California Department of Fish and Wildlife

North Central Region

Summary Report for the Central Valley fall Chinook Salmon (*Oncorhynchus tshawytscha*) Migration Study in the Sacramento-San Joaquin River Delta

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Contents

Abstract

The California Department of Fish and Wildlife conducted a study to gather information on the migration patterns of adult Central Valley (CV) fall Chinook Salmon (*Oncorhynchus tshawytscha*) Evolutionarily Significant Unit (ESU) (fall-run) in the Sacramento-San Joaquin Delta (Delta) near the Delta Cross Channel (DCC). Sampling for fall-run occurred in 2011, 2012, 2014, 2015, 2016 and 2017, and over a range of annual water year types (wet year to critical year type). Fish were captured with a drifting trammel net in the Delta areas of Jersey Point and Santa Clara Shoal. There were 400 salmon captured during sampling, all of which were measured for length, identified by sex, evaluated for condition, tagged, and released. Salmon were tagged with a uniquely numbered, externally visible anchor tag so they may be identified if later recovered. A total of 66 tagged salmon were recovered by hatcheries, anglers, and salmonid escapement surveys. Of the recovered salmon, there were 21 adipose fin-clipped salmon that allowed for coded wire tag extraction which provided information on hatchery origin, release date and release location. Hatchery salmon were found to have originated from the Mokelumne River Hatchery, Nimbus Fish Hatchery, Feather River Hatchery and Coleman National Fish Hatchery.

A subset of 128 salmon initially captured during the survey were tracked during their spawning migration using acoustic tags and an array of stationary acoustic receivers in the Delta and its tributaries. Sacramento River and San-Joaquin River flows and DCC operations were tracked using electronic online resources. During the years of the study, the DCC was open in July, August, and through mid-September, and after mid-September, DCC gate operations varied between years. There were 21 salmon with acoustic tags whose migration included routing through the DCC. All the salmon that were identified to have originated from the Mokelumne River Hatchery and Nimbus Fish Hatchery (Sacramento River Basin) strayed between their respective natal basins by way of the DCC. Information from this project indicates that proportions of adult fall-run salmon originating from the Sacramento River Basin or Mokelumne River are influenced during their migration by the DCC, and that this may occur during any annual water year type.

Introduction

Tributaries to the Sacramento-San Joaquin Delta (Delta) support the Central Valley (CV) fall Chinook Salmon (*Oncorhynchus tshawytscha*) Evolutionarily Significant Unit (ESU) (fall-run). Adult CV fall-run rearing in the Pacific

Ocean migrate to the Delta and its tributaries starting in July and continuing through December, with spawning generally occurring between September and January (Yoshiyama et al. 1998). In the Sacramento River and San Joaquin River, fall-run are the most abundant race of Chinook Salmon, though numbers since 2007 have been trending downward (GrandTab 2018). Due to reduced numbers, fall-run are recognized by the State of California Endangered Species Act and the Federal Endangered Species Act as a species of special concern. There are several factors causing decline of fall-run in the CV and various publications are available describing impacts to the population, some of which include: habitat loss (Frayer et al. 1989), introduction of foreign species (Dill 1997, Mount et al. 2012), climate change (Richter and Kolmes 2005, Moyle et al. 2013), and in recent years, a severe drought (CNRA 2021). Throughout early to mid-1900, water collection and conveyance structures were constructed throughout the CV, which have restricted or eliminated access to spawning grounds for fall-run and have been identified as the greatest cause of salmonid decline in California (Yoshiyama et al. 2000). Retention reservoirs release stored water to natural waterways throughout California creating altered hydraulic regimes and aquatic environments in migratory corridors and adult fall-run encounter these altered conditions during their return to natal spawning grounds.

One of the largest water regulating, storage and delivery projects in the world is the California Central Valley Project (CVP) operated by the United Stated Bureau of Reclamation (USBR) (USFWS 2015). A component to this project is the Delta Cross Channel (DCC), built in 1954, which is a water diversion with a set of operable gates that can convey water in the Sacramento River toward the south side of the Delta (USBR 2017). When the DCC is open, flows in the Sacramento River are diverted through the DCC to Snodgrass Slough, through the lower forks of the Mokelumne River, to the San Joaquin River and southern Delta, where it is available for diversion at the C.W. Bill Jones Pumping Plant and the Harvey O. Banks Pumping Plant. The DCC is located near the town of Locke, which is close enough to the Delta to be influenced by tidal effects. During ebb tides in the Delta, approximately 45% of the Sacramento River can flow into the DCC and when flood tides occur, nearly all Sacramento River water can be diverted into to the DCC (Burau 2007 et al., NMFS 2004, NMFS 2009).

There are several operational criteria established to protect listed species that dictate when the DCC may be open or closed (NMFS 2019, SWRCB 2000) and potential impacts from DCC operations to migrating fall-run have been a concern to fishery managers for some time (Hallock 1970). The adult fall-run migration period of June through December coincides with several

DCC operating regimes (USBR 2021). From May 21 to June 15 the DCC is open but can be closed for up to 14 days for fisheries protection if requested by federal and state fishery agencies. The DCC is open from June 16 through September 30 but may be closed intermittently during fishery experiments or maintenance. From October 1 to November 30 the DCC is open but can be closed for up to five days to provide beneficial conditions for migratory fish when real-time fishery monitoring indicates adult salmon are in the Delta. Salmon primarily rely upon chemical-based olfactory senses to be attracted to their natal waters (Groot and Margolis 1991, Groves 1968 , Scholz et al. 1976), however when the DCC is open, Sacramento River and Mokelumne River flows are mixed together and salmon entering the Delta experience altered hydrologic conditions that potentially impact their olfactory senses leading to greater chance of straying. Increased adult stray rates between Sacramento basin and San Joaquin basin fall-run adds challenges in maintaining genetic integrity among identifiable stocks of Central Valley fall Chinook Salmon (JHRC 2001, CA HSRG 2012). This is of particular concern for Mokelumne River origin fall-run given the proximity of the river to the DCC. There is also concern that fish experience conditions that create temporary delays to migration when near water conveyance structures which can reduce chance of survival (Dauble and Mueller 1993), reduce energetic reserves needed for spawning (Gowans et al. 2003), or impact gamete quantity and viability (Kinnison et al. 2001). If salmon are prevented from entering their natal tributaries, they may move away and attempt to spawn in non-natal tributaries, or they may simply die before ever finding suitable spawning habitat.

Sacramento River origin fall-run in the Delta have two very different geographic routes to navigate when the DCC is open. The direct route is from the Delta into the Sacramento River, while the other route is through the San Joaquin River from the south, into the forks of the Mokelumne River in the central Delta, then finally to the Sacramento River via either Georgiana Slough, or through Snodgrass Slough then the DCC. Mokelumne River origin fall-run in the Delta also have two very different geographic routes to navigate when the DCC is open. The direct route is through the San Joaquin to the lower forks of the Mokelumne, while the other route is from the Sacramento River, through either Georgianna Slough or through the DCC and then Snodgrass Slough.

Identifying trends or problems for migrating fall-run allows for an improved understanding of condition dependent migration strategies and mitigation of altered environmental conditions. To document upstream migration behavior, straying patterns, and to identify water management practice impacts to adult fall-run stocks, the California Department of Fish and Wildlife (Department) initiated a study in 2011 to evaluate whether fall-run were using the DCC to travel between the Sacramento River and Mokelumne River.

Materials and Methods

Sampling was scheduled to occur during the recognized period when fall-run are entering the Delta during their inland spawning migration. During the six years of the study, sampling was initiated in mid-September or early-October and continued until either 1) no acoustic transmitter tags remained or 2) the tail end of the historical fall-run adult migrant season was over; generally late November. Timing and duration of sampling efforts avoided federally listed runs of Chinook Salmon. The Sacramento River winter Chinook Salmon ESU may be present in the sampling area in December through July, and the Central Valley spring Chinook Salmon ESU from May through June.

