays (8-tray Vertical Incubator; MariSource, Fife, WA). Eggs were addled after developing eye spots and dead eggs were enumerated to calculate percent survival to the eyed stage. After hatching, alevin were placed into a deep matrix incubator (Redd Zone, Astoria, OR). As fry began to swim up, a screen was removed so that fry could volitionally enter into a swim-up tank. Fry in the swim-up tank were enumerated daily to calculate survival to swim-up stage and were then moved to a starter tank where they were fed granulated fish food before being ponded. Once fry reached a suitable size (>60 mm) they were coded wire tagged (CWT) and used for various SJRRP studies. A linear regression model was fitted using data from 42 females to establish an initial fall-run Chinook Salmon length/fecundity model specific to the lower San Joaquin River above the Merced River confluence.

2.0 Results and Discussion

2.1 Fish Capture and Relocation

Across all years of the Adult Trap and Haul Program (2012–16), and inclusive of both fyke- and dip netting efforts, a total of 2,605 Chinook Salmon and 4,583 non-salmonids (bycatch) were captured (Figure 12). Salmon capture increased each year of sampling from 2012 to 2015 (2012 n=119; 2013 n=367; 2014 n=510; 2015 n=933), but totaled 676 in 2016 (Figure 13). Across all years and sample locations combined, salmon were the most abundant species captured. In total, 76 percent of all salmon were captured using fyke nets (n=1,972), and 24 percent (n=632) were captured by dip-netting (Figure 12). Fyke-netting resulted in the highest proportion of catch across all years, outside of 2013, when canal dip-netting contributed to 55 percent of the total catch. A total of 16, 52, 111, and 198 adult female salmon were acoustically tagged 2012–15, respectively (n=377). A total of 162 female salmon were PIT tagged in 2016. Non-native species contributed to the highest percentage of bycatch across years and locations (Figure 12). Of the total bycatch, <0.1 percent (n=28) were native species (5 Sacramento Blackfish, *Orthodon microlepidotus*, 1 Sacramento Splittail, *Pogonichthys macrolepidotus*, and 22 Sacramento Sucker, *Catostomus occidentalis*). Because canal dip netting specifically targeted adult salmon, no bycatch was captured during these efforts.

Of the total Chinook Salmon captured across all years 2,425 (93 percent) were transported and released into Reach 1, resulting in the construction of 73, 81, 202, and 128 redds 2013–16, respectively (n=484; Castle et al. 2016a, 2016b). The remaining fish were used for streamside spawning (n=96, 4 percent), were not transported (n=47, 2 percent), or died in transport (n=36, 1 percent; Table 1). Fish that were not transported were either deemed in too poor a condition to transport, or were classified as a mortality at capture. From 2012 to 2016, the percentage of individuals classified as being in poor condition, yet still transported and released, ranged from 2–11 percent (n=79). The total number of female Chinook Salmon identified as spawned out but transported and released was 0, 7, 1, 3, and 3 from 2012–2016, respectively. As noted previously, no standardized criteria were established for this classification during sample years 2012–15—this should be considered before comparing this data. However, in 2016, with formal criteria established for quantifying condition of adult salmon, the percentage of salmon classified as good, fair, and poor was 81, 15, and 4 percent, respectively. As expected, the percentage of total fish classified in good condition tended to decrease and the percentage classified in fair condition tended to increase as the season progressed (Figure 14). During the initial year of sampling, survival of transported salmon was 92 percent, but survival was 99, 98, 99, and 99 percent 2012–16, respectively, totaling 1 percent transport loss (mortality) of all fish to date. The total number of adult male and female salmon captured and transported with minimal mortality, particularly after the initial program year, suggests a trap and haul program may be a suitable alternative to promote fish access to suitable spawning habitats when river conditions do not provide sufficient passage.

Coded wire tag data from captured fall-run Chinook Salmon during CDFW and USFWS carcass surveys suggest the majority of fish captured between 2013 and 2016 were from the Mokelumne River, and Merced River salmon contributed to <13 percent of the total across all years (Table 2). Feather River, Nimbus Hatchery, and Coleman Hatchery salmon (Sacramento River origin) were also present in CWT-recovered fish. No carcasses were recovered in 2012. Of all SJR tributaries (Cosumnes, Stanislaus, Tuolumne, Merced, and Mokelumne), >50 percent of the total estimated SJR fall-run escapement, 2012–15, were Mokelumne River fish (Azat 2017). In 2016, Mokelumne River fish contributed to 33 percent of the total estimated SJR fall-run escapement (Azat 2017). A high rate of straying reportedly occurs from most hatchery-produced Central Valley fall-run Chinook Salmon, including Mokelumne River fish (Smith and Workman 2004). Assuming the proportion and origin of CWT-recovered fish correspond to the total distribution of all salmon captured during Trap and Haul efforts, it is no surprise an abundance of Mokelumne River fish stray into Reach 5, and constitute the majority of fall-run Chinook Salmon in the Restoration Area.

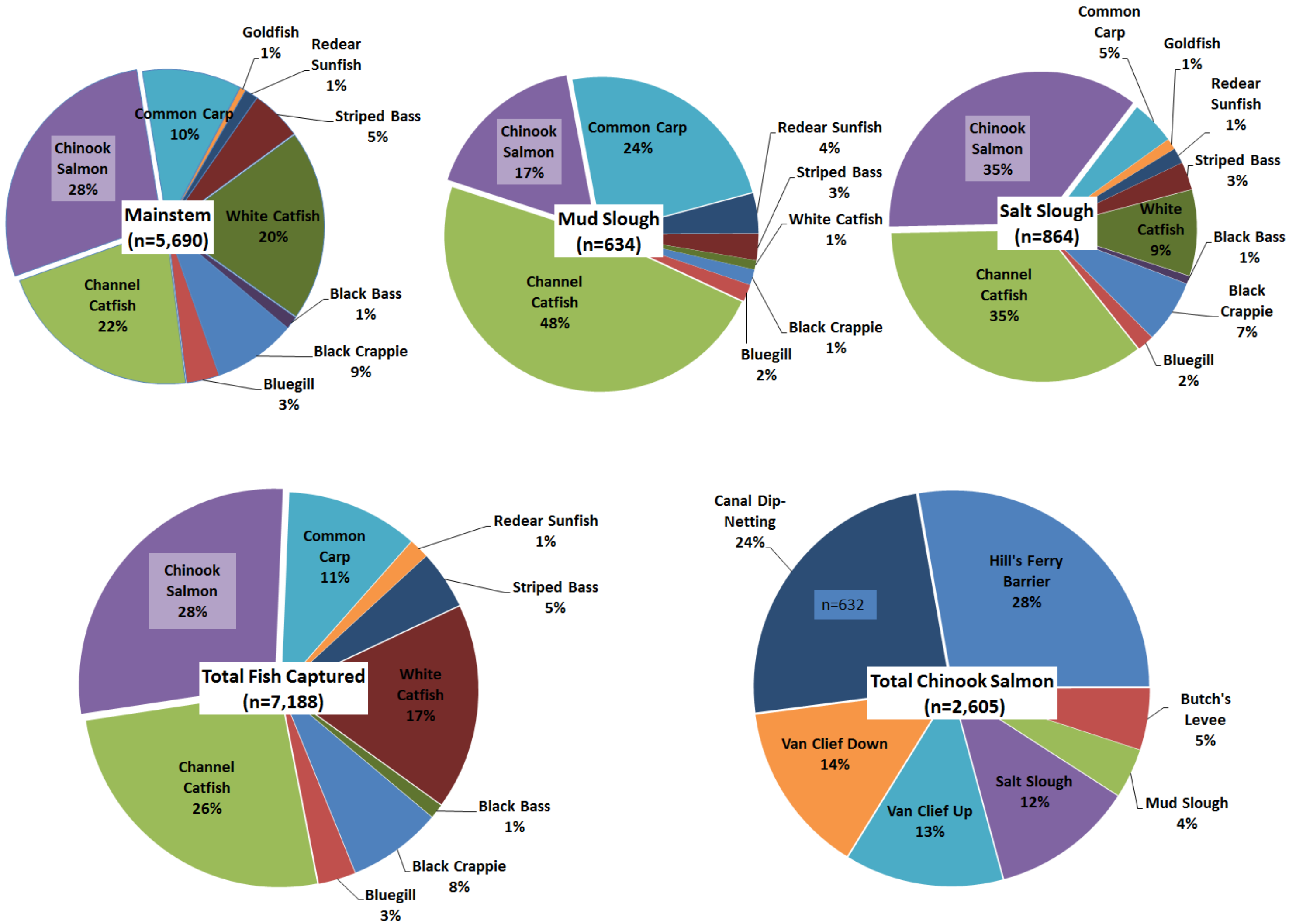

Figure 12.—Fish capture during the Fall-Run Adult Trap and Haul Program across all years (2012-16), and by location. The "mainstem" includes Hills Ferry Barrier, Butch's Levee, Lower Van Clief, and Upper Van Clief. Dip netting locations include only Chinook Salmon. Fish captured contributing to < 1% of the total were not included in the figure, but include: Black Bullhead, Brown Bullhead, Green Sunfish, Inland Silverside, Rainbow Trout, Sacramento Blackfish, Sacramento Splittail, Sacramento Sucker, Threadfin Shad, and Warmouth.

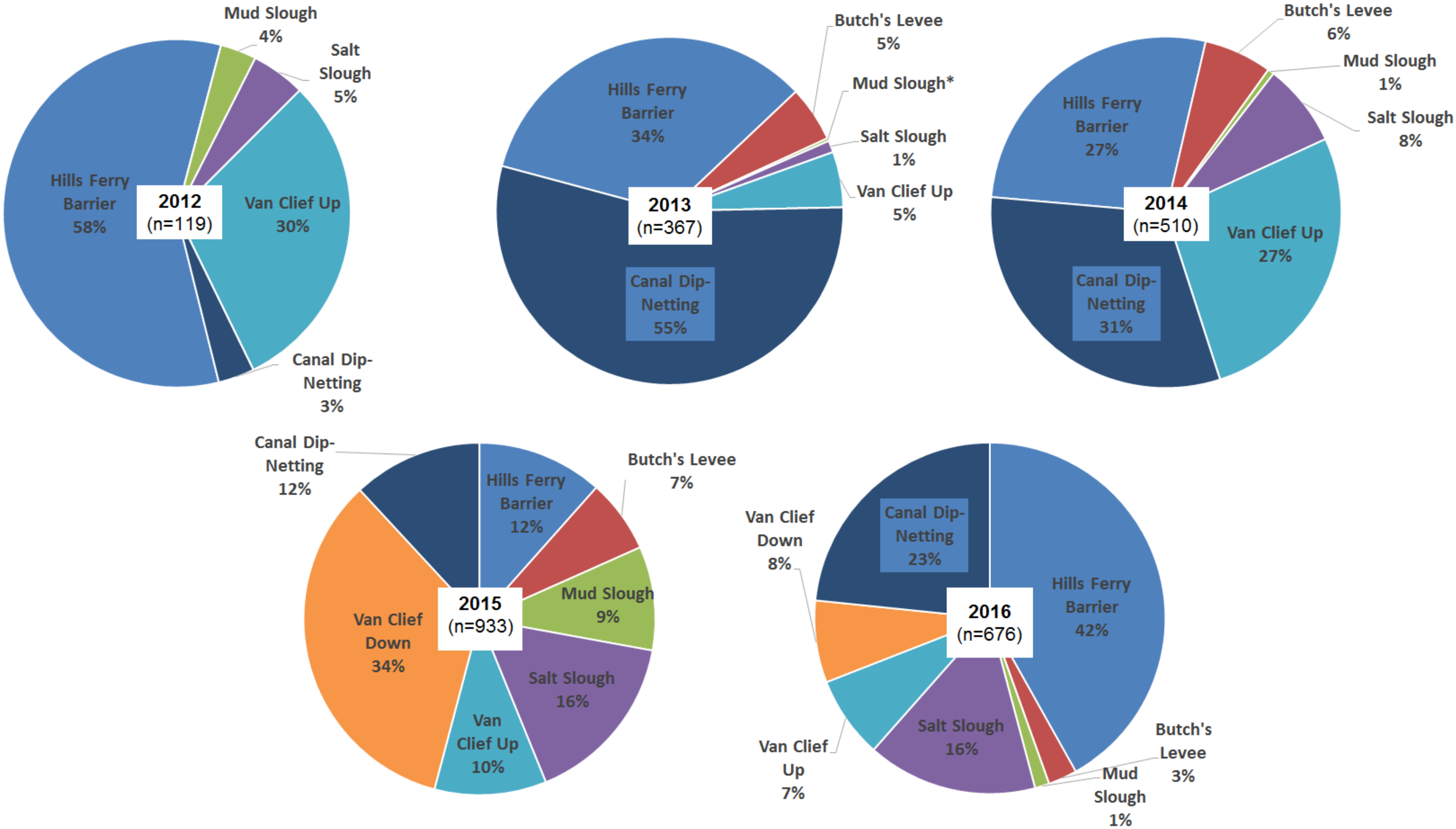

Figure 13.—Percent of Chinook Salmon captured by location from 2012 to 2016 during the Adult Fall-Run Trap and Haul Program in San Joaquin River Restoration Area.

Table 1.—Fate of male (“M”) and female (“F”) fall-run Chinook Salmon captured (cumulative percentage within year) 2012–16 above Hills Ferry Barrier in the Restoration Area of the San Joaquin River, CA. Fish beyond reproductive condition, or not expected to survive transport, were not transported.

	2012			2013			2014			2015			2016			2012-2016
Fate	M	F	*total*	M	F	*total*	M	F	*total*	M	F	*total*	M	F	*total*	*Total*
Released	75 (82%)	24 (86%)	99 (83%)	238 (98%)	115 (93%)	353 (96%)	363 (97%)	117 (97%)	480 (94%)	665 (97%)	225 (92%)	890 (95%)	427 (90%)	176 (88%)	603 (89%)	**2426 (93%)**
Spawned	2 (2%)	3 (11%)	5 (4%)	5 (2%)	5 (4%)	10 (3%)	6 (2%)	9 (7%)	15 (3%)	19 (3%)	19 (8%)	38 (4%)	13 (3%)	15 (7%)	28 (4%)	**96 (4%)**
Not Transported	5 (5%)	1 (4%)	6 (5%)	0 (0%)	0 (0%)	0 (0%)	1 (0%)	3 (2%)	4 (1%)	2 (0%)	0 (0%)	2 (<1%)	31 (7%)	4 (2%)	35 (5%)	**47 (2%)**
Transport Mortalities	9 (10%)	0 (0%)	9 (8%)	1 (0%)	3 (2%)	4 (1%)	6 (2%)	5 (4%)	11 (2%)	3 (0%)	0 (0%)	3 (<1%)	3 (1%)	6 (3%)	9 (1%)	**36 (1%)**

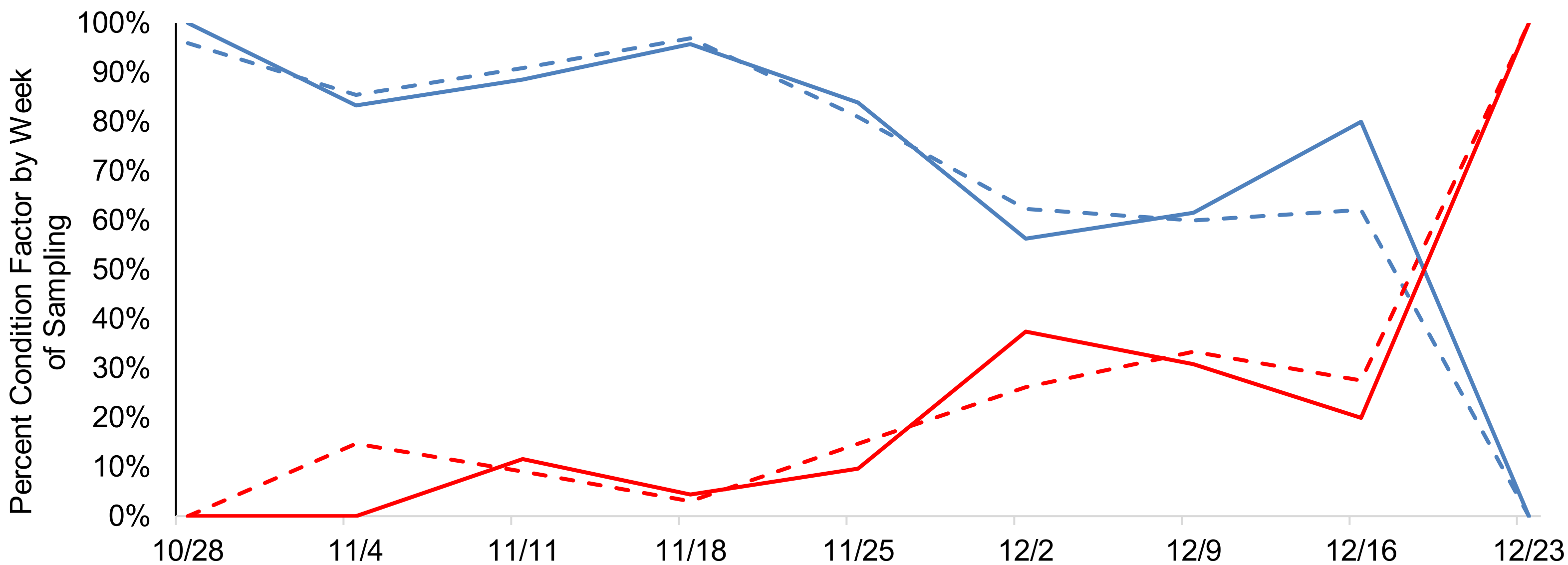

Figure 14.—Adult female (dashed line) and male (solid line) fall-run Chinook Salmon classified as being in good (blue line) or fair/poor condition(red line) during 2016 Adult Trap and Haul sampling.

Table 2.—Origin of fish recovered from coded-wire-tag data during 2013–16 carcass surveys in Reach 1 of the Restoration Area, San Joaquin River, CA.

	Hatchery of Origin				
	Mokelumne	**Feather**	**Merced**	**Nimbus**	**Coleman**
2013 (n=15)	87%	7%	-	7%	-
2014 (n=23)	70%	9%	13%	9%	-
2015 (n=16)	77%	5%	12%	3%	3%
2016 (n=19)	79%	5%	5%	0%	11%

Data provided by A. Shriver, CA Dept. Fish & Wildlife, Fresno Office CA.

Percentage of hatchery-produced salmon (indicated by an adipose fin clip) captured was highest in 2012 (55 percent), but generally contributed to about a quarter of the total captured salmon in successive sampling years (27, 25, 22, and 23 percent, 2013–16, respectively; Figure 15). However, these percentages are not necessarily reflective of the true estimate of hatchery produced fish encountered during sampling, because not all hatchery fish are adipose clipped prior to release. As indicated previously, and based on CWT data, the majority of adult fall-run salmon captured were likely of Mokelumne River origin. While the Merced River Fish Hatchery does CWT salmon, the Mokelumne River Fish Hatchery (MRFH) is the only SJR tributary hatchery that participates in the Central Valley Salmon Constant Fractional Marking Program, which aimed to adipose clip and CWT 25 percent of fall-run Chinook Salmon prior to release between 2007–13 (Nandor et al. 2010; Buttars 2013). Therefore, the percentage of adipose clipped salmon suggests the majority of captured fish were likely of hatchery origin. Additionally, the elevated percentage of adipose-clipped fish in 2012 (55 percent) is likely due to additional adipose-clipping and tagging conducted by the MRFH (targeted 100 percent CWT and ad-clip) 2009–10 (Buttars 2010).

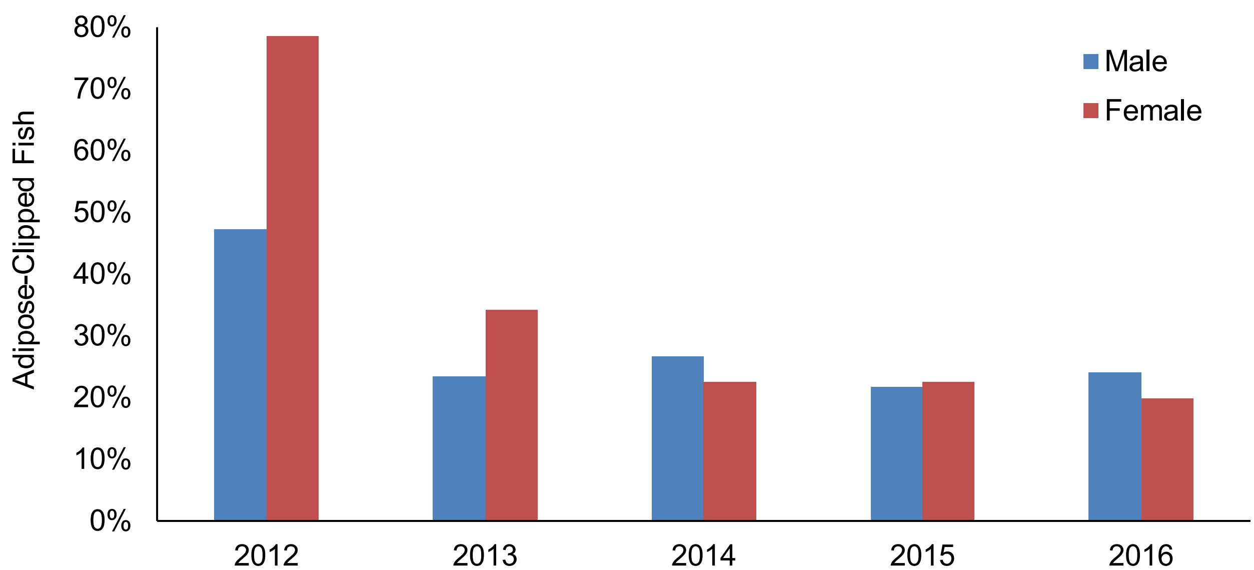

Figure 15.—Percentage of adipose-clipped adult fall-run Chinook Salmon, as a cumulative percentage of the total captured each year, during the Adult Trap and Haul Program 2012–16 in the San Joaquin River, CA.