Site Selection

The initial sampling site location for the study was in the lower San Joaquin River, near an underwater shoal named Jersey Point (38°03'00.4"N, 121°41'50.3"W) (Figure 1). This sampling location is near the release site for the Mokelumne River Hatchery fall-run juvenile production on Sherman Island. Hatchery fish were expected to pass this location when returning as adults because they were released in the same location as juveniles. Depth of the water column along Jersey point was consistently greater than 4.5 meters during outgoing and low tide swings which helped facilitate the use of a drifting trammel net to capture salmon.

The second sampling site was located at an underwater shoal named Santa Clara Shoal (38° 5'21.70"N, 121°38'27.51"W), upstream from the Jersey Point sampling site. Santa Clara Shoal is downstream from where the Mokelumne River flows into the San Joaquin River. This sampling site was selected because Mokelumne River origin salmon would pass by this location as they migrated to their natal spawning grounds in the Mokelumne River. This location consistently had favorable depth for sampling using a drifting trammel net.

Figure 1. Jersey Point and Santa Clara Shoal sampling sites, in relation to Brannan Island Boat Launch and the mouths of the Sacramento, San Joaquin and Mokelumne Rivers.

Sampling Net

Based on information found in Haegen et al. 2001, Department staff used a single panel trammel net to capture adult Chinook Salmon. Most traditional trammel nets consist of two or more layers of varying mesh for the purpose of entangling fish and keeping the body of fish intact and in good condition for commercial purposes, but with little care as to whether fish perish once entangled. Department staff used a single trammel to allow for easy removal of entangled fish by hand, reducing the chance of harm to fish during the sampling process. The single panel trammel also increased the net's selectivity toward target species; traditional trammel nets have greater amounts of non-target species bycatch. The net dimensions were 61 meter (m) (200 feet) long and 3.6 m (12 feet) deep. The mesh material was multifilament string which is less abrasive to fish than traditional materials such as monofilament. The bar measure of the trammel mesh was 8.9 centimeter (cm) (3.5 inches) creating a stretch measure of 17.8 cm (7 inches). The net had an 18-kilogram (40 pound) lead core ground rope, and a head rope outfitted with 7.6 cm (3 inch) diameter, 12.7 cm (5 inch) long egg-shaped floats spaced every 60 cm (2 feet). The net had 127 cm (50 inch) circumference and 38 cm (15 inch) diameter orange buoys on either end to facilitate deployment, tending, and retrieval.

Acoustic Transmitters

Through all the sampling seasons, acoustic transmitters were purchased from VEMCO Division of AMIRIX Systems Inc., located in Bedford, Nova Scotia, Canada. The acoustic transmitters were cylindrical in shape, 13 - millimeter (mm) diameter, 36mm long and weighed six grams. The transmitters sent a signal every 40 to 80 seconds in a 69 kilohertz frequency and had a battery lifespan of 151 days. The transmitters weighed less than 1.25% of the weight of adult Chinook Salmon while in water and were not likely to affect fish performance once implanted (Winter 1996).

External Tags

Floy® T-Bar Anchor Tags were manufactured by the company Floy Tag & Manufacturing Inc. in Seattle, Washington. The anchor portion of the Floy tags were made of monofilament, while the flag portion of the Floy tags were made of colored polyolefin tubing. The colored portion of the Floy tags were printed with a unique tag number so fish may be individually recognized once applied as described in Jones 1979. Floy tag colors used over the sampling seasons included light blue, purple, light green and grey. The wording "Please call 916-358-2900" was also printed on the colored polyolefin tubing, which allowed anyone who encountered a tagged fish to notify the lead researcher.

Field Procedures

Two boats were used during sampling and were named 'net-tending boat' and the 'transport boat'. The net-tending boat primarily dealt with the net and capturing fish, while the transport boat was primarily responsible for releasing fish after capture. To deploy the net, the net-tending boat operator approached a shore at a perpendicular angle and staff working in the breakhead areas would set the net by hand until the full extent was deployed. The angle of the net was adjusted to account for tidal currents, wind chop currents, or debris in the water.

Once deployed, the net was monitored by the net-tending boat until a fish became entangled. Entangled fish were removed from the net as quickly as possible to minimize harm to the fish. Fish were retrieved by placing the fish and the portion of net surrounding it into a 568-liter (150 gallon) plastic tub. The tub had dual aerators, was filled with locally sourced water from the Delta, was monitored for dissolved oxygen, and water was changed routinely throughout the day. Captured fish were removed from the net while in the tub. For salmon, capture time, gender, length, adipose fin absence/presence, notations of physical abnormalities, vigor, and Coded Wire Tag (CWT) absence/presence were recorded. Presence of a CWT was determined by using a handheld CWT wand detector on adipose fin-clipped fish. Fish vigor was categorized as 'lethargic' or 'active' based on 1) a fish's eyes being up or down which signals fatigue levels and 2) gill color as 'Pale', 'Bright Red', or 'Hemorrhaged' which signaled net damage to gill filaments. Non-target species bycatch was identified to species, evaluated for condition, measured for total length in millimeters and released. Bycatch observations were recorded along with other daily data evaluations.

Figure 2. The drifting trammel net was set perpendicular to shore and was closely tended by staff operating Department watercraft.

All salmon captured were implanted intramuscularly with two heavy duty Floy tags using a Mark II Long Pistol Grip, supplied by Floy Tag & Manufacturing Inc. The Pistol Grip was outfitted with a super heavy-duty needle which inserted the anchor end of the tag 9.5mm into muscle tissue. Floy tags were placed on the right and left side of the fish beneath the dorsal fin. Two Floy tags were used because double tagging would result in greater chance of tag recovery; increased chance of video recordings at several under-water salmonid monitoring stations and increased the likelihood that carcass would retain at least one Floy tag and thus be found during an adult escapement survey.

Figure 3. All salmon that were captured during sampling efforts were provided with an externally visible Floy tag prior to being released. In the above photo, a male salmon, with an intact adipose fin was given green Floy tags.

Only salmon that classified as 'active' and had gills that classified as 'bright red' were chosen to be implanted with an acoustic transmitter. Of these salmon, those found to have a CWT were primarily given acoustic transmitters in the hope if they were later found, a CWT could be recovered (e.g., carcass survey, hatchery) and provide hatchery origin information. To increase the sample size of salmon implanted with acoustic transmitters, every-other salmon with an intact adipose fin was considered to receive an acoustic transmitter.

Acoustic transmitters were activated at the time of application to maintain battery life. After activation, a veterinarian balling gun was used to insert the tag to the stomach through the pharyngeal and esophageal canal. Gastric insertion of transmitters was the preferred implantation method, as it was easy to apply and thought to be mostly benign to fish. The transmitters were large enough to be retained in the stomach of fish and not be regurgitated or pass through the pylorus.

Figure 4. A Chinook Salmon receiving an internally planted acoustic transmitter with the use of a balling gun. The entire transmitter planting process generally lasted less than 20 seconds.

After data were collected and tags were applied, salmon were placed on the transport boat. To safely transfer salmon from the net-tending boat to the transport boat staff used a specialized cradle. The cradle was made of thick rip-stop vinyl material with embedded handles with the dimensions of 79cm long, 46cm deep and 18cm wide. The cradle was sufficient in size for one large or two smaller fish to rest comfortably and was designed to carry enough water to cover the gills to reduce stress. On the transport boat, fish were placed in another tub of fresh, thermally regulated, and aerated Delta water. The tagged salmon were then released by hand approximately 1.6km (1 mile) upstream from the sampling location to reduce chances of reencountering the trammel net. Time of release was noted and recorded when the fish swam away volitionally.

Field Data

Data that were gathered and specific to field sampling included the following: date, net set time, crew members, water temperature, sampling landmark, tidal stage, capture time, release time, acoustic transmitter code, anchor tag number, anchor tag color, gender, fork length, adipose fin status (clipped or intact), condition of eyes (up or down), condition of gills (pale, bright red, or hemorrhaged), and fish lethargy (lethargic or active). All data gathered during sampling were recorded on waterproof paper while in the field, then entered in electronic spreadsheets, checked for quality assurance, and stored in a redundant fashion on devices housed at CDFW, North Central Region's main office.

Floy Tag and Coded Wire Tag Recovery

At the initiation of each sampling season, a notification letter was sent to fishery researchers and hatchery managers in the CV requesting notification of recovered Floy-tagged salmon and retention of the head of adipose fin-clipped salmon for CWT extraction (Appendix 1). The Regional Mark Processing Center (RMPC) was queried for information on recovered CWTs.[1] The RMPC provided hatchery of origin, release place, release date, and brood year records.