Size distribution of both sexes of salmon was generally consistent across years of sampling. The distribution appears to be bimodal, suggesting two age classes of fish present—likely jacks/jills as well as older returning adults (Figure 16). In addition, males consistently outnumbered females 2012–16 at ratios of 3.3:1, 2:1, 2.8:1, 2.8:1, and 2.3:1, respectively, with an overall mean ratio of 2.6:1. This male-to-female ratio is higher than fall-run Chinook Salmon returning to the lower Mokelumne River from 2013–15 (1.4:1 mean ratio; Del Real and Saldate 2013, 2014, 2015). Though there are various factors that reportedly effect sex ratios and phenotypic sex reversal in salmonids (see Craig et al. 1996, Nagler et al. 2001), population health can be compromised when a significant genetic imbalance exists, particularly in smaller populations (Frankham et al. 2002).

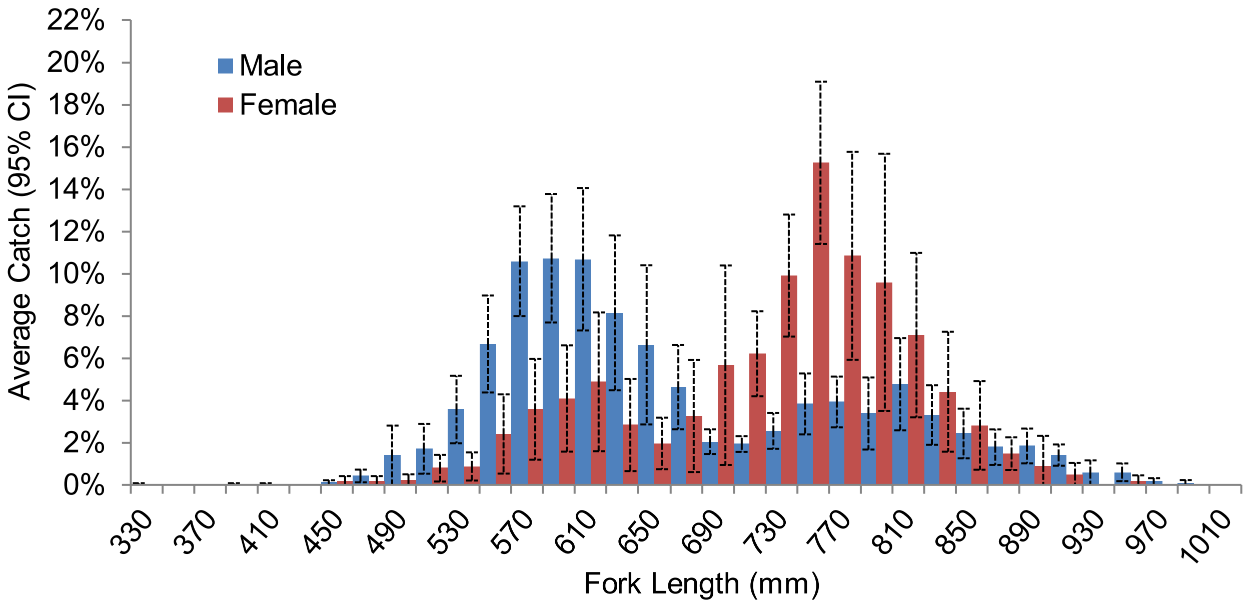

Figure 16.—Average size distribution (fork length; mm) and 95% CI, across sampling years, for salmon captured during the 2012-16 Adult Fall-Run Chinook Salmon Trap and Haul Program.

The difference in size distribution of males and females in the Restoration Area is due to the high proportion of jacks captured during sampling. As defined by Quinn (2005) jacks and jills are male and female salmon that return from the ocean 1–2 years earlier and at a smaller size than cohorts. Using a criteria of <700 mm (fork length), the same used in the Mokelumne River (Del Real and Saldate 2013, 2014, 2015) to identify grilse or jack/jill salmon, resulted in 64, 56, 78, 80, and 82 percent of male salmon captured 2012–16 identified as jacks. Females labeled as jills 2012–16 constituted 11, 31, 53, 74, and 66 percent of total salmon captured. Likewise, percentage of male fall-run Chinook Salmon returning to the Mokelumne River in 2013, 2014, and 2015 meeting this criteria (<700 mm) was higher (48, 32, and 61 percent, respectively) than jills (11, 11, and 24 percent; Del Real and Saldate 2013, 2014, 2015), but still lower than observed in Reach 5. It is not uncommon in some populations of Chinook Salmon to see a higher abundance of returning males, composed of earlier-aged individuals, than females (Halupka et al. 2000; Olsen et al. 2006). However, it is of interest that the percentage of jacks and jills captured in the study area was elevated in comparison to the Mokelumne River, and tended to increase during the study period. Mechanisms that reportedly contribute to early maturation in anadromous salmonids, include genetic effects (Unwin et al. 1999), opportunity for growth and fat storage at earlier life-stages (Silverstein et al. 1998; Shearer et al. 2006), and size of smolts at release (Brannon et al. 1982; Vollestad et al. 2004). However, there may also be a commercial fishery effect, as size-selective gill nets are not as likely to capture smaller individuals. Similarly, it is plausible the Hills Ferry Barrier contributed to this occurrence, as the picket weir may be more effective at restricting passage of larger individuals. Early maturation and return of salmonids is an alternative life history avenue. However, larger male salmon have a breeding advantage and outcompete smaller individuals (Esteve 2005), and Berejikian et al. (2010) indicates Chinook Salmon jacks have lower reproductive success and fewer offspring compared to older individuals. A more thorough review of the effects and potential consequences of an excessive abundance of smaller jack salmon in the restoration area should be considered.

Across all years of sampling, and inclusive of both sexes and sampling methods used, the highest percentages of salmon were captured the last week of November (20 percent of the total) and first week of December (20 percent of the total; Figure 17). Within year of sampling, this pattern was consistent 2013–14. However, the peak catch occurred earlier (Nov. 11–18) in 2012 and (Nov. 18–25) 2016, and later (Dec. 2–16) in 2015. In comparison to adult fall-run returns in the Mokelumne River, which CWT data suggest comprised the majority of the fish encountered in the Restoration Area, peak returns to the Restoration Area typically occurred later (~one month). In general, peak returns of fish to the lower Mokelumne River from 2013 to 2014 occurred earlier in the fall (highest peak return in late-October, with peaks continuing through November), and corresponded to pulsed flow releases (Del Real and Saldate 2013, 2014). In comparison to previous years (2013–14), and similar to what was observed during Adult Trap and Haul sampling, 2015 returns of adult Chinook Salmon to the lower Mokelumne River were later (highest peak return in early-November with peaks continuing through early-December; Del Real and Saldate 2015). However, the delay in returns to the Restoration Area is likely a function of the increased distance (~94 RM) salmon must travel from the confluence of the mainsteam SJR and the Mokelumne River. Returns of salmon to the lower Mokelumne River corresponded to management induced pulse flows—conditions that were not present during adult trap and haul activities.

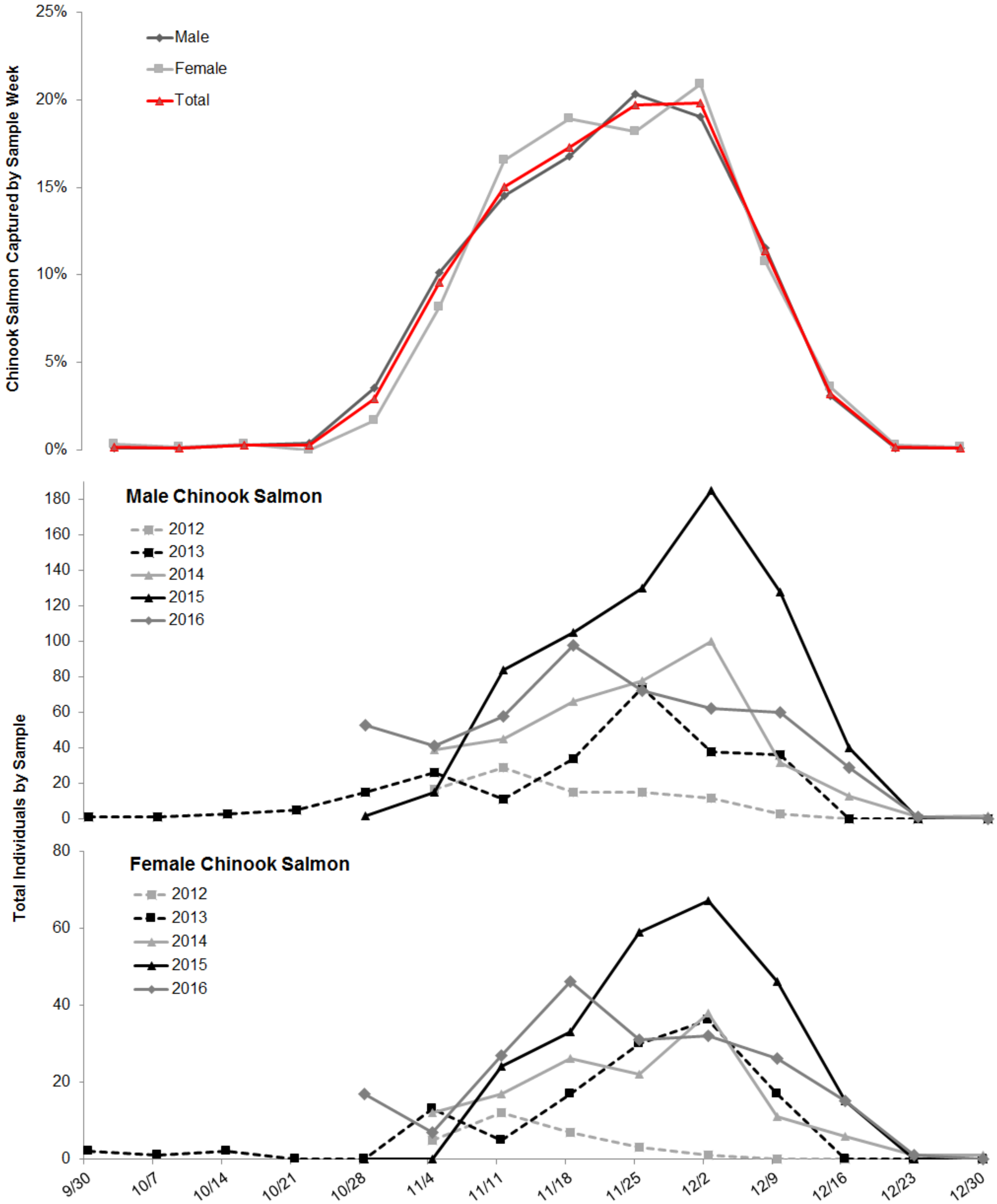

Figure 17.—Annual capture of adult fall-run Chinook Salmon, standardized across sampling seasons as a function of weekly cumulative catch (top figure), and total weekly capture of male and female Chinook Salmon (bottom two figures) by week of capture. For all figures, week is displayed as the start of the sampling week (2012–16).

Of all fyke netting sites, the single season highest CPUE (6.6 salmon/day) occurred at the Lower Van Clief net in 2015 (Figure 18). It should be noted that this site was only used in 2015 and 2016. However, since this site was the furthest upstream site in the mainstem SJR, prior to the confluence with Bear Creek/Eastside Bypass (Upper Van Clief site sampled above the confluence), the high capture rate at this site suggests a high abundance of fish moving to the San Luis National Wildlife Refuge (USFWS) in previous years, as well as the limited efficacy of the HFB and Butch's Levee nets to capture adult salmon. Aside from the Upper Van Clief location in 2015, the Hills Ferry Barrier netting location produced the greatest mean CPUE (2.2 salmon/day) across all years of sampling, with Mud Slough contributing the lowest CPUE (0.7; Figure 18). Since fish passing through the Restoration Area would encounter the HFB first, one might assume this net would be the most productive. Interestingly, the next upstream mainstem site, Butch's Levee (0.5 RM from HFB) was typically much less productive (0.9 salmon/day), indicating there are site-specific characteristics (e.g., scouring, bathymetry, excessive debris loads, net damage from local wildlife) that also influence capture efficiency.

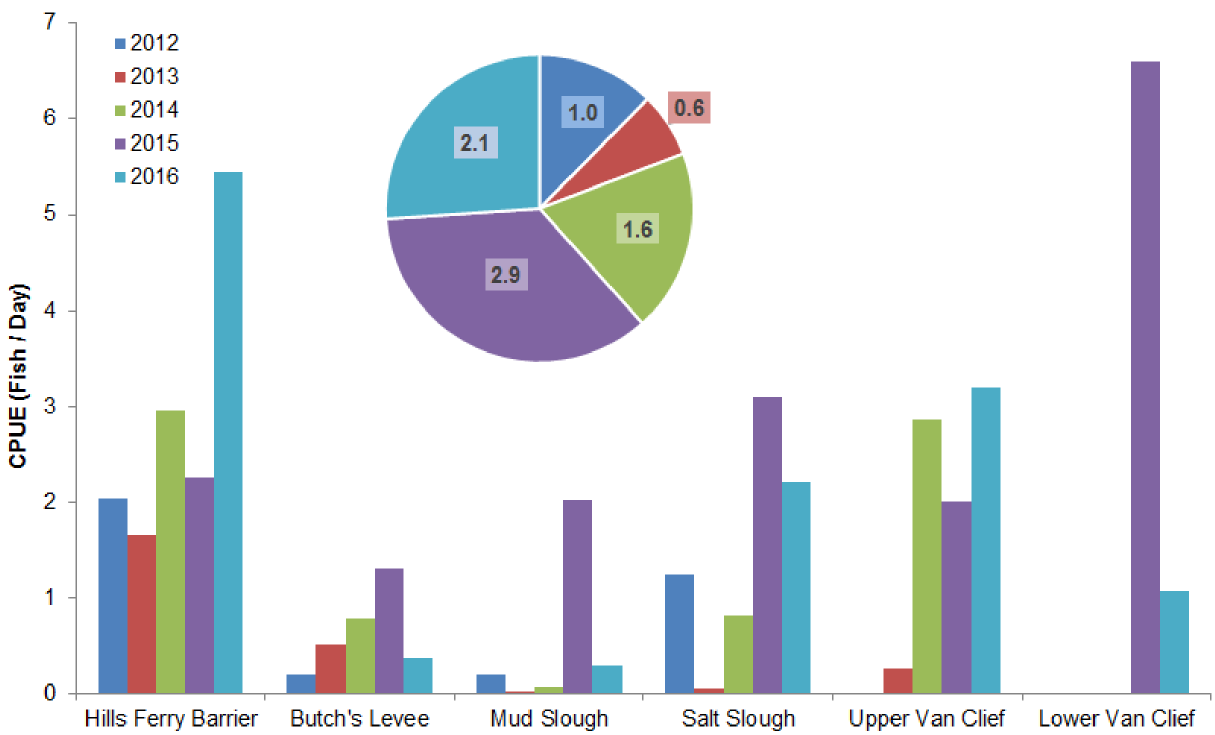

Figure 18.—Fyke net Catch-per-Unit-Effort (CPUE) 2012–16, during adult fall-run Chinook Salmon Trap and Haul efforts, San Joaquin River, CA. Pie chart summarizes annual CPUE averaged across all sites, but is not inclusive of dip-netting efforts.

Total capture across all fyke-netting locations and each sampling season, increased each year of the program from 2012 to 2015, then decreased slightly in 2016 (Figure 13). Salmon CPUE (fish/day), averaged across fyke-netting locations, followed a similar pattern, but with a decrease in CPUE 2012–13. The decrease in 2013 CPUE is likely, in part, due to the earlier start date in 2013, when very few fish were captured during October sampling. Increases in total catch and CPUE, 2013–15, and relatively high CPUE in 2016, are likely a due to a combination of flows, crew experience, and total abundance of salmon in the study area. Escapement data from all major SJR tributaries (Azat 2017), in combination, indicates no major differences in 2012 (n=20,962), 2013 (n=20,947), 2014 (n=17,717), or 2015 (n=21,785). However, an increase in total SJR tributary escapement was observed in 2016 (n=26,333). Mokelumne River escapement estimates were also not greatly different in 2012 (n=12,091), 2013 (n=12,252), 2014 (n=12,113), and 2015 (n=12,879). However, there was a drop in estimated escapement in 2016 (n =8,871). In addition, 2016 Merced River escapement estimates were highest since 2002, suggesting a higher abundance of salmon immigrating further up the SJR. Given the assumptions regarding origin of salmon (primarily Mokelumne River fish captured in study area) and proportion of hatchery-origin fish captured during Adult Trap and Haul efforts, there was likely no significant difference in abundance of adult fall-run Chinook Salmon entering Reach 5 between 2012 and 2015, but perhaps a higher abundance in 2016.

Across all years, total weekly capture of adult salmon tended to increase with a decrease in overall flows, with peak capture generally occurring ~1 month following a significant pulse flow event. In addition, high capture totals in 2014 and 2015 compared to prior years can be explained, in part, by lower flows throughout the study period (Figure 19). The low flow vs. total capture relationship is not likely a result of reduced immigration with flow, but reduced gear efficiency with increased flow. Anecdotal evidence suggests increased debris loads, wing-wall overtopping, and major increases in scouring with elevated flows—all which are likely to reduce gear efficiency and capture success. Interestingly, total salmon capture and CPUE were high in 2016, even at higher flows (more similar to 2012 and 2013 flow conditions). It is plausible to assume the higher totals observed in 2016 at higher flows is due to the higher estimated SJR escapement compared to previous years.

Pulsed and elevated flows are often used to encourage adult salmon migration (Thorstad and Heggberget 1998; Strange 2007; Hasler et al. 2014). However, when pulse flows are successful, salmon are generally observed immigrating immediately following a pulse event (Del Real and Saldate 2013; Del Real and Saldate 2015). As mentioned, peak capture of adult Chinook Salmon in the study area across all years generally followed a pulse event. However, these flow events occurred approximately one month prior to peak capture (see Figure 19). Therefore, it is assumed pulse flows from the SJR (and combined Merced River) likely had minimal effect on adult fish moving into the study area, and this, along with the other observed relationships, is likely due, in part, to the natural Gaussian distribution observed for most adult Chinook Salmon (FPC 2016). Minimal flow effect on migrating adult Chinook Salmon have been observed in other systems (Strange 2007; Hasler et al. 2014), as well as in the SJR (Peterson et al. 2017). While manipulation of stream flow to simulate natural flow regimes has been shown to benefit native fish assemblages in regulated systems (Kiernan et al. 2012), additional data should be collected prior to implementing pulsed flows as a technique to promote Chinook Salmon immigration into the restoration area.