Acoustic Tracking of Fish

Fish with acoustic transmitters were tracked by submersed stationary acoustic receivers (VEMCO Ltd. VR2 and VRW) placed throughout the San Francisco Bay, Delta, and tributaries. Acoustic receivers were deployed and maintained by the California Fish Tracking Consortium[2] (Figure 5). All tracking data recorded on the stationary receivers were accessible through the BARD website[3]. After the known migration period of adult fall-run Chinook Salmon, the project queried BARD for every acoustic transmitter code and associated tracking data for each year of the study.

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[1] RMPC is located at http://www.rmpc.org

[2] California Fish Tracking Consortium is located at http://cftc.metro.ucdavis.edu

[3] BARD is located at http://sandbox5.metro.ucdavis.edu/fishtrack

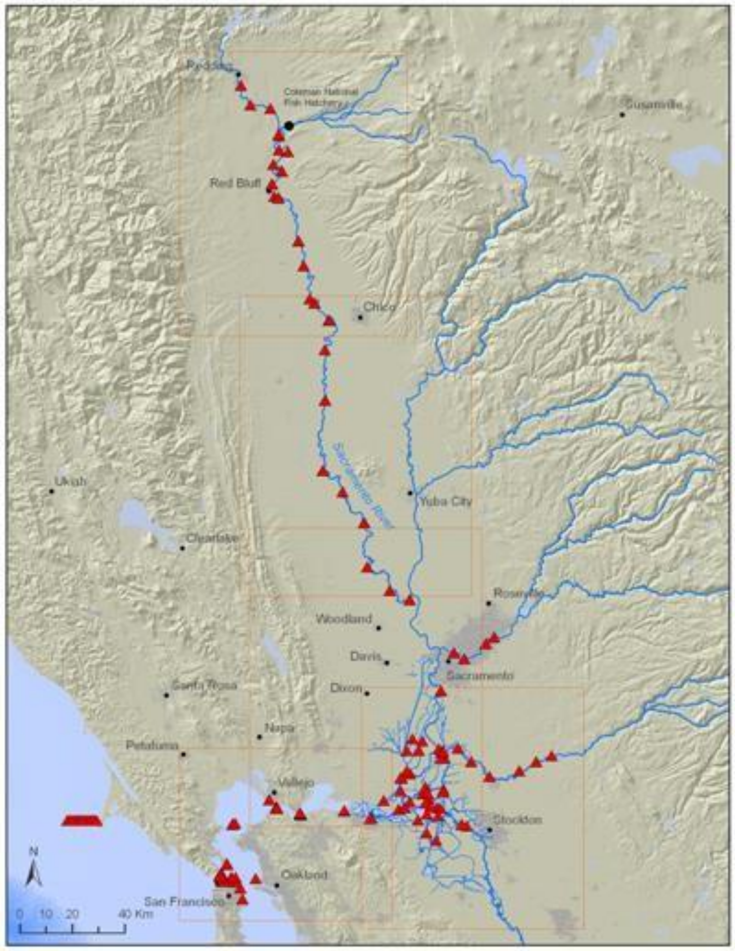

Figure 5. A map provided by the California Fish Tracking Consortium depicting the locations of stationary acoustic receivers maintained in anadromous waterways of central California.

Results

Field sampling occurred in 2011, 2012, 2014, 2015, 2016, and 2017. During these years there were 38, 85, 64, 45, 98, and 70 adult fall-run Chinook Salmon captured respectively (Table 1). Over these years of sampling, respective ratios of male to female were variable (Table 2). Field sampling was hindered on some days because of net fouling. The most common and problematic net fouling debris was water hyacinth (*Eichhornia crassipes*), water primrose (*Ludwigia* sp.), Brazilian waterweed (*Egeria* sp.) and occasional woody material. Across all years of sampling, bycatch only occurred in 2014 and 2015 and included white sturgeon (*Acipenser transmontanus*), striped bass (*Morone saxatilis*) and steelhead trout (*Oncorhynchus mykiss*) (Table 3).

Water Conditions

Annual precipitation in California varied greatly over the course of the study. The drought that occurred from 2012-2015 stand as the driest four consecutive precipitation years to ever occur, while 2017 was the second wettest ever recorded (CNRA 2021). The hydrological water year type classifications during the years sampling occurred for the Sacramento River Basin were wet in 2011, below normal in 2012, critically dry in 2014, critically dry in 2015, below normal in 2016 and wet in 2017. The water year types for the San Joaquin River Basin were wet in 2011, dry in 2012, critically dry in 2014, critically dry in 2015, dry in 2016 and wet in 2017 (DWR Water Supply Index). Flow records for Sacramento River flow were measured at Freeport, and flow for the San Joaquin River was recorded at Vernalis (CDEC), and daily average flows varied greatly over the years of sampling (Table 4).

Delta Cross Channel Operations

During all sampling years, the DCC was open in July, August, and through mid-September, however after mid-September, DCC gate operations varied between years (Table 5). The DCC was closed on December 1 in all years of the study in alignment with normal operating criteria. During the fall-run migration season of July through December, the DCC was closed only 5% of the time in 2011, 3% of the time in 2012, 4% of the time in 2014, 3% of the time in 2015, 6% of the time in 2016, 24% of the time in 2017.

Floy Tag Recovery and Distribution

All 400 salmon captured during field sampling were given externally visible Floy tags, and of these, 66 (16.5%) salmon were later recovered by various means. Floy tag recoveries were reported to CDFW by hatcheries (60%), anglers (25%) and adult salmonid escapement surveys occurring in various Central Valley tributaries (14%) (Table 6).

Coded Wire Tag Information

Twenty-one adipose fin-clipped fall-run Chinook Salmon were marked with Floy tags during sampling and found to have a CWT upon recovery. CWTs that were recovered at the Mokelumne River Hatchery, the Nimbus Hatchery, the Coleman Hatchery National Fish Hatchery, the Stanislaus River Escapement Survey, the Merced Hatchery, and one was brought to the CDFW North Central Region Office by an angler (Table 7).

Twenty CWT recovered salmon were from various fall-run Chinook hatchery programs including: 14 from broodyear (BY) 2009 Mokelumne Hatchery released at Sherman Island, 2 BY 2009 Nimbus Fish Hatchery released at

Discovery Park, 1 BY 2010 Mokelumne Hatchery released at Sherman Island, 1 BY 2011 Mokelumne Hatchery released at Sherman Island, 1 BY 2012 Nimbus Fish Hatchery released at Howe Avenue, 1 BY 2013 Feather River Hatchery released at Crockett, and 1 BY 2013 Coleman National Fish Hatchery late fall-run Chinook Salmon program released at Battle Creek (Table 7). One fish tagged during the sampling season of 2015 was produced by the USFWS Livingston Stone National Fish Hatchery Central Valley late fall-run Chinook program.

Telemetry

A total of 219 acoustic transmitters were implanted in captured salmon and of these, 128 acoustic transmitters provided useful salmon migration information (Table 6). Of the acoustic transmitters that tracked salmon during their migration, 11 went to the American River, 2 to Battle Creek, 7 to the Feather River, 19 to the Mokelumne River, 34 to the Sacramento River, 52 to the San Joaquin River, 2 to the Stanislaus River, and 1 to the Tuolumne River. Of the acoustic transmitters that did not provide useful salmon migration information, 21 transmitters were recorded at the sampling site but never left, 15 had dead batteries, 8 were deployed but were never recorded by a receiver, 20 were last recorded downstream at Antioch Bridge, 5 at Benicia Bridge, 6 at Carquinez Bridge, 2 at Chipps Island, 7 at Decker Island, 3 at Golden Gate Bridge and 4 at Richmond Bridge.

Fish Migration Near the Delta Cross Channel

Thirty-eight fall-run with acoustic transmitters were detected with acoustic receivers located at the DCC. The least amount of time spent near the DCC was four minutes while the maximum was 1,019 minutes (mean 121 minutes).