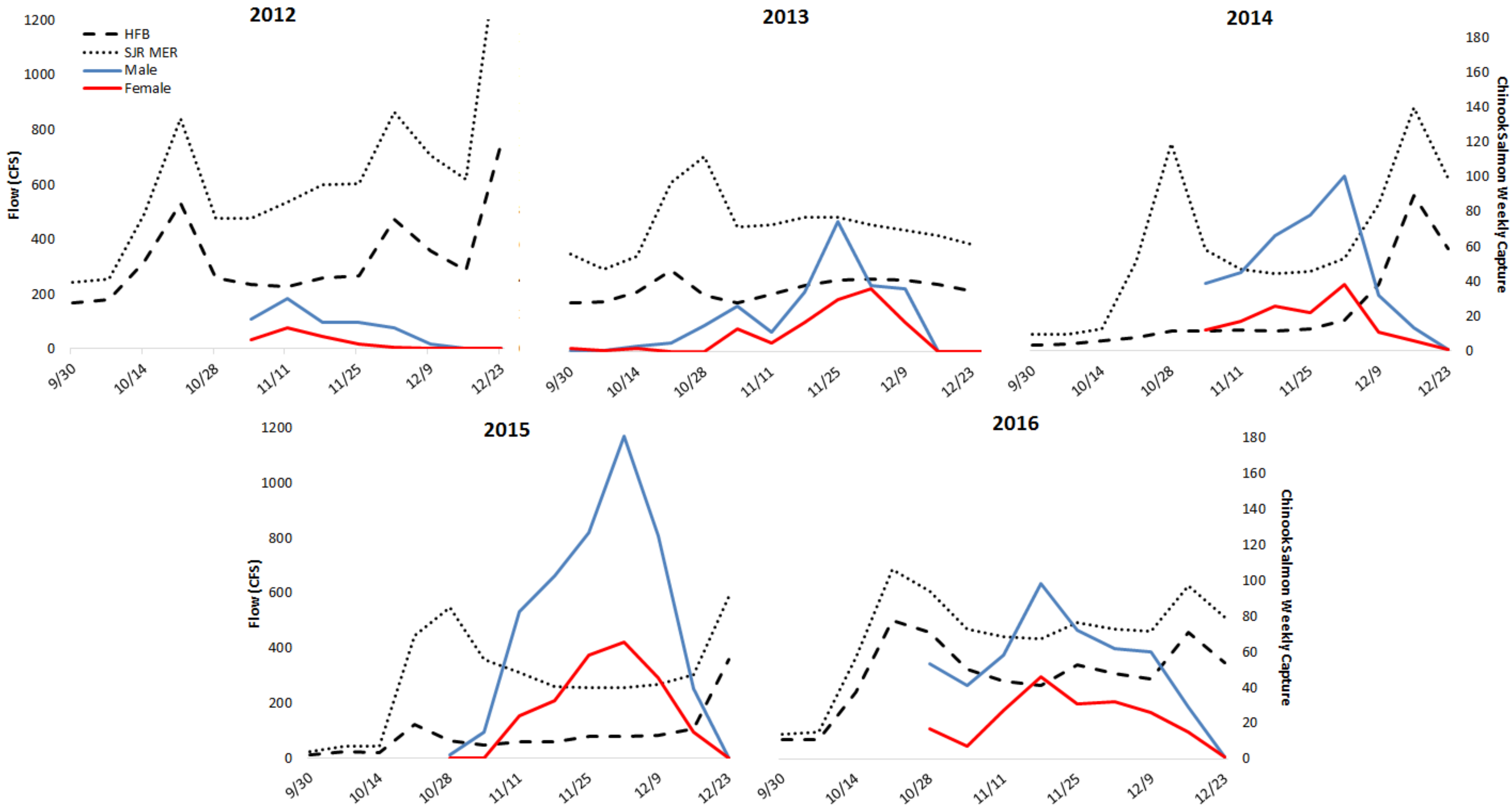

Figure 19.—Total weekly capture of adult fall-run Chinook Salmon in relation to mean weekly flows in the mainstem San Joaquin River (SJR) ~ 10 m upstream of the Hills Ferry Barrier net (USGS Station 11273400 SMN) and in the SJR immediately (150 m) downstream of the SJR and Merced River confluence (USGS Station 11274000).

Across all years of sampling, total catch and CPUE of adult salmon at Salt Slough was higher than at Mud Slough (Figure 18). Mud Slough is the first major slough upstream of the confluence of the SJR and the Merced River. However, peak immigration of adults from 2012 to 2015 generally occurred when Salt Slough flows were higher than Mud Slough (based on estimates from up and downstream sensors in the mainstem SJR) which could have contributed to the higher capture rate in Salt Slough (Figure 20). Interestingly, flows in Mud Slough were higher during peak immigration in 2016. However, poor dissolved oxygen levels (1.8–4.9 mg/L) coupled with elevated temperatures (16.6–18.7°C) November 3–21, 2016 may have presented a environmental barrier during a significant portion of sampling that could have caused fish to bypass Mud Slough. Poor water quality conditions have been identified as a barrier to past adult salmon migrations in the SJR (Hallock et al. 1970). The source of this hypoxic water was assumed to be refuge ponds that flooded and drained into Mud Slough during high precipitation events. A clearer understanding of the source, the extent of effects, and a plan to mitigate for such occurrences in the future, particularly if effects reach to the mainstem, should be considered.

Mean percent (± 1 SD) straying into the sloughs in Reach 5 (Mud and Salt Slough combined), calculated as the percentage of fish captured at each netting location, from 2012–16 was 60 percent (± 24 percent). Though straying into sloughs from the SJR in Reach 5 was high, conditions during the 2012–16 Trap and Haul Program do not necessarily represent post-restoration conditions. A relatively large proportion of flow during netting (92, 97, 89, and 77 percent annually, 2012–16, respectively) reaching the Merced River confluence was derived from these locations and not the mainstem SJR. Therefore, there was a significant environmental cue (i.e., elevated flow) likely attracting immigrating salmon into these locations. Straying loss, following introduction and maintenance of restoration flows, could result in population level effects, and should be quantified and managed.

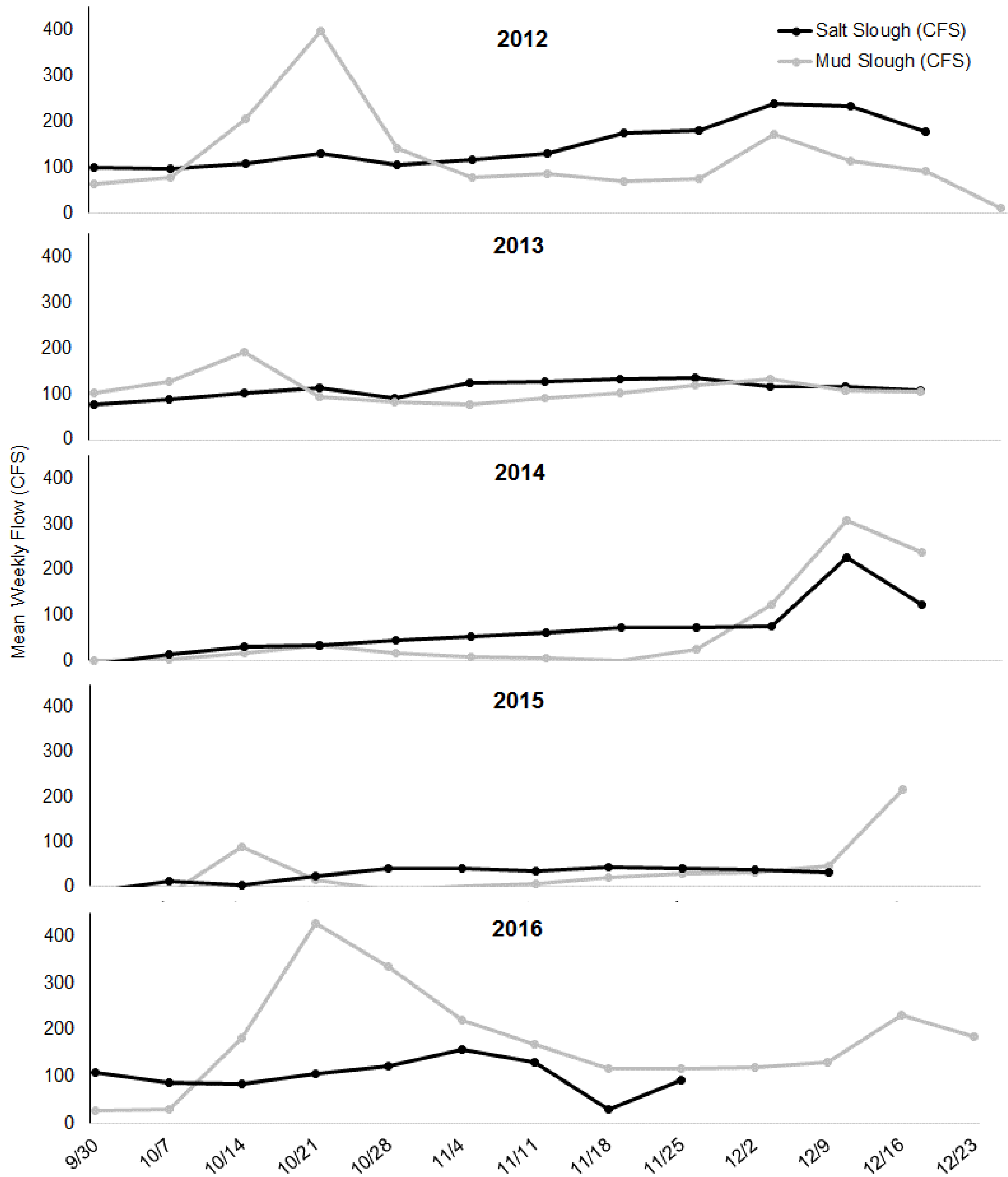

Figure 20.—Mean weekly flow (CFS) from Mud (grey line) and Salt Sloughs (black line) during Adult Fall-Run Chinook Salmon Trap and Haul Program 2012–16. Aside from 2016, Salt Slough flows were generally higher during peak immigration of adult salmon.

2.2 Acoustic Telemetry

Fall-run Chinook Salmon implanted with acoustic tags were released at Camp Pashayan (RM 243.5) from 2012 to 2015, with the exception of a 2015 single day release of 46 salmon (14 acoustically tagged) in Friant, California for a SJRRP sponsored Salmon Festival. The acoustic receiver at Camp Pashayan detected 100 percent of the released salmon in 2012 and 2013. However, in 2014 only 90 percent were detected at release due to a large mat of aquatic vegetation limiting receiver detection range. Two receivers were deployed on each side of the river at this location in 2015 to ensure better detection, and 100 percent of released salmon were detected. The receiver at RM 242.6 was used to assess and compare downstream movements of fall-run Chinook Salmon from the Camp Pashayan release location in all sampling years. Downstream movement of fall-run Chinook Salmon from the release site was detected in 2012 (n=8), 2013 (n=3), 2014 (n=8), and 2015 (n=3)—totaling 5.6 percent of salmon moving downstream upon release across all years. Downstream movement of captured and tagged adult Chinook Salmon at release has been observed in other telemetry studies (Gray and Haynes 1979; Burger et al. 1985)—Bernard et al. (1999) reporting up to 72 percent of radio-tagged salmon moving at least 3 km (1.9 miles) downstream from release compared to only 9 percent of uncaptured fish monitored by split-beam sonar. Of the 22 downstream moving salmon, all but 7 were redetected at the next upstream receiver. The receiver at the most upstream extent of the array (RM 265.5 in 2012; RM 267.4 in 2013–15; Figure 10) detected 20.6 percent (n=7), 34.6 percent (n=18), 15.2 percent (n=17), and 14.1 percent (n=28) in 2012, 2013, 2014, and 2015, respectively, totaling 17.7 percent detection across all sampling years. The average time to detection, across all sampling years, was 5.7 days, and the longest time period was 69 days.