There were 21 occasions where salmon showed noticeable altered patterns to their migration routing by entering the open DCC. Of these 21 salmon that entered the DCC, 16 were of unknown origin (Table 8) and 5 were of known hatchery origin (Table 9). Altered migration routes associated with DCC entry are described in the following generalized patterns:

a) from the Sacramento River, into the DCC, and then back into the Sacramento River (n= 1),

b) from the Mokelumne River, into the DCC, and then back into the Mokelumne River (n= 3),

c) from the Sacramento River, through the DCC, and into the Mokelumne River (n= 6),

d) from the Mokelumne River, through the DCC, and into the Sacramento River (n= 5),

e) from the Sacramento River, through the DCC, into the Mokelumne River, back through the DCC, and back into the Sacramento River (n= 4),

f) from the Mokelumne River, through the DCC, into the Sacramento River, back through the DCC, and back into the Mokelumne River (n= 1) and,

g) from the Sacramento River, through the DCC, into the Mokelumne River, back through the DCC, back into the Sacramento River, back through the DCC, and back into the Mokelumne River (n= 1).

Discussion

With acoustic telemetry, this study provides a new understanding of migration behaviors in adult fall-run Chinook Salmon during their migration through the Delta. The migration route of five hatchery origin fall-run salmon was documented and included interacting with the DCC during their migration. These are of particular interest as the presence of the CWT provides additional level of detail on the potential impact of the DCC on adult straying. There were four Mokelumne River Hatchery origin salmon that entered the DCC; one of these salmon returned to the Mokelumne River, while the other three strayed into the American River. There was one salmon that originated from the Nimbus Fish Hatchery that was attracted into the Mokelumne River for a period, was then entrained in the DCC and ultimately returned to the American River. Of the 128 salmon of unknown origin that were tracked with acoustic telemetry, 21 of those salmon, or approximately 16%, were observed to enter the DCC. Altered migration routes were observed in all annual water types that occurred during the study (wet in 2011, below normal in 2012, critically dry in 2014, critically dry in 2015, below normal in 2016, wet in 2017).

Sacramento River flows diverted through the DCC into the Mokelumne River create mixed attraction signals, which in some cases appears to prolong the migration of adult fall-run Chinook Salmon through the Delta. This was noticeable because while the DCC was in open status, several tagged salmon were observed to pause their migration and hold near the DCC for extended periods of time, migrate back and forth between the Mokelumne and Sacramento rivers via the DCC, or drop all the way back to the central Delta to then reinitiate upstream migration. Migration delay was noticed for some salmon in every year of the study, regardless of annual water year type or DCC operational regime. Delays to migration can reduce or deplete energy reserves which are critical for gamete development and for salmon to successfully reach spawning grounds, compete for a mate, construct redds and spawn. Some salmon involved with this study were observed to entirely stop migrating after encountering the DCC. While it is unknown what happened to these salmon, there may be other potential impacts for fall-run with prolong Delta residency including increased stress and poor physiological condition due to exposure to altered environmental conditions in the Delta, increased potential for disease transmission, increased vulnerability to predation and increased opportunity for harvest.

Results from this study indicate that Mokelumne River Hatchery origin salmon enter the DCC and then stray to various locations in the Sacramento River, San Joaquin River, or other places in the Delta. Hatchery origin salmon straying between basins is a concern for fishery and hatchery managers because straying is problematic for maintaining genetic diversity, particularly while stocks are in a state of decline (Waples et al. 1990). Hatcheries in the Central Valley that produce fall Chinook Salmon are supporting the state’s multimillion-dollar recreational sport fishery and commercial fishery (NMFS 2018). In some years, the Mokelumne River Hatchery has struggled to collect enough fall-run broodstock to meet seasonal egg take goals needed to meet mitigation production targets. In recent years, to help with broodstock collection and attract adults to the Mokelumne River, East Bay Municipal Utilities District has conducted planned releases from Camanche Dam to create fall attraction flows. In 2011 and 2015 the fall attraction flow from Camanche Dam coincided with short duration DCC closures and provided a noticeable increase of adult migrants in the Lower Mokelumne River (Del Real and Saldate 2011, 2015). These types of coordinated actions may provide important tools for managers to minimize straying and decrease migration delays in the Delta. Notably, this action has the additional benefit of providing increase flows in the lower Sacramento River and north Delta, thereby improving attraction signals for adult salmon natal to the Sacramento River Basin.

Anadromous hatchery managers in California are continually modifying hatchery operations based on best available science to reduce straying and improve adult return, however based on this study, these efforts may be hampered by the influence of DCC operations during the fall-run adult migration period. Across all six years of this study, salmon with acoustic transmitters were routed through the DCC which suggests fall-run Chinook Salmon migration is routinely impacted and the number of salmon from this study with altered migration behavior suggests this problem is consequential. In recognition of this, water managers should continue to evaluate opportunities for independent or coordinated actions to minimize impacts of the DCC on salmon migration. Under climate change scenarios and given multiple new planned water storage or conveyance projects, more research is needed to identify how the DCC's influence on adult migration may change with environmental variables like low flow conditions in the Sacramento and San Joaquin rivers, or elevated water temperature during years of drought. Information is also needed on how the DCC may be impacting conditions for other populations of fish in the Delta.

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Tables

Table 1. Seasonal Catch and Transmitter Summary

Total Catch and Transmitter Deployment - All Years

Year	Start Date	End Date	Number of Sampling Days	Number of Salmon Captured	Number of Acoustic Transmitter Deployments	Adipose Fin Clip Rate
2011	Sep 19	Oct 20	16	38	25	66% (n=25)
2012	Sep 19	Oct 30	20	85	56	71% (n=60)
2014	Oct 7	Nov 18	12	64	16	21% (n=13)
2015	Sep 15	Nov 25	25	45	37	29% (n=13)
2016	Sep 19	Nov23	24	98	42	25% (n=25)
2017	Sep 20	Nov15	20	70	55	39% (n=27)

Table 2. Length Frequencies of Catch Summary

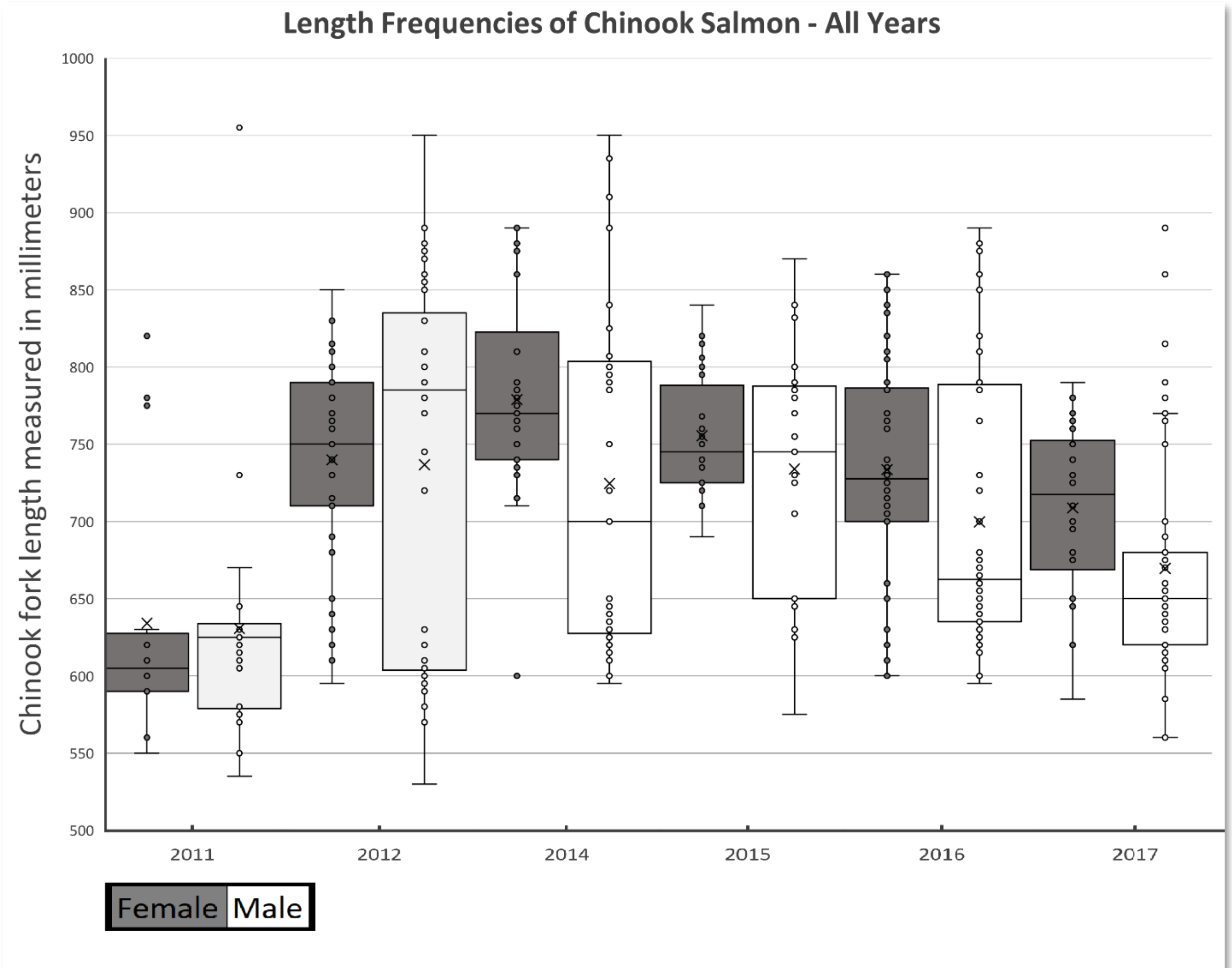
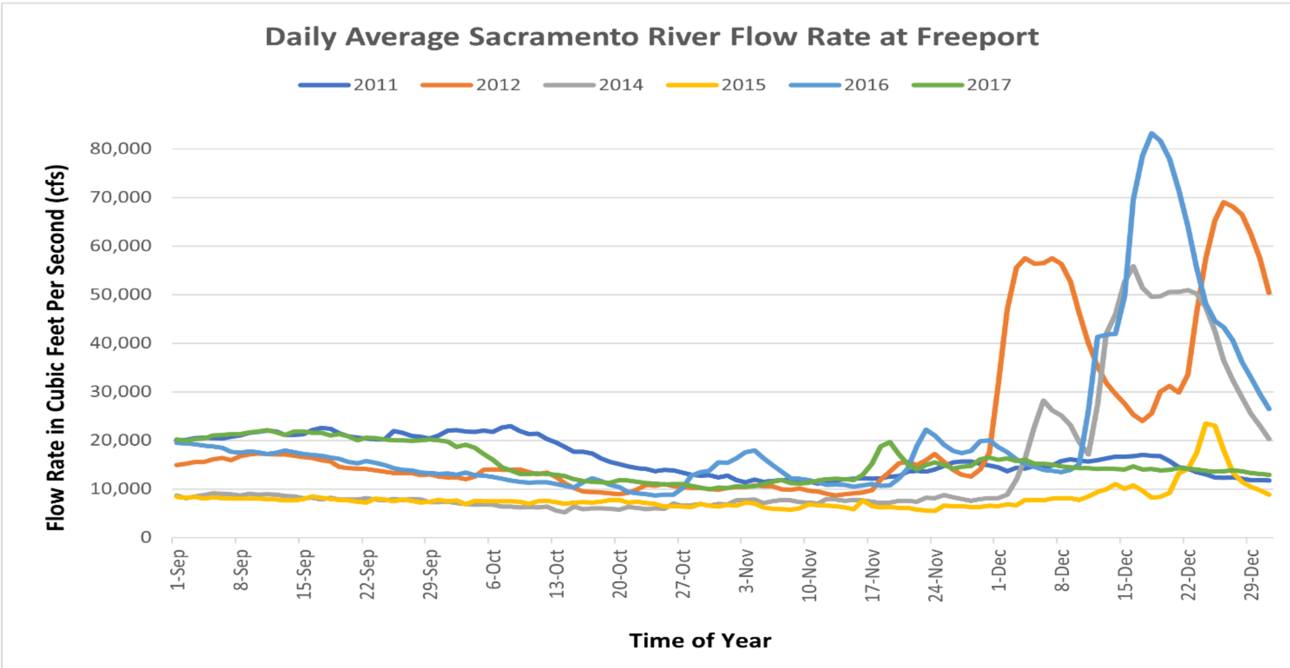


Table 3. Bycatch Summary

Bycatch Summary - All Years

Common name	Species	Year	Date	Length (mm)	Location
White sturgeon	*Acipenser transmontanus*	2014	Nov 13	960	Jersey Point
Striped bass	*Morone saxatilis*	2015	Oct 22	980	Jersey Point
White sturgeon	*Acipenser transmontanus*	2015	Nov 3	1150	Jersey Point
White sturgeon	*Acipenser transmontanus*	2015	Nov5	1470	Jersey Point
Steelhead trout	*Oncorhynchus mykiss*	2015	Nov15	755	Santa Clara Shoal

Table 4. Summary of daily average flow for the Sacramento River and San Joaquin River