Movements of fall-run Chinook salmon released into Reach 1A varied considerably between individuals. Nevertheless, mean upstream movement across sampling years was 20.5 km (12.3 mi). Total distance traveled (i.e., both up- and down-stream movement) across years averaged 32.2 km (20.0 mi). The greatest distance traveled by an individual over a season was 308.7 km (191.8 mi), and the furthest distance traveled in a 24-hour period was 38.5 km (23.9 mi). It should be noted, however, that distance estimates of acoustically monitored salmon are lower than distances actually traveled, as these fish had already traveled more than 190 km upstream upon their capture. Consequently, average distance estimates observed should be considered less as migration, but rather, as spawning movements which are often lost in the spatial extent of larger scale migration studies. For example, when comparing distances needed to reach spawning grounds by out-of-basin populations (e.g., Yukon River Basin, ~3,200 km; Eiler et al. 2015) or even other central valley Chinook Salmon populations (e.g., Merced River, ~274 km), the mean distance traveled (i.e., 20.5 km) by fish in this study is more than an order of magnitude less than those distances need to be traveled by those populations. However, these fish traveled more than 190 km upstream prior to capture, and then in some cases after release swam more than 300 km in a reach with less than 45 km of spawning habitat. To help illustrate the varied movement of released salmon over time, Figure 21–23 displays movements of individual fish during 2013. Salmon #12238 was detected over 43 days and traveled a total of 273.6 km (170.0 mi) in Reach 1A, averaging 6.4 km/d (4.0 mi/d; Figure 21). In comparison, female #12242 was detected 27 days and traveled 308.7 km (191.8 mi) within Reach 1A, averaging 11.4 km/d (7.1 mi/d; Figure 22). Further variation in distance traveled after release was exhibited by female

#12264 (Figure 23). Over 6 days of detections, female #12264 traveled 41.5 km (25.8 miles) in Reach 1A, averaging 6.9 km/d (4.3 mi/d).

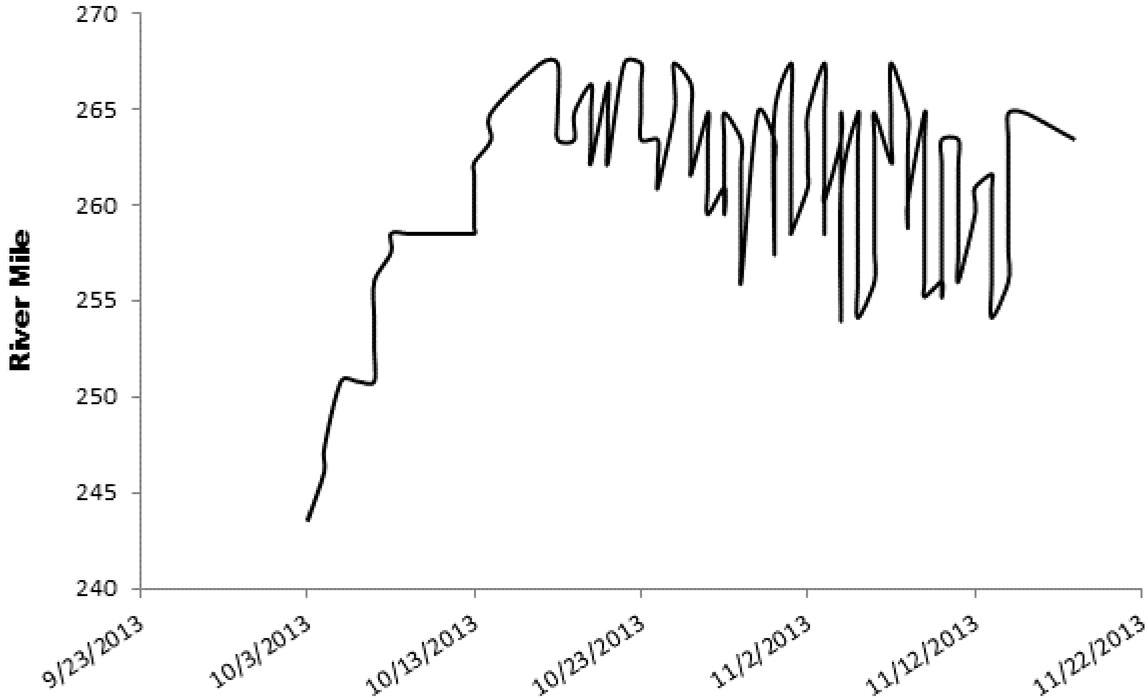

Figure 21.—Movement of female fall-run Chinook Salmon #12238 upon released at Camp Pashayan (RM 243.5) in the San Joaquin River, CA, 2013.

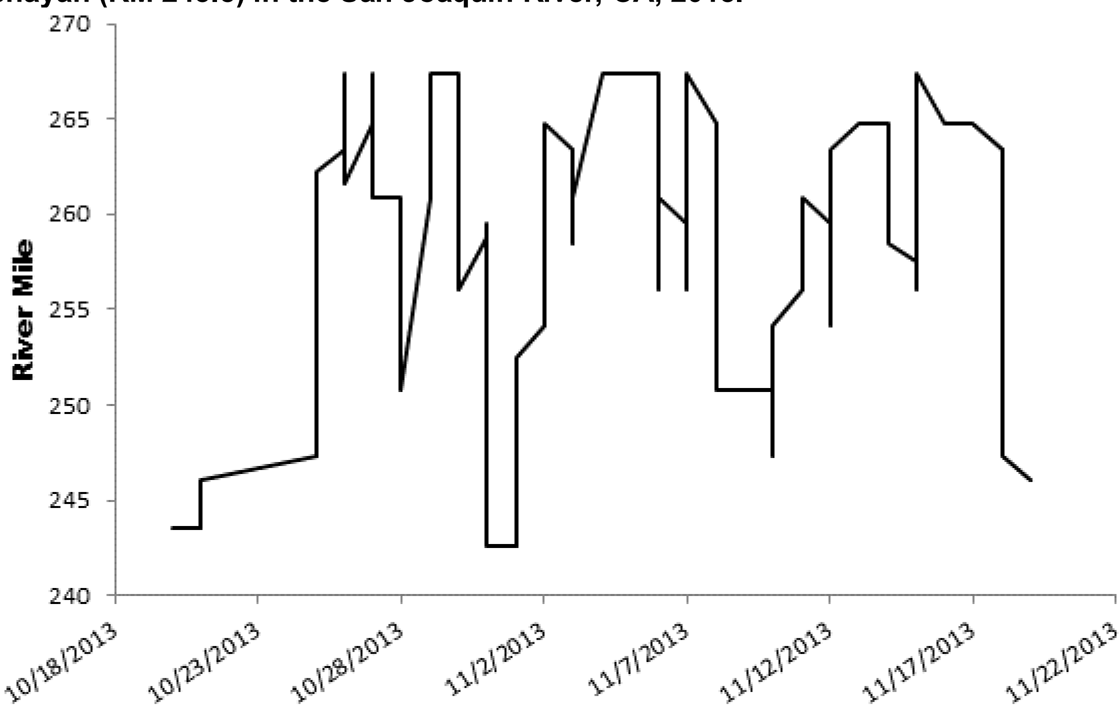

Figure 22.—Movement of female fall-run Chinook Salmon #12242 upon released at Camp Pashayan (RM 243.5) in the San Joaquin River, CA during 2013.

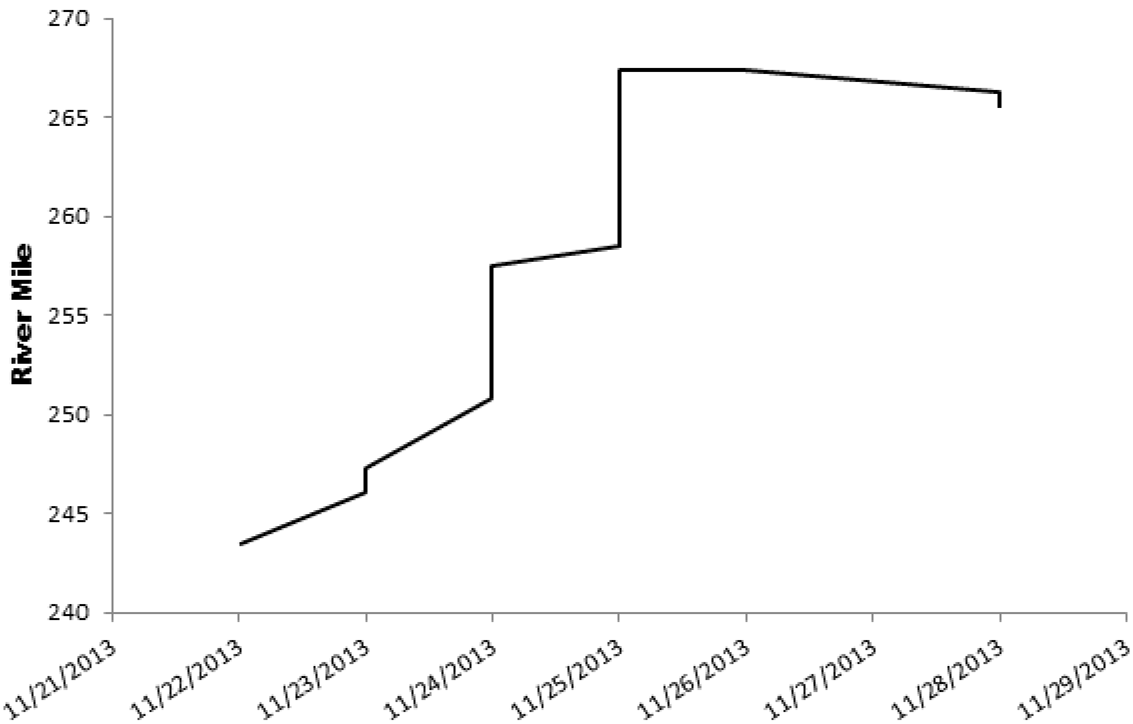

Figure 23.—Movement of female fall-run Chinook Salmon #12264 upon released at Camp Pashayan (RM 243.5) in the San Joaquin River, CA, 2013.

The first and last fall-run Chinook Salmon captured each year, in combination with the average post-release movement rates (Upstream movement/Upstream days [US/US]; Total distance moved/Total days detected [T/T]) were used to calculate theoretically expected arrival times to the spawning grounds, assuming unimpeded passage (Table 3). For example, the first fall-run Chinook Salmon captured in 2012 was on November 7, and using the average US/US migration rate (10.3 km/d) that fish would be expected to arrive to the Camp Pashayan area by November 26. In addition to US/US and T/T, one additional migration rate was calculated; total movement (Total distance moved/Days of movement [T/DM]). T/DM and US/US had similar migration rates of 9.8 and 10.3 km/d (6.1 and 6.4 mi/d), respectively, while T/T had slower rates (6.9 km/d [4.3 mi/d]) of travel (Figure 24). It is important to note that this is the best available scientific data on adult fall-run Chinook Salmon movements in the Restoration Area, and movement data in close proximity to spawning grounds may not be entirely reflective of movement through purely migrational corridors. Therefore, collection of additional data on migration rate through Reach 2-5 in the Restoration Area to provide a more accurate estimate of travel speed and arrival time to spawning grounds is warranted.