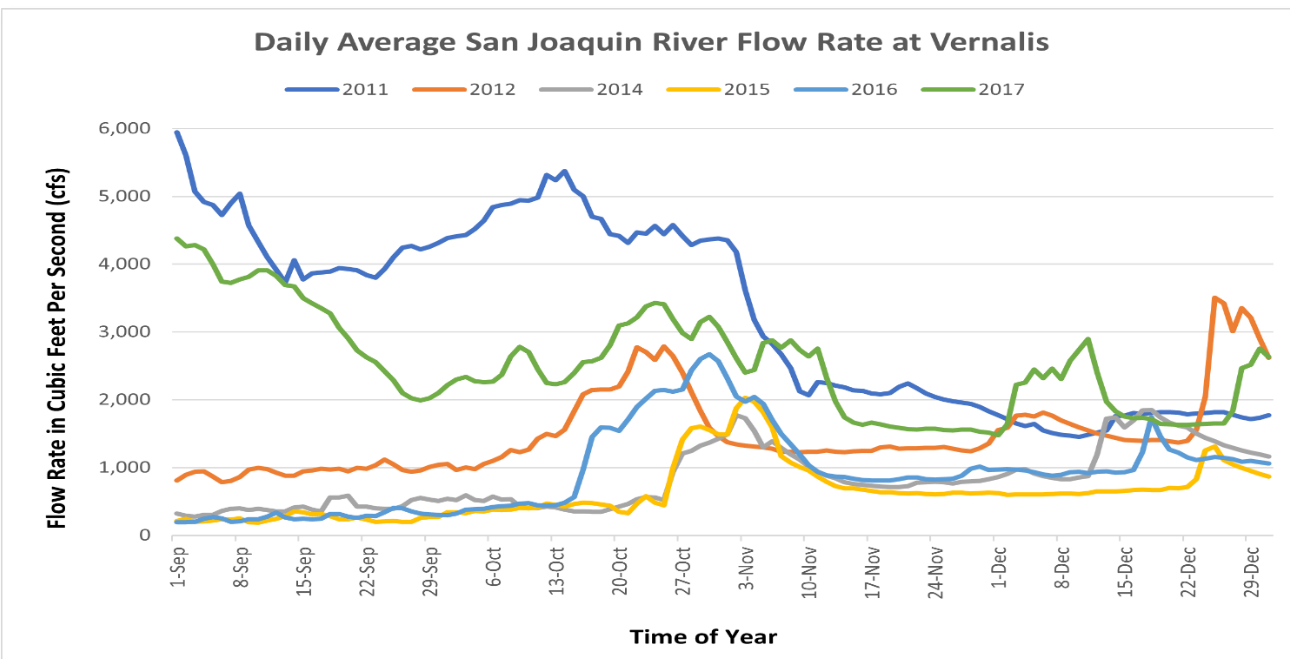


Table 5. Delta Cross Channel Operations Summary

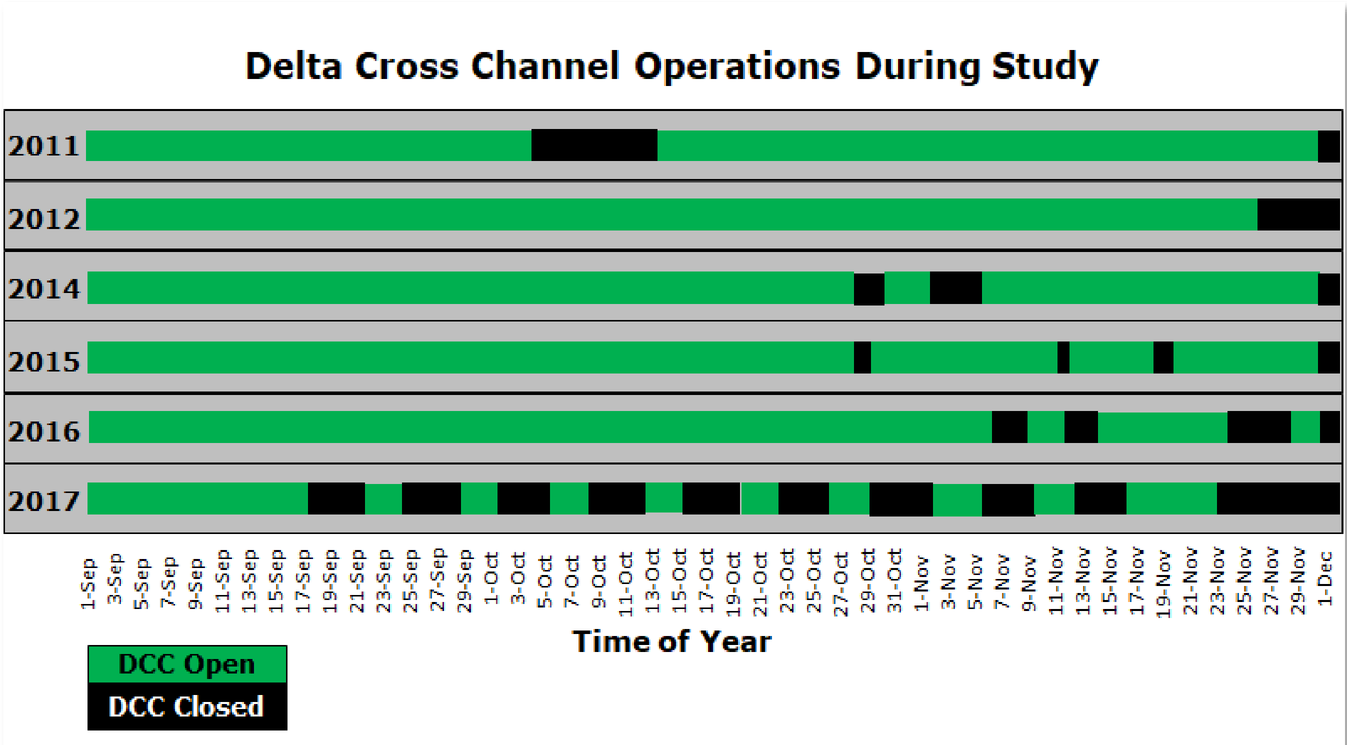


Table 6. Acoustic Transmitter Tracking by Tributary Summary

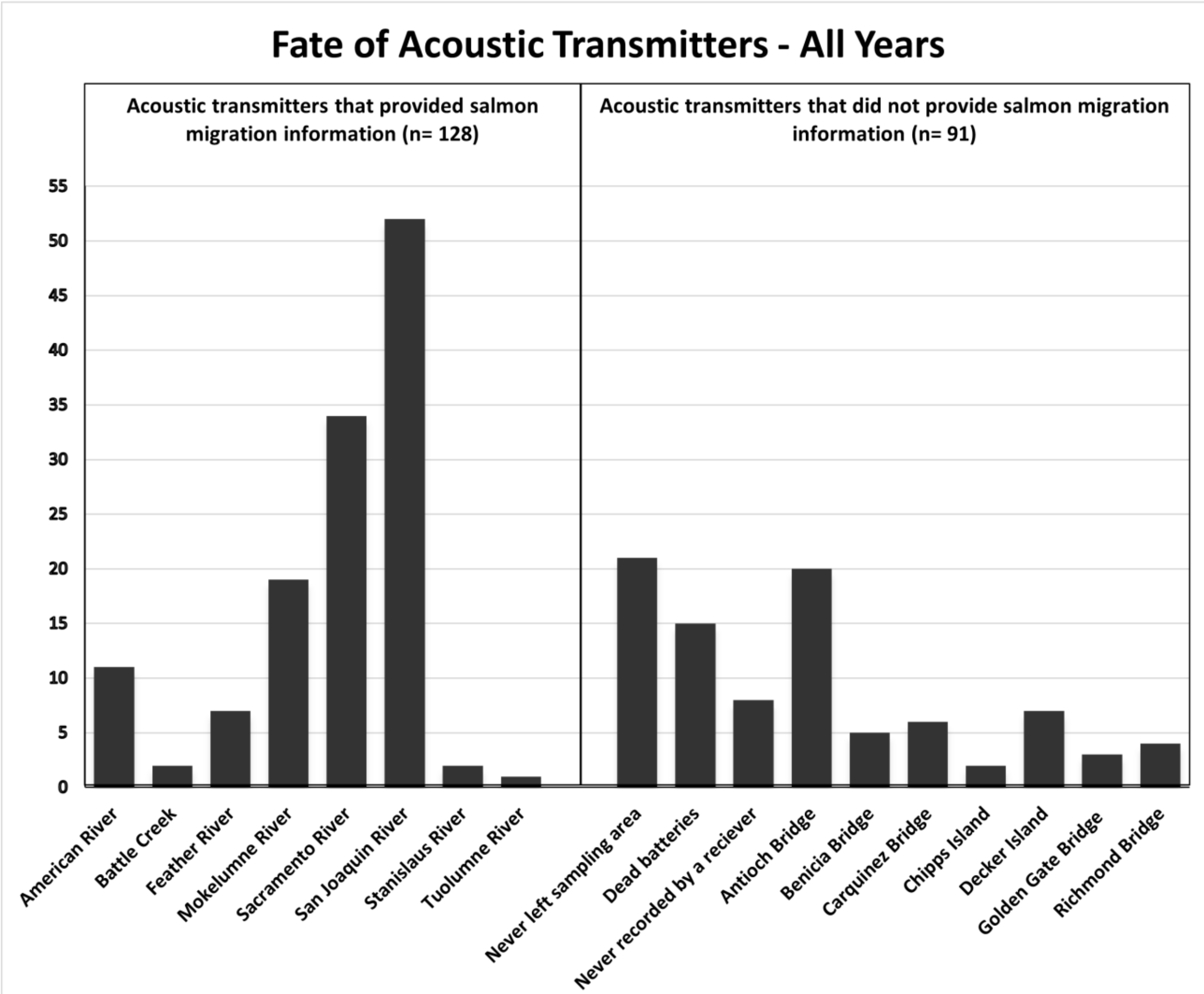


Table 7. Floy Tag and Coded Wire Tag Recovery Summary

Tag Recovery – All Years

Capture Date	Recovery Location	Recovery Date	Revery Method	Adipose Fin Clip	CWT Information
9/21/2011	American River	10/11/2011	Angler, Nimbus Basin	N	
9/21/2011	Mokelumne River	10/11/2011	Mokelumne River Hatchery	Y	FRCS, BY 2009, MOK Production,

					Release at Sherman Island
9/28/2011	Sacramento River	9/25/2011	Angler, Discovery Park	N	
9/28/2011	Mokelumne River	11/23/2011	Mokelumne River Hatchery	Y	FRCS, BY 2009, MOK Production, Release at Sherman Island
10/4/2011	American River	11/14/2011	American River Carcass Survey	N	
10/4/2011	Mokelumne River	11/7/2011	Mokelumne River Hatchery	Y	FRCS, BY 2009, MOK Production, Release at Sherman Island
10/6/2011	Mokelumne River	11/17/2011	Mokelumne River Hatchery	Y	FRCS, BY 2009, MOK Production, Release at Sherman Island
10/12/2011	Mokelumne River	11/4/2011	Mokelumne River Hatchery	Y	FRCS, BY 2009, MOK Production, Release at Sherman Island
10/13/2011	Mokelumne River	11/4/2011	Mokelumne River Hatchery	Y	FRCS, BY 2009, MOK Production, Release at Sherman Island
9/19/2012	American River	11/13/2012	Nimbus Hatchery	Y	FRCS, BY 2009, NIM Production, Release at Discovery Park
9/20/2012	Mokelumne River	11/26/2012	Mokelumne River Hatchery	Y	FRCS, BY 2009, MOK Production, Release at Sherman Island
9/20/2012	American River	11/26/2012	Nimbus Hatchery	Y	FRCS, BY 2010, MOK Production, Release at Sherman Island
9/24/2012	Stanislaus River	12/4/2012	Stanislaus River	Y	FRCS, BY 2009, MOK Production,

			Carcass Survey		Release at Sherman Island
9/26/ 2012	Mokelumne River	11/20/2012	Mokelumne River Hatchery	Y	FRCS, BY 2009, MOK Production, Release at Sherman Island
9/27/ 2012	American River	11/9/2012	Angler, Nimbus Basin	Y	Floy tags recovered, but not CWT
9/27/ 2012	Sacramento River	10/3/2012	Angler, Garcia Bend	N	
10/9/ 2012	Merced River	11/8/2012	Merced River Hatchery	N	
10/9/ 1012	American River	11/15/2012	Nimbus Hatchery	Y	FRCS, BY 2009, MOK Production, Release at Sherman Island
10/9/ 2012	Merced River	11/19/2012	Merced River Hatchery	Y	FRCS, BY 2009, MOK Production, Release at Sherman Island
10/10 /2012	Mokelumne River	11/1/2012	Mokelumne River Hatchery	Y	FRCS, BY 2009, MOK Production, Release at Sherman Island
10/12 /2012	American River	12/4/2012	Angler, Nimbus Basin	Y	FRCS, BY 2009, MOK Production, Release at Sherman Island
10/15 /2012	San Joaquin River	10/28/2012	Angler, Benicia Breakwater	N	
10/15 /2012	American River	11/8/2012	Nimbus Hatchery	Y	FRCS, BY 2009, MOK Production, Release at Sherman Island
10/16 /2012	Mokelumne River	11/15/2012	Mokelumne River Hatchery	N	
10/18 /2012	American River	12/3/2012	Nimbus Hatchery	Y	FRCS, BY 2009, NIM Production, release at Sunrise Park

10/24/2012	American River	11/21/2012	Nimbus Weir	N	
10/7/2014	Mokelumne River	10/18/2014	Angler, Beaver Slough	N	
10/7/2014	American River	11/19/2014	Angler, Nimbus Basin	N	
10/8/2014	American River	11/12/2014	Nimbus Fish Hatchery	N	
10/14/2014	American River	11/24/2014	Nimbus Fish Hatchery	N	
10/14/2014	American River	11/26/2014	Nimbus Fish Hatchery	N	
10/14/2014	American River	12/8/2014	American River Carcass Survey	N	
10/15/2014	Mokelumne River	11/24/2014	Mokelumne Fish Hatchery	N	
10/16/2014	American River	12/17/2014	American River Carcass Survey	N	
10/21/2014	American River	1/5/2015	American River Carcass Survey	N	
10/22/2014	San Joaquin River	10/27/2014	Angler, Seven Mile Slough	N	
10/22/2014	Mokelumne River	11/20/2014	Mokelumne Fish Hatchery	N	
10/22/2014	Mokelumne River	12/1/2014	Mokelumne Fish Hatchery	Y	Floy tags recovered, but not CWT
10/23/2014	Mokelumne River	11/17/2014	Mokelumne Fish Hatchery	N	

9/17/ 2015	American River	10/23/2015	Angler, Nimbus Basin	N	
9/25/ 2015	American River	11/9/2015	Nimbus Fish Hatchery	N	
10/22 /2015	American River	12/3/2015	Nimbus Fish Hatchery	Y	FRCS, BY 2011, MOK Production, Release at Sherman Island
10/29 /2015	American River	11/22/2015	Angler, Nimbus Basin	Y	FRCS, BY 2012, NIM Production, Release at Howe Avenue
11/17 /2015	Mokelumne River	12/22/2015	Mokelumne Fish Hatchery	N	
11/18 /2015	Mokelumne River	11/22/2015	Angler, Mokelumne River	N	
11/23 /2015	Sacramento River	1/6/2016	Coleman Fish Hatchery	Y	LFRCS, BY 2013, CNFH Production, Release at Battle Creek
9/21/ 2016	American River	11/10/2016	Nimbus Fish Hatchery	N	
9/21/ 2016	Mokelumne River	11/4/2016	Mokelumne Fish Hatchery	Y	FRCS, BY 2013, FRH Production, Release at Crockett
9/22/ 2016	Mokelumne River	11/7/2016	Mokelumne Fish Hatchery	N	
9/27/ 2016	Feather River	11/28/2016	Feather River Carcass Survey	N	
9/28/ 2016	Stanislaus River	11/22/2016	Stanislaus River Carcass Survey	N	
9/29/ 2016	American River	10/7/2016	Angler	N	
9/29/ 2016	Mokelumne River	11/7/2016	Mokelumne Fish Hatchery	N	

10/4/2016	American River	11/3/2016	Nimbus Fish Hatchery	N	
10/11/2016	?	12/16/2016	Angler	N	
9/20/2017	American River	10/25/2017	Angler, Nimbus Basin	N	
9/21/2017	Sacramento River	10/22/2017	Angler, Twin City	N	
10/3/2017	Mokelumne River	11/27/2017	Mokelumne Fish Hatchery	Y	Floy tags recovered, but not CWT
10/10/2017	Mokelumne River	11/9/2017	Mokelumne Fish Hatchery	N	
10/10/2017	American River	10/25/2017	Angler, SARA Park	N	
10/17/2017	American River	12/8/2017	Nimbus Fish Hatchery	N	
10/18/2017	American River	12/18/2017	Nimbus Fish Hatchery	N	
10/18/2017	Feather River	11/28/2017	Feather River Carcass Survey	Y	Floy tags recovered, but not CWT
10/18/2017	Mokelumne River	11/20/2017	Mokelumne Fish Hatchery	N	
10/19/2017	Feather River	11/21/2017	Feather Fish Hatchery	Y	Floy tags recovered, but not CWT
11/2/2017	Mokelumne River	11/20/2017	Mokelumne Fish Hatchery	N	

Table 8. Salmon of Unknown Origin Tracking Summary

Migration Routes of Salmon of Unknown Origin - All Years

Tag Number	Capture Date	Route Information
22896	October 10, 2012	The fish migrated up the Sacramento River and appeared in the American River on October 30. On October 31, the fish moved down the Sacramento River and on November 1, went through the DCC and into the Mokelumne River.
22897	October 10, 2012	On October 28 the fish ascended the Sacramento River and appeared near the American River. On October 31 the fish descended the Sacramento River and on November 1, went through the DCC and entered the Mokelumne River.
1010	September 23, 2015	On October 5 the fish migrated up the Mokelumne River, through the DCC and into the Sacramento River. On October 6, the fish went from the Sacramento River, through the DCC and into the Mokelumne River, then back through the DCC, to the Sacramento River.
1013	September 29, 2015	On October 2, the fish ascended the Mokelumne River, entered the DCC and then the Sacramento River.
1015	September 29, 2015	On October 19, the fish ascended the Sacramento River and then entered the DCC to then move into the Mokelumne River. Then the fish descended the Mokelumne River to enter the central Delta. On October 26 the fish migrated up the Sacramento River to the Freeport area, and then on October 30 descended the Sacramento River and was last seen in the central Delta.
1017	October 1, 2015	On October 8, the fish was observed to be migrating up the Sacramento River and on October 12, entered the DCC and then the Mokelumne River. Once in the Mokelumne River, the fish moved downstream to enter the San Joaquin River on October 13. On October 23, the fish ascended the Mokelumne River, entered the DCC and then the Sacramento River. On October 28 the fish descended the Sacramento River toward the central Delta, and on November 5, was last seen ascending the San Joaquin River.