Table 3.—Theoretically expected arrival times to spawning grounds base on first and last capture of fall-run Chinook Salmon at Hills Ferry Barrier and post release migration rates (Upstream movement/Upstream days [US/US]; Total distance moved/Total days detected [T/T]).

	First Capture	Last Capture	First Arrival			Last Arrival		
US/US 10.3 km/day (6.4 mi/day)	**Hills Ferry Barrier**	**Hills Ferry Barrier**	**Camp Pashayan**	**HWY 41**	**Friant Dam**	**Camp Pashayan**	**HWY 41**	**Friant Dam**
2012	7-Nov	2-Dec	26-Nov	28-Nov	30-Nov	21-Dec	23-Dec	25-Dec
2013	2-Oct	13-Dec	21-Oct	23-Oct	25-Oct	1-Jan	3-Jan	5-Jan
2014	2-Nov	20-Dec	21-Nov	23-Nov	25-Nov	8-Jan	10-Jan	12-Jan
2015	3-Nov	20-Dec	22-Nov	24-Nov	26-Nov	8-Jan	10-Jan	12-Jan
T/T 6.9 km/day (4.3 mi/day)	**Hills Ferry Barrier**	**Hills Ferry Barrier**	**Camp Pashayan**	**HWY 41**	**Friant Dam**	**Camp Pashayan**	**HWY 41**	**Friant Dam**
2012	7-Nov	2-Dec	6-Dec	8-Dec	11-Dec	31-Dec	2-Jan	5-Jan
2013	2-Oct	13-Dec	31-Oct	2-Nov	5-Nov	11-Jan	13-Jan	16-Jan
2014	2-Nov	20-Dec	1-Dec	3-Dec	6-Dec	18-Jan	20-Jan	23-Jan
2015	3-Nov	20-Dec	2-Dec	4-Dec	7-Dec	18-Jan	20-Jan	23-Jan

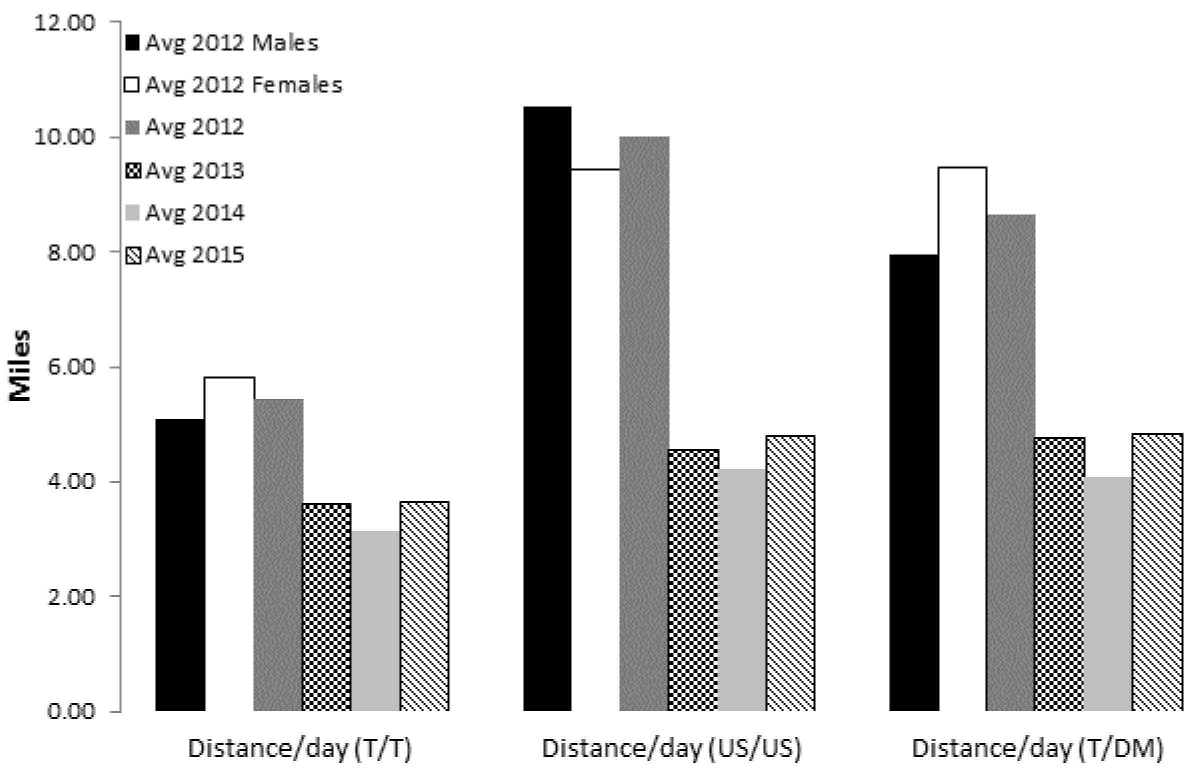

Figure 24.—Average Reach 1 migration rates of adult fall-run Chinook Salmon during the Adult Trap and Haul Program from 2012–15 in the San Joaquin River, CA.

As movement data can be biased by numerous variables (e.g., collection methods, assumptions relating to fish behavior), migration rates have been theorized as a more appropriate metric for analysis as they normalize differences in distances traveled (Eiler et al. 2015). Migration rates of fall-run released to Reach 1A were generally less than those reported of other Chinook Salmon populations (Keefer et al. 2004 [median: 10–30 km/d]; Goniea et al. 2006 [mean: 34.4 km/d, range: 1.8–75.5 km/d]; Eiler et al. 2015 [mean: 51 km/d]). Variables affecting upstream migration rates include, but are not limited to, flow, temperature, photoperiod, turbidity (Banks 1969; Jonsson 1991) and date of migration (Keefer et al. 2004). Declining migration rates as fish approach spawning grounds have been observed, and are thought to be caused by the added effort needed to search for and locate suitable spawning habitat (Eiler et al. 2015). This behavior appears to be exhibited by Female salmon #12238, #12242, and other females not graphically represented (Figure 21, 22). Differences in migration rates between other systems (largely monitoring movements from lower river reaches to terminal tributaries) and those observed within Reach 1A (spawning grounds) may therefore be a function of reduced rates of migration of Reach 1A fish locating suitable spawning grounds as opposed to elevated migration rates needed to make it to the spawning grounds captured in other studies.

While acoustic monitoring offered preliminary information regarding adult salmon movements in Reach 1A, an added benefit was that it provided an opportunity to link individual females with created redds. Substantiated through redd and carcass surveys, there were frequent instances in which acoustic tags passed from the abdominal cavity of the female to the egg pocket of a redd. This provided an opportunity to examine redd site selection and morphology based on female morphometrics. This data is being analyzed with a summary of findings being prepared in a future report.

2.3 Streamside Spawning

To produce offspring in support of various SJRRP juvenile studies, 58 artificial spawning attempts occurred at the SIRF between 2012 and 2016. Of those spawning events, 3 spawns were not included in this assessment due to variations from standard operating procedures (e.g., remote take of green eggs from expiring female) that resulted in 100 percent egg mortality, and 5 spawns that were used in a 2015 river-specific thermal tolerance study. Of the remaining 50 spawns, approximately 260,000 eggs were taken. The mean fork length of females spawned at the SIRF was 754 mm (range 499–880 mm; n=42). Excluding females that were documented as being partially spent, the mean fecundity was 5,402 eggs per female, with a mean of 99 eggs per liquid ounce (Table 4). Mean fecundity of females spawned at the SIRF was comparable to average Central Valley fall-run populations ($\bar{x}$=5,498; Fisher 1994) and similar to fecundity ($\bar{x}$=5,423, n=93) of Mokelumne River fall-run Chinook Salmon (Kaufman et al. 2009); likely result of Mokelumne River origin fish influence in the system (Table 2). Chinook Salmon length was positively correlated to fecundity (r^2 = 0.37; Figure 25). Variables influencing Chinook Salmon fecundity are generally explained by fish length and egg size (Healey and Heard 1984; Fleming and Gross 1990; Healey 1991). However, annual variations in fecundity also exist within populations and is even more apparent between populations (Healey and Heard 1984). These intra- and inter-population variation in fecundity are evident when comparing mean fecundity of SIRF females between years (Table 4), as well as to other populations (Klamath River: $\bar{x}$=3,752, n=106; Sacramento River: $\bar{x}$=7,423, n=50; as reported in Kaufman et al. 2009). Other factors suggested to affect fecundity include: flesh types (i.e., red or white) and the latitude of spawning populations (Healey and Heard 1984). Mean egg size of females spawned at the SIRF (99 eggs per ounce) were comparable to ranges observed of fall-run Chinook salmon spawned at the Mokelumne River Hatchery (71–108 eggs per ounce; Anderson 2003, 2004, 2005). Mean survival from spawn to the eyed egg stage (post addle) was 74 percent, and survival from the eyed egg stage to swim-up fry was 87 percent (Table 4).

Table 4.—Artificial spawning of fall-run Chinook Salmon and fate of offspring 2012–16.