1026	November 3, 2015	On November 8, the fish was observed starting to ascend the Sacramento River, but then turned around toward the central Delta. On November 11, the fish was observed to enter the Mokelumne River but then returned to the central Delta. On November 22, the fish ascended the Sacramento River and was observed in the Freeport area. On November 23, the fish descended the Sacramento River from the Freeport area to then enter the DCC. The fish stayed the in the DCC channel corridor for two days, migrating back and forth between the Mokelumne and Sacramento rivers, last being seen in the Sacramento River downstream from the DCC on November 25.
19002	November 17, 2015	On November 24, the fish began to ascend the San Joaquin River. On November 26, the fish was observed ascending the Mokelumne River and from November 29 through December 1, continually went between the Mokelumne River and the DCC. Then the fish descended the Mokelumne River to hold in the central Delta. On December 3, the fish was observed to be migrating into Old River and then held between Old River and the San Joaquin River until December 14. The fish then ascended the Mokelumne River and was detected entering the DCC on December 14.
1034	November 17, 2015	The fish started to migrate to the San Joaquin on November 22. On November 28, the fish moved into the lower Sacramento River. On November 29 the fish appeared and stayed near the DCC for several days and on December 2, entered the DCC and then the Mokelumne River. The fish then descended the Mokelumne River to the San Joaquin River on December 3. On December 4 the fish started to migrate up the Sacramento River and then reappear near the DCC on December 17. On December 18, the fish moved through the DCC and into the Mokelumne River on December 19. The fish repeatedly moved though the DCC and on December 24, was finally detected ascending the Mokelumne River.
1035	November 17, 2015	On November 25, the fish was observed to ascend the Sacramento River. On November 28, the fish was observed near the DCC. For three days the fish moved between the Sacrament River, DCC and Mokelumne River and on December 30 was observed descending the Mokelumne River toward the central Delta.

44707	September 19, 2016	The fish started to ascend the Mokelumne River on September 26. On September 27 the fish was observed to move from the Mokelumne River, into the DCC and then the Sacramento River. The fish ascended the Sacramento River up to the Freeport area, then moved back down stream to the DCC and on September 29, moved through the DCC, back into the Mokelumne River. The fish then descended the Mokelumne River toward the central Delta and was last seen in the lower San Joaquin River on October 12.
44712	September 19, 2016	On September 28, the fish started migrating up the Sacramento River. On September 29, the fish was observed to descend the Sacramento River and then appear in the lower Mokelumne River. On September 30, the fish migrated up the Mokelumne River and into the DCC. The fish stayed near the DCC until October 2, then descended the Mokelumne River and entered the San Joaquin River on October 3. On October 8, the fish was observed to migrating the Sacramento River again and was last seen in the Sacramento River near Freeport on October 13.
19030	November 16, 2016	On November 22, the fish started to ascend the Mokelumne River. On November 22, the fish moved from the Mokelumne River into the DCC and then the Sacramento River. The fish was last observed ascending the Sacramento River on November 23.
767	September 26, 2017	The fish was detected in the lower San Joaquin River on September 27, and then the lower Mokelumne River on September 28. On October 1, the fish moved from the Mokelumne River, through the DCC and into the Sacramento River where it was last seen on October 26.
768	September 28, 2017	The fish was detected to enter the lower San Joaquin River on October 5, and then move into the lower Sacramento River on October 8. On October 9, the fish entered the DCC and then the Mokelumne River. The fish then migrated downstream toward the central Delta and on October 14 started moving up the Sacramento River. The fish was last detected in the Sacramento River on October 15.
769	September 28, 2017	The fish was observed near the confluence of the Mokelumne and San Joaquin rivers on September 30. On October 2, the fish ascended the Mokelumne River and then entered the DCC where it was last detected.

Table 9. Salmon of Known Origin Tracking Summary

Migration Routes of Salmon of Known Origin - All Years			
Tag Number	**Capture Date**	**Hatchery Information**	**Route Information**
1024	October 22, 2015	Mokelumne River Hatchery - BY 2011	The fish stayed in Mokelumne-San Joaquin confluence area until October 27. The fish entered the lower Mokelumne River on October 28, and on November 11, swam through the DCC into the Sacramento River. The fish swam up the Sacramento River, into the American River and entered the Nimbus Fish Hatchery on December 3.
22900	October 10, 2012	Mokelumne River Hatchery - BY 2009	On October 15, the fish migrated up the Sacramento River and appeared near the DCC. On October 17, the fish entered the DCC and then into the Mokelumne River. The fish was finally observed entering the Mokelumne River Hatchery on November 1.
22901	October 12, 2012	Mokelumne River Hatchery - BY 2009	On October 24, the fish entered the Mokelumne River and on November28, it entered the DCC, then into the Sacramento River. The fish was caught by and angler on December 24, while fishing in the American River at the Nimbus Basin.
22904	October 15, 2012	Mokelumne River Hatchery - BY 2009	The fish ascended the Sacramento River and on October 21, appeared in the area near the DCC. On December 21, the fish entered the DCC and then the Mokelumne River. The fish swam downstream toward the central Delta and back into the Sacramento River. The fish appeared again near the DCC on October 27. The fish migrated up the Sacramento River and entered the American River on October 29. The fish was recovered at the Nimbus Hatchery on November 11.

1025	October 29, 2015	Nimbus Hatchery - BY 2012	The fish entered the lower Mokelumne River on October 31. The fish then backed down to the central Delta and on November 20 reentered the lower Mokelumne River. On November 21, the fish appeared at the DCC and traveled through the gates into the Sacramento River. The fish migrated up the Sacramento River and was caught by and angler on November 22 near the confluence of the American and Sacramento.

Appendices

Appendix 1. Memorandum to Researchers

State of California
Department of Fish and Wildlife

M e m o r a n d u m

Date: September 2017

To: California Central Valley salmon hatcheries and adult escapement surveys

From: Christian J. McKibbin
Environmental Scientist
Department of Fish and Wildlife

Subject: Adult Chinook Salmon (*Oncorhynchus tshawytscha*) Migration Study Using Acoustic Transmitter Tags in the Sacramento-San Joaquin River Delta

During September, October and November of 2017, the California Department of Fish and Wildlife North Central Region (Department) and East Bay Municipal Utility District (EBMUD) will be attempting to capture and tag adult Mokelumne River Hatchery origin fall-run Chinook salmon (*Oncorhynchus tshawytscha*). This will be the last year of a six year study examining the effects of water operations on stray rates for returning adult hatchery origin salmon. Sampling for salmon will occur in the San Joaquin River arm of the Sacramento-San Joaquin Delta (Delta) near Jersey Point and Santa Clara Shoal.

All salmon captured during the survey will be evaluated for length, sex, physical condition and presence or absence of an adipose fin (indicating hatchery origin). All captured salmon will receive two externally visible t-bar anchor tags before being released. Anchor tags will be placed on the right and left side of the fish, below the dorsal fin. Salmon with an intact adipose fin will receive green anchor tags while those without an adipose fin will receive blue anchor tags. Each anchor tag will be numbered 0001 - 9999 and printed with: CDFW #### Please call (916) 358-2900

Along with anchor tags, up to sixty salmon will receive an acoustic transmitter tag (Vemco V13 69kHz) through gastric insertion to the stomach. Acoustic telemetry data will allow for analysis of migratory pathways and migration timing of individual salmon throughout the Delta and its tributaries. Acoustic transmitter detection information will be compiled after the fall-run Chinook salmon migration period.

Recovery of coded wire tag (CWT) information from anchor tagged hatchery origin salmon is an important component of the study. Recovering CWTs will allow for analysis of multiple factors that may influence migration patterns and stray rates of hatchery produced salmon. Salmon with CWTs that will be anchor tagged during this study are primarily expected to return to the Mokelumne River and Hatchery, but some may appear at other Central Valley (CV) hatcheries or CV adult escapement surveys.

This memorandum shall be distributed to researchers at hatcheries and adult escapement surveys in the CV requesting notification if anchor tagged salmon are recovered as well as that researchers retain the head of adipose fin-clipped salmon for CWT extraction. If there are questions about the study or to notify the Department of a tag recovery, please contact Chris McKibbin by phone at (916) 202-9325 or by email at chris.mckibbin@wildlife.ca.gov