Spawning Year	Spawns	Mean Fecundity (n=48)	Mean eggs per liquid oz. (n=49)	Mean survival to eyed egg stage (n=50)	Mean survival eyed stage to swim-up (n=5)
2012	2	6406	86	91%	96%
2013	12	6396	78	66%	84%
2014	7	4604	107	67%	93%
2015	14	5220	114	89%	84%
2016	15	5147	95	69%	79%
Total Average		**5402**	**99**	**74%**	**87%**

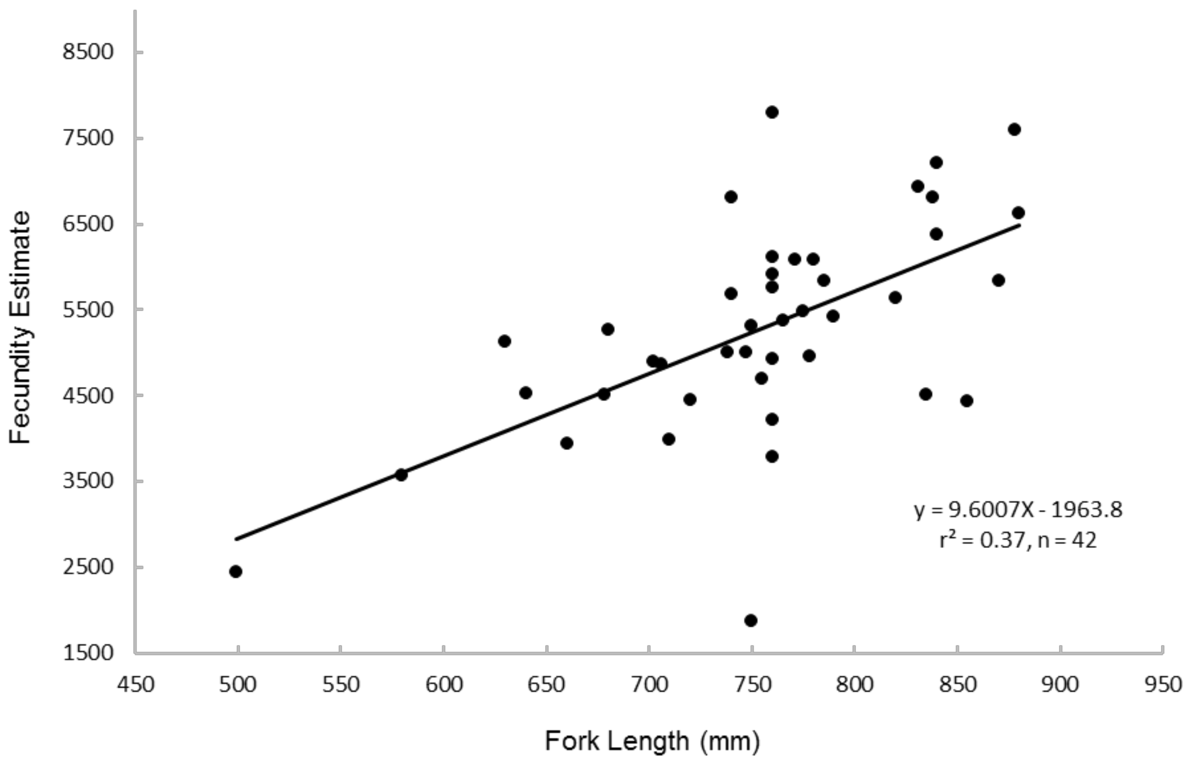

Figure 25.—Regression of fork length and fecundity data collected from streamside spawned fall-run Chinook Salmon, 2013–16 in the San Joaquin River Restoration Area, CA.

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4.0 Appendix A

Table A-1.—Receiver location during 2012–15 Adult Trap and Haul sampling seasons, San Joaquin River, CA.

Location	River Mile	2012	2013	2014	2015
Friant Dam	267.4		X	X	X
Interim Facility	266.3		X		
Lost Lake	266				X
Lost Lake	265.5	X	X	X	
Lost Lake Cascade	264.8	X	X	X	
Lost Lake Riffle	264.65				X
Ledger Island	263.4	X			X
Ledger Island	263.1		X	X	
Ball Ranch Bridge	262.2	X	X	X	X
Willow ER Up	261.6	X	X	X	X
Willow ER Down	260.9		X	X	X
Rank Island Split	260.2		X	X	
Vulcan (Broken Culvert)	259.5	X	X	X	X
Owl Hollow	258.8	X	X	X	X
Lower Vulcan	258.5		X		
Brown	257.5		X	X	
Fort Washington	256	X	X	X	X
Wildwood	255.2		X	X	
Sycamore Island Up	254.1	X	X	X	X
Sycamore Island Down	252.5	X	X	X	X
Lower Sycamore Island	251.2				X
Scout Island	250.8		X		X
Lower Scout Island	248.9				X
Milburn	247.3		X	X	X
Lower Milburn	246.3				X
Mosios	246.1		X	X	X
Upper Santa Fe	245.8				X
Lower Santa Fe	244.75				X
HWY 99 Up RR	243.5	X	X	X	X
HWY 99 Up RL	243.51				X
HWY 99	243.1				X
Hwy 99 Down	242.8	X			
HWY 99 Down	242.6		X	X	X
Donny Bridge	240.7				X
Total		**12**	**22**	**19**	**25**

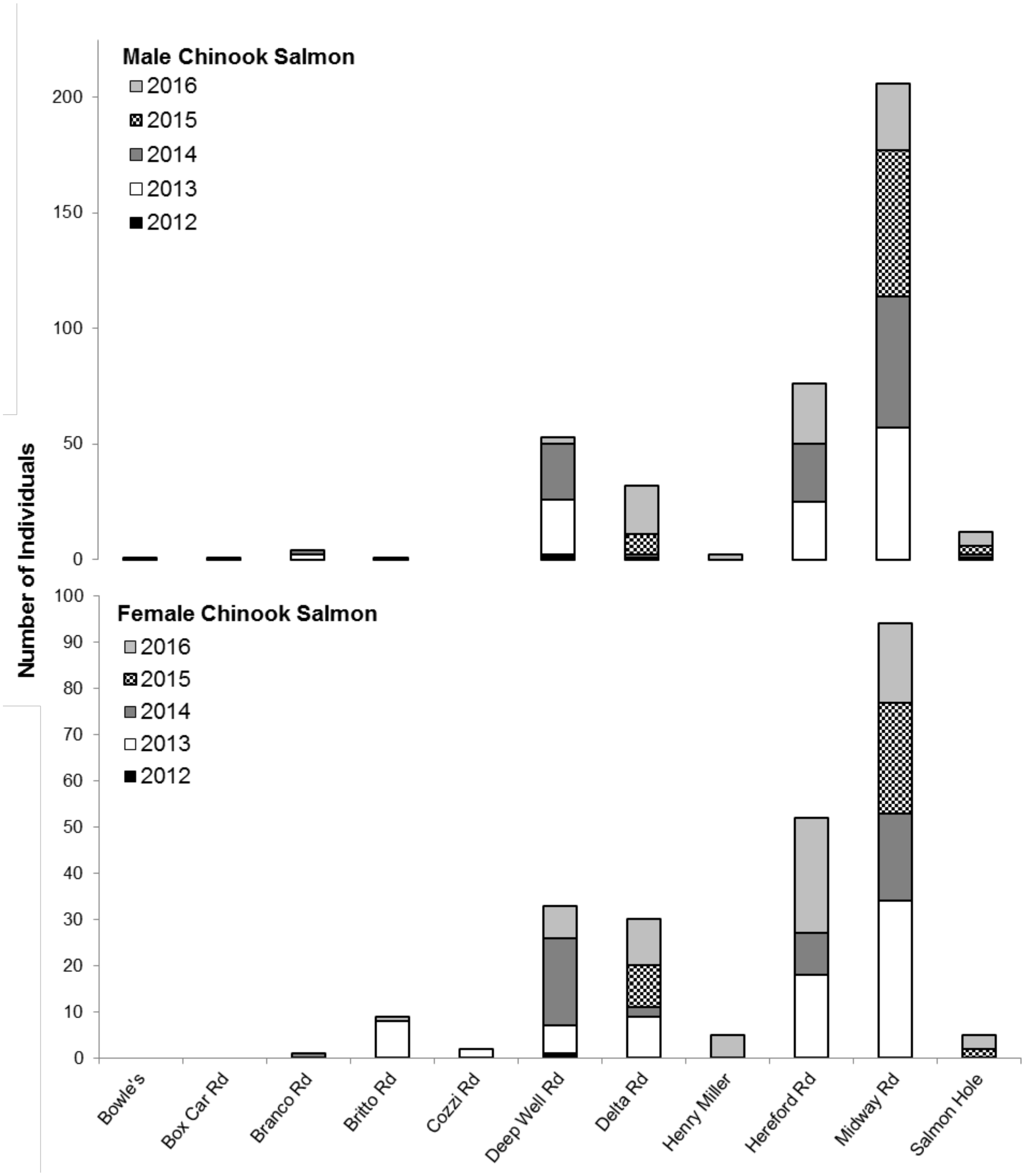

Figure A-1.—Distribution of Chinook Salmon capture, by dip netting location, 2012–16.

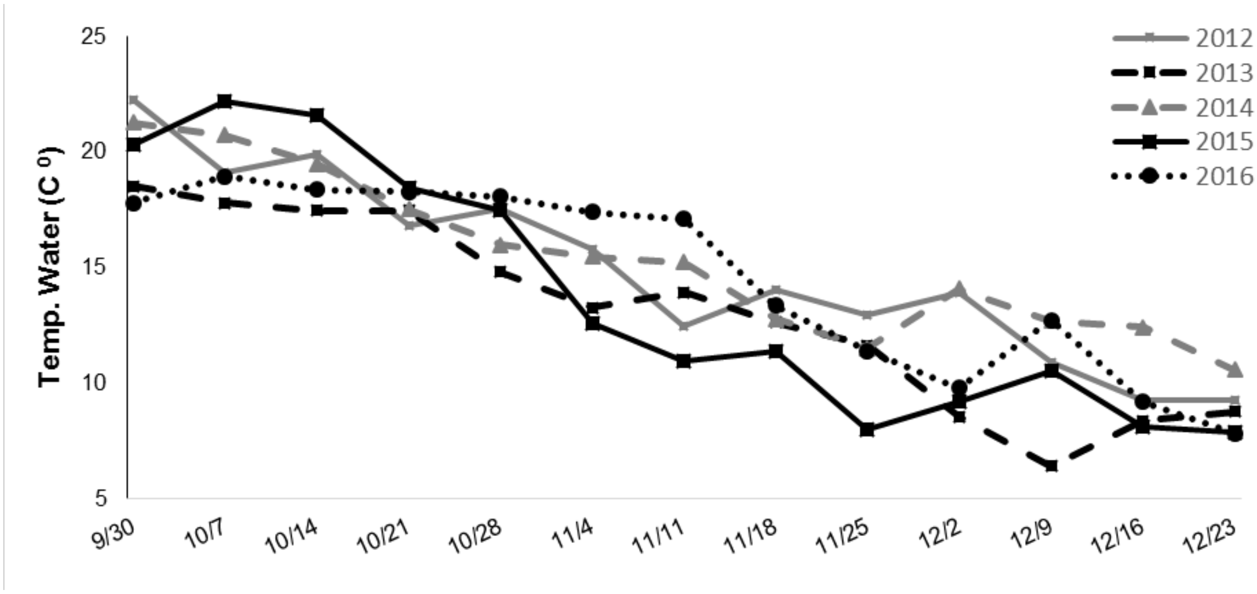

Figure A-2.—Temperature (°C), at the Hills Ferry Barrier, during the Trap and Haul Program (2012–16), Reach 5 of the San Joaquin Restoration Area, CA.